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ANTONI TAJDUŚ[1*], STANISŁAW TOKARSKI[2]

GENERATION CAPACITY OF NATIONAL POWER SYSTEM IN VIEW OF COMMODITY CRISIS AND WAR IN UKRAINE IN 2022: DIAGNOSIS, RISK ASSESSMENT AND RECOMMENDATIONS

The article assesses the production capacity of the Polish Power System, taking into account the military operations in Ukraine and the related resource crisis. An analysis was made of how the war in Ukraine will affect the validity of Poland's energy policy adopted a year ago. The sensitivity of the Polish Energy System to the import of energy resources from Russia was assessed as well as the possibilities of filling the gap caused by the lack of these raw materials were described and measures were proposed. It shows how electricity prices in the EU countries developed in the last year and what the energy mix of these countries looked like. Alternative scenarios for the transformation of the domestic system were discussed, including the coal – renewable energy – nuclear energy scenario, with the minimization of gas as a fuel of the transition period.

Keywords: Efficiency of electricity generation; Fossil fuels; Sources of electricity generation; Polish Power System production capacity; Risk assessment of the energy transition

1. Introduction

The turn of 2020 and 2021 envisioned a dynamic acceleration in activities for the implementation of the European climate and energy policy. Already in 2019, the newly elected European Commission presented an ambitious plan for the European economy to achieve climate neutrality by 2050, called the European Green Deal [1,6]. However, the COVID-19 pandemic triggered the collapse of the global economy in 2020, resulting in the European Council to adopts new targets in December 2020 to reduce greenhouse gas emissions by 55% in 2030 and plan for the recovery

[1] UNIVERSITY OF SCIENCE AND TECHNOLOGY (AGH), AL. MICKIEWICZA 30, 30-059 KRAKOW, POLAND
[2] CENTRAL MINING INSTITUTE, 1 GWARKÓW SQ., 40-166 KATOWICE, POLAND
* Corresponding author: tajdus@agh.edu.pl

of the European economy by determining the amount and sources of financing (i.e. €750 billion from the additional EC budget). The European Green Deal has been approved as the only direction for transforming and recovering the economy after the pandemic. As a consequence of the adoption of the new emission reduction target, in July 2021 the EC proposed a package of new efficiency and share of renewable energy targets in final consumption, as well as the inclusion of the transport and individual heating systems in houses into emission charges, called Fit for 55 [5]. Preparations have begun for negotiations on the level of the targets, as well as their distribution among the Member States and the economic areas covered by them. Since the starting point of individual countries is different, it was expected that tough negotiations were to be held along with specific financial demands.

However, the second half of 2021 brought an unexpected twist on the market of energy commodity prices and, consequently, electricity prices. These prices supplied to end users suddenly began to be influenced by two factors. Firstly, the increase in the price of CO_2 emission allowances, which appreciated from EUR 30 to EUR 90 per Mg. This increase resulted from the assumption that the decarbonisation of the economy must accelerate in the coming years, and it is only possible with the prices of allowances, which enforce serious modernisations that eliminate the carbon footprint in production chains. Secondly, the unexpected increase in the prices of energy raw materials, in particular gas prices, which reached a level above EUR 100 per MWh, determined the marginal cost of electricity from the most expensive generating source, closing the balance of the energy system.

The table below provides information on the sources of electricity generation in individual European countries, including all European Union member states (Energy Information Administration data from 2020 was used here) [4] and electricity prices in EUR/MWh (according to Quarterly Report on European Electricity Markets, Market Observatory for Energy, DG Energy Volume 15, issue 1, covering the first quarter of 2022) [3]. In addition, an estimated rating of the difficulties in meeting the demand for fossil fuels due to the embargo on raw materials from

TABLE 1

Electricity prices in the EU in the first quarter of 2022

European country	**Price „P" in EUR/MWh of electricity**	$\frac{P}{P_{av}} \cdot 100\%$	**Sources of electricity generation in a given country. Average energy mix of the country**	**Dependence of a given country on fossil fuel imports from Russia**
1	**2**	**3**	**4**	**5**
Sweden	63.8	29	Fossil fuels 1.2%, nuclear power 36.9%, RES 61,9% (incl. hydropower 50.7%),	Independent country self-sufficient
Finland	91.4	48	Fossil fuels 24.4%, nuclear power 40.9%, RES 34.7% (incl. hydropower 30.4%),	Moderately dependent country (24% of fossil fuels import)
Estonia	132.5	63	Fossil fuels 91.7%, RES 8.3%	Independent country
Poland	134	67	Fossil fuels 91.3%, RES 8.7%	Moderately dependent country
Lithuania	138.5	69	Fossil fuels 63.3%, RES 36.7%	Moderately dependent country
Latvia	140.2	70	Fossil fuels 56.6%, RES 43.4% (incl. hydropower 40.2% and firewood)	Moderately dependent country (30% of fossil fuels import)

TABLE 1. Continued

1	2	3	4	5
Denmark	152.3	76	Fossil fuels 37.1%, RES 62.9%	Weakly dependent country
Germany	167.7	83	Fossil fuels 59.6%, nuclear power 15.6%, RES 24.8%	Moderately dependent country
Czech Republic	198.2	98	Fossil fuels 59.2%, nuclear power 34.5 %, RES 6.3%	Weakly dependent country (own coal mines)
Luxem-bourg	200.6	100	Fossil fuels 72.4%, RES 27.6%	Moderately dependent country
The Ne-therlands	204.2	101	Fossil fuels 87.1%, nuclear power 3.9%, RES 8.8%	Weakly dependent country (own natural gas)
Bulgaria	209.3	104	Fossil fuels 50%, nuclear power 31.8%, RES 18.2%	Weakly dependent country (80% of own energy resources)
Austria	213.2	106	Fossil fuels 23.8%, RES 76.2%	Weakly dependent country (65.6% of RES hydropower)
Belgium	215.1	107	Fossil fuels 42.3%, nuclear power 42.4%, RES 15.3%,	Moderately dependent country
Slovakia	215.1	107	Fossil fuels 21.5%, nuclear power 60.5%, RES 18%,	Weakly dependent country (15.9% of RES hydropower)
Romania	218.2	108	Fossil fuels 42.2%, nuclear power 17.1%, RES 40.7%,	Weakly dependent country (26.3% of RES hydropower)
Ireland	223.3	111	Fossil fuels 72%, RES 28%,	Moderately dependent country
Spain	228.4	114	Fossil fuels 44.2%, nuclear power 21.1%, RES 34.7%,	Weakly dependent country (mainly imports of petroleum)
Portugal	228.6	114	Fossil fuels 54.1%, RES 45.9%	Moderately dependent country (19% of RES hydropower)
Hungary	229.2	114	Fossil fuels 39.4%, nuclear power 56.6%, RES 4%	Moderately dependent country
France	230.7	115	Fossil fuels 7.3%, nuclear power 77.2%, RES 15.5%	Independent country (10.1% of RES hydropower)
Croatia	231.8	115	Fossil fuels 32.8%, RES 67.2%	Weakly dependent country (59.2% of RES hydropower)
Slovenia	231.9	118	Fossil fuels 32.5%, nuclear power 38.6%, RES 28.9% (incl. hydropower 30%)	Independent country (26.9% of RES hydropower)
Great Britain*	237.3	118	Fossil fuels 58.8%, nuclear power 22.3%, RES 18.9%	Moderately dependent country
Greece	237.8	118	Fossil fuels 70.8%, RES 29.2%	Strongly dependent country
Cyprus	237.8	118	Fossil fuels 91.8%, RES 8.2%	Strongly dependent country
Switzer-land*	244.7	121	Fossil fuels 1%, nuclear power 35.8%, RES 63.2%	Independent country (61.2% of RES hydropower)
Italy	248.8	124	Fossil fuels 64.3%, RES 35.7%	Strongly dependent country (above 90% of oil and gas import)
P_{av} – average EU price	201.4	100	—	—

TABLE 1

Russia is also provided. Taking into account the dependence of a given country on imports of fossil fuels from Russia, the countries are divided into: independent (self-sufficient), which will not be affected by the crisis related to fuel imports from Russia; weakly dependent on imports of fuels, which should not experience major problems with supplementing the energy balance, moderately dependent and strongly dependent, which will have significant problems with the import of fuels and the production of the proper amount of electricity.

Over the past two years, average electricity prices on European exchanges have quadrupled from around EUR 50 per MWh to over EUR 200 per MWh.

The beginning of Russia's hostilities in Ukraine on 24 February 2022 exacerbated the crisis in the raw materials markets. The European Council (10 March 2022) decided at its meeting in Paris to phase out the supply of energy resources from the Russian market. Intensive work has begun on a roadmap to replace Eastern imports with other supply directions to increase energy efficiency and accelerate the green transition so that from 2027 onwards, the European Union will be able to become energy independent of Russia. Noteworthy, in 2020, EU countries were 57.5% dependent on imports of energy resources from global markets. This indicator has not changed significantly to this day. The situation of Poland seems slightly better, as the country depends on the imports of energy resources from global markets by about 43%. Since a substantial part of imports comes from Russia (Table 2), changing the direction of fuel supplies requires time and may involve significant costs.

TABLE 2

Consumption of energy resources in EU countries in 2020. Estimates collected on the basis of Eurostat and internet data

No.	Resource	Consumption in EU in 2020 [billion m^3]	Import from Russia to EU in 2020 [billion m^3]	Russia's share in imports to EU in [%]	Consumption in Poland in 2020 [billion m^3]	Import from Russia to Poland in 2020 [billion m^3]	Russia's share in imports to Poland in [%]
1	Natural gas	541.0	153	40	20.6	9.6	55
2	Petroleum [mln Mg]/[billion m^3]	477/574	129/155	27	26.1/31.4	16.0/19.3	66
3	Hard coal	144.0	52	64	62.6	9.4	75

The economy of Poland, from the historical perspective, has been dependent on coal. In 2020, out of the volume of 157.7 TWh of net electricity produced, almost 70% was generated based on coal fuels. Also, heating and technological needs should be added to the above, which in 2020 resulted in total consumption of 54 million Mg of hard coal and 46 million Mg of lignite [13,14]. In 2021, electricity production reached a level of 173.6 TWh, with low imports of only around 0.8 TWh (a reduction of imports from 13.2 TWh in 2020) [2] (PSE – a state-owned electricity transmission system operator in Poland).

In fact, Poland supported the new target of reducing emissions by 55%, but in the National Energy and Climate Plan [NECP], submitted in 2019 to the European Commission, the country declared a much lower contribution of the national economy to the implementation of the European target than the European proposals (reduction of emissions by 30% in 2030), [9].

In February 2021, the Council of Ministers adopted a document entitled: Energy Policy of Poland until 2040 [11]. PEP 2040 and the NECP (National Energy and Climate Plan) were

TABLE 3

PEP 2040 targets against the background of European climate and energy policy goals
(PEP 2040 – Poland's Energy Policy until 2040)

Target	First climate change and energy package (2009)	Second climate change and energy package (2014)	Second climate change and energy package – final targets (2019)	Council conclusions (December 2020)	Polish targets according to PEP 2040 and NECP	*Fit for 55* package of July 2021
CO_2 reduction in [%]	20	40	40.0	55.0	30	55
Increase in the share of RES – gross consumption in [%]	20	27	32.0	32.0	23	40
Energy efficiency in [%]	20	27	32.5	32.5	23	36–38

correlated and constituted a response to European policy as it had stood before the new 55% emission reduction target. PEP 2040 presents a holistic approach to energy issues, taking into account the pillars of a just transition, reconstruction of the energy system and clean air. In the field of transformation of the energy system, a total reconstruction of the sources of electricity generation, heating systems and distributed heating sources is assumed, as well as electrification of heating and transport. Currently, domestic coal-fired system power plants are coming to an end of their technical capacity, and from this point of view, their replacement with new sources seems economically optimal. PEP 2040 presents a forecast of technological directions for the reconstruction of generation sources and a mix of primary energy sources. It was assumed that electricity production would be based on wind (offshore) and solar sources, as well as nuclear power plants. A special role is to be played by the so-called prosumers, who are both producers and consumers of energy. During the transitional period, natural gas is to be the fuel providing controllable electricity generation. The directions of reconstruction of the national production system developed and adopted a year ago should be considered, in accordance with the conditions of the time, as appropriate. The problem, however, is the proper assessment of the implementation of the schedule of a huge investment program, especially in the field of nuclear energy, as well as the impact of new reduction challenges (by 55%) on the change in the energy mix envisaged in PEP 2040.

As a result of Russia's aggression against Ukraine, new challenges are emerging, which can be generally included in two questions: How will the hostilities in Ukraine translate into the timeliness of the energy policy of Poland adopted a year ago? How sensitive is the domestic energy system to the import of energy resources from Russia?

In April 2022, the government announced a correction of PEP 2040, specifying a change in coal policy during the transition period. The Polish operator of the electricity transmission system (PSE) has published preliminary data on electricity production in 2021 [2].

Table 4 contains preliminary data on the increase in electricity generation from 154.6 TWh to 173.6 TWh y/y. This increase in electricity production occurred mainly in coal-fired power plants (as much as 30% more on hard coal and 19% more on lignite). Until 2020, a gradual decrease in electricity production from coal was observed. In 2020 less than 70% of electricity

TABLE 4

Electricity production in 2020 and 2021, including the dynamics of the changes (data from PSE; the presented values were determined on the basis of measurements collected by the transmission system operator during the operation of the domestic power system (KSE), and for this reason they may differ from the final data presented by energy companies for statistical purposes)

No.	Specification	December			Cumulatively from January to December		
		2020 [GWh]	2021 [GWh]	Dynamics of change in [%] [(b-a)/ax100]	2020 [GWh]	2021 [GWh]	Dynamics of change in [%] [(e-d)/dx100]
		a	b	c	d	e	f
1	Total production (1.1 + 1.2 + 1.3 + 1.4)	14535	16654	14.58	152308	173583	13.97
1.1	Commercial power plants	11816	14830	25.5	126137	154599	22.59
	A) hydroelectric	250	208	–16.54	2698	2830	4.88
	B) thermal	11597	14621	26.41	123439	151769	22.95
	– hard coal	7039	8487	20.57	71546	93037	30.04
	– lignite	3028	4805	58.67	37969	45367	19.48
	– natural gas	1499	1329	–11.32	13924	13366	–4.01
1.2	Renewable power plants (excluding wind)	154	111	–27.7	2198	4749	116.09
1.3	Wind power plants	1638	1714	4.59	14174	14234	0.42
1.4	Industrial power plants	927	—	—	9799	—	—
2	Foreign exchange balance	756	–428	—	13224	820	–93.8
3	Domestic electricity consumption	15291	16227	6.12	165532	174402	5.36

from coal was produced, and in 2021 this share again increased to almost 80%, which is shown by the structure of electricity production in 2021 (*cf.* Fig. 1; according to PSE data).

During 2021, the demand for power in the national energy system changed significantly. The highest demand for power in the PPS amounted to 27,617 MW on February 12, whereas the minimum was 12,133 MW on June 6, 2021.

Table 5 shows the changes in electricity exports and imports over 16 years (from 2005 to 2021). In recent years, Poland has gone from being an importer of electricity to an exporter. In 2021, a significant amount of electricity was exported to the Czech Republic and Slovakia.

TABLE 5

Changes in the export and import of electricity from 2005 to 2021 (according to PSE and Statistic Poland (GUS) data)

Specification	Years								
	2005	2010	2015	2016	2017	2018	2019	2020	2021
Imports in [GWh]	5002	6310	14459	14017	13271	13839	17869	20434	15100
Exports in [GWh]	16187	7664	14792	12018	10984	8121	7245	7210	14280
Export-import difference in [GWh]	11185	1354	333	–1999	–2287	–5718	–10624	–13224	–820

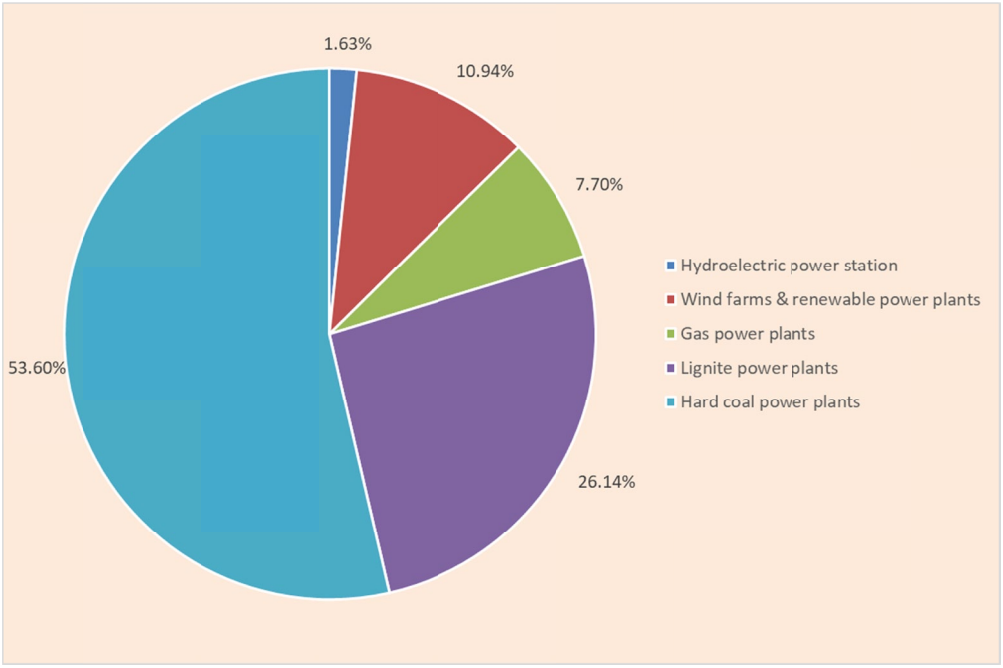


Fig. 1. Structure of electricity production in 2021 (according to PSE data) (in %)

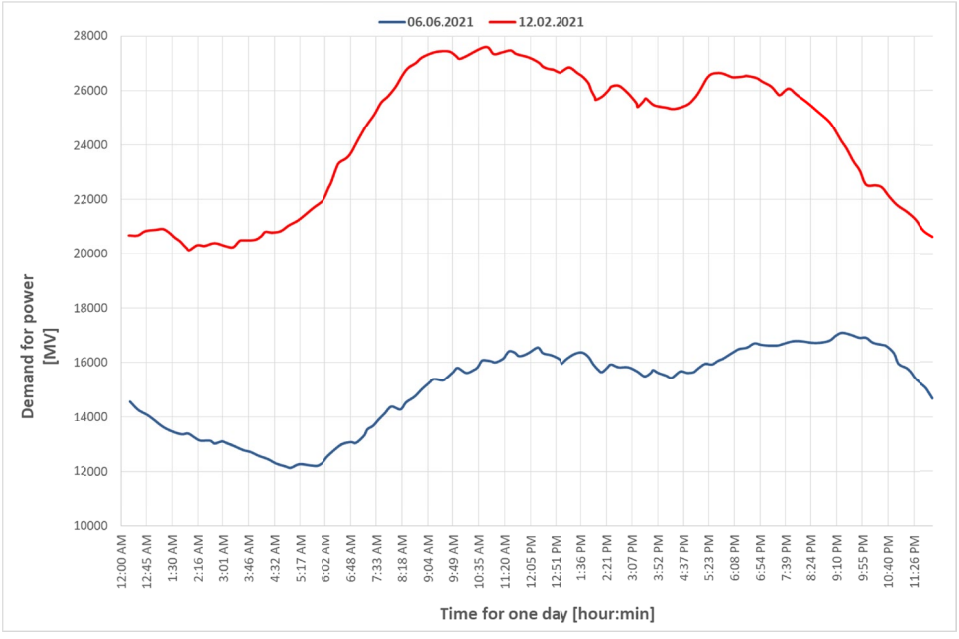


Fig. 2. Demand for power in MW (coordinate axes) in the national system in 2021 (according to PSE)

2. Diagnosis of Polish Power System (KSE) production capacity

In May 2021, the last of the large power units, the 496 MW unit at PGE, the Turów Power Plant, was put into operation. This unit, like four hard coal units of the 1,000 MW class, in Kozienice, Opole and Jaworzno, was constructed as a result of decisions taken before 2015, which marks the end of an era for investments in large-scale power plants for solid fuels. After 2015, apart from two gas units at Polish Energy Group (PGE), Dolna Odra Power Plant, no significant decisions were taken regarding the construction of new capacities ensuring regulatory opportunities in the KSE system. The limitation of the possibility of building onshore wind farms (LFW) through the 10 H Act resulted in an increase in renewable capacity in this technology after 2015 from about 5 to only 7.3 GW. The largest increase occurred in the area of photovoltaics (PV), where, among other things, through the government program called "My Electricity", the level of approx. 7 GW of power in this technology was reached. A barrier to further growth of PV, especially for the connection of large solar farms, is the limitation of the connection capacity to transmission and distribution networks. The amount of renewable capacities that can be connected to the KSE system is related to the provision of an adequate amount of controllable power, which will ensure the ability of the system to operate during the period of power outage from uncontrollable sources (sun, wind) and the development of energy storage technologies.

Assessments of the state of ensuring sufficient generation capacity in the national energy system have recently been presented by institutions responsible for the country's energy security, i.e. PSE, the President of the Energy Regulatory Office and the Ministry of Climate and Environment.

In 2020, PSE published a report titled "Development Plan to Meet Current and Future Electricity Demand for 2021-2030" [10]. The report was prepared based on surveys on planned decommissioning of coal-fired units for technological and economic reasons and investments in generation units from 2019. The report's conclusions indicate a significant deterioration of generation capacity in the national system in the event of the liquidation of older coal units in 2026, for which support from the capacity market will terminate.

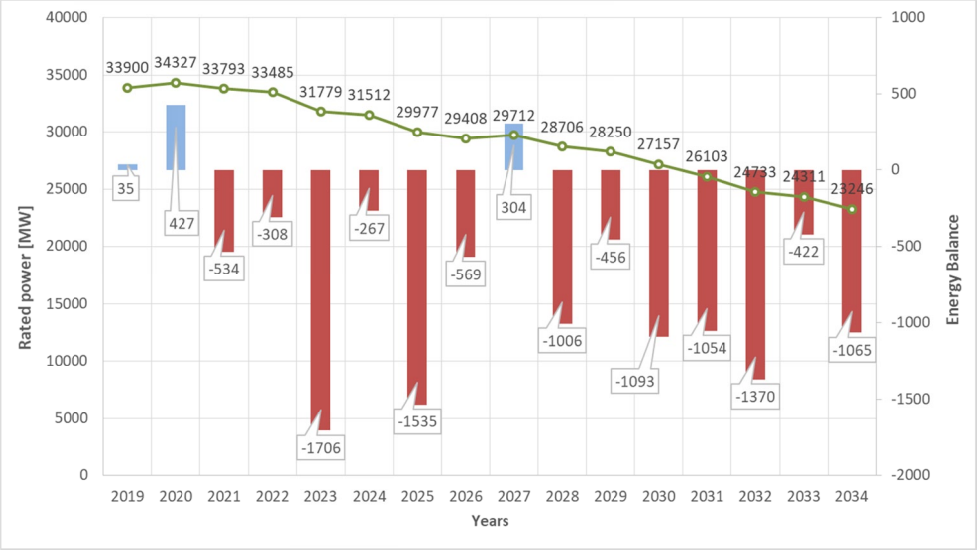
In June 2021, the President of the Energy Regulatory Office (URE) presented "Information on Investment Plans in New Generation Capacities in the Years 2020-2034". The document was prepared based on surveys on planned investments among entities in the sector as of 2020. The balance of reported investments and modernisations after taking into account the decommissioning of power units, assuming a correction factor for the availability of power for individual technologies, indicates the risk of a lack of about 10 GW of needed capacity in 2030 [7].

In July 2021, the Minister of Climate and Environment published the "Report on the Results of Monitoring the Security of Electricity Supply for the Period from January 1, 2019, to December 31, 2020". Without taking into account the short-term risks of a threat to the security of supply, the Ministry pointed out that if the pessimistic scenario materialises, it will be necessary to build new capacities of up to 11 GW, including projects in the combined heat and power (CHP) plants [12].

The conclusions of the expert analysis and documents of PSE, the President of URE and the Minister of Climate and Environment are convergent. Ensuring a smooth transition of the power generation sector requires urgent action in the area of investment and maintaining the availability

of existing coal capacities (not decommissioning) with a mechanism for financing the strategic reserve to be completely replaced by new non-emission sources. Fig. 3 shows the potential loss of power in the KSE system until 2034, after taking into account the planned investments, according to a survey conducted in 2020.

At the end of 2021, the European Commission presented to the Member States a draft delegated an act, a taxonomy for nuclear and gas investments, which is sustainable and can be financed on the European market. This project assumes that investments in gas units are possible during a transitional period before 2030 if their specific emissions do not exceed 270 kg/MWh or the average annual emission is lower than 550 kg/kW of installed capacity, for the next 20 years. In practice, this means blocking investments in large CCGT (Combine Cycle Gas Turbine) gas-fired blocks; such units can work in currently available technologies for about 1,600 hours per year, i.e. at peak. The question arises, what controllable sources will provide power in the national system during the transition period?



Description: A bar graph – Balance: new capacity achievable + modernis ation – decommissioning, Line graph – Achievable power on 31 December of a given year

Fig. 3. Loss of domestic power system (KSE) generation capacity, after taking into account the power availability coefficient (KWD), different for continuous and discontinuous generation technologies (based on the URE Report 2021)

Hostilities in Ukraine do not significantly affect the work of the national system in Poland. Electricity imports from Ukraine amounted to approx. 1.5 TWh in 2020, and in 2021 about 0.8 TWh. In the current situation, attempts have been made to synchronise the power system of Ukraine (UKRENERGO) with the Western European system. PSE is working on the possibility of synchronous operation of connected systems. In the event of a threat to the operation of the Ukrainian system (damage to the power plant), this may mean that the systems of the interconnected countries assume a significant risk of maintaining the continuity of the power supply.

3. Diagnosis of the possibility of filling the gap after the import of gas and steam coal from Russia

Preliminary data for 2021, presented in Table 6, indicate that almost 10 billion m^3 of gas and 8 million Mg of steam coal were imported into Poland from Russia [14]. According to the Statement of the Ministry of State Assets (MAP) [8], the production of hard coal in Poland in 2021 amounted to 55 million Mg, of which 11 million Mg was coking coal.

Is it possible and, if so, how to replace 8 million Mg of coal and 10 billion m^3 of Russian gas in such a short time, especially for the production of electricity and heat?

TABLE 6

Demand for energy resources in Poland. Data compiled on the basis of information from the Industry Development Agency (ARP) and mining companies, as well as the Ministry of State Assets statement

Energy resources	2020			2021 (preliminary)		
	Domestic consumption	Import	Import from Russia	Domestic consumption	Import	Import from Russia
Natural gas [billion m^3]	20.6	17.9	9.6	22.0	18.0	9.9
Including electricity and heat generation from gas	7.9	—	—	8.0	—	—
Hard coal [million Mg]	62.6	12.9	9.4	63.6	12.6	8.3
Including steam coal	52.0	10.5	9.0	53.0	9.3	8.0

Polish mining companies have presented production plans for steam coal for 2022. According to the announced and available public data, the possible production will amount to the following volumes:

- Polska Grupa Górnicza: 24 mln Mg,
- Lubelski Węgiel Bogdanka: 10 mln Mg,
- Jastrzębska Spółka Węglowa: 3 mln Mg,
- Tauron Wydobycie: 5 mln Mg,
- Other coal mines: 1 mln Mg.

In total, the mining plan is about 43 million Mg of steam coal. Due to the lack of adequate progress in preparatory works, increasing production in 2022 and 2023 is possible only by an additional 1-2 million Mg (according to unofficial information). In the coming years, the forecast demand for hard coal will remain close to 53 Mg, and the question arises, how to make up for the shortage of a massive 8-10 million Mg.

4. Risk assessment of the energy transition

Currently, the document from February 2021, titled "Energy Policy of Poland Until 2040" [PEP 2040], constitutes the directional program of the transformation of the Polish energy sector. It concerns, in particular, the power generation subsector. PEP 2040, less than a year after its adoption, as a result of dynamic regulatory and technological changes, as well as the COVID-19 pandemic and disturbances in the energy prices market, and recently the war in Ukraine, has

practically lost its relevance. In the context of the proposal of the Fit for 55 packages of July 2021, a proposal should be made for a quick modification of the policy and adapting it to the directions and pace of change (to the extent possible and acceptable for the national economy).

The most important risks analysed, which should be taken into account when recommending further actions are:

- The risk of lack of access to primary energy sources, in particular hard coal and natural gas, which could replace imports from the Russian direction,
- The risk of high prices of energy raw materials, which may affect the ability of the national system to ensure the supply of competitively priced electricity and heat to industry and individual customers,
- The risk of not providing sufficient controllable capacities and reserving renewable sources in the national system during the transitional period (lack of investment in new controllable capacities and too early decommissioning of coal-fired units for technical and economic reasons). After 2025, coal-fired units whose unit emissions exceed 550 kg/MWh will not be able to benefit from support from the capacity market and will become permanently unprofitable. This applies to approx. 12 GW in older coal-fired units. Before 2030, based on the implemented investments, 1.4 GW will arrive in the KSE system at the Dolna Odra Power Plant and new capacities in Ostrołęka (in the gas version) and Grudziądz, a total of approx. 1.3 GW – the latter two projects will be financed using the capacity market, settling the auction of 2021,
- The risk of improper forecasting of electricity demand in the context of the ongoing electrification processes of transport and heating. PEP 2040 assumed a path of increasing demand for electricity to the level of approx. 204 TWh in 2040 (an increase from 171 TWh in 2020). The growth dynamics in 2021 (consumption of approx. 174.4 TWh, an increase of 2% compared to 2020), and above all the EU climate policy, indicate an underestimation of forecasts by up to 10% in the perspective of 2040,
- The risk of delaying the implementation of the nuclear power plant construction program. The timetable for commissioning the first nuclear unit for operation in 2033 is completely unrealistic from the perspective of the experience of domestic investments in large energy projects (about 10-12 years from the decision to commissioning) and the European experience (Olkiluoto, Flamanville). In the decade 2030-2040, an alternative supply to the KSE network of about 3 GW of controllable power and about 20 TWh of electricity, annually, should be expected, which must replace the nuclear units planned at that time,
- The risk of postponing the schedule of investments in offshore wind farms and a smaller than assumed capacity. In 2030, 5.9 GW of offshore wind farm capacity is scheduled to be put into operation. One should take into account the risk of delaying the schedule for several years due to: the need to build coastal infrastructure to carry out investments, and power output and send it from the north to the south of the KSE system, the time necessary for domestic entities to „learn" a brand new technology. The missing volume of energy can be replaced from other sources, including imports,
- The risk of underestimating the volume of investments in photovoltaic sources and the emergence of barriers to connecting them to the power grid. In PEP 2040, less than 10 GW of photovoltaic capacity is planned. At the end of 2021, the capacity installed in this technology is about 7 GW. A further increase in capacity is expected in prosumer photovoltaics, as well as in large solar farms. There is a risk of network investments in terms of investors' needs in new PV sources.

5. Disscussion – Proposed actions

The diagnosis of the situation in the energy and mining sector and the risk analysis of the implementation of the energy transition program in accordance with the directions and schedule of PEP 2040, as well as the changes planned in the Fit for 55 packages, taking into account the impact of hostilities in Ukraine, leads to the following conclusions:

1. Energy Doctrine: Power and Energy. The national power system is connected to the European system. Further integration and increase of transmission capacity of the KSE system and an increase in trade flows should be assumed. By 2030, cross-border transmission capacity may reach 30 TWh per year. It is recommended to separate the security of the national system in the sense of ensuring sufficient capacity from own resources, from the free movement of electricity at favourable prices from the European market. The doctrine defined in this way allows for longer use of power resources in older coal-fired power plants, with a decreasing period of their operation during the year. At the same time, it allows for the dynamic growth of renewable generation in national resources and an efficient for the economy game in European markets;
2. Thermal coal: Increase in coal extraction by a minimum of 5 million Mg within 5 years. During the transitional period, the gas-based part of the production, or planned to be put into operation, must be replaced by coal sources. Production in domestic mines should be increased, and the launch of the reserve lignite deposit should be re-analysed;
3. Production from renewable sources: Urgent removal of barriers to the production of energy from renewable sources. As a matter of urgency, it is necessary to adopt a package of regulations removing barriers and facilitating the implementation of investments in renewable sources instantaneously. In particular, this applies to the elimination of restrictions from the so-called Act 10H (adoption of the principle of delegation of decisions to the local government level and participation in profits), ensuring the possibility of controlling the power of RES by the system operator, and the possibility for the operator to finance investments in energy storage. Keep in mind that each kilowatt of power in photovoltaics is 0.5 Mg of saved coal per year;
4. Prosumers, cooperatives and energy clusters: The power of civic capital. Investment incentives and tax deductions effectively break down barriers to investing in small-scale energy generation. The initial enthusiasm around energy clusters slowed down over time. Without compromising the regulatory capacity of distribution network operators, barriers to network access and energy self-sufficiency of areas at the local government level should be removed;
5. Industrial energy: Investments in own generation sources. To maintain competitiveness, energy-intensive companies should invest in their generation sources. Regulations are needed to shape such an internal energy strategy, including direct line regulations and mechanisms to protect against production escape outside the ETS system. The CBAM tax mechanism proposed at the EU level may not be beneficial for exporters from Poland to EU countries;
6. Gas generation: Are we in danger of a gas trap? PEP 2040 predicts that during the transition period, gas will be an important component of the energy mix (up to 16 billion m^3 for the power industry). Due to the war situation in Ukraine, the program of investment in gas sources must be revised. Gas in combination with RES sources can be effectively

used in heating, in high-efficiency cogeneration systems. The likely scenario here may be a direct „leap“ from the era of coal-fired energy to renewable energy and nuclear power, with a minimal share of gas;

7. Coal-fired power plants: The cheapest power reserve in the KSE system. Class 200 coal units powered with hard coal and 360 MW lignite-fired plants, with a total capacity of approx. 12 GW, after 2025 will not be able to benefit from the support from the capacity market and thus will become permanently unprofitable. At the same time, their technical condition allows further operation in some units even until 2035. Therefore, it will be necessary to adapt them to the forthcoming BAT (Best Available Technology) emission requirements after 2028, as well as a small modernisation in terms of flexibility of work in the system (possible use of the conclusions from the “Blocks 200+” project, completed in the first quarter of 2022, in three implementations, by the National Center for Research and Development (NCBiR – Narodowe Centrum Badań I Rozwoju)). Estimated capital expenditures for the modernisation: approximately PLN 100 million per block;
8. Strategic reserve for the KSE system: the creation of the National Energy Security Agency (NABE): Yes, but in a different way. To increase financial capacity from the European market, Polish Energy Utilities (the big three groups) are preparing an operation to separate coal assets to the National Energy Security Agency, a State Treasury company, which would include about 80% of the electricity produced. The structure of the energy market would be significantly disturbed. It is recommended to separate coal generation resources into separate entities within energy groups and then liquidate units unnecessary from the point of view of the system operator (PSE) and keep the remaining ones in the strategic reserve. The units would operate outside the energy market and would be activated at the request of PSE (a mechanism similar to the previously existing mechanism of the so-called“ intervention cold reserve” (IRZ), completed in 2020). Financing of fixed costs of blocks would be carried out through an auction mechanism, notified to the EC;
9. Nuclear energy: Yes, but nuclear energy will have a real share in the KSE system, predicted around 2040. The observed slow progress of the implementation of the nuclear program indicates the risk of a significant delay in its implementation compared to the assumed year 2033 (the experience of building large conventional power plant projects in the country shows that the minimum time from the decision-making to commissioning a power plant was around 10 years). Private investors declare the construction of small modular reactors of the SMR type, whose first commercial units should appear in Poland around 2030. This seems very unlikely since the concept of SMR reactors appeared 10 years ago in the USA, and to this day, they have not been produced. It is assumed that the first SMR will appear only after 2026. In fact, Poland will not quickly become a leader in this technology due to the lack of experience in nuclear energy and unresolved security measures. If the SMR technology is intensively developed and there are no surprises, it should be expected that in Poland, the construction of these reactors on a larger scale will commence only after 2040;
10. Energy mix in the period 2030-2040: How to cope without nuclear energy in this period? As shown above, there is a huge risk in the period 2030-2040. There will be no nuclear power plants in Poland, and it will be necessary to provide the KSE system annually with approx. 3 GW of controllable capacity and approx. 20 TWh of electricity. Possible alternative scenarios for the period 2030-2040 are presented in Table 7.

TABLE 7

Alternative scenarios for additional power supplies to the KSE system. Own forecasts [15-[18]

Specification	RES + import + gas scenario	RES + import + coal scenario	RES + coal and CCSU scenario
Capital expenditures [billion PLN]	8-9	2.7-3.5	15-17
Electricity production/year [TWh]	10-15	up to 10	20
Fuel demand	gas, 1.5-2 billion m^3	coal, up to 5 million Mg	coal, 10 million Mg
Impact on the cost of electricity produced [EUR/MWh]	increase of approx. 35	Increase of approx. 95	Increase of approx. 60
Unit and annual emissivity	340 kg/MWh 3.4-5.1 million Mg	950 kg/MWh up to 9.5 million Mg	50 kg/MWh 1 million Mg
Energy independence	*	**	***

NOTE: the higher the number of stars, the greater the energy independence

In each scenario, it is assumed to maximise its production from renewable sources. Scenario I introduces more gas into the domestic mix (increasing demand by about 1.5-2 billion m^3). Scenario II proposes greater imports with the assurance of coal capacity as a reserve of the system. Scenario III assumes the introduction of CCS technology for new units, CCS ready (2-3 units) and a part of new gas units. At an emission allowance price level of EUR 80/Mg, sequestration becomes a business option. Before the gas crisis of the second half of 2021, the recommended scenario was scenario I. Rising prices of emission allowances and uncertainty about the directions of gas supplies and their prices, and above all, the military operations in Ukraine, moved the recommendation towards scenario II. This scenario means adopting a strategy of "leapfrogging" gas technology in significant size, maximising the construction of renewable sources instead, and using older coal-fired units as the reserve capacity in the system. If we were to consider scenario I, it would be necessary to prepare for increased demand for gas in the years 2022-2030 at a later period. These activities include expansion of the terminal in Świnoujście and increase of import capacity to about 7.5 billion Nm^3/ year, construction of new gas storage facilities (Poland currently has gas storage facilities with a capacity of about 15% of domestic demand, the minimum capacity of storage should amount to about 25% of domestic gas demand). Due to environmental challenges, a gradual departure from gaseous fuel should be foreseen, through the "greening of natural gas" with biogas from RES (bio-methane), with natural gas parameters and/or receiving "blue" hydrogen from natural gas using CCUS (Carbon Capture and Usage or Storage) (which includes: capture, transport, utilisation and storage of CO_2) and its purification from sulphur compounds.

6. Conclusion

The hostilities in Ukraine, and the action taken by the EU member states and the US to completely discontinue any imports of energy resources from Russia from 2027, point to the need for a temporary increase in demand for domestic coal, including the substitution of natural gas, wherever possible. The increase in coal production can be achieved by investing in the develop-

ment of existing mines, and/or the construction of an open-pit mine. In authors opinion, actions described above (points 1-10), should be taken immediately. Similar actions must be taken by the EU countries that import about 50 million Mg of Russian coal per year. The energy transition aimed at increasing the share of renewable sources in the energy mix remains relevant, and we should even expect an accelerated pace by the European Commission.

In the dimension of the European economy, the green energy transition means a target of freeing it from imports of raw materials, but in the coming decades, we should expect significant restrictions on continuity of supply and price competitiveness.

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