The distributed energy sector in Poland - current status, challenges, barriers, and the Danish experience

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Abstract: The article presents the current state of distributed energy in Poland, with particular emphasis on the energy transition plans, analyzing the document Polish Energy Policy until 2040 (PEP2040). Additionally, describes three types of entities: prosumers, energy clusters and energy cooperatives. The author explains their current status, funding sources and barriers. The second part of the publication presents the author's reflections on the problems and challenges related to the development of biogas and wind energy. Additionally, the author focuses on the impact of distributed generation on the power system. Social and local governmental aspects are also presented. In the third part, the author presents the Danish experience in the development of renewable energy sources and distributed generation. The author presents two examples of solutions: a civic foundation in Hvide Sande and a district heating company in Gram. Conclusions of the article includes the proposal of changes to the legislative system that will enable further RES development. In addition, the author draws attention to the impact of the Mój Prąd programme, responsible for the high growth of installed capacity.
Key words: decarbonization, distributed energy, PEP2040

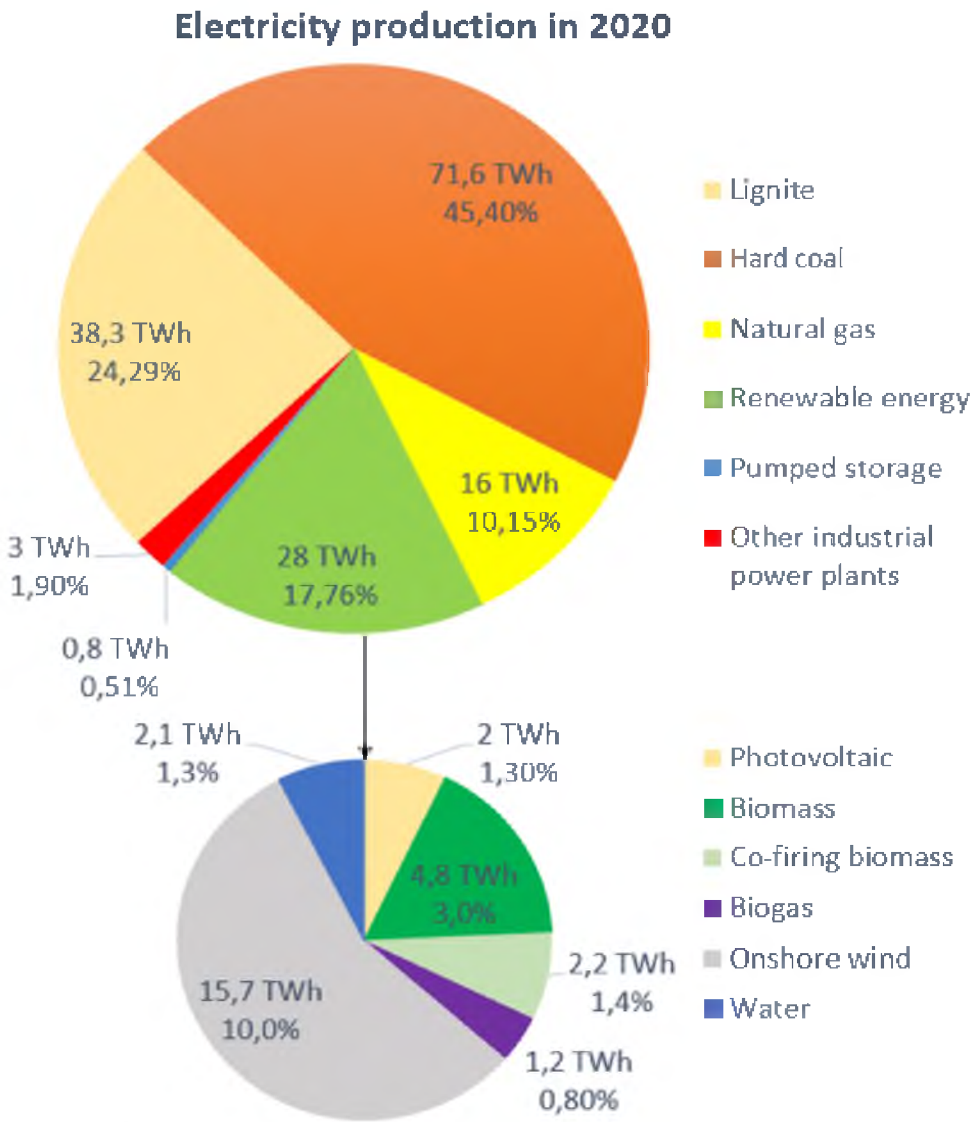
1.0 Introduction

In connection with international involvement in mitigating the effects of climate change, necessary steps are being taken, including measures to reduce fossil fuel consumption and greenhouse gas emissions. In the case of Poland, all actions require adjustment of the country's climate and energy policy to the requirements of the European Union (EC, 2019), which plans to create an energy union system containing a common energy market for all EU entities.

1.1 The state of the power industry in Poland

Poland's current energy mix is still based on outdated coal-fired power stations, the average age of which in Poland is 47 years. There is no doubt that this information indicates a requirement to shut down these units for technical reasons or to carry out uneconomic modernizations of the units (Tygodnik, 2021). Referring to the data (Jędra, 2021) of 2020, it can be seen that the COVID-19 pandemic has left a significant mark on past power sector performance. There has been a significant decline in coal-fired power generation, with its share falling below 70% to 69.7% for the first time in Poland's history (figure 1), despite the introduction of new coal-fired capacity into the system. In addition, the new commissioning of gas-fired units and the decline in electricity demand have contributed to this. In addition, the weakening competitiveness of power generation in domestic units and the impact of cheap energy imports with the development of renewable energy.

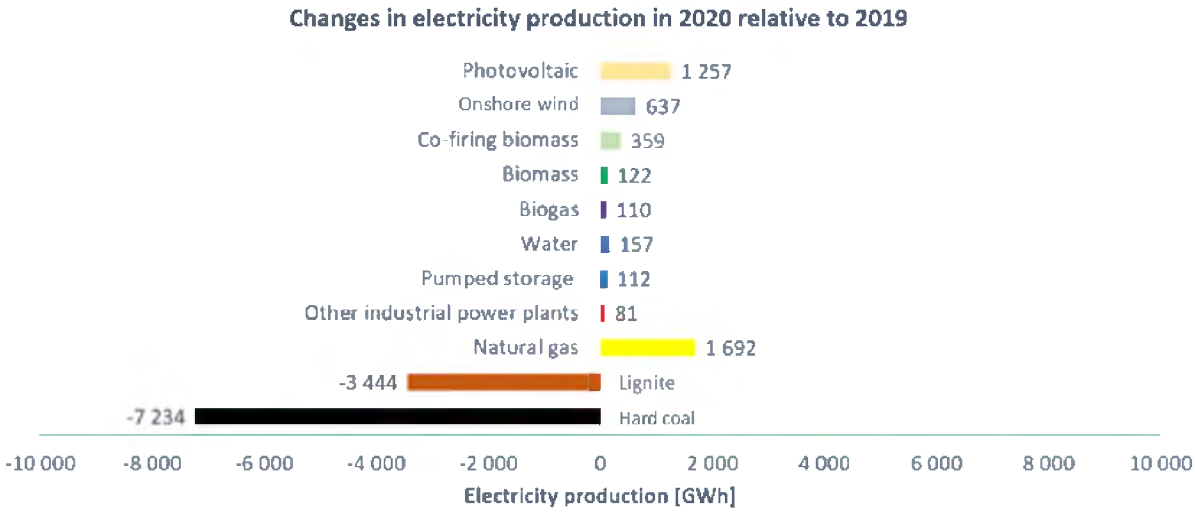
Figure 1. Electricity production in 2020



Source: Own elaboration based on: (Jędra, 2021)

Analyzing the data summarized in figure 2, it can be seen that the most dynamically developing source of electricity was photovoltaics, which increased the amount of electricity produced by 3.5 times compared to 2019. In addition, there was an increase in energy volumes from onshore wind power and natural gas, which according to the Polish Energy Policy until 2040 (PEP 2040) is to be a transitional fuel in Poland's energy transition. Referring to this document, it can be said that it provides an important roadmap for the development of Poland's electricity sector.

Figure 2. Changes in electricity production in 2020 relative to 2019



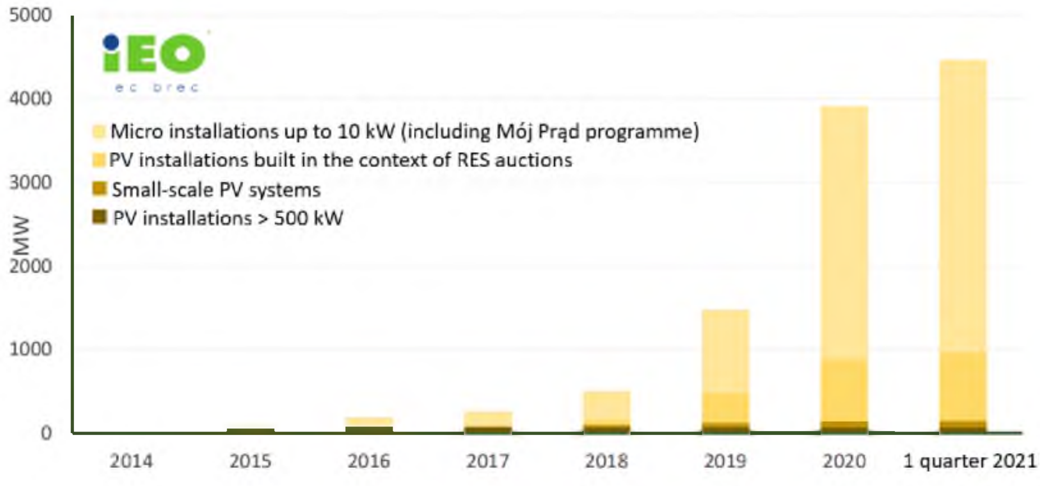
Source: Own elaboration based on: (Jędra, 2021)

Through ambitious plans, PEP 2040 assumes a sharp increase in the share of renewable energy sources in the total generation system. It is estimated to achieve around 40% of renewables in the electricity sector in 2040 (PEP 2040). Currently, referring to the data of the Energy Market Agency (ARE, 2021) in the period January-May 2021, more than 17.96% of energy came from RES. Additionally, it is expected that from 2030 1/3 of MWh generated on Polish territory will come from RES (Kurtyka, 2021). The PEP 2040 document assumes that the above-mentioned targets will be achieved through the development of offshore wind farms on the Baltic Sea reaching a total installed capacity of 11 GW by 2040 and increasing onshore capacity volumes, the construction of nuclear energy reaching 6 to 9 GW and photovoltaic investments yielding 10 to 16 GW within two decades. In addition, the biogas and biomethane sector is to be an important focus of the energy transition. The development of micro-cogeneration biogas and biomethane plants is planned, which will enable, among other things, the greening of natural gas by injecting the methane produced in this technology into the national distribution network and the development of bioLNG and bioCNG as alternative fuels for transport. The significant development of other revolutionary low and zero carbon technologies such as heat pumps, hydrogen, electromobility and energy storage should also take note.

There is no doubt that the development of renewable energy sources is an opportunity to create an electricity system with a completely different, decentralized model. The increasing prices of CO2 emission rights, which currently oscillate within the range of 53-55 EUR/tonne (CIRE,2021), impose ever-increasing costs on electricity, hitting industry and household end users. Prices in the future will also be driven by the implementation of the 'Fit for 55' package by the European Commission, which assumes, e.g. gradual inclusion of the transport and construction sectors in the EU-ETS emission trading scheme, or amendment to the RES Directive (the so-called RED II), planning to increase the share of renewable energy in the energy mix in 2030 from 32% to probably ca. 40% (Europarl, 2021). To align to this, Poland should strive to create an optimized system by creating socially acceptable prices. Therefore, one of the megatrends related to the energy of the future is the reliance on low-carbon stabilized distributed generation units of RES, which will form self-balancing energy areas.

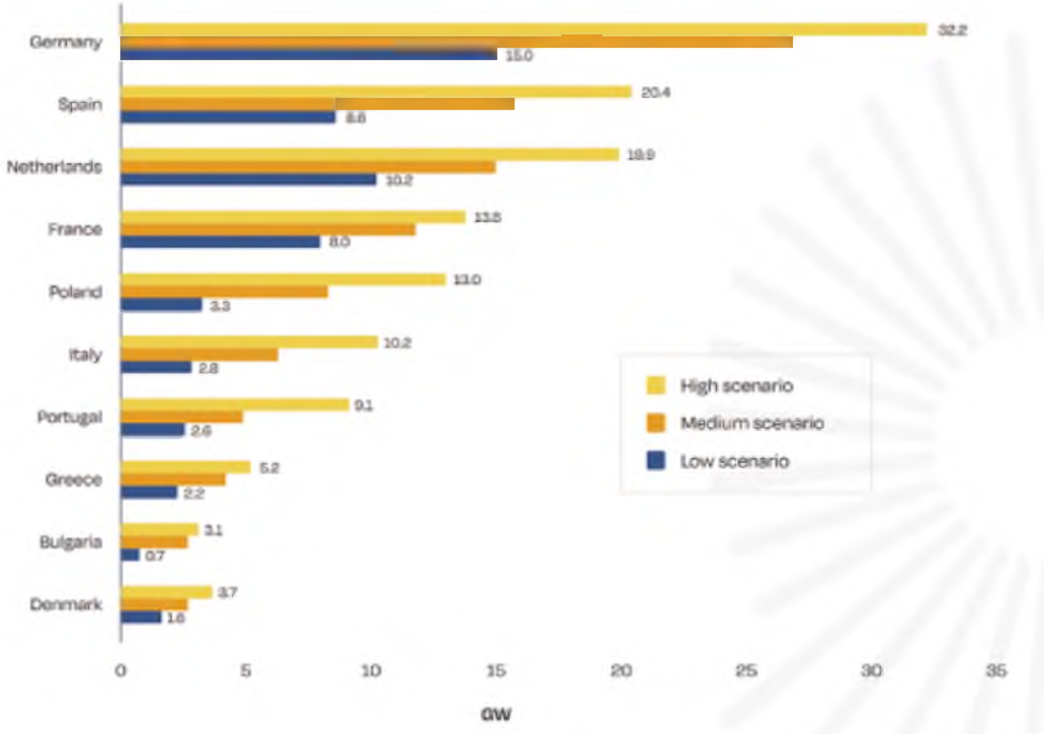
PEP 2040 assumes activation of this area of power industry by creating up to 300 collective entities called energy communities by 2030, including energy clusters and energy cooperatives. Additionally, the goal is to develop the prosumer movement, which is to form the backbone of the civic energy sector by generating 1 million prosumers by 2030. The progressive change of the generation model from coal-centralized to decentralized, i.e. distributed, in the future may bring many positive aspects. Apart from the fact of creating a certain self-balancing, stable energy area along with a reduction in electricity prices, there is also the activation of local communities with their energy potential. In addition, it will enable to relieve the pressure on the National Power System and increase the competitiveness of local enterprises and industry by bringing them together in these areas, enabling the creation of synergies. Additionally, it will improve air quality and reduce the demand for electricity, which is observed in the summer (Mataczyńska & Kucharska, 2020). A particularly important element of support for distributed energy is the development of photovoltaics, which has become a kind of "game changer" of the prosumer movement, mainly due to the government programme Mój Prad (GOV, 2021). This programme supports citizens by allowing co-financing of investments connected with installation of domestic photovoltaic installations. Currently, referring to ARE data, at the end of May 2021 the number of prosumers amounted to over 560 thousand, generating an installed capacity of 4 973 MW (ARE, 2021). The historical growth of photovoltaic installations in Poland can be seen in (figure 3) which, shows that over the past 7 years.

Figure 3. The cumulative installed capacity in Poland for successive years, distinguishing between installation types. (Rynek Fotowoltaiki w Polsce, 2021).



Poland has been ranked first in the EU, with a cumulative growth rate of 114% (EU average is 10.3%). Data (Solar Power Europe, 2020) shows that Poland is ranked 4th in the European Union in terms of installed PV capacity (figure 4). This was mainly due to individual prosumers, which confirms the high potential and strength and position of the Polish photovoltaic market (Rynek Fotowoltaiki w Polsce, 2021).

Figure 4. Three-year forecast of added PV capacity for the 10 largest EU markets in 2021-2024 (Solar Power Europe 2020).



1.2 The state of prosumers, energy clusters and energy cooperatives

In Poland there are currently 66 collective entities acting as energy communities as energy clusters. Energy clusters can be understood as a civil law agreement that may include natural persons, legal persons, scientific entities, research institutes or local government units, concerning the generation and balancing of demand, distribution or trade in energy from RES or from other sources or fuels, within a distribution network with a voltage rating lower than 110 kV, in the area where the cluster operates not exceeding the borders of one county or 5 municipalities. The main objectives of clusters are: providing energy security, especially within local borders; improving the environment; and enhancing the competitiveness of businesses operating within them. Agreements of this type have a direct impact on increasing the energy efficiency of the local, and indirectly also the national energy system. Moreover, they create self-sufficient and self-balancing electricity areas, reduce energy prices, relieve the budgets of local governments and inhabitants living within their scope, create new jobs and contribute to the expansion of the RES share in national energy consumption by using the local potential of the regions covered by the agreement (Siudek & Klepacka, 2020).

Unfortunately, in the case of energy cooperatives, there is only one located in Raszyn, Mazowieckie voivodeship (GlobEnergia, 2021). Energy cooperatives are very similar structures to clusters. The purpose of their existence is to produce energy for their own use and in case of overproduction to sell it back to the national grid system. They have legal personality and are established to carry out economic activities. Very importantly, they primarily use RES. Energy generation inside such institutions is limited depending on the type of energy and is 10 MW for electricity and 30 MW for heat (KOWR, 2021).

Apart from the highly active development of the prosumer movement, it is in the area of collective entities that barriers to the implementation of distributed energy are encountered. The main problem of development is the failure to adapt legal regulations to European requirements in the field of distributed energy. In the case of energy cooperatives there is a kind of paradox. This entity, having a comprehensive legal regulation, i.e. a support mechanism eliminating the distribution fee, allowed the creation of only one such entity, where in the case of energy clusters, despite the lack of support mechanisms, over 60 entities were created. In addition, the problem is the statutory requirement to install sufficient RES capacity to ensure demand for no less than 70% of the cooperative's and its members' needs. The result of this provision is increased financial outlays already at the initial stage of investment implementation, even before the cooperative is transformed into an energy entity. Another barrier is the prosumer model of the support system, which gives the possibility to give surplus energy to a virtual power plant in the distribution network, which can be received at a ratio of 1:0.6 in net-metering system. The net-metering it is the accounting of the electricity produced from the PV installation with the electricity consumed during the billing period - kWh produced for kWh consumed (Górnowicz & Castro, 2020). This system makes it impossible for the entity to sell electricity, which discourages potential investors. At the same time, the very system of settlements between the cooperative and the obliged seller is complicated and, through the lack of appropriate procedures and regulations governing this aspect, effectively discourages future owners of the entity (Marzec, 2021). An additional problem is the requirement for a limit of 1,000 members of a given energy cooperative and the limitation of capacity to 10 MW. Moreover, there is no extension of this model to urban areas, which is quite a popular practice e.g. in Denmark (Mizieliński, 2019). It is worth noting that in these areas there are housing communities with fairly large free spaces where photovoltaic façade systems (building integrated photovoltaics, BIPV) can be installed, which are becoming increasingly popular. This will reduce the rising costs of electricity and heat for housing associations and communities (Agathokleous et. all, 2018). Information (Energetyka24, 2021) gives hope for an improvement of the current situation. At the end of July 2021, a draft amendment to the Law on Renewable Energy Sources was submitted to the Polish Parliament, which assumes, among other things, the abolition of the power limit, the extension of cooperatives' activities to urban areas and the possibility to store and sell energy, provided that this is not the main focus of the entity. These measures give hope for an acceleration of the energy transition, but the assumed amendment of the law will have to wait.

Returning to the subject of barriers and the number of 66 energy clusters without support mechanisms in place, it should be mentioned that this procedure took place in connection with two editions of a competition that gave interested parties the opportunity to obtain certificates. The Ministry of Energy at that time, when deciding on this step, guaranteed priority in access to funds for entities holding a certificate. So far, the energy clusters that have been awarded certificates have not had a dedicated support system developed, apart from the fact that investors had previously been involved (Biznesalert, 2020). However, referring to July 2021, the National Fund for Environmental Protection and Water Management has announced a call for proposals for the third edition of the New Energy programme. This programme offers for the first time co-financing in one of the six areas which are energy clusters. The programme is to be implemented until 2025 and up to 150 million PLN in repayable and non-repayable loans have been allocated to support clusters (NFOŚIGW, 2021). An additional positive aspect is the project launched by the Minister of Agriculture and Development on 30 March 2021 called "Rural development through renewable energy sources - Renew(albe) your Region - RENALDO. It is aimed at 6 municipalities in the Podlaskie and Kujawsko-Pomorskie Voivodeships and is designed to provide substantive support in the preparation of pilot energy cooperatives. In addition the project aims to transfer expert knowledge and experience in the operation and design of these entities in German rural areas (Marzec, 2021). Undoubtedly, the abovementioned measures constitute an important beginning of creating a support mechanism for such entities operating in the area of distributed energy.

1.3 The state of biogas technology

The complicated and unstable legal system has for some time also reached one of the most promising renewable technologies in Poland, namely biogas technologies. Referring to the operation of the legal system, attention should be drawn to the fact that one of the main barriers to development is the administrative and procedural difficulties and the widespread bureaucratization, which make it difficult to obtain a building permit for an installation or to connect it to the grid. Additionally, the legal system, being too slowly updated to meet the requirements of the European Union, intensifies the unwillingness of potential investors (Igliński et. all, 2020).

According to data (Rynekbiogazu, 2018) Poland, due to the specific nature of its economy with a strong agricultural focus, has the potential to produce 19 bcm of biogas per year, not including energy crops. The main problems for the development of this sector have been the lack of an appropriate legislative framework, the low level of support from the banking sector and the protests of local communities concerned mainly about the odour problems of installations (Wysokienapięcie, 2017; Fernandez et al., 2021). The biogas market in Poland is currently undergoing a renaissance with the introduction of a feed-in-premium (FIP) for installations >1MW covering 90% of the difference between the announced reference price and the average market value of energy sales. The reference prices are determined on the basis of the Regulation of the Minister of Climate and Environment of 16 April 2021 on the reference price of electricity from renewable energy sources in 2021 (Regulation, 2021) and the periods applicable to generators that won the auctions in 2021 (URE, 2021). In addition, a popular feed-in tariff (FIT) system was introduced, which for installations >500kW enables electricity to be sold at a fixed 90% of the reference price. (Magazynbiomasa, 2021).

1.4 The state of onshore wind energy

Another complication for the implementation of distributed energy is the proper preparation of the ground for the development of the cheapest renewable energy source, i.e. onshore wind energy. A certain limitation is the currently binding law on investments in wind power plants, commonly referred to as the 10H distance law. Under it, wind turbines may not be installed at a distance of no less than 10 times the height of the turbine (counting the highest point of the blade) from residential buildings and forest complexes including forms of nature conservation. The amendment to the Act, planned for autumn 2021, assumes, among others, flexibility of the 10H rule to adopt an absolute minimum distance of 500 meters from residential buildings, maintaining the requirement to locate installations on the basis of Local Spatial Development Plans, changing the area delimited by the 10H rule to the projected sector of impact (Infor, 2021). Analyzing the problems of the wind industry in Germany, e.g. the fear of low-frequency and infrasound noise and the impact on the landscape postulated by residents, or the protests of pro-environmental organizations and the blocking of defensive air corridors, it is necessary to keep in mind not to allow the over-saturation of onshore installations by designing regulations in such a way that they are socially acceptable (Kędzierski, 2020). This aspect is extremely important, because thanks to local involvement, giving the community a chance to participate in location decisions, it is possible to effectively develop distributed energy. Thanks to this, there is a prospect of increasing the ecological awareness of the inhabitants, which should be driven by local governments activating the local community through educational campaigns and ecological activities using available EU and national programmes. (Mataczyńska & Kucharska, 2020).

1.5 The impact of distributed generation on the power system

Commenting on the aspect of barriers and challenges, the impact of distributed generation on the electricity system should be mentioned. It is worth mentioning that renewable energy sources developing in dispersion, although they ensure lower transmission losses over a short distance to the final consumer, complicate the operation of the entire management system. This is due to the large number of energy exit points, through which the system is obliged to increasingly complex control and monitoring of network operation. Control problems may manifest themselves in losses, e.g. in the form of dissipated heat. In addition, frequency, voltage or phase shift disturbances are likely to occur. The legal requirement of the National Power System to receive energy from RES itself limits the autoregulation mechanism of the grid by a deviation of the nominal frequency: a decrease of the frequency when the grid is overloaded and an increase when it is underloaded. mode of operation of generation turbines with a deviation of a few percent, if there are larger deviations, problems arise with the operation of the grid, forcing, for example, the shutdown of inverters in PV installations. Referring to photovoltaics, but also to wind power plants, some daily and weather conditions have to be mentioned, i.e. passing cloud banks, windless periods, which influence the overall balancing of the grid. As a result of sudden drops in energy generation from RES, e.g. PV, dynamic increases in power demand can occur due to shortfalls in energy production. The more connections are integrated into the network, the more difficult it is for proper operation through problems with advance planning and ongoing stabilization measures. The cooperation of actors with distribution network operators should be supported by advanced ICT technologies, the development of smart meters and appropriate metering. Thus, by creating an active distribution network, the balance between electricity supply and demand will be improved (Skomudek, 2021; Piotrowski, 2021)

There is no doubt that the dynamic growth of RES capacity should be covered by stable generation sources, e.g. biogas plants, and intensive development of energy storage technologies (liquefied or compressed gases, chemical conversion of hydrogen). Referring to energy storage, information (Wysokienapięcie, 2021) show a certain upward trend. Energy storage projects are being implemented and planned, e.g. by Polish Energy Group - PGE, which plans to have 800 MW (figure 5), primarily in Tesla modular battery systems (GKPGE, 2021).

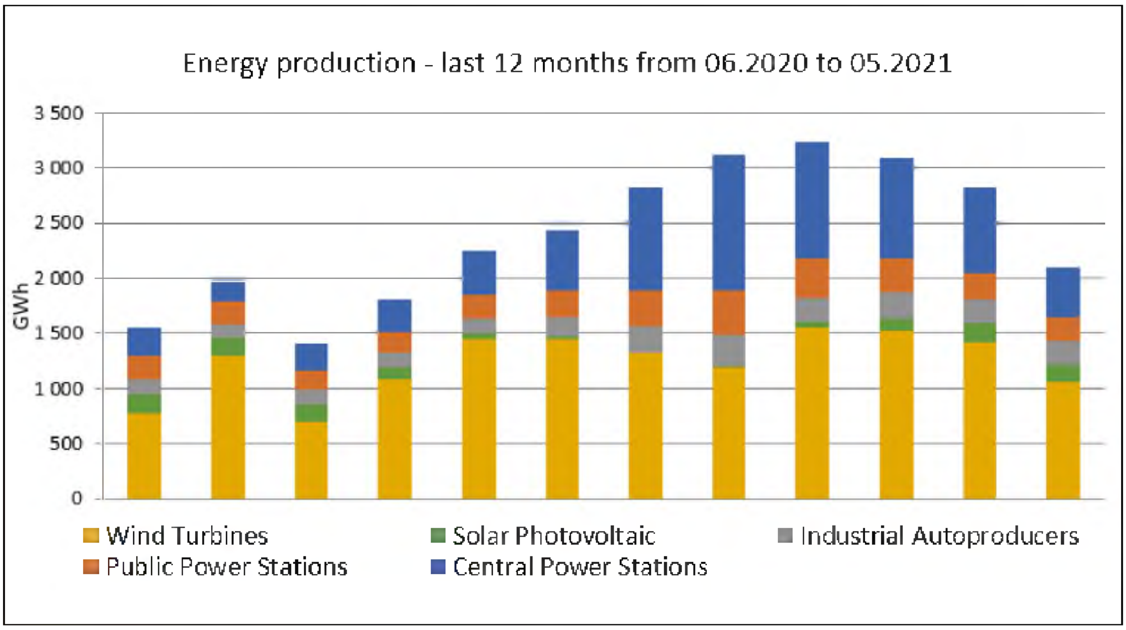
Figure 5. Planned and completed energy storage by PGE.

Source: Own elaboration based on: (Wysokienapięcie, 2021)

2.0 Distributed energy in Denmark

Denmark is a precursor of wind energy development and a clear leader in its implementation through local communities. Analyzing data from 2020, as much as 61% of electricity was generated from wind power supported by photovoltaic installations, with total production from wind at 46.5% (ENERGINET, 2021). Local energy communities forming cooperatives and wind energy guilds are a key element of the Danish model. By 2001, as many as 150,000 households were owners in wind projects; in 2015, small private wind power operators accounted for 50% of the total electricity market share (Johansen, 2021).

Figure 6. Energy production in last 12 months in Denmark (Energinet, 2021)



The history of development of Danish distributed energy goes back to the 1980s, when during the oil crisis it was decided to introduce a stable system in the form of FIT tariffs. In addition, Denmark with its very good weather and location conditions proved to be an ideal place for the development of this type of energy, including in particular wind turbines. The development was interrupted to some extent in 2003-2008, when legislative and political problems were encountered that limited the development of this energy segment. It was not until the introduction of the "Act on the Promotion of Renewable Energy Sources" allowed the reactivation of the energy transformation process (Mizieliński, 2019). The most important clause requires wind energy developers to offer for sale at least 20% of the value of projects in ownership shares to local investors, including individuals. The new provisions gave individuals the option to receive a right of first refusal of up to 50 shares if they reside within 4,500m of the development. It additionally introduced an increase in the FIT for installations that have a provision in the agreement to transfer a further 10% of ownership shares to citizens (residing within 16 km). In addition, a special early project risk mitigation measure for local groups has been introduced in the form of a guarantee fund, which, if the project comes to fruition, is converted into low-interest loans of up to a maximum of EUR 70 000 to cover the costs of a feasibility study. In addition to the state guarantees, citizens have the possibility to apply for compensation payments for the siting of wind installations at distances exceeding 25 metres. This is possible if there is a loss of property value of more than 1%. It should also be mentioned that the basic support scheme in Denmark based on a feed-in-premium (FIP) system since 2014 is financed directly by the relevant tax law. For wind energy, on-shore turbines are supported at a maximum of 0.33 PLN/kWh. Small wind turbines >25 kW are supported by a fixed FIT tariff depending on year of allocation and capacity for 12 years. Off-shore installations use an auction system, where the Danish Energy Agency determines the FIP together with its payment period by determining the number of hours the turbine operates under maximum load (Gorroño-Albizu, 2020; Mizieliński, 2019).

For PV installations in Denmark, there is a FIP system with net-metering. Energy producers with installations up to 50 kW are exempted from additional taxes, e.g. the Polish equivalent of the RES fee. Installations above this ceiling are only exempted from part of the obligation.. (Dziaduszyński et al., 2018). An interesting solution is a form of prosumer acting in groups. The 2013 Energy Agreement, which was signed by the government side, business representatives and pro-environmental organizations included a project called "zip code rose". This project involves the creation of a distanced net-metering model. In this model, energy consumers receive an energy tax deduction for the amount of energy produced by a collective RES project located in their postcode area or in a contiguous area. This deduction amounts to up to 10 Euro cents per kWh (Kooij et al., 2018).

2.1 Examples of local initiatives in Denmark

The wind turbine project in Hvide Sande is a flagship example of local initiative and citizen-business cooperation in the creation of local zero-carbon energy. The project in Hvide Sande came about after an unsuccessful initiative by private developers that was met with a lack of public acceptance. It was only with the establishment of the civic foundation 'Hvide Sande Business Development' in 2010 that as much as 9 MW of power could be implemented on the site, which was under the authority of Denmark's fifth largest port. Provisions were made to ensure 80% ownership of the wind farm by the foundation, with the remaining 20% belonging to the local community. Generated profits are used by the foundation to develop port infrastructure and other local facilities, providing a lever for employment and generating profits for the city. A model has been created aimed at activating the region by allowing citizens, local communities and the city to be a driving force towards the use of renewable energy sources (Folkecenter, 2016).

Another interesting solution is the local district heating company Fjernvarme Amba, which is co-owned by the heat consumers, i.e. the residents of the city of Gram. Almost all residents are connected to the network (2,500 people), the number of connected buildings is more than 1,200. Figure 7 shows the photovoltaic installation for water heating and the storage tank. In the background you can see the town and the heat storage tank at the gas CHP plant.

Figure 7. The solar water heating and heat storage pit. (Neimeier, 2021).

The project is innovative in that the heat store, which is powered by, among other things, solar energy that provides up to 61% of the demand and low-emission production, makes it possible to use the stored heat at times of fluctuating energy production from wind and PV power plants. In addition, at times when electricity prices are low (there is an oversupply of energy from renewable sources) a 10 MW electric boiler is used to produce energy, which accounts for 15% of the total heat production. Heat pumps, on the other hand, produce heat continuously except when the price of electricity is too high or the grid voltage is too low. If one of these reasons applies, heat can be produced by a cogeneration unit that is combined in an appropriate way with the heat pump and the electric boiler (Neimeier, 2021).

3.0 Summary

Progressive change in the electricity sector is a reality. A new energy mix based on new low- and zero-emission energy sources is a challenge that can be supported by exploiting opportunities for the development of distributed generation. The new configuration of the Polish energy sector is a great opportunity to build sustainable, local energy security, thus increasing the competitiveness of the region and activating the local community. In order to do so, Poland faces a number of challenges and barriers, which must be overcome to some extent in order to achieve the intended objectives contained in strategic documents, i.e. PEP2040.

Conclusions:

1. The lawmaking system needs to be improved, especially in the area of renewable energy sources. Current legislative processes should be brought in line with current EU legislation. Particular attention could be focused on reducing the level of bureaucracy and facilitating administrative and decision-making procedures. Additionally, it is necessary to accelerate authorization procedures for both the construction of installations and the connection to the grid.
2. In order to raise funds efficiently, Poland needs to create efficient regulatory tools and appropriate, clearly written laws that will enable and encourage more investment projects. Furthermore, it is recommended to implement a rule on support for the energy transformation process by local government units which will conduct educational campaigns to raise awareness of climate and energy issues among the inhabitants and encourage them to promote the development of RES.
3. The creation of laws must take place on the basis of previously developed standards, good practices e.g. from other countries such as Denmark or Germany, as well as public consultations. An interesting way of activating local societies is the Danish model giving the possibility to buy ownership shares in e.g. wind farms, thus increasing the competitiveness of the region.
4. Support programs i.e. Mój Prąd promote changes in the structure of electricity generation. There is a visible increase in the share of solar energy, which is the leader of distributed sources in Poland.
5. The development of local energy entities should be focused on diversified sources of electricity. Poland, due to its large potential of stable sources of green energy from biogas and biomethane, should focus on the development of this segment of the energy sector drawing on experience from other countries and using modern Polish technologies.
6. The National Electricity System requires continuous modernization and development of transmission and distribution infrastructure to meet the demands of weather-dependent renewable sources. Development should be based on the use of the latest information and communication technologies that will enable real-time and future planning. Additionally, it will enable the creation of new tools to support local energy solutions.
7. Analyzing the Danish experience, it is necessary to create areas based on a closed-circuit economy, aiming to maximize the use of energy, heat and cold.

Bibliography

1. Agathokleous, R. A., Kalogirou, S. A., & Karellas, S. (2018). Exergy analysis of a naturally ventilated Building Integrated Photovoltaic/Thermal (BIPV/T) system. Renewable Energy, 128, 541–552
2. Tygodnik, G. P. (2021). Tygodnik Gospodarczy PIE (PIE Business Weekly) p.2-3, 6.
3. Dziaduszyński, K., Tarka, M., Trupkiewicz, M., & Szydłowski, K. (2018). Rozwój odnawialnych źródeł energii w sektorze Mikro , Małych i Średnich Przedsiębiorstw , w tym możliwość zastosowania rozwiązań Stan obecny i perspektywy rozwoju *(Development of renewable energy sources in the sector of Micro , Small and Medium Enterprises , including the possibility of applying solutions The current state and prospects for development*). Ministry of Energy, p.17-24
4. Fernandez, M.-, Cetnarski, R., & Wawrzyniak. (2021). Lokalny wymiar energii - Raport z prac. (*The Local Dimension of Energy - Work Report)*, KlastER, s.56-86
5. Gorroño-Albizu, L. (2020). The benefits of local cross-sector consumer ownership models for the transition to a renewable smart energy system in Denmark. An exploratory study. Energies, 13(6).
6. Górnowicz, R., & Castro, R. (2020). Optimal design and economic analysis of a PV system operating under Net Metering or Feed-In-Tariff support mechanisms: A case study in Poland. Sustainable Energy Technologies and Assessments, 42, 100863, p.134-143
7. Igliński, B., Piechota, G., Iwański, P., Skarzatek, M., & Pilarski, G. (2020). 15 Years of the Polish agricultural biogas plants: their history, current status, biogas potential and perspectives. Clean Technologies and Environmental Policy, p.7-17
8. Johansen, K. (2021). Blowing in the wind: A brief history of wind energy and wind power technologies in Denmark. Energy Policy, 152, p112-139.
9. Kędzierski, M. (2020). Kryzys branży wiatrowej w Niemczech Kolejne zagrożenie dla Energiewende. (*Wind industry crisis in Germany Another threat to the Energiewende*) Ośrodek Studiów Wschodnich Im. Marka Karpia (*Marek Karp Centre for Eastern Studies*), 309, p.1–8.
10. Kooij, H. J., Oteman, M., Veenman, S., Sperling, K., Magnusson, D., Palm, J., & Hvelplund, F. (2018). Between grassroots and treetops: Community power and institutional dependence in the renewable energy sector in Denmark, Sweden and the Netherlands. Energy Research and Social Science, 3, 7(2017), p.52–64
11. Marzec, T. (2021). Prawne perspektywy rozwoju spółdzielni energetycznych w Polsce (*Legal perspectives for development of energy cooperatives in Poland*). Internetowy Kwartalnik Antymonopolowy i Regulacyjny (*Internet Antimonopoly and Regulatory Affairs Quarterly*), 2(2), p.3–14.
12. Mataczyńska, E., & Kucharska, A. (2020). Klastry energii. Regulacje, teoria i praktyka (*Energy Clusters. Regulation, theory and practice*). Intytut Polityki Energetycznej im. I. Łukasiewicza (*I. Łukasiewicz Institute for Energy Policy*), p.46-85
13. Mizieliński, R. (2019). Energetyka rozproszona na świecie: modele funkcjonowania, regulacje, systemy wsparcia, wnioski dla Polski (*Distributed energy sector in the world: models of operation, regulations, support systems, conclusions for Poland*). KlastER, p.1–42.

14. Neimeier, R. M. (2021). Energy Master Planning for Resilient Public Communities — Best Practices from Denmark. ASHRAE Transactions, 127, p.1-19.
15. Rynek Fotowoltaiki w Polsce (*Photovoltaic Market in Poland*). (2021). Instytut Energetyki Odnawialnej (*Institute of Renewable Energy*), 1–66.
16. Skomudek, W. (2021). Wpływ energetyki rozproszonej na proces kształtowania elektroenergetycznego systemu dystrybucyjnego (*Impact of distributed generation on the process of shaping the power distribution system*). Energetyka Rozproszona (*Distributed Energy*), 5–6, p. 69–74.
17. Siudek, A., & Klepacka, A. Energy Clusters in Poland – a Theoretical Approach. Annals of the Polish Association of Agricultural and Agribusiness Economists, XXII(4), p.192–205

Internet sources:
1. ARE, 2021. Informacja statystyczna o energii elektrycznej, biuletyn miesięczny, Agencja Rynku Energii, 05.2021, nr 5(329), p. 1-24 (access: 30.07.2021)
2. Biznesalert, 2020. https://biznesalert.pl/oze-polska-farmy-wiatrowe-biogaz-klastry-spoldzielnie-prawo-energetyka (access: 30.07.2021)
3. EC, 2019. European Commission: Clean energy for all Europeans, 2019 https://ec.europa.eu/energy/en/topics/energy-strategy-and- energy-union/clean-energy-all-european (access: 28.09.2021)
4. Cire, 2021. https://handel-emisjami-co2.cire.pl/st,34,514,me,0,0,0,0,0,ceny-uprawnien-do-emisji-co2.html (access: 30.07.2021)
5. Energetyka24, 2021. https://energetyka24.com/spoldzielnie-energetyczne-teraz-takze-w-miastach (access: 30.07.2021)
6. ENERGINET. https://en.energinet.dk (access: 30.07.2021)
7. Eurparl,2021.https://www.europarl.europa.eu/legislative-train/theme-a-european-green-deal/package-fit-for-55 (access: 30.07.2021)
8. Folkcenter, 2017. https://folkecenter.wordpress.com/hvide-sande (access: 30.07.2021)
9. Globenergia, 2021. https://globenergia.pl/zarejestrowano-pierwsza-spoldzielnie-energetyczna-w-rozumieniu-ustawy-o-oze (access: 30.07.2021)
10. GOV, 2019. https://mojprad.gov.pl (access: 28.09.2021)
11. GKPGE, 2021. https://www.gkpge.pl/relacje-inwestorskie/magazyny-energii (access: 28.09.2021)
12. Infor, 2021. https://mojafirma.infor.pl/nieruchomosci/wiadomosci/5266784,Ustawa-odleglosciowa-uelastycznienie-zasady-10H.html (access: 30.07.2021)
13. Jędra M., Transformacja energetyczna w Polsce, Edycja 2021., FORUM ENERGII, www.forum-energii.eu /03.2021, s. 1-36 (access: 30.07.2021)
14. KOWR, 2021. https://www.kowr.gov.pl/odnawialne-zrodla-energii/spoldzielnie-energetyczne (access: 28.09.2021)
15. Regulation, 2021. Regulation of the Minister of Climate and Environment of 16 April 2021 on the reference price of electricity from renewable energy sources in 2021. https://isap.sejm.gov.pl/isap.nsf/download.xsp/WDU20210000722/O/D20210722.pdf (access: 28.09.2021)
16. Magazynbiomasa, 2021. https://magazynbiomasa.pl/systemy-wsparcia-dla-produkcji-energii-i-ciepla-z-biogazu (access: 30.07.2021)

17. NFOŚIGW, 2021. http://www.nfosigw.gov.pl/oferta-finansowania/srodki-krajowe/programy-priorytetowe/nowa-energia/nowa-energia-iii (access: 30.07.2021)
18. URE, 2021. https://www.ure.gov.pl/pl/oze/aukcje-oze/ceny-referencyjne/6539,Ceny-referencyjne.html (access: 28.09.2021)
19. Rynekbiogazu, 2018. https://rynekbiogazu.pl/2018/03/21/potencjal-rozwoju-sektora-biogazu-w-polsce (access: 30.07.2021)
20. Wysokienapięcie, 2018. https://wysokienapiecie.pl/2164-problem-z-regulami-wsparcia-dla-energii-z-biogazu-rolniczego (access: 30.07.2021)

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