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Wind energy in Poland – History, current state, surveys, Renewable Energy Sources Act, SWOT analysis

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ABSTRACT

The history, current state and prospects for the development of the wind power sector in Poland have been presented. Poland has a long tradition of using wooden windmills, mainly post mills for economic purposes. Basing on the data of the Institute of Meteorology and Water Management, the speed of wind was calculated in Poland at a height of 100 m. The highest wind speed in Poland is noted in the northern part, the central part and, most of all, in the south-western part. In the December 2015 there were 1016 wind installations in Poland of total power of 5100 MW in Poland. There are also 37 wind farms. At the largest farm – Margonin – there are 60 wind turbines in operation, each of power of 2 MW. The new formal and legal framework for the wind power sector in Poland was described in relation to the new Renewable Energy Sources Act (RES Act). The new regulations on funding the wind power sector; that is, an auction system, were presented. The outcomes of the sociometric surveys conducted among investors were described. The SWOT analysis of the wind power sector in Poland was presented. The three scenarios of the development of the wind power sector in Poland were described.

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1. Introduction

Since the Digital Revolution, which commenced in the middle of the 20th century, there has been a systematic global increase in demand for energy. This growth is exponential and, according to various forecasts for the near future, energy demand will reach 599 EJ in 2020 and 657 EJ in 2025 [1].

Wind power has been used by people since a long time ago. Along with the Sun, wind has been used to dry among others agricultural crops. The immense force of wind inspired our ancestors to harness it for economic purposes. Not many people realise that the great geographical exploration was possible due to wind energy that powered the sailing ships. Wooden windmills were used to grind grain, water or dry the fields [2,3].

The first description of a windmill used to transport water was created in India 400 BC; in China windmills in the shape of a windlass were used to water the fields 200 BC. At the beginning of the AD era windmills appeared in China and in the Mediterranean countries. The year 644 AD is considered to be the date of the first documented reference to windmills. The Persians ground grain by means of windmills since the 6th century AD. Unlike the construction design that became widespread in Europe, the Persian windmills had sails moving on a horizontal plane on a vertical cylinder. In the 8th century in the whole of Europe windmills with four sails appeared. The Dutch specialised in this type of construction [2,3].

The industrial development meant that new sources of electricity were sought. At the turn of 1887/1888 Charles F. Brush built the first automatic wind turbine that produced electricity. The power plant was constructed from cedar wood and consisted of 144 blades, had 17 m diameter and weighed 80 tonnes. Brush's power plant operated for 20 years and powered accumulators. Despite its large size, the power plant had the power of 12 kW, which was due to using a multi-turn and multi-blade rotor [4].

The wind energy sector plays an increasingly more important part in the global economy. Low fossil fuel prices had no negative impact on the wind sector. Wind power leads the way among environmentally-friendly methods of power generation in the world [5–8]. The global growth rate was 16.4% in 2014 and 17.2% in 2015. Poland, Brazil, China and Turkey were the most dynamic countries and saw the strongest growth rates (Table 1). China is a world leader in wind power generation – in adding 33 GW of new capacity. This represents a market share of 51.8%. The US market saw good performance with 8.6 GW of added capacity. Germany, in anticipation of changes in legislation, installed 4.9 GW. Wind power contributed a new record of 13% of the country's power demand in 2015. Brazil was the fourth largest market for new turbines with a market volume of 2.8 GW. India saw 2.3 GW of new installations by November 2015, enough to bypass Spain as fourth largest market in terms of total capacity [9].

Table 1
Top 15 countries by total wind installations [9].

Position	Country	Total capacity 2015 [MW]	Added capacity [MW]	Growth rate 2015 [%]
1.	China	148,000	32,970	29.0
2.	United Sates	74,347	8598	13.1
3.	Germany	45,192	4919	11.7
4.	India	24,759	2294	10.2
5.	Spain	22,987	0	0.0
6.	United Kingdom	13,614	1174	9.4
7.	Canada	11,205	1511	15.6
8.	France	10,293	997	10.7
9.	Italy	8958	295	3.4
10.	Brazil	8715	2754	46.2
11.	Sweden	6025	615	11.1
12.	**Poland**	**5100**	**1266**	**33.0**
13.	Portugal	5079	126	2.5
14.	Denmark	5064	217	3.7
15.	Turkey	4718	955	25.4
	Rest of the World	40,800	5000	14.0
	TOTAL	434,856	63,690	17.2

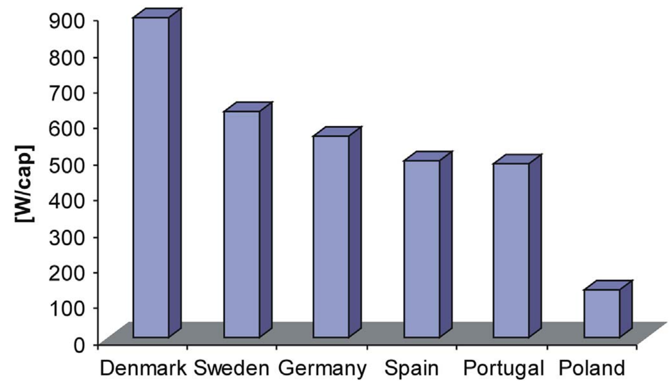

Fig. 1. Installed capacity per capita in 2015 in top five countries and in Poland [W/cap] (own calculations).

Fig. 1 represents the installed power of wind farms per person. The unquestionable leader is Denmark (888 W/cap). According to our calculations, Poland had the power of 132 W per person.

It is also worth mentioning that the global market of small wind turbines is developing very well. It is estimated [10] that there are at least 870,000 of small wind turbines in the world, with an annual increase of 8–10%. Around 625,000 turbines operate in China, 157,700 in the USA, 24,000 in Great Britain, 14,500 in Germany, 11,000 in Canada, and about 3,200 turbines in Poland [10–12].

The aim of this paper is to examine the history, current state and prospects for the development of the wind power sector in Poland. Included is the description of sociometric surveys sent to both the companies [13] and the owners of wind turbines [14]. The research presented in the paper is the continuation of further investigations into bioenergy in Poland [15], geothermal energy in Poland [16] and solar power in Poland [17] carried out by our research team.

The wind power sector already plays a huge part in power generation in Poland. Along with hydropower, solar energy and biomass energy, wind power is a part of the energy mix in Poland. The high price of Polish coal and its negative environmental impact result in ever growing support for the renewable energy in the Polish society. As the new Act on Renewable Energy Sources in Poland came into force, a new SWOT analysis new bill on wind power investment in Poland were also presented. The strategy for the development of wind power sector in Poland for the coming years was presented.

2. Use of wind energy in windmills in Poland

Wind turbines used to harness renewable energy are becoming more frequent in Poland. It is worth mentioning that wooden windmills have been known in Poland for a few hundred years. According to Gloger [18], windmills were introduced to Poland from the west whilst Małyszczycki [19], Sackiewicz [20] and Klaczyński [21] see their origin in the east. The 15th century images of windmills that were found in Poland unequivocally indicate the type of a windmill with a horizontal axis, which is a western type.

The first preserved documents related to the economic use of wind power date back to the 13th century. The first document is a construction permit for mills powered by water or wind granted to the monastery in Biały Buk (the north-western Poland) by prince Wiesław of Rügen [22]. Although the note mentioned earlier cannot be treated as evidence of a windmill construction, it proves the knowledge of harnessing wind power to move millstones. It is the document in which the Pomeranian princes gave the Cistercian monastery in Szczecin seven water mills and land between the monastery and the water windmill [22]. In the 14th century windmills became an integral part of Poland [23]. In 1303 a windmill was in use in Kobylin (between Wroclaw and Poznań) [22], another source is from Wschowa, dates back to 1325 and concerns the ownership of mills, including a windmill for Wschowa.

In 1377 a permit was granted to construct two windmills in the vicinity of Chojnice. In 1394 the chapter of Bishopric of Pomerania gave permission to construct a windmill in Rusinowo near Kwidzyn. In 1396 the Malbork convent gave permission to build a windmill in Święta Lipka near Gdańsk [24].

The first images of windmills in Poland also date back to the 14th century. An example of these is found on a seal (Fig. 2) attached to a document from 1382; the seal itself thus could be even older [25,26]. Despite the obvious simplicity of the image, it is easy to identify certain construction details: sails, a vertical wooden post around which the whole building rotated known as sztember as well as mill's trestles. This type of a windmill, with a horizontal rotation axis and vertically aligned sails, is a western type of a windmill.

The number of windmills increased regularly in the following centuries; however, this increase was spread unevenly in different regions. In places with adequate hydrographic conditions water mills dominated, which was due to their greater efficiency and reliability. The greatest boom of windmills in Poland took place in the 19th century as a result of numerous favourable administrative regulations. The enfranchisement of peasants took place in all parts of Poland under partition; there was no longer an obligation for the inhabitants of a given village to grind their grain in an allocated mill. The technological development meant that windmills were increasingly built to meet the own needs of a farm [23,26].

The Polish sector of windmills was virtually destroyed as a result of World War II. In 1939 there were over 7000 windmills in operation, of which 60% was totally obliterated. The remaining ones fell into disrepair due to lack of maintenance after the war. According to Pawlik [27], in 1954 there were 3280 windmills, of which only 63 were deemed fit for exploitation. The centuries – long tradition of windmills in Poland came to an end. Well-preserved windmills can nowadays be found mainly in open-air ethnographic museums.

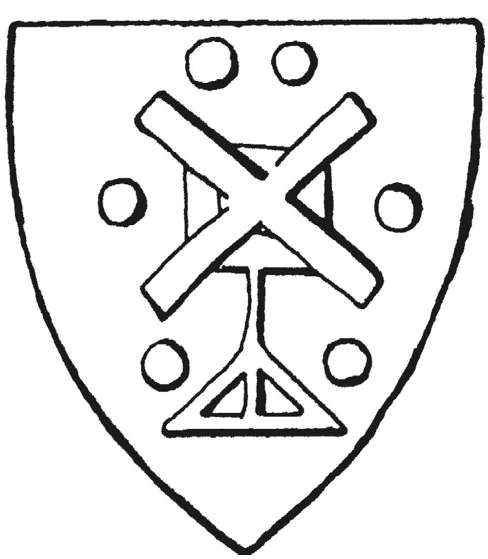

Fig. 2. An image of a windmill on the seal from 1382 [23,26].

Windmills used in Poland are characterised by various construction designs. Post mills, which can be found throughout Poland, have a stationary base on which mounted is a huge stationary axis around which the whole mill building rotates. This category includes trestle post mills (in Polish known as koźlak type of a mill) and Sokółka types of a windmill [26].

2.1. Trestle post mills – design and operation

The trestle post mill is the oldest type of a European windmill and the most common windmill in Poland. It was first constructed in Belgium or northern France in the 12th century; however, its prototype can be found in the 7th century in China and Persia. The trestle (in Polish kozioł) was a special base supporting a post – a vertical axis around which the whole building and machinery rotated so as to align the sails according to the wind. A more durable brick or stone construction replaced the wooden trestle, especially from the 19th century onwards. Concrete was later used for the same purpose. A wooden 8–9 m long rod (in Polish known as dyszel – a drawbar or łogon) attached by one end to the inner beams of the windmill and specially supported at the other end was used in order to rotate a windmill. At the outer end of the wooden rod there was a chain attached to a wheel and axle. When the rod approached the wheel and axle, the setting was stopped, the chain was unwound and the wheel and axle device was moved to an already prepared location where the wheel and axle would stay in place during its operation. Horses were sometimes used instead of a wheel and axle. Sails powered by wind were most often employed to move the devices to grind grain for flour. The rotation speed was regulated by removing (in order to lower the speed) or by adding (to increase the speed) wood staves on the mill's sails. The trestle construction consisted of two crossing ground beams (known in Polish as przyciesie). In the place where ground beams crossed, joined with a complex cruciform joint, a huge vertical axis was erected (known in Polish as sztember), at the end of which there were four runners reaching the bottom edge of the ground beams. The vertical axis – sztember was usually made of pine wood and less often of oak wood [23,26].

A trestle post mill could grind between 60 and 70 tonnes of grain during 120–150 windy days. The whole post mill was made of wood with the outside most often covered with shingles. A trestle post mill had three floors – the bottom one housed the stabilising construction of a trestle and the two top floors were assigned to flour production (the mill stones were contained on the middle floor). The shingle-covered walls did not initially reach the ground (due to cost and weight) and exposed the trestle, which could be seen from a distance. Post mills appeared in Poland as early as in the 14th century, the earliest in the regions of Wielkopolska and Kujawy. Their use was already widespread in the 15th century. Without major design changes, they survived as long as the second half of the 19th century. Fig. 3 represents a trestle post mill located in the Museum of the Mazovian Countryside in Sierpc. The windmill was constructed circa 1860 and was brought to the open-air ethnographic museum from nearby Zalesie [28].

A different type of a windmill is the Sokółka type of a windmill, which can only be found in the vicinity of Sokółka in the north-east of Poland. In terms of the structure of buildings and inner mechanisms, they are similar to trestle post mills. Their stone base

Fig. 3. A trestle post mill in the Museum of the Mazovian Countryside in Sierpc (photography: B. Igliński).

Fig. 4. A statue of a windmill in the Museum of the Mazovian Countryside in Sierpc (photography: B. Igliński).

in the shape of a truncated cone is another characteristic feature of this type of a windmill [28].

Drainage scoop windmills were used to remove the excess water. In Poland drainage scoop windmills were found mainly in the Żuławy region; unfortunately, none survived in this area. A trestle post mill was the most popular and simplest type of a drainage windmill in the Żuławy region. Its small working building, which had the form similar to a cube and which was placed on a wooden or brick foundation, was rotated towards the wind. Drainage scoop windmills were placed at the canals equipped with appropriate sluice gates. Sluice troughs were slightly wider than the blades of a wheel. Using these troughs, rotating scoops pushed water to an adjacent to a windmill, higher reservoir. During drought periods, the wheels rotated in the opposite direction – their function changed from drainage to irrigation [28].

Throughout centuries, including the present times, windmills have been frequently represented in pictures and sculpture. Fig. 4 represents a small windmill statue, which is a part of the exhibition in the Museum of the Mazovian Countryside in Sierpc (summer 2012).

It is worth mentioning that in Poland millers enjoyed great authority in the countryside; they tended to be rather wealthy. A windmill was not only a place where services were offered, but also where all kinds of business were made. It can be even said that it was the centre of social life. Due to their comfortable economic situation, millers were the first to introduce new tools or crops in their smallholding. Plenty of evidence that has survived until the present times suggests that throughout nearly six centuries wooden windmills played an important part in the lives of Poles. This is exemplified by local names (e.g. a locality of Śmigło (Rotor) in the Wielkopolskie Voivodeship) or dance styles "wiatraki" (windmills) in both ballroom dancing and group dancing [28].

3. Recent development in renewable energy sector in Poland

After World War II the renewable energy in Poland was solely provided by the hydropower sector and its percentage did not exceed 2%. For more than a decade other types of RES have been developed in Poland: bioenergy, solar power and, most of all, wind power. The renewable energy sector in Poland has been recently developing increasingly dynamically. The percentage of primary renewable energy kept systematically increasing in Poland in 2000–2015 (Fig. 5) [29–31].

The renewable energy sector in Poland is developing in accordance with the government's guidelines. According to the National Renewable Energy Action Plan [32] the power of renewable energy installations in Poland was supposed to reach 5204 MW in 2014, but the power was actually bigger – 6029 MW. This was mainly caused by the much quicker development of wind power plants than originally assumed; their total power reached 3834 MW at the end of 2014.

It is worth mentioning that in December 2015 in Poland there were 747 hydropower plants of total power of 980 MW, 36 biomass power plants of total power of 1008 MW, 259 biogas power plants of power of 152 MW [33] and 1016 wind power installations of total power of 5100 MW.

According to Poland's Energy Policy until 2030 [34], a balanced use of different types of renewable energy will be supported. In terms of biomass utilisation, a particular preference will be given to the most energy efficient solutions, among others, those using

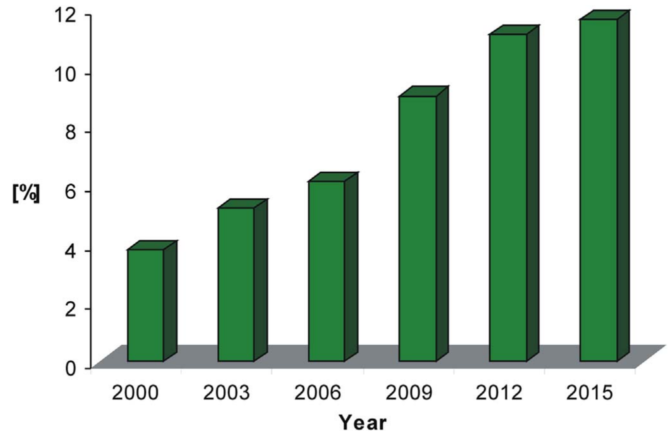

Fig. 5. The percentage of RES in energy production in Poland (own calculations based on: [30,31]).

different gasification techniques and conversion into liquid fuels, especially second generation biofuels. With regard to the wind power sector, its development is planned both on land and off shore. This is supposed to result in:

- at least 15% increase of renewable energy percentage in the final energy consumption in 2020 and a further growth of this indicator in the following years,
- achieving a 10% share of biofuels in the transport biofuels market in 2020.

4. The wind power sector in Poland – the current state

The first papers on use of wind as a source of energy in Poland appeared in the 1980s [35,36]. The first extensive expert assessment of the wind power resources in Poland was the paper by Halina Lorenc in 1996 [37].

An inverse distance weighted interpolation was carried out using the data from the Institute of Meteorology and Water Management in Warsaw: the monthly average wind speed, the monthly average wind direction (8 directions) for the years 1990–2014. The data on wind speed were obtained from 450 stations of the Institute of Meteorology and Water Management. Obtained average speed values at 10 m were used to calculate average speed values at a height of 100 m:

$$v_1 = v_p (h/h_o)^k \tag{1}$$

where v_1 – wind speed at 100 m [m/s],
v_p – average speed at 10 m [m/s],
h – rotor's height, here 100 m,
h_o – height 10 m,
k – index exponent, k=0.14–0.30 [38], was assumed to be 0.22.
substituting:

$$v_1 = v_p (100/10)^{0.22} = v_1 = 1.66 v_p \tag{2}$$

Obtained results were shown in Fig. 6 – the highest wind speed in Poland was noted in the northern and central parts. It is worth mentioning that the average wind speed in Poland keeps increasing (Fig. 6).

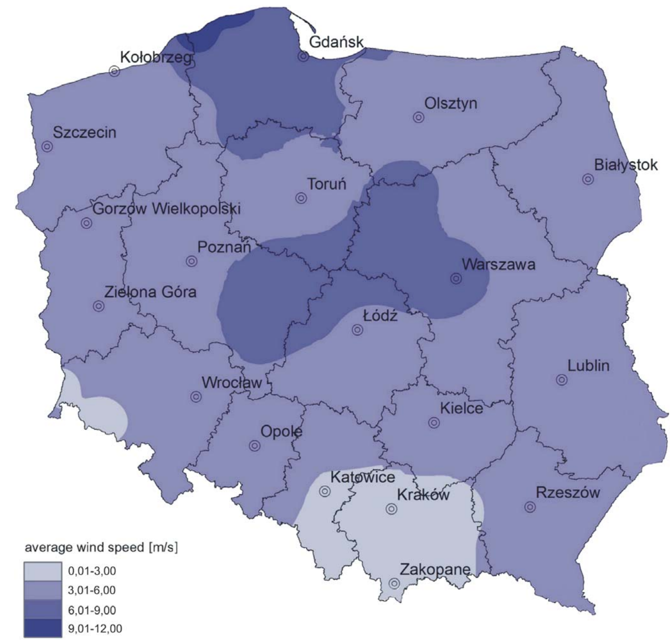

Fig. 6. Wind speed in Poland at 100 m (own calculations).

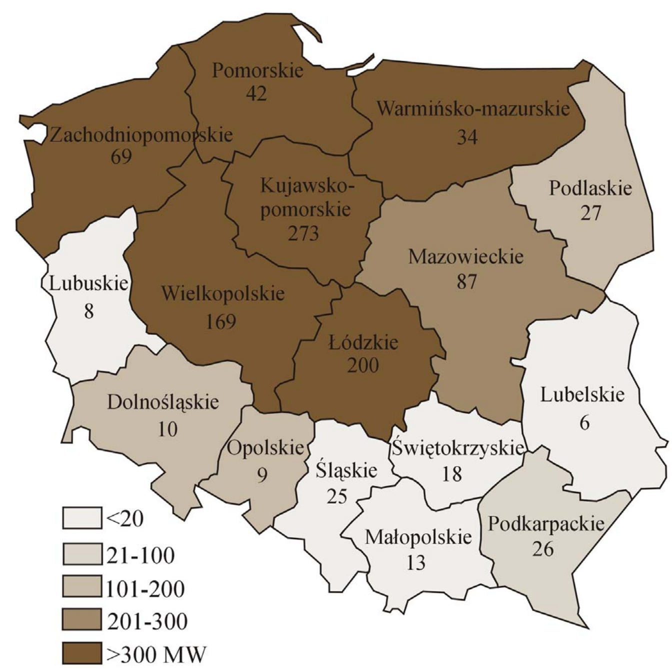

Fig. 7. The power and number of wind power installations in individual voivodeship regions (own calculations based on [30]).

Wind power generation is the most dynamically developing branch of renewable energy sector in Poland. According to the data of the Energy Regulatory Office [18], the total power of wind turbines in Poland was 1600 MW at the end of 2011. The amount of 3090 GW h of electric power was produced. In the end of 2015 there were 1016 wind installations (single turbines and farms) operating in Poland, of the total power of 5100 MW, which results in a nearly double increase in power [30] (Fig. 7). According to “The National Renewable Energy Action Plan” [32], the wind power sector will play a major role in implementing 15% of the

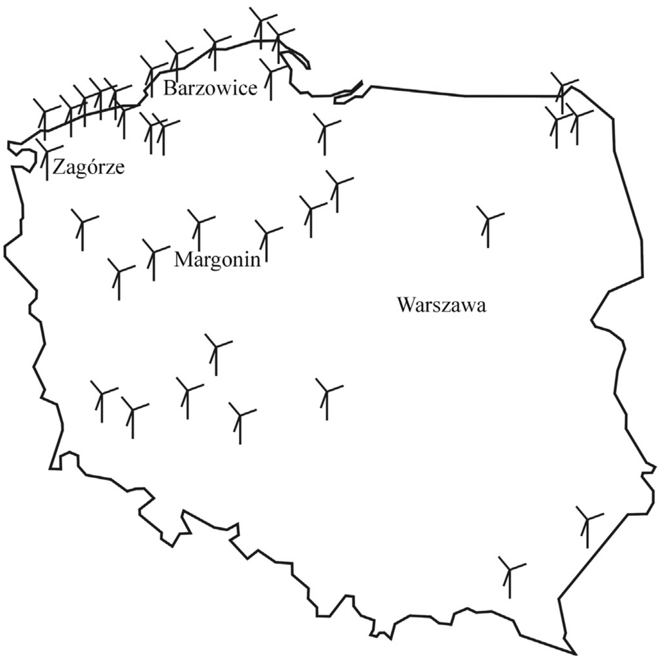

Fig. 8. The location of wind farms in Poland (own data based on [20]).

renewable energy target in the final energy consumption in 2020 (with the percentage reaching 13%). It is worth noting that in accordance with the stipulations of "The National Renewable Energy Action Plan", a further growth of power produced by inland wind farms, currently leading in wind power generation, will be complemented by a quick development of small wind power generation and off-shore wind power generation [32].

When analysing Fig. 7, it needs to be concluded that the wind power sector is experiencing a robust development in the Pomorskie Voivodeship (470 MW), Kujawsko-Pomorskie Voivodeship (480 MW), Wielkopolskie Voivodeship (500 MW) and above all Zachodniopomorskie Voivodeship (1200 MW). There is virtually no development of the wind energy sector in the Małopolskie Voivodeship (3.6 MW), Lubelskie Voivodeship (6.2 MW), and Świętokrzyskie Voivodeship (9.6 MW) [39–41]. Fig. 8 represents the location of wind farms in Poland [38]. The largest number of farms operate in the north and north-west of Poland [30].

The first wind farm in Poland of power of 5 MW was established in the locality of Barzowice (the Darłowo commune) in April 2001. Many years of trials, preparatory work and a few years of wind speed measurements in that region were followed by the investment implementation. The total cost of the investment exceeded the amount of 26 million PLN (1 USD=3.94 PLN, 18.02.16.). The farm consists of 6 wind turbines, each of power of 833 kW made by Vestas A/S company. The wind turbines are equipped with an automated control system that adapts the angle that the blades are set against the wind. The turbines work at the wind speed of 4–25 m/s. In case of wind speed exceeding 25 m/s, the power plant equipment is switched off automatically and the blades are set parallel to the wind direction. Each wind turbine is equipped with a rotor of three blades and diameter of 52 m; the tower's height is 67 m. Asynchronous generators have nominal power of 850 kW each, limited to the total power of the wind farm – 5 MW. Despite producing clean and cheap energy, the first wind farm in Poland met with the opposition of the energy companies, which refused to purchase renewable energy [28]. Other energy producing installations in Poland also encountered similar difficulties. This problem was solved by the Decree of Minister of Economy from 19th of December 2005 [42], imposing an obligation to purchase renewable energy.

The wind farm Zagórze is located near the village of Zagórze at the Bay of Szczecin, south-east of the island of Wolin. There are 15 wind power turbines, each of power of 2 MW, placed on the foundations, which were built using 5.26 km of reinforcing wire and 6750 m^3 of concrete. The total power of the wind farm is 30 MW. Each wind power plant is equipped with a Vestas V80 wind turbine with a rotor, consisting of blades and a hub placed at a height of 78 m, in the front part of the gondola set towards the wind. The total weight of the turbine is about 265 tonnes. The average wind speed in the vicinity of the Wind Farm "Zagórze", at the rotor's height, is 6.9 m/s. Every year 56–72 million kW h of electric power is generated by the farm, which corresponds to energy consumption by about 25 thousand Polish households [28].

The largest wind farm has been located in the locality of Margonin in the Wielkopolskie Voivodeship since 2009. The farm consists of 60 wind turbines of total power of 120 MW, which meets energy demand of 90 thousand households. The investment cost is 166 million Euro. At the start-up time, the total power of the farm reached nearly 10% of power from wind power plants currently operating in Poland [28].

5. The development of the wind power sector in Poland in relation to the new Act on RES

One of the most important legal regulations on energy trade in Poland is a duty to purchase electric power from renewable energy sources by companies trading in electric power and selling it to the final consumers [43,44].

A support system in the form of certificates has been in operation in Poland since 1 October 2005 and is based on the amended Act of 10 April 1997 – the Energy Law [45]. Green certificates can be sold, which in Poland takes place on Energy Exchange at the specially organised Proprietary Rights Market. There are two ways to participate in it; either directly or through brokerage houses. The support for energy sources of power up to 40 kW means that subjects stipulated in the act have an obligation to purchase energy. Certificates of origin for renewable energy sources are sold at the Power Exchange, where prices are subject by supply and demand. In 2013 prices varied between 129.55 PLN/MW h in March and 192.59 PLN/MW h in September. The sale of certificates of origin can also be subject to individually negotiated, long-term, bilateral contracts [28].

On 4 May 2015 a new Act on Renewable Energy Sources came into force [46]; it stipulates new regulations and conditions of electric power generation from renewable sources as well as mechanisms and tools supporting renewable energy generation. Formally, the Act will be binding from 1 January 2016; if a wind turbine has produced energy for the first time before the end of 2015, it will be supported by means of green certificates.

The new Act introduces auctions to replace green certificates that have been used until now. The minister responsible for economic matters defines by means of an ordinance, no later than 60 days prior to the first auction to be carried out in a given calendar year, the maximum price in PLN for 1 MW h, at which renewable electric energy can be sold by its producers by means of an auction in a given calendar year. This maximum price is later called "the reference price" and refers to:

- the total installed electric power no bigger than 1 MW, generated using on-shore wind power,
- the total installed electric power bigger than 1 MW, generated using on-shore wind power [46].

At least once a year auctions are announced, organised and conducted by the President of the Energy Regulatory Office. Separate auctions are conducted for renewable energy sources of power up to 1 MW and those of power above 1 MW. An auction is conducted electronically by means of an electronic auction platform with the condition of at least three valid offers having been submitted [46]. Auction participants cannot view the offers made by the remaining participants. Offers with prices above the reference price are discarded. An auction is won by those participants who offer the lowest sale price of renewable energy – until the limit of renewable energy set in an announcement for a given auction has been used up. If there are a few auction participants who offered the same lowest sale price for electric power, then the sale is determined by the order of submitting offers.

According to the Act on Renewable Energy Sources, in case of an auction for new investment projects, when setting reference prices, the Minister of Economy should consider among others the following: technical and economic parameters of an installation's operation, investment costs incurred during preparation and construction of the project and necessary technical infrastructure and operating costs as well as additional investment costs incurred during the exploitation period when the installation is still covered by support mechanisms and instruments. According to the draft of the Regulation, reference prices for the new investments in renewable energy sources will be as specified below for each technology:

1) agricultural biogas plants of power up to 1 MW–450 PLN/MW h,
2) agricultural biogas plants of power above 1 MW–435 PLN/MW h,
3) waste site biogas plants – 210 PLN/MW h,
4) sewage treatment biogas plants – 400 PLN/MW h,
5) biogas plants using biogas different than specified in point 3 and 4–340 PLN/MW h,
6) combustion of biomass in designated co-firing installations or hybrid systems of power up to 50 MW–415 PLN/MW h,
7) combustion of biomass in designated co-firing installations or hybrid systems of power up to 50 MWe, in highly efficient co-generation – 435 PLN/MW h,
8) combustion of biomass in designated co-firing installations or hybrid systems of power up to 50 MWe and combined thermal generating capacity of up to 150 MW tonnes, in highly efficient co-generation – 420 PLN/MW h,
9) electric power generation from biodegradable industrial or municipal waste, including waste from water purification and sewage treatment, especially sludge from a thermal waste processing plant – 385 PLN/MW h,
10) electric power generation solely using bioliquids – 475 PLN/MW h,
11) on-shore wind turbines of power up to 1 MW–415 PLN/MW h,
12) on-shore wind turbines of power above 1 MW–385 PLN/MW h,
13) hydropower plants of power up to 1 MW–445 PLN/MW h,
14) hydropower plants of power above 1 MW–480 PLN/MW h,
15) geothermal energy – 455 PLN/MW h,
16) photovoltaics of power up to 1 MW–465 PLN/MW h,
17) photovoltaics of power above 1 MW–445 PLN/MW h,
18) off-shore wind turbines – 470 PLN/MW h [46].

In the Regulation on the auction basket for the projects of power up to 1 MW it was assumed that the average energy price for the winning projects in this group will be 470.01 PLN/MW h.

In 2016 the government will purchase by means of auction for the existing RES installations a total of 4,579,491 MW h of power, of which 2,289,745 MW h can come from sources that use less electric installed power than 4000 MW h/MW/year. The Regulation indicates that the maximum value of electric power in this project group will be 1,744,694,319 PLN.

A new solution mentioned by the Act is a 15-year support period which applies when a given issue is not regulated by the current stipulations of the Energy Law [45]. Until now there has been a lack of clearly defined period for being covered by mechanisms supporting renewable energy generation or agricultural biogas production. It needs to be stressed that the regulations aim at securing a 15-year support period for renewable energy producers. A separate issue is to limit to 10 years the maximum time during which the auctions to purchase renewable electric energy can be conducted. This is due to the European Commission's regulations on supporting the environmental protection and energy generation. This period of time does not impact on the preservation of the acquired rights of the producers, who by means of auction gained a right to purchase renewable electric power for the whole period of 15 years. The above statement means that the European Union's regulations allow a possibility of an auction being carried out in the 10th year of the system's operation, where energy producers can receive support for the next 15 years (the formula: $10+15$) [28].

It is worth stressing that in order to keep proportions between the development of large and small installations, it is planned to have separate auctions for objects with installed power of up to 1 MW and objects with the installed power exceeding 1 MW. However, energy produced by installations with installed power below 0.5 MW will be purchased by so called “obliged purchasers” whilst energy generated by installations with installed power equal to or above 0.5 MW will be sold directly on the market. It is assumed that at least 1/4 of electric power should be generated by renewable energy installations of total installed electric power of up to 1 MW, which should result in utilising locally available resources [46].

An energy company's tariff for electric power transfer or distribution takes into account a fee for making renewable energy available in the national power network. The Act enables the development of the prosumer energy sector due to a guaranteed purchase price for renewable energy. A seller is obliged to purchase electric power from newly built renewable energy installations, including an energy producer from micro installations of power of up to 3 kW, at a set unit price, which in case of on-shore wind power is 0.75 PLN per 1 kW h. The price of purchasing electric energy from renewable energy installations of power of up to 3 kW, which have been described above, is valid until the total power of new sources starting their operation exceeds 300 MW or until this value is changed by an ordinance of minister responsible for economic matters, which is discussed below. A seller is obliged to purchase electric energy from newly built renewable energy installations, including an energy producer from micro installations of power from above 3 kW to 10 kW, at a set unit price, which in case of on-shore wind power is 0.65 PLN per 1 kW h [46].

The price of purchasing electric energy from renewable energy installations of power above 3 kW and up to 10 kW, which have been described above, is valid until the total power of new sources starting their operation exceeds 500 MW or until this value is changed by an ordinance of minister responsible for economic matters, which is discussed below [46].

A minister responsible for economic matters determines by means of an ordinance new prices for purchasing electric energy, which has been discussed above, taking into consideration Poland's energy policy and the information from the National Action Plan as well as the pace of technical and economic changes in particular electric power generation technologies from renewable energy installations [46].

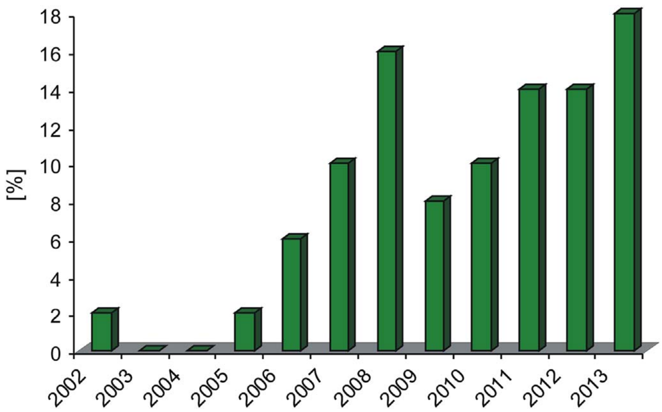

Fig. 9. The percentage of newly constructed wind turbines based on the survey data.

6. The wind power sector in Poland – survey research

Over 100 sociometric surveys on wind power in Poland were prepared and sent put to both the owners of wind turbines/wind farms [13] and companies selling/installing wind turbines [14]. We appreciate your valuable feedback. The surveys were prepared by authors and sent out as a hard copy. Over 50% of surveys were returned. This is far more than during the previous survey research [15–17]. Moreover, respondents provided us with a wealth of information about the investment and operation of their wind turbines.

Fig. 9 shows how many owners (percentage) manager to start their wind power plants. It can be seen that there was a wind turbine boom since 2006. The decrease between 2009 and 2010 was likely to be a result of the economic crisis. The number of erected wind turbines has been again on the rise since 2011.

Respondents stated that the waiting time for an investment was 2–6 years, with 4 years being the most frequent. It can be seen that the process of investment in wind power plants is long and time-consuming. In majority cases, planned investments depended on the size of a planned farm as well as obtaining necessary documentation (e.g. conditions of connection to the power grid, environmental certificates or a construction permit). Whilst the process of installation itself is very short, the above mentioned requirements necessitate a lot of commitment and patience during the investment process [13].

A few of the respondents emphasised that the wind power sector in Poland could develop much faster. The following were mentioned as the main barriers: lack of the law on renewable energy sources, complicated procedures and a long waiting time for necessary permits as well as the lack of political will to support the wind power sector [13,14].

Respondents had 2–60 of wind turbines, often located in different parts of the country. According to the survey, investors most often had 6 or 17 wind turbines. The cost of constructing a wind turbine depended mainly on its power and the year of its construction. It was 5–10 million PLN/MW on average. Nearly half of all the survey participants refused to answer the question about the costs.

Respondents provided the following reasons for commencing their activity:

- profit from the investment,
- following the example of the owners of other farms,
- something new at the Polish market,
- a desire to protect the environment.

Media often broadcast the information about numerous protests of the local community linked to wind power. Thus, such a question was posed. 42% of respondents experienced the opposition from the local community or/and an environmental group. The remaining 58% did not have any problems when constructing their power plants. A few of the respondents concluded that the appropriate choice of a wind power plant's location as well as education and consultation with the local community were very important [13,14].

Despite many challenges encountered by wind power investors in Poland, 86% of survey participants were satisfied with their investment. In addition, nearly 75% of respondents planned the installation of further wind turbines [13].

7. SWOT analysis of the wind power sector in Poland

SWOT analysis is a complex method of strategic analysis which includes both the inner part of organisation/project and environment. This tool identifies the most important strengths and weaknesses and comparing with the current and future weaknesses and threats [47,48]. The degree to which the internal environment of the firm matches with the external environment is expressed by the concept of strategic fit (Fig. 10):

- Strengths: characteristics of the business or project that give it an advantage over others,
- Weaknesses: characteristics that place the business or project at a disadvantage relative to others,
- Opportunities: elements that the project could exploit to its advantage,
- Threats: elements in the environment that could cause trouble for the business or project [47,48].

A SWOT analysis for the wind power sector in Poland was presented in the paper [49]. Since then the situation of the wind power sector in Poland has significantly changed since the Act on RES [46] came into force. In comparison to the paper [48], survey research was carried out in order to prepare this SWOT analysis (Table 2). Whilst preparing the SWOT analysis, the literature data, ordinances and legal regulations relating to the wind power sector in Poland were also used. The description of the SWOT analysis contains suggested solutions to the problems occurring in the areas of weaknesses and threats.

7.1. *Strenghths*

Poland has good wind conditions in the majority of its areas, which leads to a large theoretical wind power potential. The

Fig. 10. Scheme of SWOT analysis.

Table 2
SWOT analysis of the wind power sector in Poland.

Strengths	**Weaknesses**
• Good wind conditions in the majority of areas • Well-developed technology • Very high interest among investors • Financial support, including green certificates • Possibility of using micro power plants	• Complicated and time-consuming procedure to apply for a construction permit • High investment costs • Problems getting new wind turbines connected to the power grid • Potential threat to people and fauna • Impact on the landscape
Opportunities	**Threats**
• Technological progress improving the efficiency of wind power installations • Development of industry connected to the wind power sector • Improved energy security through diversification and decentralisation of electric power generation • Development of the off-shore wind power sector • Reduced emission of greenhouse gases • Development of a prosumer society	• Opposition from local communities • Possibility of introducing regulations restricting the location of wind turbines • Underbidding • No transition period between the certificate system and the exchange system • New bill on wind power investment in Poland

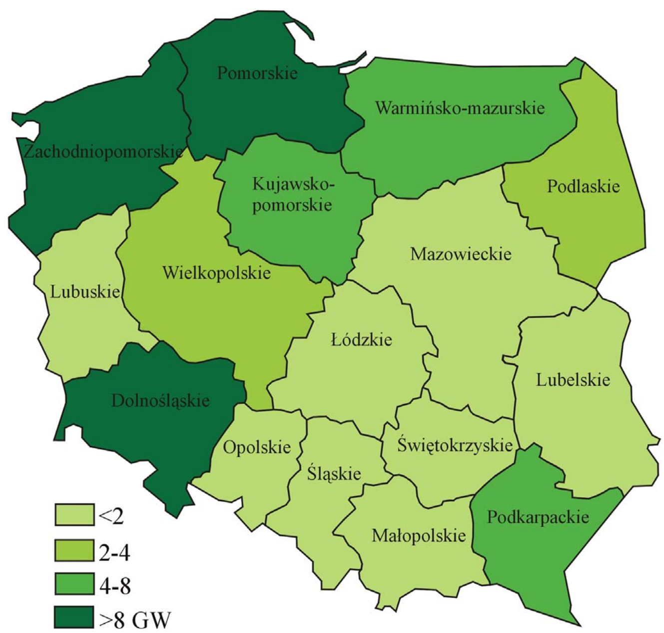

Fig. 11. The economic potential of the wind power sector in Poland, including environmental barriers [52].

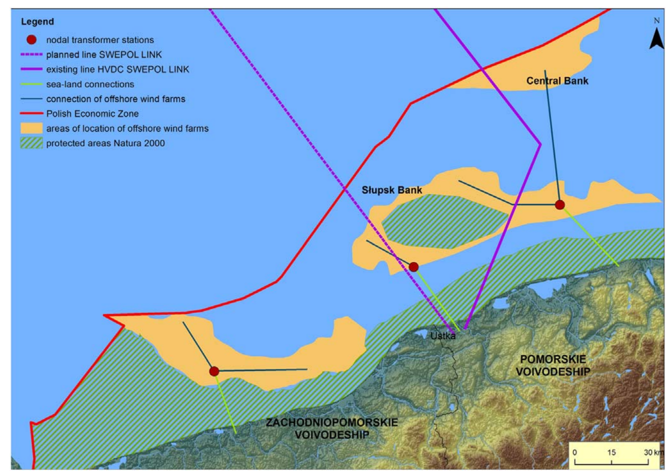

Fig. 12. Localisation of offshore wind farms in Poland till 2030 (own data based on [53]).

technical potential of wind power is mainly linked to the spatial distribution of open areas (characterised by low terrain roughness and lack of objects disrupting the air flow) [50,51]. This type of terrain tends to be the arable land, of which in Poland there is 18 million ha, which is 59% of the country's total area. Taking into consideration, the development of wind turbine technologies for the terrain with low wind speed, it can be concluded that about 5% of agricultural land is suitable for technical exploitation by the wind power sector [52].

In terms of spatial expansion, a significant barrier to the development of the wind power sector, especially inland wind farms in Poland, is the increase in the amount of protected land, including areas belonging to Natura 2000 network. It needs to be stressed that the fact that a given stretch of land is protected does not necessarily mean that wind turbines will not be located there. According to the assessment's [52] stringent criterion, all protected areas will be excluded from the wind power sector's development. In addition, the buffer zones of protected land as well as densely populated areas will also be excluded. As a result, it was concluded that in 50% of arable land where it would be possible to harness wind power, it will not be practically possible to implement investments or investments will face significant challenges. The largest number of barriers occur in the northern and southern parts of the country, which is partly due to the overlap of the areas of high wind speed with the protected ones. It is also caused by the fragmentation of farm holdings and difficulties with finding location for turbines, which results from high distribution of settlement developments (e.g. Podkarpackie Voivodeship). Fig. 11 shows the economic potential of the wind power sector in Poland, including environmental barriers, calculated using the data from the Renewable Energy Institute [52]. The highest economic potential of the wind power sector in Poland is in the following voivodeship regions: Zachodniopomorskie, Pomorskie and Dolnośląskie.

Due to the length of its coastline and the area of its territorial waters, Poland has one of the greatest technical potentials of offshore wind power on the Baltic Sea – 130 GW (Fig. 12) [53,54]. The estimated potential of 130 GW was calculated by the Renewable Energy Institute [52].

Wind power producers in Poland have a wealth of experience – wind turbines have been working from over 20 years; the first wind farm was established as early as in 2001. Wind power generation is enjoying great interest from investors. This is due to: significant investment profits, following the example of other owners of wind turbines/wind farms as well as a desire to protect the environment. Investors generate profits from the sale of electric power and from the sale of green certificates. It comes as no surprise that as many as 75% of the wind turbines' owners are planning to purchase and install more [55]. Moreover, an increasing number of investors show an interest in constructing further wind turbines.

The total power of the wind power sector in the published conditions of connection to the grid and in the connection contracts is considerably greater than 18 GW [56]. The financial support in the form of green certificates is available to currently operating wind turbines and those that will begin operation before the end of 2015. The new Act introduces auctions to replace the green certificates that have been used until now.

The guaranteed price of purchasing electric power exerts a positive impact on the development of wind micro installations. They are already very popular in Poland. These tend to be commercial wind turbines of power of a few kW which are installed on roofs or at a mast near the house. Hybrid systems, combining wind turbines with other renewable energy sources, are used more often.

7.2. Weaknesses

Investors interested in the wind power sector in Poland need to show a great degree of patience and determination. The barriers they encounter are linked to a prolonged and complicated investment process, the success of which depends not only on the investor's competency and determination, but also on the attitude of the local authorities as well as self-government and environmental organisations.

The investment process can be divided into following stages:

Stage I – the conceptual stage (2–5 months):

1. Search for a location.
2. Initial analysis of wind conditions.
3. Analysis of environmental restrictions.
4. Analysis of social conditions.

Stage II – the formal-legal stage (2–4 years):

1. Securing rights to the land.
2. Wind measurement and choice of a wind turbine category.
3. Securing a change to the spatial development plan.
4. Obtaining conditions of grid connection from the Operator.
5. Drawing up the environmental impact report.
6. Signing the grid connection contract with the Operator.
7. Preparing a construction design of the farm and connections.
8. Obtaining environmental decisions.
9. Securing a construction permit.

Stage III – the financial stage (1–2 years).

1. Preparing financial engineering.
2. Contracts regarding the sale of power and certificates of origin.
3. Securing co-financing (credit, subsidies).

Stage IV – the implementation stage (1–3 years)

1. Choice of a turbine provider.
2. Choice of work contractors.
3. Investment implementation [28].

In order to obtain a construction permit for a wind power plant it is essential to secure decisions about environmental conditions, as a result of which it may be necessary to conduct the environmental impact assessment. Having a legally binding decision about environmental conditions, investors can apply for a decision about land development or, if the area has already a local spatial development plan, straight away for a construction permit [56,57].

The course of action regarding environmental conditions decisions, duties and rights of investors and local authorities as well as the public participation are stipulated by the act of October 3rd 2008 on providing information on the environment and environment protection, public participation in environmental protection and on the environmental impact assessment [56,57]. The course of action regarding conducting an environmental impact assessment is taken by the following bodies:

- local authorities – a commune head, mayor or a city mayor.
- Regional Environmental Protection Director – when a wind power plant is to be constructed in an enclosed area (airports, railway land, military land etc.).

Before the decision is taken, it is necessary to obtain an opinion of the district public health inspector. Once the application for a decision about environmental conditions for wind power plants which do not necessitate the environmental impact assessment (below 100 MW of total power), the body in charge of the process requests the opinion re necessity of the environmental impact assessment from:

- General Environmental Protection Director.
- District Public Health Inspector.

In order to do so, the investor submits the project outline specification with an initial analysis of potential environmental impact caused by the planned investment. If there is no need to conduct the environmental impact assessment in a particular case, the body in charge of the process can begin evaluating the evidence and take a decision about environmental conditions. Otherwise, the investor is obliged to conduct the analysis of environmental and natural as well as social conditions, including among others:

- monitoring of specific species of live organisms, which the project can impact on. In case of wind power plants, it is most often the monitoring of birds and bats, less frequently of particular insect species or vegetation,
- description of natural components of the environment influenced by the anticipated environmental impact,
- a power plant's impact in terms of noise pollution,
- the investment's impact on air, soil, water, landscape, climate, material goods,
- the investment's impact on people – including an analysis of existing and potential public conflicts, their causes and possibilities of negotiating with the inhabitants [56,57].

The local authorities in charge of decision on environmental conditions consider the results of agreements and opinions obtained from the General Environmental Protection Director and the District Public Health Inspector. The body in charge of procedure should also indicate which of these have been taken into consideration and which have not and why. When appealing against the decision on environmental conditions, the parties of the proceedings can argue against not only the final decision of the leading body, but also the decisions of bodies providing opinions or agreement [28].

The majority of investors complain about high investment costs. According to the respondents of the conducted survey [13,14] the cost of constructing a wind turbine in Poland reaches 5–10 million PLN/MW, which means that the waiting time for investment return is at least 8 years. Investors who want to develop wind power generation in Poland encounter increasing problems with connection to the power grid. The available connection power values published on the websites of distribution network operators (PGE Dystrybucja, Energa Operator, ENEA Operator, Tauron Dystrybucja, RWE Stoen Operator) indicate a very high number of areas where the connection of power plants of power of even 1 MW by 2018 is unlikely. This is due to a poor condition of the power grid in Poland as well as too many connection permits that have been so far granted, of which many are not implemented.

On the other hand the conducted analysis [58] focused on assessing the impact of wind power generation on the national power grid system and checking whether in the near future it would lead to an increase in balancing requirements of conventional units. The authors analysed possible power generation restrictions linked to balancing on wind farms. According to the research, wind farms that would be created by 2020 (12,000 MW; an estimate close to the potential calculated by the Institute for Renewable Energy) will not exert a significant impact on the national power system. The research findings indicate that the total number of hours for which power generation restrictions should be considered due to balancing should not exceed five hundred per year, and the duration of the largest restrictions does not exceed 10 h per year. The authors explain that these, on the whole not too great, restrictions result from considerable territorial distribution of farm location and thus result from differences in wind conditions and lack of correlation between changes in wind speed and random demand changes. Due to this, the wind power sector on principle does not increase its requirements towards balancing capacity of conventional units.

This issue can also be approached from a broader perspective of system costs, taking into account more versatile participation of variable renewable power in the system other than wind power, including photovoltaic sources. The international project GIVAR (The Grid Integration of Variable Renewables) also focused on this issue; its findings were published in the most recent report by the International Energy Agency (IEA 2011) [59]. The report's findings indicate that in Europe the wind power sector and the photovoltaic sector complement each other and thus additionally reduce total balancing needs and costs in regional power grid networks. The extension and modernisation of the power grid (especially the construction of cross-border interconnections will be of particular significance), changes to the power generation structure as well as currently introduced pilot solutions in terms of smart power grid systems will promote an increase in utilisation of wind power and easier grid integration in Poland, especially in 2016–2020 [59].

Weaknesses include negative impact exerted by wind turbines on people and fauna, in particular birds and bats. In Poland this happens in case of badly located, older wind turbines. The very close vicinity of wind turbines as well as noise and infrasound emitted by them can lead to a combination of symptoms that start when wind turbines commence their operation [60–65]. These are sometimes described as “a wind turbine syndrome”:

- headache,
- disrupted sleep pattern,
- vertigo and dizziness,
- nausea,
- concentration problems, irritability.

Wind turbines exert an impact on the landscape because they are high constructions (up to 150 m), have a colour contrasting with the background of the sky and the land surface and its many different forms of use and, in addition, they move. A wind farm is a system comprising of a few, a dozen or a few dozen of wind turbines together with so called related infrastructure (a transformer, access roads, a tower for measuring wind speed etc.) and is scattered over an area of a significant size. Therefore, it becomes the dominating component of the landscape of a given region [60–65].

The majority of cases when wind turbines had a significant negative impact on the value of the landscape are linked to location mistakes made in the early stages of wind power development. This is often due to a relatively small area having a concentration of power plants of different types and sizes distributed irregularly, which creates a sense of spatial chaos. Currently in Poland the local landscape conditions are analysed during the stage of designing a wind turbine so as to avoid any disruptions to the main view corridors [66].

7.3. Opportunities

The opportunities of the wind power sector include the continued global research into new types of turbines or improving the existing ones [67,68]. The development of the wind power sector boosts economic growth. As the growth of wind power sector in Poland is slow and hindered by administration barriers, the production of complete wind turbines has not developed in our country. On the other hand, the production of components and accompanying equipment for the wind power sector is significant and has a great development potential. For example, Aarsleff, a company from Świnoujście, produces concrete foundations for off-shore wind farms. Energomontaż Północ produces steel constructions, Shipyard Crist builds construction vessels for off-shore wind farms, Gdańsk Shipyard produces wind turbine towers, KK Elektronic manufactures control systems for off-shore wind farms. In addition, in Poland there are about 10 producers of small wind turbines. A further growth of the domestic wind power market would support the development of new manufacturing companies in this field. It is possible to utilise here the significant production potential of the Polish shipbuilding and electrical engineering industry as well as others [52].

Bilfinger Crist Offshore (BCO) has operated in Szczecin for two years. The company produces foundation for the jacket-type and monopole-type off-shore wind turbines as well as temporary platforms and other steel constructions using the most up-to-date batch production technologies. In December 2013 during an official ceremony the flag was raised on “Vidar” – a vessel for constructing and servicing wind farms. ”Vidar” is a specialised heavy lift jack up vessel equipped with a heavy lifting system for constructing and servicing off-shore wind farms. It is 140 m long and 41 m wide; it will be able to reach the speed of up to 11 knots. The vessel can be quickly transformed into a 1200 tonnes crane for installing off-shore wind farms. This is possible due to a special self-lifting system; that is, so called ”legs” of 90 m height, lowered to the sea bottom. This construction enables work to be carried out at a depth of even 50 m. The vessel has a positioning system of accuracy up to 1 m and houses among others a helipad on board [28].

The wind power sector in Poland employs about 5000 people. Assuming the full utilisation of the market potential, the number of jobs in the wind power sector could grow to about 60,000 in 2020 [52]. A positive impact of wind farms on communes' budgets also matters. In line with the results of earlier simulations and the accepted scenario for the development of wind power sector in 2020, communes could receive about 21.2 million PLN in the form of the property tax calculated from wind power plants located within the commune's area [52]. The main components of wind power plant and corresponding industry branches include:

- construction of towers, nacelles as well as rotor hubs (steel and metallurgical industry),
- generators, transformers, control systems (electric engineering industry),
- gear sets, rollers, couplings, brakes, bearing, hydraulic and pneumatic systems (engineering industry),

- composite blades for rotors (aviation industry),
- automation and control systems (manufacturers of industrial automation and electronic engineering) [28].

The development of renewable energy sources, including the wind power sector, improves the energy security through diversification and distribution of electric power generation. Electric power in Poland is produced in a few very large power plants. In case of a failure of any of them, electric power would not be available to even a few hundred thousand houses. Blackout is becoming a more common occurrence in Poland due to violent atmospheric phenomena caused by the climate change. For example, in 2008 as a result of significant wet snowfall there was a blackout in Szczecin (408,000 inhabitants) and neighbouring communes [28]. A failure of a few wind turbines (or another renewable energy source) would not disrupt the operation of the power network.

Due to the length of its coastline as well as the size of its territorial waters and exclusive economic zone, Poland has one of the biggest technical potentials of the off-shore wind power sector in the Baltic Sea [69,70]. Achieving 6 GW of power in 2025 will foster Poland's economic growth by fulfilling orders from related sectors and will lead to:

- reaching 73.8 billion PLN of total added value,
- 14.9 billion PLN of income for the public finance sector, including 12.2 billion PLN for the central budget, 2.7 billion PLN for local authorities,
- Avoiding emission of about 40 million $MgCO_2$ and related costs (about 1.6 million PLN).

The development of the wind power sector is an opportunity to reduce the emission of greenhouse gases, which will also help to improve the air quality in Poland. As a result of the power and heat sector that is based on coal, the air quality standards are not met in many regions of Poland throughout most of the year. A long-lasting exposure to toxic gases in the atmosphere leads to vascular diseases, cardiac arrest, stroke, asthma and allergies as early as during gestation period. The new Act on RES will foster the development of a prosumer society. According to the analyses carried out by the Ministry of Economy, there could be 37,500 of small renewable energy installations created next year, of which wind turbines will be a significant part. The dynamic development of renewable energy use will boost the growth of domestic companies providing installations for the renewable energy sector. This could significantly increase the competitiveness of the Polish economy, considering that the industry branches of economy are based on supply of innovative products (e.g. renewable energy installations) [46].

Due to its large domestic market, Poland could become more attractive as a place where foreign investment is located (both related to the production of renewable energy installations as well as research and development).

7.4. Threats

The construction of some wind turbines/wind farms is met with great opposition from the local community. Farmers are concerned about their health, crops and farm livestock. In certain regions of Poland attempts are made to restrict the new locations of wind turbines. For example, in the Kujawsko-Pomorskie Voivodeship (which has the highest number of wind turbines) there have been attempts to increase restrictions on locating wind turbines for the last few years [71].

The first RES auction will have about 140 investment opportunities of total power above 3700 MW. The very fact that the representatives of wind power sector submit over 3500 MW show the extent of the price competition within this renewable energy technology. This could lead to underbidding; that is, a situation when producers submit offers below their capacity to deliver. This is most likely to happen when there is a high number of projects in one of the baskets (> 1 MW and productivity up to 4000 MW h/MW/year) and the insufficient amount of megawatt hours available at auction in the same basket. In order to win auction and have guaranteed support for the next 15 years, wind power producers will submit low price offers. Producers who won auctions having declared too low prices might not be able to construct new energy generating installations. Another threat to the wind power sector in Poland is lack of a transition period between the certificate system and the exchange system. In 2016 there could be very few new wind power installations created as investors will wait to win an auction before commencing construction. This means that the new installations will begin only by the end of 2017 [46].

The bill on wind power investment [72] determines the conditions, rules and process of locating, implementation and exploitation of wind turbines as well as conditions of locating housing buildings in the vicinity of wind turbines. The most important stipulation of the Bill is that the minimum distance between houses and a wind turbine has to be 10 times the height of a wind turbine, including the highest point where its rotor could be located. The minimum distance will apply not only to housing buildings, but also to the border of land of environmental value – a national park, a nature reserve, a protected landscape park, Natura 2000 protected area or promotional forest complex. The wind power industry is concerned that when this act comes into force the development of wind power generation in Poland will be hindered.

8. Discussion

Wind power has been used in Poland for a few centuries. In the past wooden mills were used to grind grain. Wind power plants have been producing electric power for about 20 years; the first wind farm was established in 2001. The central parts of the country as well as the coastal areas have very good conditions for the development of wind power. The wind power sector generates a lot of interest among investors. This is due to: significant investment profits, following the example of other owners of wind turbines/wind farms as well as willingness to protect the environment. Investors reap profits from the sale of electric power as well as the sale of green certificates. Thus, it is not surprising that 75% of the owners of wind turbines are planning to purchase and install more wind turbines.

Barriers to the development of the wind power sector in Poland include most of all a long and complicated investment process, the success of which depends not only on how competent and determined investors are, but also on the attitude of local authorities and self-government and environmental organisations. It is very important for investors to choose the appropriate location of a wind turbine/wind farm, taking into consideration not only wind conditions, but also environmental aspects, impact on the landscape and interests of the local community.

The development of wind power also provides a huge boost to the economic growth. Although complete wind turbines are not produced in Poland, the production of components and accompanying equipment for the wind power sector is significant and has a huge development potential. The wind power sector in

Table 3
Comparison of production costs for different technologies [74].

Type of power plant	Cost of energy production (LCOE) [euro/MW h]	External costs [euro/MW h]	Cost of energy production taking into account external costs and the value of support [euro/MW h]
Coal-based	75	95	160–230
Nuclear	90	20	130
Gas	100	35	130–165
Wind (on-shore)	80	< 4	105
Photovoltaic	90	20	215

Poland employs about 5000 people. Assuming the full utilisation of the market potential, the number of jobs in the wind power sector could grow to about 60,000 in 2020 [52,73].

With regard to the paper [49] it needs to be concluded that the possibility of off-shore location of wind turbines is more of an opportunity rather than a strength, as currently there are no such installations in operation. We cannot agree with the statement that wind power generation is more expensive than conventional power generation. Table 3 contains the European Commission data “Subsidies and costs of EU energy” [74]. The cost of power generation (LCOE) from coal and wind is the lowest; however, when taking into account external costs and support costs, energy produced by wind power plants is by far the cheapest.

It is not true either that in Poland there is no development of the industry related to wind power generation. This industry has been previously described. In this paper [49] an increase in electric power generation was included among opportunities. We think that the electric power production in Poland will stay at a similar level due to the following reasons: there are no plans for new large economic investments, electric appliances are increasingly more energy-efficient, fewer children per woman are born, a number of elderly people who use less electricity is rising. It needs to be mentioned that the planned construction of a nuclear power plant will have no adverse impact on the growth of wind power sector in Poland. This plan will commence its operation no sooner than more than 12 years and will fill the gap left by closed down, non-efficient coal power plants.

According to ”Poland Energy Policy until 2030” [34] activities will be undertaken to increase the energy security by fuller utilisation of renewable energy sources. This programme necessitates significant legislative changes that would enable the development of the power grid infrastructure and the construction of new generating powers from renewable energy sources.

“The action plan for the years 2009–2012” [34], which was included in Annex no 3 to the Energy Policy, contains a list of measures aimed at removing some of the above mentioned barriers, including:

- implementing Directive 2009/28/EC (Action 4.1) into the Polish law,
- maintaining support mechanisms for renewable energy producers (Action 4.2),
- creating conditions favouring investment decisions about the construction of off-shore wind farms (Action 4.6).

Improving the energy security of the country is one of the nine priorities of the maritime policy of the Republic of Poland, which was included in a governmental document “The principles of the maritime policy of the Republic of Poland until 2020” [48]. This priority issue includes the development of the off-shore wind power sector. The document pays particular attention to the issues of the location of wind farms as well as distribution and transfer networks in selected internal marine areas. The document stresses the need to carry out research to identify the most favourable areas for their location, giving special consideration to the investment's impact on the environment and marine ecosystems as well as the costs of investment, exploitation and marine security. In addition, the document emphasises the necessity to make the procedures of granting construction permits for the Polish marine areas more efficient.

According to “The national renewable energy action plan” [34] there are three scenarios for the development of the wind power sector in Poland:

Scenario A

According to Scenario A, the development of the wind power sector at a current rate – annual increments will grow by 10% on average every year. This scenario does not assume the construction of off-shore wind farms or the development of small installations.

Justification: This scenario assumes it will not be possible to remove the majority of barriers hindering a faster growth of the wind power sector, including the construction of off-shore wind farms.

Feasibility study of the scenario: It contradicts the accepted “Energy Policy of Poland until” it does not assume that the barriers will not be removed [34].

Scenario B

A modified scenario from the accepted “Energy policy of Poland until 2030” was used as Scenario B.

Justification: It is cohesive, well justified and best supported by an analysis of conditions. Feasibility study of The scenario: It stands great chances of implementation provided there is a consistent economic policy, including energy policy.

According to Scenario B the size of installed power was to be at a level of 1100 MW in 2010. In the years 2011–2012 the installed power was anticipated to increase by 450 MW/year (wind farms on land). In addition, it was assumed that in 2020 it would be possible to start exploitation of an off-shore wind farm of power of 500 MW. It was also assumed that in the years of 2013–2015 power would increase by 60 MW/year, in the years 2015–2019 it would increase by 70 MW/year and in 2020 the installed power would grow by 80 MW [34].

Scenario C

A project prepared for the Polish Wind Energy Association by the Institute for Renewable Energy was used as Scenario C.

Feasibility study of the scenario: It is not possible to implement a full list of favourable changes, including a possibility to switch off the power grid components as needed for modernisation and extension. The number of possible switch-offs of power grid components at a time of increased electric power demand will be restricted as it is necessary to keep up reliable energy supplies to final recipients [34].

The development of off-shore wind farms in the Polish marine areas will bring measureable benefits to the Polish economy. Achieving 6 GW of power in 2025 will foster the economic growth of Poland due to processing orders from related industry branches and will result in:

- achieving 74 billion PLN of total added value,
- 14.9 billion PLN of income for the public finances sector, including 12.2 billion PLN for the central budget and 2.7 billion PLN for local governments,

- avoiding emission of about 40 million of tonnes CO_2 as well as the resulting costs (about 1.6 billion PLN).

In terms of the Polish presence on the international stage and encouraging foreign investors to invest in our country, Public Relations and reacting to international trends are of the utmost significance. Environmental protection is a very important part of policies all over the world and leads to the improvement of existing technologies and creation of new solutions, provides a basis for investment, generates new jobs and motivates research centres. Due to a dynamic development of the off-shore wind power sector, it is expected that the unit cost of electric power generation will decrease considerably. This could lead to a situation where the wind power sector will be one of the most economically competitive renewable energy technologies. This mainly results from the sector successfully learning, an increased scale of investment and the improved efficiency of wind farms.

9. Conclusions

1. Poland has an 800-year tradition of harnessing wind power for economic purposes.
2. Poland has good wind conditions. The northern and central parts of the country have particularly favourable wind conditions.
3. The power of wind turbines in Poland exceeded 5100 MW. There are a few dozens of operating wind farms, mainly located in the north of the country.
4. The new RES Act introduces auctions.
5. Respondents of surveys stated that the waiting time for an investment was 2–6 years, with 4 years being the most frequent.
6. Respondents provided the following reasons for commencing their activity:

- profit from the investment,
- following the example of the owners of other farms,
- something new at the Polish market,
- a desire to protect the environment.

7. The SWOT analysis has shown that the wind power sector in Poland has good chances for development. The greatest threat could be posed by introducing the new Act bill on wind power investment in Poland.
8. Small domestic wind turbines with a vertical rotation axis should be promoted to a greater degree. This would boost the development of energy prosumers in Poland.

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