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ANALYSIS OF THE DEVELOPMENT OF RENEWABLE ENERGY SOURCES IN POLAND

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Purpose: The analysis of the development of electricity obtained from renewable sources such as solar, wind and hydro in Poland.
Design/methodology/approach: The volume of electricity produced from three renewable energy sources in Poland: wind, hydro and solar, annually, from 2000 to 2020, was collected from Eurostat. Data were analyzed using the dynamics of phenomena tools and of time series forecasting.
Findings: The largest share of renewable energy sources for wind energy. Energy obtained from water has an ever-smaller share. The fastest-growing renewable energy source in Poland is photovoltaics. The arrangement of the share of individual resources will probably change in favour of solar energy.
Originality/value: The comparison analysis of three sources o renewable energy share from 2000 to 2020 was conducted. Forecasts for the next two years were made.

Keywords: photovoltaic, hydropower, wind energy, renewables.

Category of the paper: research paper.

1. Introduction

From the beginning of the 21st century, people facing the global warming effect are becoming increasingly conscious of the need to be concerned for the environment. On the other hand, the energy demand is growing very fast. Conversely, traditional energy sources are running out. The solution that combines environmental problems and the lack of energy resources is obtaining energy from renewable energy sources (RES). Overall, renewable energy sources are much more environmentally friendly than fossil fuels. It reduces the harmful effects of the energy sector on the natural environment (e.g. by reducing the emission of toxic substances, including greenhouse gases). In addition, increasing the use of these sources entails a greater degree of independence from imported energy supplies, which since the war in Ukrainian has begun, seems to be crucial. Legislative programs are introduced at the

government level to increase the share of renewable energy sources in the total energy supply (Fit for 55 2021; PEP2040 2021).

Regarding fit for 55, greenhouse gas emissions should be reduced by at least 55% by 2030 in European Union countries. Also, the share of renewable energy in gross final energy consumption should increase to 40%. Thus, in Poland, the PEP2040 program was introduced, which indicated that the share of renewable energy in the national structure should be at least 32% in 2030.

This article aims to analyze the development of RES as an electricity source in Poland from the beginning of the XXIst century. An analysis of electricity obtained from renewable sources such as solar, wind, and hydro was carried out to achieve this goal. Solar energy is converted into electricity using photovoltaic panels for direct electricity generation. Wind energy is used to generate electricity in wind turbines. Hydro energy is mechanical energy obtained from flowing water.

2. Literature review

Renewable energy sources are the subject of many scientific works. Researchers emphasize the significant role of RES in preventing climate change (Lin, Zhu, 2019; Cronin et al., 2018). Some scenarios of the development of RES in terms of the global warming effect were made by (Luderer et al., 2014). So the role of education in the development of RES was indicated in (Mehmood, 2021). The critical factor in the development of RES seems to be the attitude and motivation of potential investors in these sources. The factors influencing the decision to instal photovoltaics (Angowski et al., 2021; Zdonek et al., 2022; Ali et al., 2020; Jasiński et al., 2021; Tsaur, Lin, 2018; Angowski et al., 2021) as well as wind energy (Kaldellis et al., 2013) green technologies (Jabeen et al., 2021), and RES on the whole (Ropuszyńska-Surma, Węglarz, 2018) were investigated.

The situation of renewable energy has been explored in different regions of the world. In the European Union, research was conducted (Tutak, Brodny, 2022; Bórawski et al., 2019; Wolniak, Skotnicka-Zasadzień, 2022), also focusing on separate energy sources, like solar (Wolniak, Skotnicka-Zasadzień, 2022) or wind power potential (Enevoldsen et al., 2019; Leiren et al., 2020).

The research was also performed in individual countries such as Bangladesh (Uddin et al., 2019), China (Lin, Zhu, 2019), Spain (Heras-Saizarbitoria et al., 2011), Malaysia (Ahmad et al., 2017; Kardooni et al., 2016), Greece (Tsantopoulos et al., 2014), Brasil (Corrêa da Silva et al., 2016), Nigeria (Wojuola, Alant, 2017), New Zeland (Stephenson, Loannou, 2010) or Afghanistan (Jahangiri et al., 2019).

In Poland, research on renewable energy development was carried out on the whole (Piwowar, Dzikuć 2019; Mularczyk 2016; Kaldellis et al., 2013; Zarębski et al., 2021; Ropuszyńska-Surma, Węglarz, 2018; Brodny et al., 2020) or focusing on solar sources (Szałata et al., 2016; Zdonek et al., 2022; Mularczyk, Hysa, 2015), wind (Gnatowska, Moryń-Kucharczyk, 2019; Drożdż, Mróz-Malik, 2020; Pronińska, Księżopolski, 2021) or hydropower (Igliński, 2019; Rabe et al., 2020; Kałuża et al., 2022a, 2022b; Kubiak-Wójcicka, Szczęch, 2021).

Solar photovoltaics and wind energy are the most efficient and well-known renewable energy sources rapidly developing (Lehtola, Zahedi, 2019).

Literature research prompted to focus on three renewable sources of electricity: wind, water and sun, assessing their use. Therefore, the following research questions were formulated:

RQ1: What were the analyzed renewable energy sources' dynamics in the studied years?

RQ2: How has the share of solar, wind and hydro energies in RES changed in the studied years in Poland?

3. Methods

Data for analysis have been obtained from the open data website: Eurostat (Database - Eurostat 2022). Data was collected on the volume of electricity produced from three renewable energy sources in Poland: wind, hydro and solar, annually, from 2000 to 2020 (in GWh). The methods of analyzing the dynamics of phenomena and of time series forecasting were used in analyzing the data. The visualizations needed to illustrate the phenomenon have been created.

4. Results and discussion

Figure 1 shows the volume of electricity produced from researched renewables. Renewable electric energy production has been increasing, especially in the last decade. Overall, the electricity production from renewables raised from 4152 GWh in 2000 to 22 111 GWh in 2020. That means a total increase of 433% over twenty years, with an average yearly growth of 9%. Simultaneously, the renewables share in total energy production changed from the level of 3% in 2000 to the level of 14% in 2020. That means a fundamental change of 389%, with an average yearly increase of about 8%. It can be assumed that this growth is mainly due to the development of wind farms.

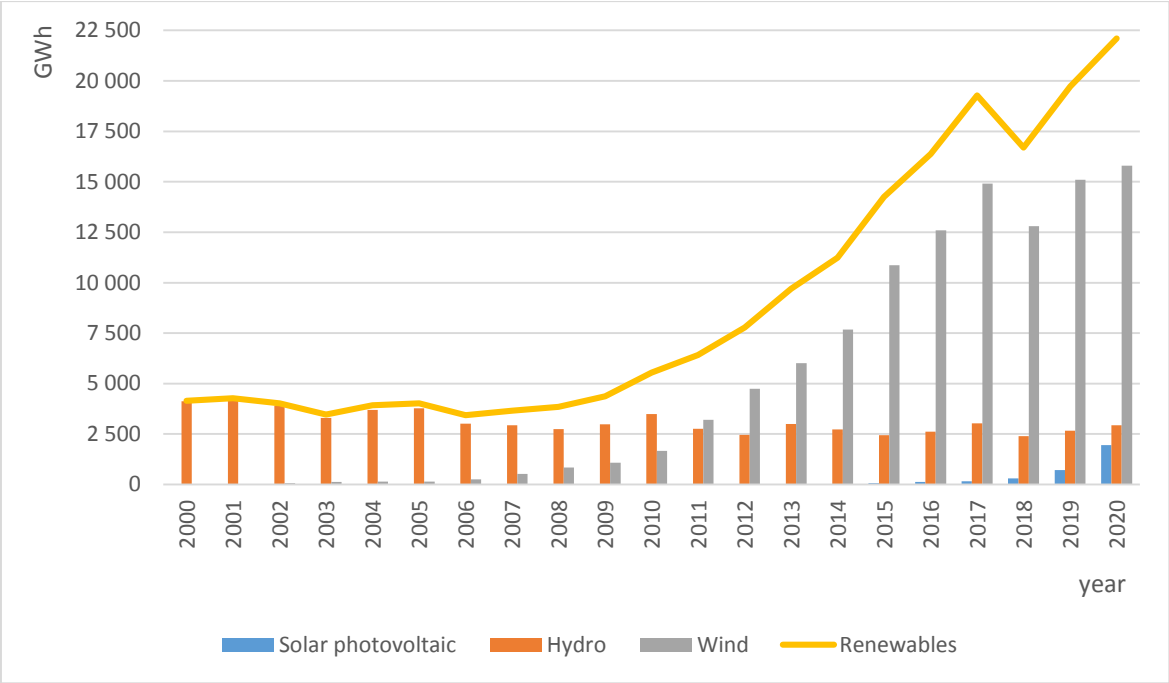

Figure 1. The production of electricity from solar, hydro and wind from 2000-2020.

Source: Eurostat.

In Figure 2, absolute changes in electricity production obtained from analyzed sources during the period studied are presented. To compare it, Table 1 illustrates individual chain indexes calculated for each source.

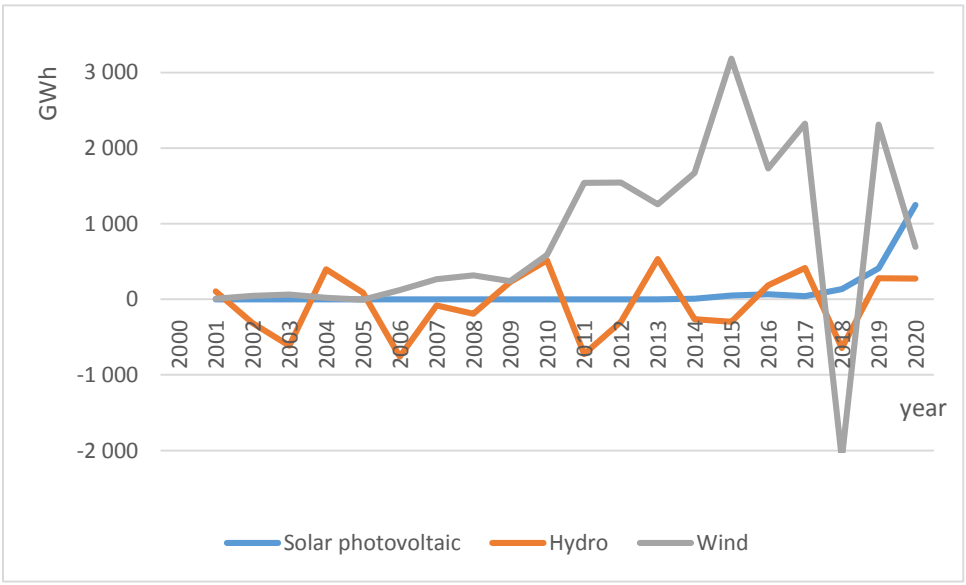

Figure 2. Absolute changes in the production of electricity from solar, hydro and wind from 2000-2020.

Source: own calculations based on Eurostat.

Table 1
Individual chain indexes

Year	Solar photovoltaic	Hydro	Wind	Renewables	Share of renewables in total energy
2001	-	1,03	2,80	1,03	1,03
2002	-	0,93	4,36	0,94	0,95
2003	-	0,84	2,03	0,87	0,82
2004	-	1,12	1,15	1,13	1,11
2005	-	1,02	0,95	1,03	1,01
2006	-	0,80	1,89	0,85	0,83
2007	-	0,97	2,04	1,06	1,08
2008	-	0,93	1,60	1,05	1,08
2009	-	1,08	1,29	1,14	1,17
2010	-	1,17	1,54	1,27	1,22
2011	-	0,79	1,93	1,16	1,11
2012	6,52	0,89	1,48	1,21	1,22
2013	1,30	1,22	1,26	1,25	1,23
2014	4,65	0,91	1,28	1,16	1,20
2015	8,22	0,89	1,41	1,27	1,22
2016	2,19	1,08	1,16	1,15	1,14
2017	1,34	1,16	1,18	1,18	1,15
2018	1,82	0,79	0,86	0,87	0,87
2019	2,37	1,12	1,18	1,18	1,23
2020	2,76	1,10	1,05	1,12	1,16
Geometric mean	**2,82**	**0,98**	**1,50**	**5,33**	**4,89**
Average growth from year to year	**182%**	**-2%**	**50%**	**433%**	**389%**

Source: own study.

As seen in Figure 2, the expansion of wind farms, starting from 2006, was very dynamic. The electricity produced through wind power increased from 5 GWh in 2000 to 15 800 GWh in 2020. That is more than 3 000 times growth, with an average yearly growth of 50% (Table 1). The sharp decline in electricity production in 2018 resulted from legislative fluctuations: changes in the scope of taxation of wind farms. 2019 is again seeing a significant increase (probably compensating for the decline in some way) followed by a slight decrease. Regarding hydropower, the amount of electricity produced from this source seemed to be more or less constant in the analyzed years. However, there is a 29% decrease over the studied period. An average decline takes about 2% yearly (from 4116 GWh in 2000 to 2937 GWh in 2020). On the other hand, observing solar electric energy volume produced by photovoltaics, there has been immense growth in the last years. Although the interest in this form of renewable energy sources began in Poland only in 2011, a constant, even exponential development of this industry can be observed. It developed from less than 0.2 GWh in 2011 to 1958 GWh in 2020, which means more than 11 000 times growth in only ten years. At that time, the average annual increase from year to year was 182%.

Willing to broaden the spectrum of the analysis, Table 2 presents the changes in shares of electricity from the three analyzed sources in renewables.

Table 2
Share of electricity from solar, hydro and wind in renewables in 2000-2020

Year	Solar photovoltaic	Hydro	Wind	Other
2000	0,00%	99,1%	0,1%	0,7%
2001	0,00%	98,7%	0,3%	1,0%
2002	0,00%	97,3%	1,5%	1,2%
2003	0,00%	94,8%	3,6%	1,6%
2004	0,00%	94,2%	3,6%	2,2%
2005	0,00%	93,9%	3,4%	2,8%
2006	0,00%	87,9%	7,5%	4,7%
2007	0,00%	80,4%	14,3%	5,3%
2008	0,00%	71,6%	21,8%	6,6%
2009	0,00%	68,0%	24,6%	7,3%
2010	0,00%	62,8%	30,0%	7,2%
2011	0,00%	43,0%	49,9%	7,0%
2012	0,01%	31,7%	61,0%	7,3%
2013	0,02%	30,9%	61,9%	7,1%
2014	0,06%	24,3%	68,3%	7,3%
2015	0,40%	17,1%	76,2%	6,4%
2016	0,76%	16,0%	76,9%	6,4%
2017	0,86%	15,7%	77,3%	6,1%
2018	1,80%	14,3%	76,6%	7,3%
2019	3,60%	13,5%	76,6%	6,3%
2020	8,86%	13,3%	71,5%	6,4%

Source: own calculations.

Solar energy started to develop in about 2011, and its share in total renewables increased from almost 0% (0,03%) to 9% in 2020. The percentage of photovoltaics in renewables grew yearly by 123% on average. Regarding hydropower, it is worth noting that while in 2000, this energy was the basis of Polish renewable energy (it accounted for 99% of it), in 2020, it remained only 13% of the total. The annual average decrease was about 10%. The share of wind power in renewables has risen from 0,1% in 2000 to 77% in 2019, ending at 71% in 2020. That meant a 38% average annual increase. To sum up, in 2020, almost ¾ of electrical energy from renewables came from wind power, 13% was produced by hydropower, 9% by solar and 6% from other sources (among these are, for example, renewable municipal waste). It appears that energy obtained from the water has already reached its maximum. In turn, wind energy began to slow down, although it is still developing. However, the wind potential may develop further. There is progressively more debate about home wind farms. On the other hand, the amount of electricity from the solar sources shows a systematic exponential growth. Here, as well, inexhaustible potential can be assumed. Thus, the composition of shares will probably change in favour of solar energy in the coming years.

Attempting to discover what would occur in the future, forecasts for the share of the examined sources in renewable energy sources for the next two years were made. That was achieved through adjusting time trends: fourth and third-degree polynomial for hydro and wind and exponential for solar energy. Results are presented in figure 3, figure **4** and figure **5** and in table 3, table 4 and table 5.

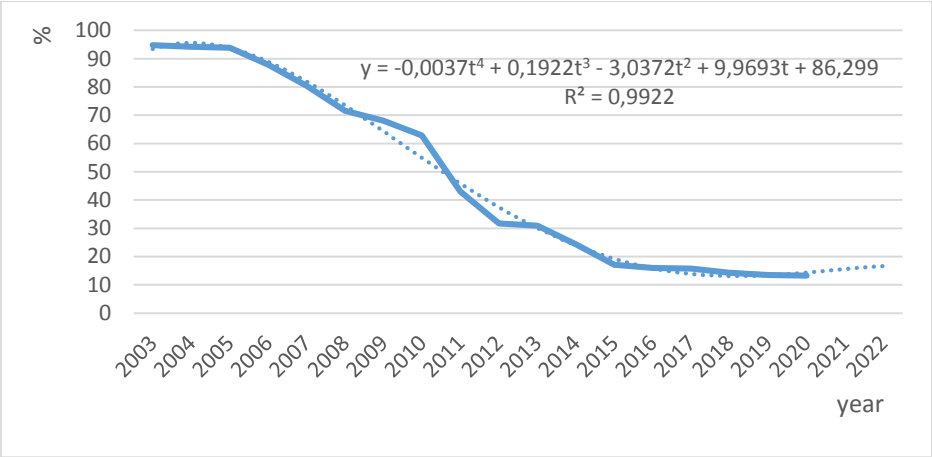

Figure 3. The prediction of share in renewables of hydroelectricity.

Source: own calculations.

Table 3.

Projected share of hydropower in renewable energy sources

Regression Statistics				
	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	86,29945	5,62328	15,34681	*0,00000*
t	9,96926	3,86080	2,58218	*0,02276*
t^2	-3,03717	0,79588	-3,81612	*0,00214*
t^3	0,19217	0,06215	3,09205	*0,00858*
t^4	-0,00370	0,00162	-2,27584	*0,04043*
R Square	0,99217	*F*	411,8014	
Adjusted R Square	0,98976	*Significance F*	*0,0000*	
Standard Error	3,28668			
Forecasts:	**16%** *(2021)*	**17%** *(2022)*		

Source: own calculations.

The estimated trend model for hydropower share in renewables is statistically significant and can be used for forecasting (all p-values are less than 0.05). According to calculations, the share of hydropower in renewables should be around 16% in 2021 and 17% in 2022. That means a very slight increase.

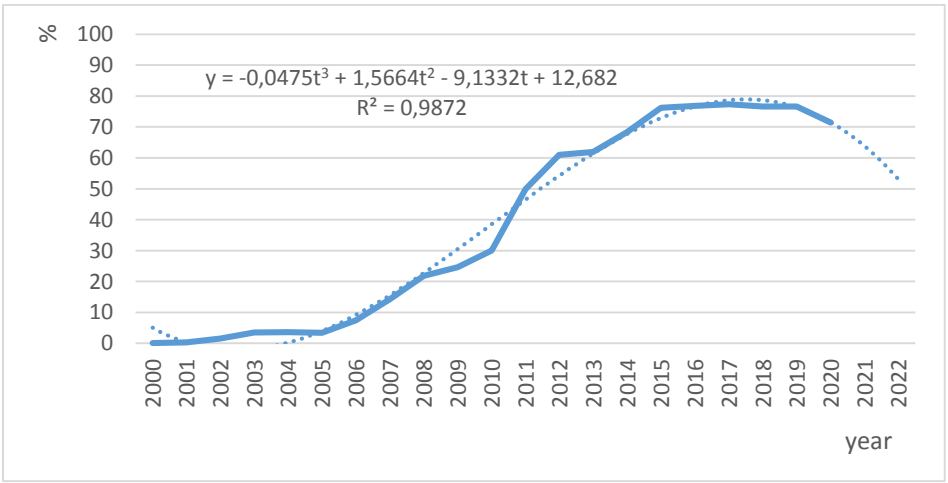

Figure 4. The prediction of share in renewables of wind electricity.

Source: own calculations.

Table 4
Projected share of wind energy in renewable energy sources

Regression Statistics				
	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	0,12682	0,04157	3,05079	*0,00723*
t	-0,09133	0,01598	-5,71376	*0,00003*
t^2	0,01566	0,00167	9,39202	*0,00000*
t^3	-0,00048	0,00005	-9,52281	*0,00000*
R Square	0,98715	*F*	435,3517	
Adjusted R Square	0,98488	*Significance F*	0,0000	
Standard Error	0,03939			
Forecasts:	**64%** *(2021)*	**53%** *(2022)*		

Source: own calculations.

Similarly, the trend model is statistically significant in this case, allowing for forecasts. According to the estimate, the projected share of electricity generated by wind farms in renewable energy sources should be at the level of 64% and 53% in 2021 and 2022. That means a significant decrease in this share.

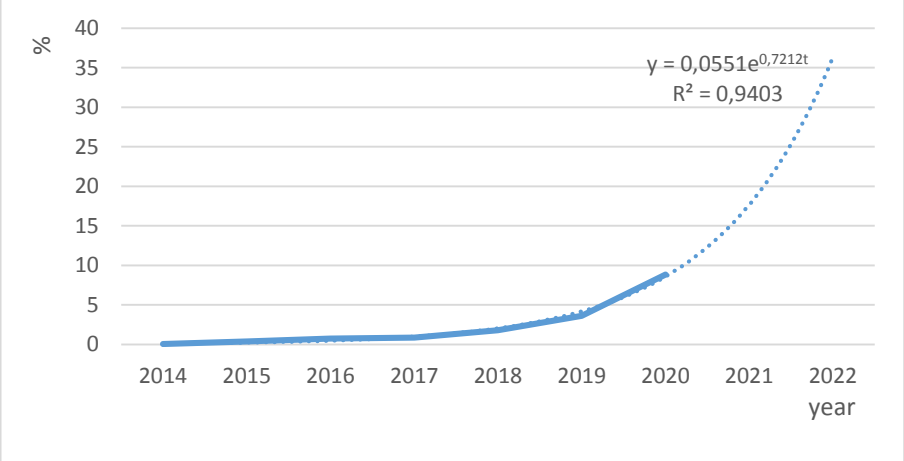

Figure 5. The prediction of share in renewables of solar electricity.

Source: own calculations.

Table 5.
Projected share of solar energy in renewable energy sources

Regression Statistics				
	Coefficients	*Standard Error*	*t Stat*	*P-value*
Ln(Intercept)	-2,8984	0,3636	-7,9725	*0,0005*
t	0,7212	0,0813	8,8713	*0,0003*
R Square	0,9403	*F*	78,7005	
Adjusted R Square	0,9283	*Significance F*	0,0003	
Standard Error	0,4302			
Forecasts:	**18%***(2021)*	**36%** *(2022)*		

Source: own calculations.

Photovoltaics develop currently the most dynamically. The pace of expansion takes an exponential form, so the exponential trend turned out to be the best suited to empirical data. Due to the good fit of the model, this trend could be used for the forecast. According to calculations, the share of electricity produced by photovoltaic panels may increase even to 18% and 36% in 2021 and 2022.

By examining the changes in the amount of electricity produced in the researched renewable sources, it is inevitable to observe a diminishing role of hydropower along with the growing percentage of the energy from wind and sun. Hydropower has been used in Poland for years (Igliński, 2019; Kałuża et al., 2022b). Its use, historically established (mills), however, becomes to have a lower share in the mix of energy from renewable sources, which, according to calculations, fell from 99% to 13%. Even even though forecasts have shown a slight increase, it should never again reach the point of 99%. Contrary to hydropower, wind energy has developed in the last two decades and nowadays is the most used source of renewable energy in Poland (Gnatowska, Moryń-Kucharczyk, 2019). The volume of electricity produced from this source is growing systematically, although not so fast as photovoltaics. As a result of various funding programs and tax reliefs, photovoltaics is one of Poland's fastest-growing renewable energy sectors (Fotowoltaika w Polsce, 2022; Zdonek et al., 2022; RaportPV2021, 2021). Even though the statement that solar photovoltaics and wind energy are the most efficient renewable energy sources rapidly developing (Lehtola, Zahedi, 2019) was confirmed in Poland.

5. Summary

The article's subject examined the development of renewable electricity sources from wind, water and sun from 2000 to 2020. A dynamic analysis of phenomena was conducted to answer the first research question about the dynamics of the researched renewable energy sources development in the studied years. The electricity produced through wind power increased from 5 GWh in 2000 to 15 800 GWh in 2020, with an average yearly growth of 50%. The electricity produced from hydro sources decreased from 4116 GWh in 2000 to 2937 GWh in 2020, meaning an average annual decline of about 2%. Regarding photovoltaics, it developed from less than 0.2 GWh in 2011 to 1958 GWh in 2020, with an average yearly increase of 182%.

Shares have been calculated to answer the second research question of how the segments of solar, wind and hydro energies in RES changed in the studied years in Poland. Afterwards, three trend models were estimated – to estimate the projected values for the next two years.

Despite the issue that photovoltaics has been very popular in recent years, wind farms have dominated Poland's renewable energy market so far. The reason for this could be presumably the country's temperate climate. However, comparing the average growth speeds, renewables' structure will almost certainly change in favour of solar energy in the coming years. According to forecasts, the share of solar energy should increase to 18% and 36% in the following years. Predicted hydropower is to be around 16% and 17%, respectively. In turn, the share of wind energy fell to 64% and then to 53%. It should be mentioned that this decrease is not equivalent to the production volume reduction. It simply indicates that the amount of wind energy

production is growing slower than the total amount of RES production. It should be considered that energy production from renewable sources is constantly and dynamically increasing. The substantial increase in interest in solar energy observed in recent years would constitute, if not competition, then an essential supplement to the basket of renewable energies in the study area. Legislative conditions are undeniably conducive to this situation.

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