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RESEARCH ARTICLE

Sławomir DYKAS, Artur SZYMAŃSKI, Xiaoshu CAI

Real prospects for the development of power technologies based on renewable energy sources in Poland

Abstract In Poland more than 40% of the power units have been operating for over 40 years now and more than 10% are over 50 years old, which indicates a high degree of decrease in the value of the energy sector. An analysis of the energy market shows that every year a new power plant should be built with a capacity of 1000 MW to ensure the national energy security. An energy market research indicates that in Poland the structure of energy production is changing in recent years—the share of fossil (solid) fuels in electricity and heat production was approximately 88% in 2009, while in 2004 it reached 93%. According to the analysis of the market, it can be seen that conventional energy, mainly based on coal and lignite, has been the most important segment of the sector for a long time. In this paper the prospects for the development of power technologies based on renewable energy sources (RES) in Poland are presented.

Keywords renewable energy sources, energy sector, energy mix, Poland

1 Introduction

Considerable progress has been made in recent years in the development of what is referred to as "zero-emission" power technologies used to generate electricity and/or heat from more or less renewable energy sources (RES). Undoubtedly, Germany is at the forefront of these changes, setting the tone and directions of development of power technologies based on RES, especially on solar and wind energy. As an European Union (EU) member state, Poland is obliged to follow the guidelines laid down in the EU programming documents such as the Energy Charter Treaty (1994), the White Book (1997), and the Green Book (2001 and 2006) [1]. The important decisions arising from presented action plans include a 20% reduction in greenhouse gas emissions compared to 1990 by the year 2020, a reduction in the primary energy consumption by 20%, an increase in the use of renewable energy by 20%, and a rise in the use of biofuels in transport to 10%. The latest plans [2] assume a further reduction achieved by the year 2030 in greenhouse gas emissions by 40%, in primary energy consumption by 27% and a rise in the share of RES to the level of 27% compared to 1990. The overriding aim of these actions is an improvement in energy security, diversification of energy sources, and a reduction in greenhouse gas emissions into the atmosphere. In the years 1990–2014, carbon dioxide emissions in the 28 EU countries dropped by 20% compared to 1990, which means that the assumed requirements were satisfied. It does not mean, however, that in that period, emissions were reduced in all EU countries — some of them in fact increased their volume [3]. It should be noted that the good result achieved by the EU as a whole is the effect of efforts made by countries with considerable global emissions such as Poland, Germany or Great Britain. The primary energy consumption dropped by almost 4% compared to 1990, while the energy obtained from renewable sources reached 15.3%. The assumed achievement of the 10% level of the share of biofuels in transport poses a difficult challenge to every member state considering the fact that only 5.7% of fuels sold on the EU markets in 2014 contained biocomponents [4]. In Poland, where heat and electricity generation are based on coal mainly, there is still a great potential for implementation of power technologies using RES. But, taking into account the present state of technology, it has to be emphasized that the potential for the use of solar or wind energy for electricity generation in Poland is rather poor. The situation is much better in the

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Sławomir DYKAS, Artur SZYMAŃSKI (✉)
Silesian University of Technology, Institute of Power Engineering and Turbomachinery, Konarskiego 20, 44-100 Gliwice, Poland
E-mail: artur.szymanski@polsl.pl

Xiaoshu CAI
Institute of Particle and Two-Phase Flow Measurement, University of Shanghai for Science and Technology, Shanghai 200093, China

area of heat production, where solar collectors are becoming increasingly popular and where the potential for utilization of biofuels and waste is considerable. The heating season in Poland lasts from October to March (or April), and hot water is prepared all year round. Biofuel and waste combustion/co-combustion technologies for centralized and distributed heat production (and electricity generation as well) are being investigated and developed intensively by Polish research centres and institutions, including the Silesian University of Technology.

This paper presents the real prospects for implementation of power technologies based on RES to generate electricity and heat in Poland in the present economic and political conditions.

2 Energy mix in Poland

2.1 Electricity

At the end of 2015, installed electric power capacity in Poland exceeded 40.4 GW_e. Most of it comes from power stations and combined heat and power plants fired with hard or brown coal (cf. Fig. 1) [5]. The share of RES in it is more than 14%. But the actual availability of RES is lower, mainly due to their strong dependence on changeable atmospheric conditions, and the amount of energy really obtained from them is only a bit higher than 6% of the total electricity produced in Poland. Attention should be paid to the high share of fossil fuels ($>85\%$) in the energy mix. Moreover, the industrial sources shown in Fig. 1 and constituting 6% are, to a great extent, based on fossil fuels.

RES accounted for 6.25% of the total electricity consumption in Poland in that time (cf. Fig. 1). The RES are listed in Table 1 [6]. More than 90% of renewable energy comes from combustion of biofuels, which are mainly solid biofuels and account for 80%, including forestry biomass, and liquid biofuels which account for 8.2% [6]. It should be mentioned that in 2015 in Poland only 0.4% of electricity was generated by wind farms [6]. This is primarily due to Poland's unfavourable climatic conditions — low wind speed and considerable weather changeability, which result in poor availability of the farms. Moreover, most wind farms are located inland, whereas offshore farms, despite higher investment costs, offer much higher availability and higher power outputs owing to favourable climatic conditions — a fairly constant wind direction, intensity, and speed. The commissioning of a Polish 600 MW offshore wind farm planned for 2021 may substantially improve the unfavourable balance. In total, less than 1% of the electricity consumed in Poland was generated from RES non-related to combustion (geothermal, solar, wind and water energy).

Taking into account the energy mix presented above, consideration should be given to identification of actions that could be taken to intensify electricity generation from RES. One of the ways, although some experts find it controversial, is to classify waste incineration plants as a renewable energy source. In Poland, more than 10.5 Tg of municipal waste is generated per year, only 15% of which is thermally neutralized in incineration plants, whereas 53% is stored in landfill sites [7]. Considering the municipal waste calorific value of 17.15 MJ/kg on average (which is quite high compared to hard coal which is 22.35 MJ/kg [8]), waste, if fired or co-fired, offers a great potential for improving the share of RES in electricity generation. At the moment, there are six municipal waste incineration plants in Poland (state as of November 2016). Some of them have already produced heat and electricity. The act signed by the President of the Republic of Poland in March 2015 [9] requires that a 15% share of renewable energy in the total energy consumption be achieved by 2020. This requirement means that Poland will have to face many challenges, both technical and organizational.

2.2 Heat

In 2015, the total thermal power capacity installed in licensed heat producers was 56 GW_t, whereas the maximum capacity was 54.7 GW_t. There are two main sectors in the Polish economy characterized by the highest demand for heat — households and industry. In 2007, the

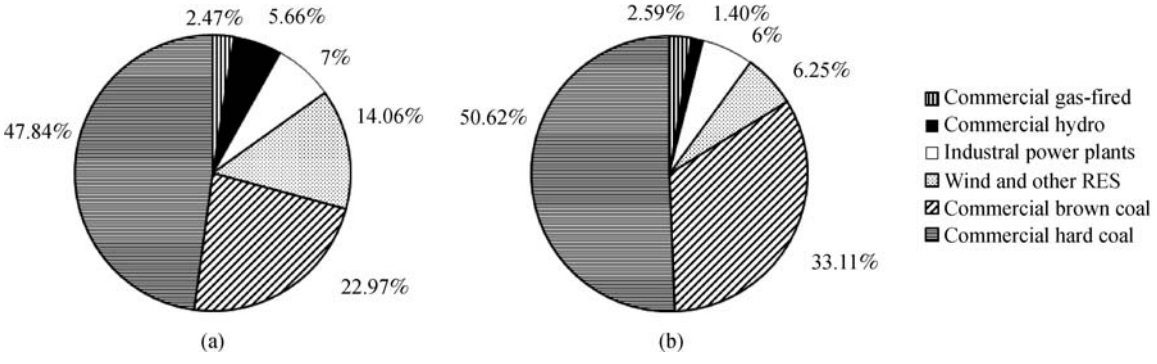

Fig. 1 Energy mix in Poland in 2015—electricity generation
(a) By installed load (installed power); (b) by produced energy

Table 1 RES in Poland

Solid biofuels/%	Liquid biofuels/%	Wind energy/%	Water energy/%	Others (Photovoltaics, Geothermal energy) /%
80	8.2	6.1	2.5	3.2

heat consumption in these two sectors accounted for almost 94% of the total heat demand in Poland (51% and 43%, respectively). Surveys of licensed district heating enterprises have been conducted in Poland since 2002. It is worth mentioning that about 50% of Polish citizens buy heat from systemic district heating enterprises. Most of them live in towns with a population exceeding 50 thousand inhabitants. Poland is doubtless the European leader in district heating. There are few countries in the EU where the percentage of people using district heat is higher, and these are countries with a small population — Iceland, Denmark or the Baltic states. It should be noted that the EU supports the development of district heating [10] because it is usually cleaner (in terms of emissions of air pollutants) and more efficient compared to individual heat sources or small boiler houses. More than 63% of the heat is co-generated with electricity, and a considerable regional diversity can be observed. In district heating, diversification of fuels used for heat generation proceeds very slowly (cf. Fig. 2) [11]. 75% of them are still coals and RES (biomass mainly similarly as electricity generation, see Fig. 3) constitute only 7.4% (cf. Fig. 2) [11].

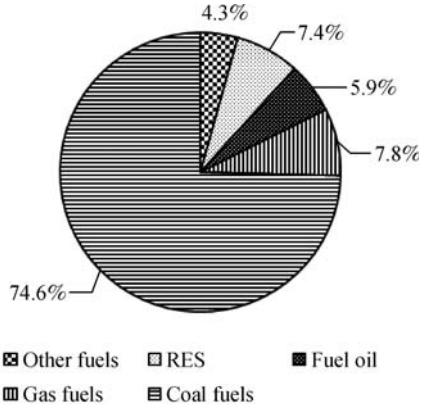

Fig. 2 Energy mix in Poland in 2015 – heat generation

3 Evolution of the energy mix in Poland

3.1 Electricity

Over the last 55 years, there has been a significant increase in installed power capacity in Poland, from 7 GW_e in 1960 to 40.5 GW_e in 2015. The energy mix is also interesting. In 1960, practically all the power was produced by hard coal combustion, with a considerable contribution of industrial power plants. The period marks a considerable increment

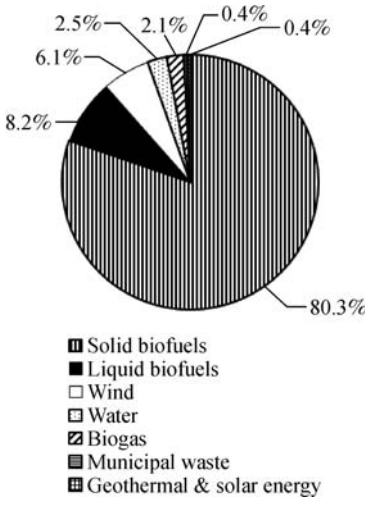

Fig. 3 Energy mix in Poland in 2015 – electricity generation from RES

in the share of hard coal- and gas-fired power stations as well as water power plants. Installed power obtained from hard coal combustion has remained at the same level since the early 1990's, except for the decline observed recently. The increment in RES is remarkable. It has totalled 5 GW_e in the last 10 years. However, the rise in installed power obtained from RES does not involve a rise in the amount of electricity generated. The large share of hard coal in the Polish energy mix is dictated mainly by the fuel easy accessibility and the policy of the state authorities, who for years have been unable to decide whether to go for the coal mining industry restructuring. Additionally, high prices of gas and the low rate of return on RES require special regulations to encourage investment in these areas.

Plans are now being made in Poland for further diversification of energy sources by 2030 [12]. The energy mix assumed for the year 2030 anticipates a rise in the share of gas and wind energy (cf. Figs. 4 and 5) [5,12], with a considerable drop in the energy obtained from hard and brown coal, from 86.4 to 56.2 percentage points. The decline in electricity generation from fossil fuels should also be noted, from almost 90% in 2010 to 63% in 2030 (cf. Fig. 6) [12]. In order to compensate for missing power, tentative proposals are put forward for incorporation of nuclear power plants or an increase in the share of gas and wind energy.

3.2 Heat

In 2015, three hundred and forty-six PJ of thermal energy

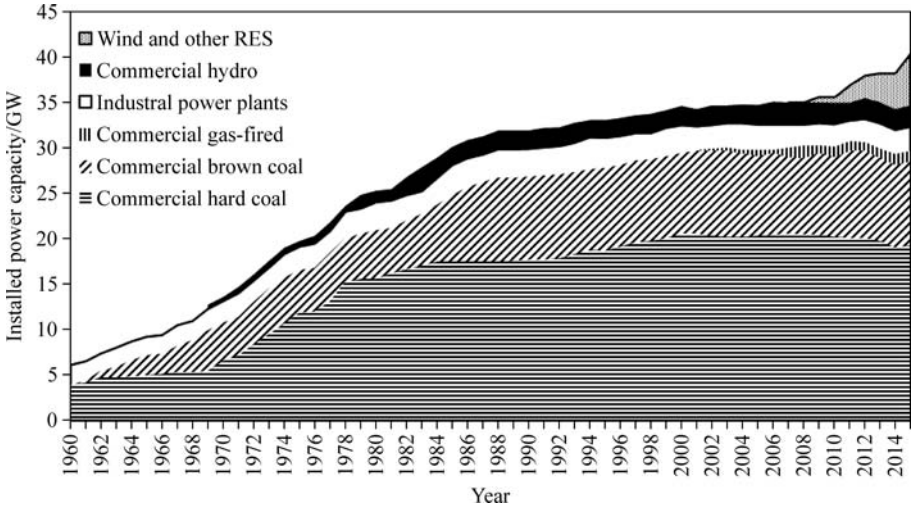

Fig. 4 Increase in installed power capacity in Poland

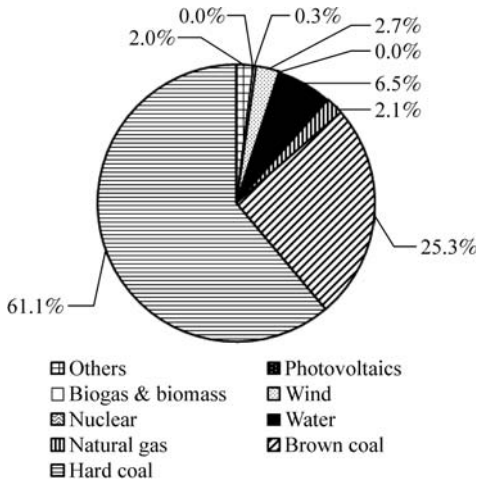

Fig. 5 Installed electric power capacity in Poland by energy sources (%), 2010

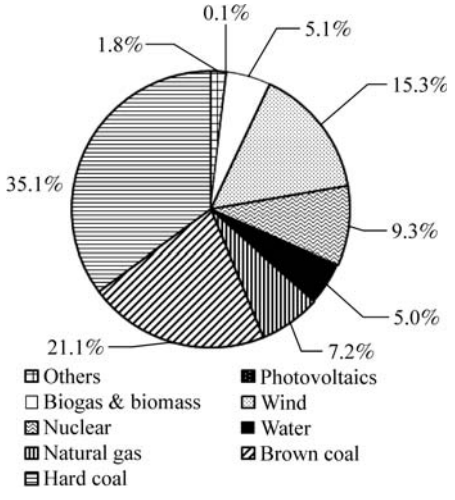

Fig. 6 Planned energy mix of installed electric power capacity in Poland (%), 2030

were produced in Poland to heat homes and prepare hot tap water [13]. In total, over 700 PJ of heat were produced to satisfy municipal and industrial needs. Compared to 2002, there is a substantial decrease by 26.5%, which results mainly from the upgrade of sources and thermal insulation of buildings reducing the demand for heat. The scenarios of district heating development in Poland up to the year of 2030 anticipate stabilization of heat production at the level of 450–500 PJ, to satisfy both industrial and municipal needs, with a downward trend [14]. Heat production statistics have been prepared in Poland since 2002, which is adopted as the reference year for the comparison of any indices. Detailed information about changes on the Polish heat market is presented in Table 2 [13].

A similar trend can be observed across the EU, where the drop in heat consumption has exceeded 20% since 1990. At the same time, there has been a rise in revenues of the domestic heating sector and the market has been centralized. The number of energy enterprises has been nearly halved. Also, the share of enterprises with low installed power capacities (10 MW and less) has declined with a parallel rise in the number of companies with higher power capacities. In this period, the Polish heating sector has improved its performance indices substantially. A considerable rise can be observed in generation efficiency, and the volume of emissions (CO_2, SO_2, NO_x or dust) has declined. The output rate of the plants has improved even though there has been a natural increase in unit costs of production [13]. It should be noted that in current prices, district heating in Poland is the cheapest in the entire EU [15], and the selling price of heat, depending on individual regions, varied at the end of 2015 from € 9.40/GWh to

Table 2 Heat market evolution in Poland in the years 2002–2015

Index	2002	2015	2015/2002 dynamics/%
Installed power/MW	70952.8	56048.7	79.0
Maximum capacity/MW	67285.4	54767.9	81.4
Generation efficiency/%	79.7	86.7	108.8
Transmission efficiency/%	88.2	86.3	97.8
CO_2 emissions/(Mg·TJ^{-1})	120.8	100	82.8
SO_2 emissions/(Mg·TJ^{-1})	0.73	0.27	37.0
NO_x emissions/(Mg·TJ^{-1})	0.26	0.21	80.8
Dust emissions/(Mg·TJ^{-1})	0.14	0.03	21.4
Output rate/(PLN·GJ^{-1})	237.6	581.7	244.8
Average price/(PLN·GJ^{-1})	28.37	48.97	172.6

€ 14.34/GWh, at the nationwide average of € 11.33/GWh[1)]. As of now, there is no uniform long-run scenario of the development of thermal power engineering in Poland (which is the case for electricity generation for example). Nonetheless, a rise can be observed in the significance of highly efficient technologies (based on gas turbines in the first place). The certificates of origin of electricity produced in cogeneration, which have been introduced in Poland recently, are also important. They support gas-fired CHP plants with the capacity of less than 1 MW_e (yellow certificates, PLN125/MWh), energy producers in cogeneration units fired with coal mine methane or biogas (violet certificates, PLN 63/MWh) and CHP plants with the capacity higher than 1 MW_e (red certificates, PLN 11/MWh). Energy enterprises that meet specific requirements concerning cogeneration are exempted from relevant fees, which provides economic justification for investment in first of all gas-fired and biogas (RES) installations. The regulation is valid until the end of 2018.

Unfortunately, in Poland the ecological burden index related to the use of 1 kWh is still the highest of all the EU countries in all burden classes (taking into account the depletion of fossil resources, CO_2 emissions, human toxicity, SO_2 emissions, photo-oxidation and eutrophication) [16]. This is a result of the very large share of coals in the overall volume of fuels fired in Polish power plants and the low values of electricity transmission efficiency at mediocre levels of the efficiency of energy generation. Moreover, Poland still does not have any nuclear power plants, which do not generate harmful emissions directly.

4 State-of-the-art power technologies based on RES

In view of Poland's obligation to the EU to satisfy by 2020 15% of the total energy demand by using RES, it will be extremely difficult to meet the requirements arising there from by means of wind, solar or water energy. Unfavourable weather conditions, relatively weak energy of wind even in coastal areas, the small number of insolation hours per year and the low number of rivers that could be developed for energy generation purposes do not favour RES-based technologies. The opportunity for the development of RES exists in offshore wind farms. Such farms would take advantage of more favourable weather conditions, but they are more expensive due to higher investment costs. The development of RES is also strongly dependent on political and legal factors. The act passed by the Polish parliament on investments in wind farms [17] involves imposing many regulations on new installations. The key changes include the obligation to erect new turbines under the local area development plan only, the set minimum distance between the wind farm and residential buildings of the tenfold of the windmill total height and new taxation obligations. In practice, the new regulations will minimize, if not eliminate, the chance of developing new inland wind farms. A more important aspect is the development of technologies of combustion and co-combustion of biomass and alternative fuels (waste included). The big number of power stations and CHP plants fired with solid fuels and the considerable experience related there to create a great opportunity for the development of RES in Poland. The chance that they will be utilized for energy generation purposes is additionally increased by the fact that a relatively high percentage of waste (almost 60%) is stored in landfill sites.

5 Major investments in the conventional power generation sector in Poland, as of the end of 2016

The ongoing restoration of power in Poland is focused mainly on centralized energy generation by means of fossil fuels. Fuel diversification is becoming visible in the sector,

1) 1€ = 4.323 PLN, the NBP average exchange rate as at 27 October 2016

which is related to the large share of highly efficient energy generation based on gas. Newly built gas-fired power units constitute 30% in terms of capacity. The investments in the Polish power sector are now being made on a historically unprecedented scale. The investment level is the highest in the EU (the worth of investments planned for the years 2016–2020 exceeds 110 billion zlotys, which is 23.1 billion euros). The biggest investment projects now under way are listed in Table 3 [18,19].

The total capacity of currently built power units exceeds 11.5 GW_e, which is as much as 28% of the present installed power capacity. The list presented above does not include all investments now being made in Poland, e.g. some small-scale ventures or the planned nuclear power station which, according to plans, is to be commissioned by 2030 with two units with a capacity of 3000 MW_e each. These huge-scale investment projects are of key importance to economy. The average age of a power unit in Poland is now 40 years, which has a substantial impact on national energy security.

6 Major investments in RES in Poland, as of the end of 2016

In Poland, the share of small-capacity facilities using RES is small. The dominant element is distributed generation characterized by small unit capacities. It should be noted that, according to the EurObserv'ER data, Poland occupies the 5th place in primary energy production from solid biomass in the EU. In this area, Poles have both experience and technical potential. Poland is also the leader of the EU new member states when it comes to new installed capacities generated by wind farms and development of gas-fired plants using agricultural and landfill waste as well as waste from sewage treatment plants. The list presented in Table 4 illustrates the scale of distribution of RES installations across Poland [20]. Moreover, there area certain number of micro scale RES installations with capacities lower than 40 kW that should be taken into consideration. Most of them are small hydro or photovoltaic power plants.

Further development of RES in Poland has to take into account the need to meet the obligations to the EU as well as technical and organizational feasibility. At the moment, the biggest power unit fired in 100% with biomass is in Poland and it is one of the power units of the Połaniec power station. It is fired with wood chips (80%) and agricultural waste (20%) with a power of 205 MW. This proves that RES can exist in Poland. Nevertheless, this is the only power unit in Poland fired with biomass only. Other plants co-firing biomass/alternative fuels include this in their balance. Of the investment projects now under way, the offshore wind farm with the target capacity of 1200MW_e deserves a special mention. Attention should also be paid to the great emphasis on utilization of waste for energy generation purposes. It is planned that six waste incineration plants will have been commissioned by the end of 2016. By contrast, in Germany their number exceeds one hundred. This is one of the directions of the development of RES. Especially in view of the fact that municipal waste is not sufficiently reused (almost 60% is stored in landfill sites). Table 5 presents major investments in RES in Poland.

Table 3 Investment projects in the Polish power sector

Name of coal-fueled power plant	Power capacity /MW_e	Cost, billion zlotys	Planned date of commissioning	Name of natural gas-fueled power plant	Power capacity /MW_e	Cost, billion zlotys	Planned date of commissioning
Peplin	2000	12-15	tba	Włocławek	463	1.50	2017
Opole	1800	11.5	2017	Łagisza	430	1.5	2018
Ostrołęka	1000	7	2017	Wrocław	400	1.50	tba
Kozienice	1000	5.5	2017	StalowaWola	400	1.90	2019
Jaworzno	900	5.5	2017	Bydgoszcz	430	-	2017
Turów	460	2.5	2016				

Table 4 Number of installations in Poland by type

Installation type	Number	Power capacity/MW
Biogas power plants	302	233.277
Biomass power plants	38	1273.115
Photovoltaic installations	453	96.847
Wind power plants	1188	5782.735
Hydro power plants	755	989.973
Co-combustion technology power plants	38	n/a

Table 5 Major investments in RES in Poland

	Power capacity /MW	Cost, billion zlotys	Planned date of commissioning	Fuel
BałtykŚrodkowy III	1200e	10	2021	Wind energy – offshore
Olsztyn	10e + 30t	0.4	2020	Waste
Lublin	50e	0.6	2018	Biomass
Zabrze	75e + 145t	0.8	2018	Waste
Kraków	65e + 280t	no data	n/a	Waste
Biogas-fired plants distributed all over Poland	105 e	0.5 – 1	n/a	Biogas from agriculture/landfill sites/waste

7 Conclusions

The explicit conclusion is that, considering the current investments aiming to restore the Polish energy generation sector and the process economic and political conditions, the rise in the share of RES in heat and electricity production will be slow. The real prospects for a significant increase in the share of RES in the energy mix lie in the combustion of biofuels, biomass in particular, and municipal waste. One of the reasons behind that is the easy availability of cheap domestic technologies, which in the case of local, no nationwide investments is the dominant factor. This direction of the RES development may not be too popular. Waste does not look too good and waste combustion sounds much less appealing than photovoltaics or wind turbines, but it may contribute to a real rise in the share of RES in the energy mix in Poland.

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