6th International Conference on Contemporary Problems of Thermal Engineering
CPOTE 2020, 21-24 September 2020, Poland

Analysis of electricity generation variability in 2019 with special consideration of electrical energy generation from wind sources

Rafał Hyrzyński[1*], Bartosz Kraszewski[1], Paweł Ziółkowski[2], Marcin Lemański[1], Janusz Badur[1]
[1] Institute of Fluid-Flow Machinery Polish Academy of Sciences,
Fiszera 14 st., 80-231 Gdańsk, Poland
email: rafal.hyrzynski@imp.gda.pl

[2]Gdańsk University of Technology, Faculty of Mechanical Engineering,
Narutowicza 11/12 st., 80-233 Gdańsk, Poland

Keywords: Wind farms, Climate, Megatrends, Full load equivalent operating hours, Transmission system operator.

Abstract

This article presents issues related to the broadly understood development of wind energy. The state of the art of wind energy in the world has been discussed. This paper also shows issues related to factors affecting the development of renewable energy sources and their impact on the natural environment on the basis of available research. The focus is, however, on the critical analysis of phenomena in the data of the Transmission System Operator (TSO) in the period from 1 January 2019 to 31 December 2019. This analysis concentrates primarily on capturing the correlation between demand for TSO power capacity and the electrical power output generated by wind farms. As part of the article, specific operating condition for the TSO has been presented, in particular from the point of view of generating energy by wind sources. These were the days of 2019, in which there occurred: the maximum national demand for electrical capacity of 26,135.6 MW, the minimum national demand for capacity of 11,399.6 MW, the maximum generation of power output from wind farms of 5,222.1 MW, the minimum generation of power output from wind farms of 8.18 MW and maximum hourly variability of wind farm generation - a decrease by 954 MW. The presented work closes with a forecast indicating the need to invest in making conventional generating units more flexible as well as in increasing the system's installed capacity. The article does not take up issues related to power system security. It should be noted that even the most insightful analyses do not predict cadastral events with a global dimension, and certainly such an event is the SARS-CoV-2 pandemic. Electricity consumption in April 2020 compared to April of the previous year decreased by 1,310 GWh, i.e. by 9.76%, which allows us to deduce the size of reserves in the society.

1 Introduction

In 1988 UNEP (United Nations Environment Programme) together with the World Meteorological Organization (WMO) established The Intergovernmental Panel on Climate Change (IPCC) [1]. The IPCC is an international body whose main objective is to provide governments with reliable, scientifically based knowledge about climate change, its causes, assessment of risks resulting from climate change and to identify (recommend) actions to be taken to avoid catastrophic effects of climate change [2].

This knowledge is communicated through reports (summary and special reports) available on the IPCC website, accepted at subsequent sessions of the IPCC, and publicly presented to the Conferences of the Parties to the United Nations Framework Convention on Climate Change, which are referred to as the COP (Conference of the Parties).

This was also the case with the last report of the IPCC, which was presented at COP24 in Katowice. The general direction that emerges from the IPCC reports is the need to move away from the economy based on sources emitting greenhouse gases as soon as possible. The report does not point here to the perspective of many decades, but to the perspective of one decade in terms of reducing greenhouse gas emissions by half, in order to limit the increase in temperature on Earth at 1.5°C.

The actions of the UN (through the Conferences of the Parties, COP) have a measurable impact on the global energy policy of most countries or even regions of the world. However, they have a special place in the policy of the European Union. It is in its climate and energy policy until 2030 that the EU has defined three basic objectives:

- to reduce greenhouse gas emissions by at least 40% (compared to 1990 levels);
- to ensure a minimum 27% share of energy from renewable sources in total energy consumption;
- to increase energy efficiency by at least 27 %.

These targets were adopted by the European Council of 23-24 October 2014. [3].

These objectives are also consistent with the identified leading megatrends, which in turn indicate that the development of renewable energy will be one of the most noticeable consequences of the transformation of power systems [2]. Is this really the case? Are individual countries systematically increasing the share of renewable sources in their energy systems?

In 2017, 25 551.3 TWh (20 046.5 TWh in 2007) of electricity was produced worldwide and 3 286.6 TWh (3 384.3 TWh in 2007) in the European Union. In the same year 2017, in the world balance 6 211.4 TWh came from renewable sources (24.31%), while in the European Union 1 009.0 TWh came from renewable sources (30.7%[1]). In 2007, the world produced 3,409 TWh of electricity from renewable sources, which accounted for 18.3% of the total production, while in the European Union 544.9 TWh of electricity from renewable sources, which in turn accounted for 16.1%1 [4], [5], [6]. The increase in the share of energy production from renewable sources is so important that it does not require any further comment.

One of the driving forces behind the development of renewable energy is wind energy. The dynamics of investments in wind energy in the world is shown in Figure 1. Such a rapid development of sources which are difficult to forecast does not leave the other sources included in the power system unaffected. In particular, the requirements imposed on conventional sources, on which a change in the nature of their operation is forced, have been significantly modified: from base load operation to intermediate peak operation.

[1] Share of electricity from renewable sources in gross electricity consumption.

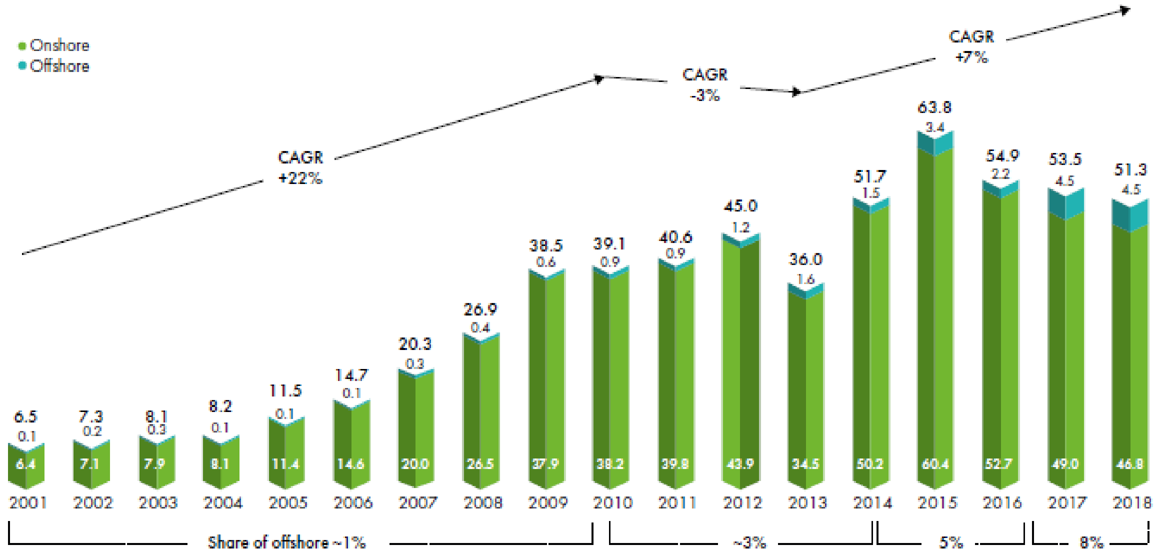

Figure 1: Development of wind energy in the world. Installed power in wind sources [GW]. Source: Global Wind Energy Council. Global Wind Report 2018 [7].

1.1 Aim of the work

The aim of this work is to show the variability of electricity demand in the power system over one year of its operation. Analyses such as those presented below allow us to observe the changes resulting from megatrends[2] that transform the world's power industry, both in the sector dimension and in terms of costing the attitudes of customers, who are more and more often prosumers. The analysis of the variability of the electricity demand of the power system is particularly important in the face of extremely large challenges, such as the implementation of the principles and objectives of the European Green Deal[3], which will shape the European power industry for the next decades and transform its current structure early on. The choice of appropriate tools and technical solutions to implement this ambitious strategy should be appropriate to the operational characteristics of each national electricity system until there are physical constraints on the power and energy flows between these (national) systems. In this context, the analysis as presented below adds value to the issues related to the development of the European energy of tomorrow.

2 National Power System (NPS). Power demand.

The National Power System is mainly based on coal and lignite fired thermal power plants. These sources constitute in total 69.6% of the installed power. These sources are supplemented by natural gas-fired power plants, renewable energy sources (mainly wind and hydro power plants) and industrial power plants. The detailed structure of the installed capacity is presented in Table 1.

---

[2] Megatrends. Wave changing the future. (Megatrendy. Fala zmieniająca przyszłość). Market analysis, Alcatel-Lucent, 2012 r., s. 8

[3] COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE EUROPEAN COUNCIL, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS The European Green Deal COM/2019/640 final, https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1588580774040&uri=CELEX:52019DC0640, [online, 07.07.2020].

Table 1: Structure of installed power in the PPS [MW][4]

Source type/State per day	31.12.2016 r.	31.12.2017 r.	31.12.2018 r.	Percentage structure [2018]
Professional power plants	32 318	34 268	36 638	79,8%
Professional hydropower plants	2 292	2 328	2 341	5,1%
Professional thermal power plants, including:	30 025	31 939	34 296	74,7%
on hard coal	19 083	20 247	23 215	50,5%
on lignite	9 332	9 352	8 752	19,1%
gas	1 610	2 341	2 330	5,1%
Wind power and other renewable electricity	5 706	6 341	6 621	14,4%
Industrial power plants	2 828	2 813	2 680	5,8%
CDGU	25 097	26 952	29 128	63,4%
nCDGU	15 755	16 470	16 811	36,6%
Total	40 852	43 421	45 939	100,0%

3 Polish electricity energy demands, production and consumption

Domestic demand for electricity is mainly covered by commercial thermal power plants, where the chemical energy contained in hard coal and lignite is converted into electricity, as shown in Table 2. In 2018, these power plants produced a total of 141 037 GWh of electricity.

In connection with the policies implemented to support renewable energy sources (RES), they play an increasingly important role in the NPS. In 2018, these sources produced a total of 14 155 GWh of electricity (including wind and water power plants).

The third group of generation sources are industrial power plants, which produced 10 022 GWh of electricity.

Brief description of the most important information concerning the operation of the NPS for 2018:

- the total installed capacity in the Polish Power System as of 31 December 2018 was 45,939 MW and increased significantly compared to the previous year, i.e. by 2,518 MW;
- the total capacity available in the Polish Power System as of 31 December 2018 was 45,650 MW and increased proportionally to the increase in installed capacity compared to the previous year, i.e. by 2,318 MW;
- at the end of 2018, the total available capacity of utility thermal power plants amounted to 34,296 MW and represented 74.7 percent of the total capacity available in the power system;
- the maximum domestic power demand in the evening peaks of working days in 2018 occurred on 28 February at 6.15 pm and amounted to 26,448 MW. The minimum domestic power demand in the night-time valley occurred on 24 June at 4.45 a.m. and amounted to 12 211 MW. The difference between the maximum and minimum demand was 14 237 MW (53.8% of peak demand);
- the average annual reserve volume in domestic power plants from daily peaks in load on working days available to the Transmission System Operator (TSO) in 2018 was 6,498 MW;
- in 2018, there were no power consumption restrictions or customer shutdowns due to lack of capacity in the power system

[4] Summary of quantitative data on the operation of the PPS in 2018 [12].

- electricity production in 2018 amounted to 165,214 GWh and was 0.39 percent lower than in the previous year;
- domestic electricity consumption in 2018 was 170,932 GWh, more than 1.6 per cent lower than in 2017;
- the balance of electricity exchange between Poland and the neighbouring countries in 2018 was 5,718 GWh (predominance of exports over imports), and the dynamics in relation to 2017 was 150.05%.

Table 2: Polish domestic production and consumption of electricity in 1990÷2018 [GWh][5].

Year	Domestic energy production	out of:					Domestic energy consumption
		Professional power plants	Professional power plants		Wind power plants and other renewable	Industrial power plants	
			Hydroelectric power plants	Thermal power plants			
1990	136 336	128 199	3 300	124 899	0	8 137	135 275
1991	134 610	126 783	3 388	123 395	0	7 827	131 922
1992	132 835	124 557	3 564	120 993	0	8 278	128 803
1993	133 747	125 264	3 553	121 711	0	8 483	131 336
1994	134 890	126 422	3 744	122 678	0	8 468	132 211
1995	138 701	130 176	3 814	126 362	0	8 525	135 900
1996	142 717	134 352	3 839	130 513	0	8 365	139 593
1997	142 414	134 380	3 739	130 641	0	8 034	140 228
1998	142 244	134 554	4 243	130 311	0	7 690	138 770
1999	141 286	133 692	4 157	129 535	0	7 593	136 351
2000	144 417	136 762	3 984	132 778	0	7 655	138 043
2001	144 574	136 412	4 057	132 355	0	8 159	137 843
2002	143 233	135 123	3 722	131 401	0	8 110	136 165
2003	150 751	142 494	3 146	139 348	0	8 257	140 590
2004	153 362	144 821	3 525	141 296	0	8 541	144 069
2005	156 024	147 616	3 587	144 029	0	8 407	144 838
2006	160 848	152 498	2 822	149 676	69	8 280	149 847
2007	159 528	150 865	3 908	146 957	446	8 216	154 170
2008	155 567	146 845	2 515	144 330	678	8 044	154 980
2009	150 923	141 872	2 751	139 121	846	8 203	148 718
2010	156 342	146 107	3 268	142 839	1 312	8 923	154 987
2011	163 153	151 319	2 529	148 790	2 833	9 000	157 909
2012	159 853	146 833	2 264	144 569	4 025	8 991	157 013
2013	162 501	147 435	2 762	144 673	5 895	9 171	157 980
2014	156 567	140 290	2 520	137 770	7 256	9 020	158 734
2015	161 772	141 901	2 261	139 640	10 114	9 757	161 438
2016	162 626	140 727	2 399	138 328	11 769	10 130	164 625
2017	165 852	141 790	2 767	139 023	14 005	10 057	168 139
2018	165 214	143 234	2 197	141 037	11 958	10 022	170 932
Δ 2018-1990	28 878	15 035	-1 103	16 138	11 958	1 885	35 657

5 Summary of quantitative data on the operation of the PPS in 2018 [12].

3.1 Variability of electricity demand in Poland - characteristic circumstances

To illustrate the variable characteristics of electricity generation from wind energy sources, the author analysed the profile of electricity generation from wind farms from 1 January 2019 to 31 December 2019, as shown in Figure 2. For each of the drawings, the value axis on the left refers to the "*Actual NPS demand*" and the "*Demand covered without WF*", while the axis on the right refers to the "*Total WF generation*".

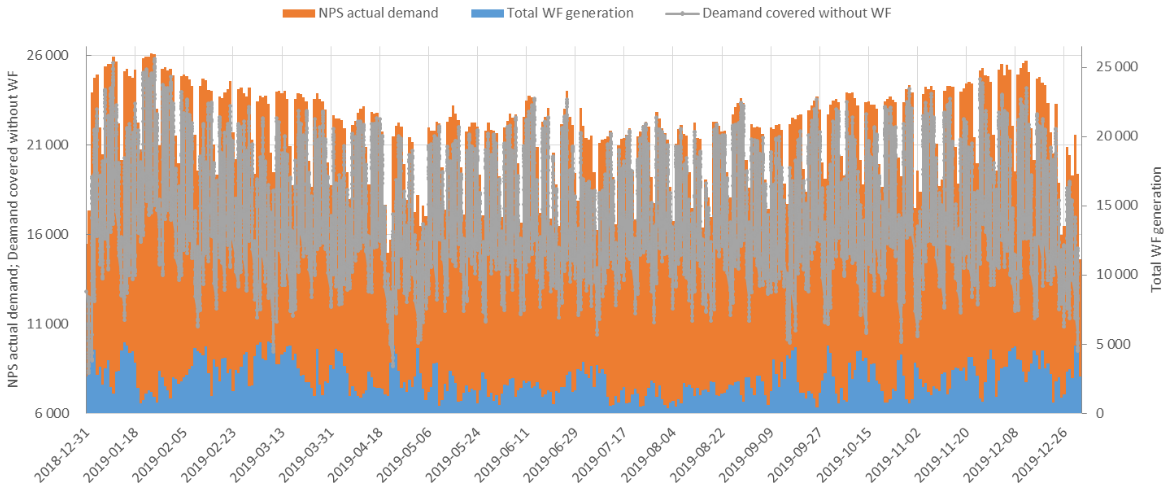

Figure 2: Coverage of electricity demand for the period from 1 January 2019 to 31 December 2019 [MW]
Source: Own study based on [8].

As we can observe in the above graph, the Polish power system shows characteristic variability, depending on the operating schedule of receivers, in particular industrial receivers, weather conditions, seasons, cultural and social events, etc. [9]. We can distinguish between periods of peak power demand (morning and evening peaks) and periods of minimum load that fall on the night valley, as shown in the figures 3 and 4.

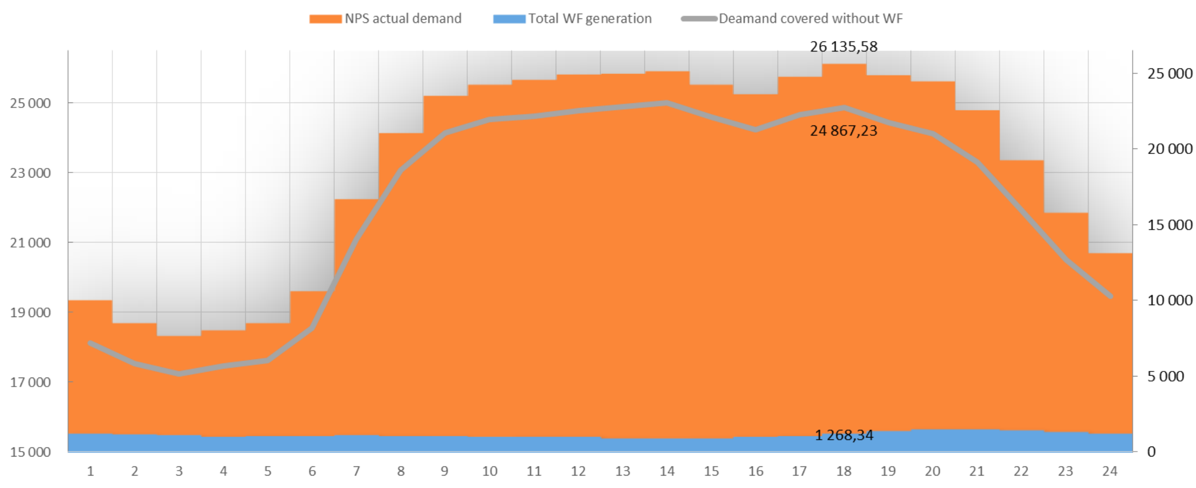

Figure 3: Power demand on the day when the maximum national demand occurred in 2019 (24 January 2019). [MW]
Source: Own study based on [8].

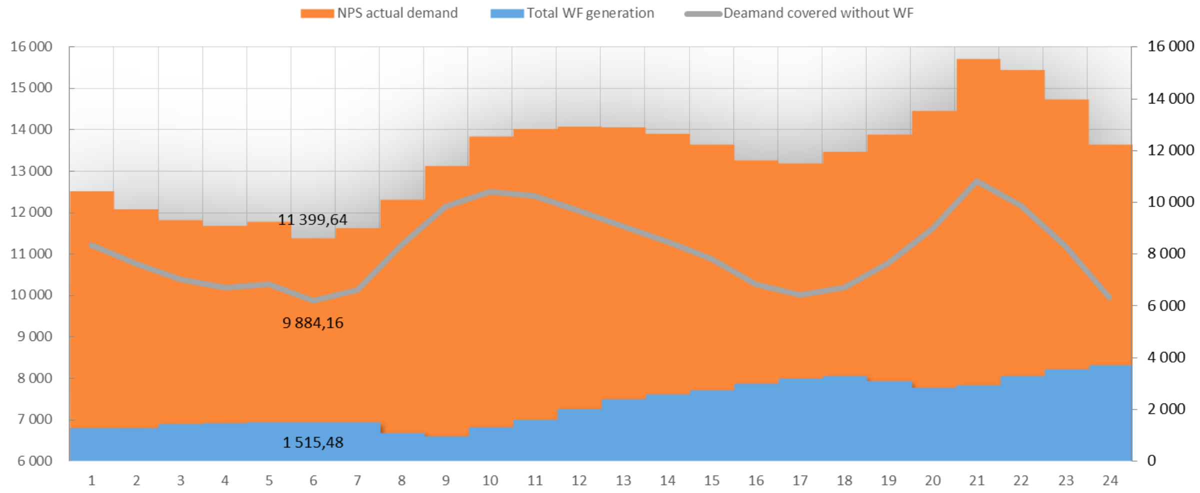

Figure 4: Courses of power demand on the day when the minimum national power demand occurred in 2019 (22 April 2019). [MW]
Source: Own study based on [8].

The maximum domestic power demand occurred on Thursday 24 January and amounted to 26 135.58 MW, while the minimum load in the night valley took place on Easter Monday, i.e. 22 April and amounted to 11 399.64 MW. During these characteristic hours of the PPS maximum and minimum power demand, the generation of energy from wind sources was 1,268.34 MW (FLEOH% 21.6%) and 1,515.48 MW (FLEOH% 25.8%) respectively.

From the point of view of daily variability of operation of conventional sources, it would be more practical to present the days on which the maximum and minimum generation from wind sources occurred and the days on which the maximum hourly variability of generation from wind sources occurred (the maximum difference that occurred between hour n and hour n+1). The higher the variability of energy generation in sources that are difficult to predict, the less optimal the operating conditions of conventional sources. The data showing the above are presented in the following graphs, and in particular in the graph in Fig. 5.

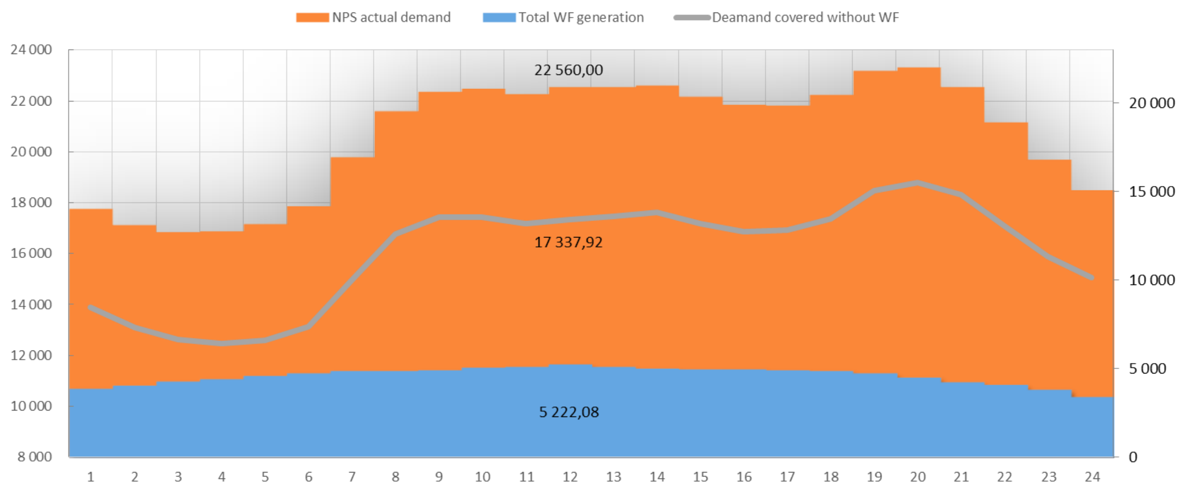

Figure 5: The power demand on the day when the maximum generation from WF occurred (8 March 2019). [MW]
Source: Own study based on [8].

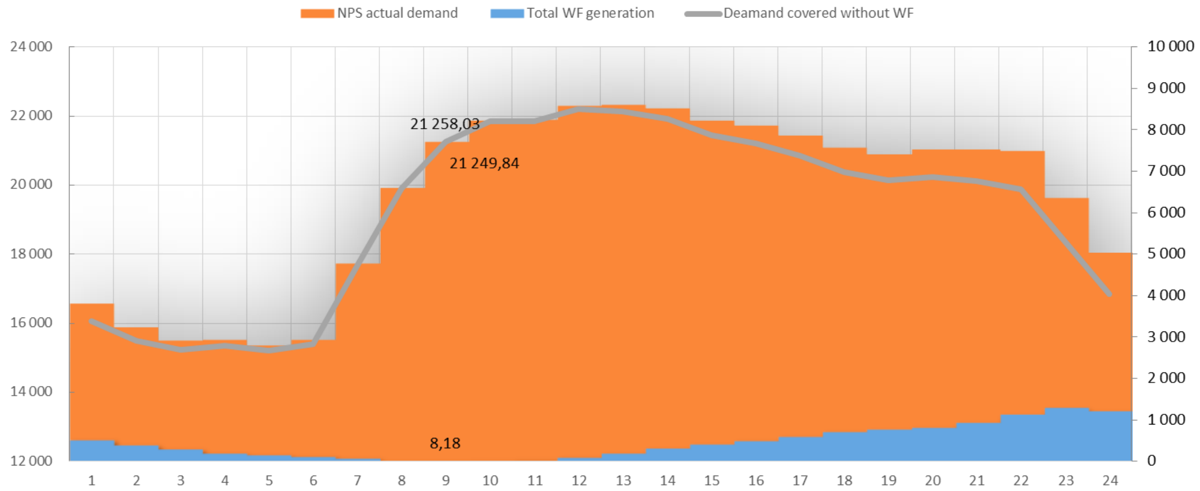

Figure 6: Power demand on the day when the minimum generation occurred from the WF (25 July 2019). [MW]
Source: Own study based on [8].

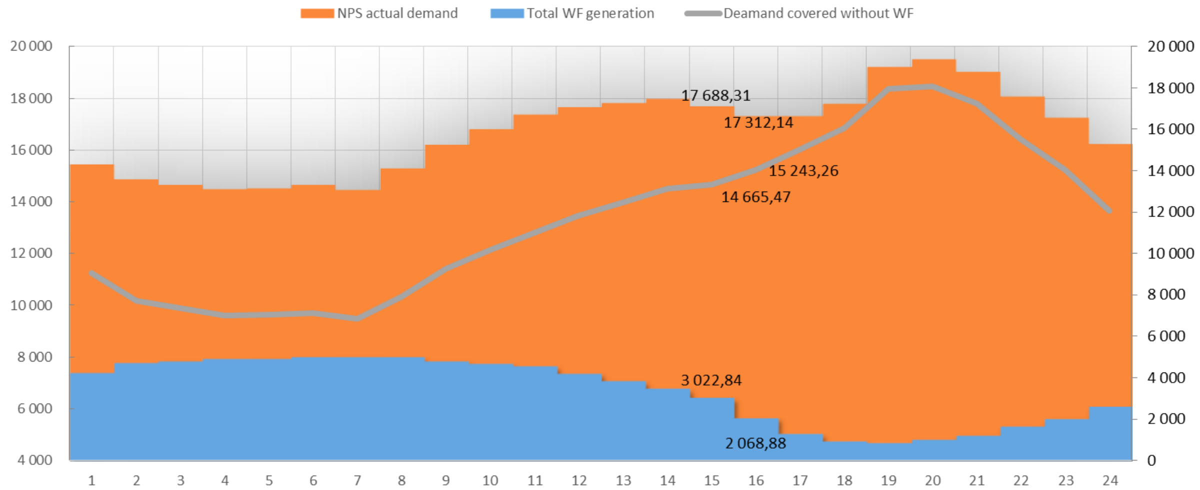

Figure 7: Power demand on the day when the maximum-hour variability of generation power from WF occurred (954 MW; March 10, 2019 between 15 and 16 hours). [MW]
Source: Own study based on [8].

The analysis of the data presented in the above graphs shows that in the period covered by the analysis (between January 1, 2019 and December 31, 2019), the wind sources operated at the maximum capacity on Friday, March 8, 2019, i.e. with a capacity of 5,222.08 MW (FLEOH% 89.0%), as shown in Figure 5. The minimum generation from wind sources, shown in Figure 6, took place on Thursday 25 July 2019. At that time, these sources operated at a capacity of 8.18 MW (FLEOH% 0.14%).

The course of wind energy generation on Sunday, 10 March 2019, shown in Figure 7, deserves a more detailed analysis. On that day there was a maximum 2-hour variability of the wind farm generation capacity. This situation took place between 3 p.m. and 4 p.m. Within an hour, the change in wind farm capacity was -954 MW. The change in demand for power of the National Power System itself was -376 MW. This means that this sudden reduction of the capacity generated by the wind farms forced an increase of 578 MW in the capacity generated by the other sources included in the National Power System. This capacity is close to the capacity installed in three units in the Ostrołęka power plant (690 MW), which is moreover necessary for start-up in less than 60 minutes. This individual case of wind farm capacity reduction is obviously not too much of a challenge for the Transmission System Operator (in the absence of emergency situations, e.g. a sudden failure of a large unit in the system or the failure of several units). Such a power loss (frequency drop in the system) can be quickly made up for by starting up several hydropower units in pumped storage power plants for generator operation, by taking advantage of the possibility to increase the capacity on cross-border connections in the direction of imports, as well as by forcing the opening of control valves in individual conventional generating sets to change the capacity generated in the system in the direction of power balance equalization [10].

3.2 Impact of the pandemic on electricity demand

The scale of consumption reduction is indirectly evidenced by the graph of electricity demand in April 2019 (before the pandemic) and 2020 (during the pandemic after the government introduced the so-called lockdown), shown in Figure 8. The Polish domestic electricity consumption in April 2019 and 2020 is presented in Table 3. Electricity consumption in April 2020 compared to April of the previous year decreased by 1,310 GWh, i.e. by 9.76%, which allows us to deduce the size of reserves in the society.

Table 3: Electricity consumption in April 2019 and 2020.

	April	
2019	2020	Dynamics [(b-a)/a*100]
[GWh]	[GWh]	[%]
[a]	[b]	[c]
13 426	12 116	-9,76

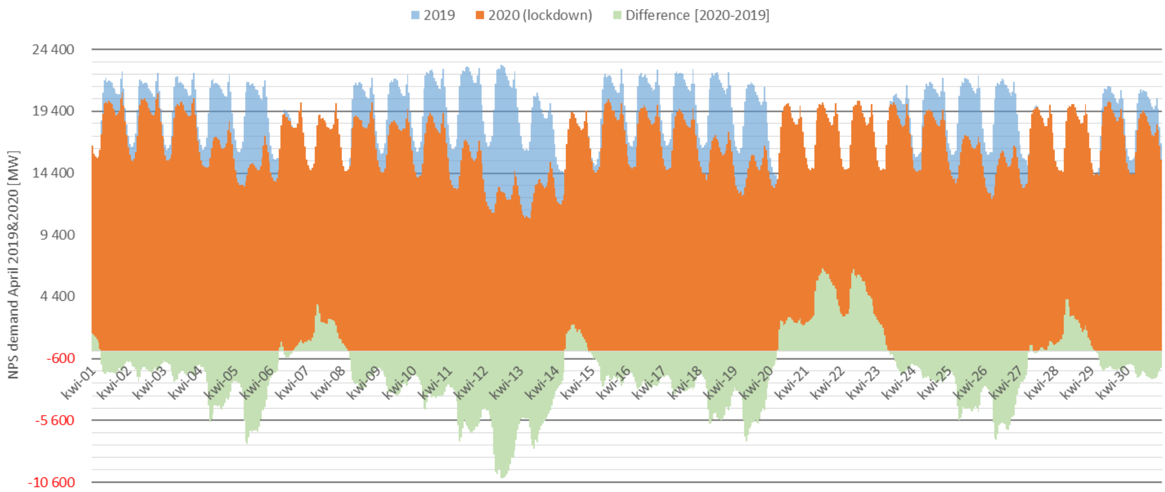

Figure 8: Comparison of electricity demand with the determination of power differences in the period from 1 April to 30 April in 2019 and in 2020 [data from Polskie Sieci Elektroenergetyczne SA. System data. Pr NPS 2019 and 2020].

It is worth mentioning that Easter both in 2019 and 2020 was in April. This can be seen in Fig. 8, where there is a significant reduction in electricity demand: 21 and 22 April 2019 and 12 and 13 April 2020. Drawing 8 clearly shows that the demand for electricity in 2020 was higher only on 6 days compared to April 2019. (7, 14, 20, 21 22 and 28 April). However, the biggest difference appeared for two days, i.e. Sunday and Easter Monday, when the average demand difference between 2020 and 2019 was respectively: -8 013.21 MWe (Sunday) and -=5 781.12 MWe (Monday). On the other hand, if we trace how much the electricity demand for the whole of April 2020 decreased compared to April 2019, it averaged -1 825.8 MWe. The biggest difference between 2020 and 2019 was -10,296.45 MWe for Easter 2020. (Monday, 12 April at 1pm). It is worth mentioning that the analyses do not take into account the electricity generated in photovoltaics, which is increasingly visible in terms of installed capacity (approx. 2.1 GWep). However, Polish databases do not allow for such an analysis, as hourly data on the operation of generation equipment connected to the network of DSOs are not available in any open database. By the way, this fact should be commented on as a reason to be ashamed of DSOs, which spend nearly PLN 7 billion a year on investments, including significant funds for IT systems and databases, and in principle do not publish any data that could be used in scientific research or commercially, e.g. when developing various types of applications. An exception to this is the TSO (PSE SA), which for many years has consistently and regularly published data on the operating parameters of the NPS.

4 Conclusions

Increasing the capacity installed in sources that are difficult to forecast will require more sophisticated countermeasures from the TSO (in situations of sudden reduction or increase of the capacity generated in these sources). For operators of conventional sources, on the other hand, an increase in capacity of RES sources that are difficult to forecast will force the modernization of generation units to increase their flexibility understood as [11]: the capacity to safely operate the unit in the planned transient states while taking actions to control the generation unit. This concept applies both to changes in the unit load and to its shutdown from reserve or start-up.

It should be noted that even the most insightful analyses do not predict cadastral events with a global dimension, and certainly such an event is the SARS-CoV-2 pandemic.

Electricity consumption in April 2020 compared to April of the previous year decreased by 1,310 GWh, i.e. by 9.76%, which allows us to deduce the size of reserves in the society.

References

[1] The General Assembly. Protection of global climate for present and future generations of mankind. 1988.

[2] Hyrzyński R, Badur J, Jaroszewska M, Ziółkowski P, Gotzman S, Froissart M.: Climate impact of wind power plants. Energ. - Probl. Energ. i Gospod. Paliw.; Issue 2, 2019, pp. 77–83 (in Polish).

[3] European Council. European council, 23-24.10.2014. Framework for climate and energy policy until 2030, 2014. Available at: https://www.consilium.europa.eu/pl/meetings/european-council/2014/10/23-24/.

[4] BP Statistical Review of World Energy. Electricity. 2018.

[5] Eurostat. Share of electricity from renewable sources in gross electricity consumption, 2004-2017 (%), 2019.

[6] International Energy Agency. World Energy Statistics. IEA Renewables Inf 2018, 2018.

[7] Global Wind Report. Annual market update 2018. Global Wind Energy Council, 2019.

[8] Polskie Sieci Elektroenergetyczne SA. System data. Pr KSE, 2019.

[9] Wasiak I. Power engineering in outline. Transmission and distribution of electricity. Politechnika Łódzka, Łódź, 2010 (in Polish).

[10] Zajczyk R. Frequency and power regulation in the power system. Politechnika Gdańska, Gdańsk, 2002 (in Polish).

[11] Polish Wind Energy Association; Lower Silesian Institute for Energy Studies. Cooperation of conventional coal sourcesand large scale res., 2019 (in Polish).

[12] PSE SA. The summary of quantitative data concerning the PPS functions in 2018. Available at: https://www.pse.pl/dane-systemowe/funkcjonowanie-rb/raporty-roczne-z-funkcjonowania-kse-za-rok/raporty-za-rok-2018 (in Polish) [accessed 02.01.020]

[13] Average annual rate of return - CAGR 2014 model. Available at: https://www.inwestycjegieldowe.com/2014/09/19/średnia-roczna-stopa-zwrotu-model-cagr/ (in Polish) [accessed 02.01.020].