REFERENCE SCENARIO (RS)

Current situation and projections with policies and measures existing as at the end of 2017

(without implementing the NECP)

Annex 1 to the ***2021-2030 National Energy and Climate Plan***

Rev. 5.2 of 18/12/2019

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Introduction

This document is an analytical contribution to the preparation of the 2021-2030 National Energy and Climate Plan (NECP), being the first of two analytical annexes to the NECP.

The study explores the impact of policies and measures that existed until the end of 2017, representing a business-as-usual scenario that does not take into account the implementation of policies and actions determined after 31 December 2017. This is the reference scenario (RS) for the Energy and Climate Policy (ECP) scenario, which is presented in Annex 2 of the NECP – *Impact Assessment of planned policies and measures*. **The ECP scenario is an analysis of the impact of policies and measures that set out how and with what results the climate and energy targets and targets implementing the Energy Union will be achieved.** Both documents present a multi-faceted impact analysis of the effects of implementation until 2030, with an outlook to the year 2040.

This part of the report and the information it contains are consistent with guidelines stemming from Regulation (EU) 2018/1999 of the European Parliament and of the Council of 11 December 2018 on the Governance of the Energy Union and Climate Action, amending Regulations (EC) No 663/2009 and (EC) No 715/2009 of the European Parliament and of the Council, Directives 94/22/EC, 98/70/EC, 2009/31/EC, 2009/73/EC, 2010/31/EU, 2012/27/EU and 2013/30/EU of the European Parliament and of the Council, Council Directives 2009/119/EC and (EU) 2015/652 and repealing Regulation (EU) No 525/2013 of the European Parliament and of the Council.

4. CURRENT SITUATION AND PROJECTIONS WITH EXISTING POLICIES AND MEASURES (as at the end of 2017)

4.1 Projected evolution of main exogenous factors influencing energy system and greenhouse gas emission developments – general parameters and variables

4.1.1. Population

The size of the population residing in Poland was estimated on the basis of the census conducted in 2011, with calculations for the consecutive years being based on data from administrative records of births, deaths and long-term internal and international migration (undocumented and illegal migration is not included in resident population estimates)[1].

Table 1. Number of resident population [million]

[1] Residents (resident population), Statistics Poland (GUS), access: http://stat.gov.pl/obszary-tematyczne/ludnosc/ludnosc/rezydenci-ludnosc- rezydujaca,19,1.html

	2005	2010	2015	2020	2025	2030	2035	2040
Total	38.1	38.1	38.0	38.1	37.9	37.5	37.1	36.5
Urban	23.4	23.1	22.9	22.6	22.3	21.8	21.2	20.7
Rural	14.7	14.9	15.1	15.4	15.6	15.7	15.8	15.8

Source: 2015-2050 projection of Poland's resident population. Statistics Poland (GUS), Warsaw, January 2016.

The presented demographic projection shows a decrease in resident population over the analysed period from the current 38 million to 36.5 million. Notably, the decrease concerns the urban population alone, with the number of rural residents increasing steadily. This is mainly due to the progressing pattern of population movement from urban to rural areas, most often suburban municipalities near large cities, which has been observed since around 2000.

4.1.2. GDP

The macro-economic scenario underlying the projection of energy demand in Poland towards 2040 was based on GDP growth forecasts published by the Ministry of Finance (MF)[2] in May 2017. While updated forecasts are currently available, e.g. from May 2019, an informed decision was made not to change the model assumptions formulated at an earlier stage of work on the NECP due to the insignificant differences in the forecasted values and the resultant negligible impact on the following analyses. Table 2 presents a projection of Poland's GDP growth in absolute terms (adopted in model calculations) and Table 3 presents average annual growth projections.

Table 2. Gross domestic product [EUR'2016 million]

	2005	2010	2015	2020	2025	2030	2035	2040
GDP	317,010	400,114	462,370	551,249	649,661	748,029	843,849	938,089

Source: Eurostat, MF

Table 3. GDP forecasts 2016-2040 (average annual growth rates)

	2016-2020	2021-2025	2026-2030	2031-2035	2036-2040	2016-2040
GDP	103.6	103.3	102.9	102.4	102.1	102.9

Source: Ministry of Finance, ARE S.A.

As the projections demonstrate, the average annual GDP growth rate in Poland in the period under analysis is 2.9%. The rate is higher than that assumed in the PRIMES[3] Reference Scenario by approx. 0.7 percentage points. The government's path of economic development should be regarded as rather optimistic, yet feasible if the State takes an active role in supporting domestic consumption, improving innovation of enterprises and stimulating investment activity. The reindustrialisation of the economy as announced by the government in its *Strategy for Responsible Development* is expected to be a major driver of future economic growth.

4.1.3. Sectoral gross value added

The structure of gross value added generation is estimated on the basis of the anticipated GDP growth path and macroeconomic assumptions derived from the PRIMES model (Reference Scenario).[10]

Table 4. Sectoral gross value added [EUR'2016 million]

	2005	2010	2015	2020	2025	2030	2035	2040
Gross value added	**278,683**	**351,994**	**402,825**	**475,640**	**555,687**	**636,721**	**714,785**	**790,729**
Industry	61,282	86,857	103,904	119,117	137,327	156,588	171,983	185,218
Agriculture	10,298	10,267	9,537	9,735	9,937	10,143	10,351	10,564

[2] *Wytyczne dotyczące stosowania jednolitych wskaźników makroekonomicznych będących podstawą oszacowania skutków finansowych projektowanych ustaw. Aktualizacja - maj 2017 r.* [Guidelines on the use of uniform macroeconomic indicators underlying the estimation of financial consequences of proposed legislation. Update of May 2017], Ministry of Finance, Warsaw 2017.https://www.gov.pl/web/finanse/wytyczne-sytuacja-makroekonomiczna

[3] Poland: Reference Scenario. Detailed Analytical Results. Primes Ver. 4 Energy Model. E3MLab, National Technical University of Athens.

Transport	18,277	18,613	25,905	31,207	33,929	36,469	38,943	41,184
Construction	22,971	29,885	35,389	35,166	38,852	42,636	44,560	46,727
Services	165,855	206,373	228,090	280,416	335,641	390,886	448,947	506,982

Source: Eurostat, MF, PRIMES Ref2016, ARE S.A.

In accordance with the projected increase in gross value added, services will be the fastest growing sector of the economy (its value added is expected to double in the period under analysis). An increase in the importance of services for Polish economy will take place mainly at the expense of industry. The share of this sector in GDP generation will decrease from 26% in 2015 to 23% in 2040 (see the figures below).

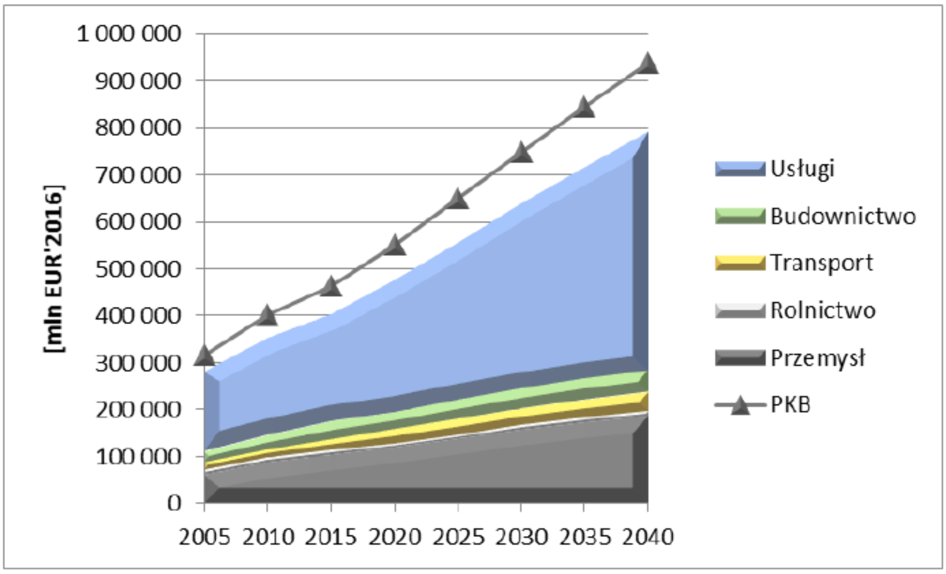

Figure 1. GDP and the breakdown of gross added value generation in Poland

[mln EUR'2016]	**[EUR'2016 million]**
Usługi	Services
Budownictwo	Construction
Transport	Transport
Rolnictwo	Agriculture
Przemysł	Industry
PKB	GDP

4.1.4. Number and size of households

The projections of the number of households (Table 6) and the average number of household members (Table 7) reflect the projected size of Polish population. The estimates are based on an analysis of historical trends and comparisons with the corresponding projections of Statistics Poland (GUS). The following breakdown shows a gradual improvement of housing conditions in Poland, as manifested by a decrease in the number of household members. In 2015, there were on average 2.7 persons per household. This figure is expected to drop over the period under analysis to approx. 2.3 in 2030 and 2.2 in 2040.

Table 5. Number of households

	2005	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**
Total	**12,776**	**13,471**	**13,962**	**14,742**	**15,443**	**16,044**	**16,530**	**16,922**
Urban	8,580	9,088	9,398	9,875	10,301	10,646	10,905	11,102
Rural	4,196	4,383	4,564	4,867	5,142	5,398	5,625	5,820

Source: GUS, ARE S.A.

Table 6. Number of persons per household

	2005	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**
Total	3.0	2.8	2.7	**2.6**	**2.5**	**2.3**	**2.2**	**2.2**
Urban	2.7	2.5	2.4	2.3	2.2	2.0	1.9	1.9

Rural	3.5	3.4	3.3	3.2	3.0	2.9	2.8	2.7

Source: GUS, ARE S.A.

4.1.5. Disposable household income

In accordance with the Eurostat methodology, which has been applied in Polish statistical analyses, disposable household income is the sum of annual gross cash incomes of all household members minus income tax, property taxes, social and health insurance contributions, inter-household cash transfers paid, and settlements with the Tax Office (cash that households can use for consumption, investments or savings). This indicator can be used for assessing the real purchasing power of households. For the purposes of this document, use is made of statistical data on the level of average monthly disposable income per capita as published by GUS.[4] The forecast for this indicator (table below) is based on the projected growth of GDP in Poland and the average household size.

Table 7. Projected available household income [EUR'2016]

	2005	2010	2015	2020	2025	2030	2035	2040
Country total	8,640	11,111	10,731	12,700	14,383	16,019	17,607	19,493

Source: GUS, ARE S.A.

According to the above projection, disposable householdincome in Poland will have almost doubled in 2040 compared to the current figure. An increase in this indicator reflects an improvement in the financial situation of the Polish society at large and will, amongst others, determine the future growth of energy demand in the country.

4.1.6. Passenger transport performance

Demand for transport performance is the primary driver of demand for fuels and energy, and therefore also of emissions from the transport sector.
The forecasts of this demand are based on the preliminary 2015 data and have been compared with the respective assumptions underlying the PRIMES model,[5] as well as the figures from the *Transport Development Strategy.*[6] They are the result of adopting a bottom-up approach in the forecasting model in which the following general calculation method was applied:

transport performance for a given mode of transport [passenger-kilometres (pkm)]
*= number of vehicles of a given type [units] * average annual mileage [km] * number of passengers carried*

According to the projection adopted for calculation purposes, the number of passenger cars registered in the country will increase from 20.7 million in 2015 to 28.3 million in 2030 and to 30.3 million in 2040. Please note the specific situation in Poland, where the total number of vehicles registered is several million higher than the number of vehicles actually in use (this has been factored in in fuel consumption forecasts, which is why the number of passenger vehicles actually in use has been reduced according to the estimates of the Automotive Market Research Institute SAMAR[7]). Forecasts of average mileage were prepared on the basis of expert analyses informed by data from the Central Register of Vehicles and Drivers (CEPiK) and estimates performed by the Motor Transport Institute (ITS).[8] To determine the number of vehicles of a given type, dedicated econometric models were fed with information concerning population size and structure, disposable income per capita, users' preferred forms of transport, the quality of mass transport services and forecasts for the

[4] *Budżety gospodarstw domowych w 2016 r.* [Household budget survey 2016], GUS, Warsaw 2017.

[5] Ibidem.

[6] Resolution No 6 of the Council of Ministers of 22 January 2013 on the Strategy for Transport Development towards 2020 (with an outlook to 2030), Official Gazette *Monitor Polski*, 14 February 2013.

[7] *Park pojazdów 2014. Strefa Biznesu* [Vehicle Park 2014. Business Zone], IBRM SAMAR, Warsaw 2015.

[8] Waśkiewicz J., Chłopek Z., Pawlak P., *Prognozy eksperckie zmian aktywności sektora transportu drogowego (w kontekście ustawy o systemie zarządzania emisjami gazów cieplarnianych i innych substancji)* [Expert forecasts of activity changes in the road transport sector (in the context of the Greenhouse Gas Emission Allowance Trading Scheme Act], Motor Transport Institute, Warsaw 2012.

development of mass transport, as well as the availability and conditions of operation of private road transport vehicles.

Table 8. Passenger transport performance [billion pkm]

	2005	2010	2015*	2020	2025	2030	2035	2040
Passenger motor vehicles (private)	No data	281.0	332.5	389	442	489	526	558
Motorcycles (private)	No data	5.1	6.7	8	10	12	14	16
Scooters, mopeds, bicycles	No data	1.5	1.7	1.9	2.1	2.2	2.4	2.6
Buses (urban)	No data	11.7	11.7	12	12	12	12	12
Buses (extra-urban)	21.6	21.5	21.5	20	19	19	18	17
Railways (public)	18.2	17.9	17.4	18	22	30	31	31
Airplanes	8.5	8.3	13.5	17	20	22	24	26
Inland waterway transport	No data	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Rail vehicles (trams, trolleybuses, metro)	No data	3.2	3.5	4	5	6	6	7
Total	**No data**	**350**	**408**	**470**	**532**	**592**	**633**	**671**

** Estimated data*
Source: Primes Ver. 4 Energy Model. National Technical University of Athens, 7 January 2013, Transport - wyniki działalności [Transport – operational results] – GUS. Warsaw, 2011, 2012, 2013, 2014, 2015, Transport Development Strategy towards 2020 (with an outlook to 2030) – Official Gazette Monitor Polski. Warsaw, 2013, and ARE S.A. estimates.

In summary, there is an increase in demand for transport performance in passenger transport in 2015-2040 from 408 billion pkm to 671 billion pkm, i.e. by approx. 64%. In terms of modes of transport, private road transport is the single largest contributor to this demand, with its share increasing from 332 billion pkm in 2015 to 558 billion pkm in 2040. A significant increase in demand is also noted in relation to rail transport (which is attributable to an improved quality of services and the development of a high-speed rail system) and air transport (as a result of an increasing availability and popularity of this form of transport).

4.1.7. Freight transport performance

In addition to economic growth as measured by a number of macroeconomic indicators, demand for freight transport is driven by factors such as changes in transport intensity of economic activity (this intensity tends to decrease with an increase in the share of highly processed goods and services), the volume of Polish foreign trade, modal shifts in transport, and developments on international transport markets. The projections of demand for freight transport used in the energy forecasts are derived directly from a model based on the following algorithm:

transport performance for a given mode of transport [tkm]
= weight of transported loads [tonne] average transport distance per tonne of load [km]*

According to the adopted projection, demand for freight transported by Polish carriers will increase from 1,824 million tonnes in 2015 to 2,398 million tonnes in 2030, and then to 2,437 million tonnes in 2040. The forecasts of the average distance over which loads will be transported by individual means of transport are based on a historical trend analysis. Table 9 summarises projections of freight transport performance resulting from the application of the bottom-up model.

Table 9. Freight transport performance [billion tkm]

	2005	2010	2015*	2020	2025	2030	2035	2040
Rail transport	50.0	48.9	50.7	66	73	80	83	86
Road transport	119.7	214.2	273.1	302	331	357	369	373
Pipeline transport	25.4	24.2	21.8	24	25	27	27	27
Inland waterway shipping	1.3	1.0	2.2	1.4	1.4	1.3	1.2	1.1
Maritime shipping	No data	112	158	180	200	220	235	245
Air transport	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2
Total	**No data**	**400**	**506**	**574**	**631**	**686**	**715**	**732**

** Estimated data*
Source: ARE S.A., Primes Ver. 4 Energy Model. National Technical University of Athens, 2013-01-07, Transport

- wyniki działalności [Transport – operational results] – GUS. Warsaw, 2011, 2012, 2013, 2014, 2015, Transport Development Strategy towards 2020 (with an outlook to 2030) –Official Gazette Monitor Polski. Warsaw 2013.

As shown by the presented results, demand for freight transport increases from 506 billion tkm in 2015 to 686 billion tkm in 2030 and to 732 billion tkm in 2040. In terms of modes of transport, road transport is the single largest contributor to this demand, accounting for approx. 51% of transport performance over the considered timescale.

4.1.8. International fuel import prices

The projected prices of fuels imported into the European Union used in the model calculations, as presented in Table 10 and Figure 2, come from the latest projection of the International Energy Agency (IEA)[9] – World Energy Outlook 2017, New Policies Scenario. These figures are used as a basis for determining trends in fuel price projections on the domestic market.

Table 10. Prices of fuels imported into the EU [EUR'2016/GJ (NCV)]

	2005	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**
Crude oil	7.73	9.94	6.83	8.0	10.7	12.1	13.3	14.3
Natural gas	5.17	6.28	6.64	5.5	6.9	7.6	8.0	8.4
Coal	2.18	2.66	1.97	2.2	2.6	2.7	2.7	2.7

Source: ARE S.A. on the basis of the World Bank, IMF, European Commission, and IEA's New Policies Scenario 2016.

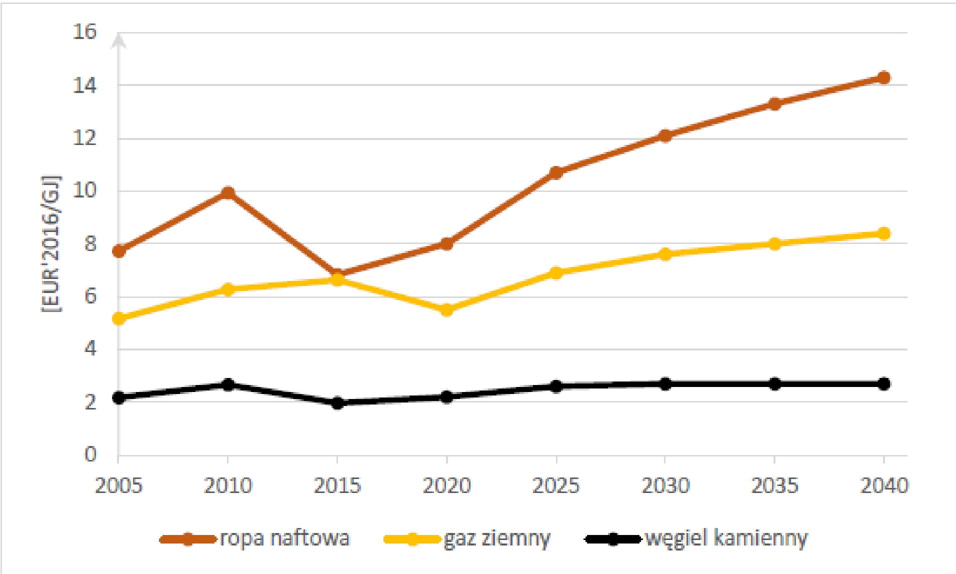

Figure 2. Prices of fuels imported into the EU

[EUR'2016/GJ]	**[EUR'2016/GJ]**
ropa naftowa	crude oil
gaz ziemny	natural gas
węgiel kamienny	hard coal

4.1.9. Prices of EU ETS CO_2 emission allowances

For the purpose of consistency, the projected prices of EU ETS CO_2 allowances (EUA) are also based on the IEA's latest World Energy Outlook 2017 (New Policies Scenario)[15]. The Outlook foresees a substantial increase in EUA prices over the time horizon under study. The projected prices of carbon emission allowances used in the analysis are presented in Table 11. It is assumed that the cost of carbon emission allowances will increase

[9] World Energy Outlook 2017, International Energy Agency, Paris 2017.

[15] Ibidem.

linearly in the periods between the boundary years.

Table 11. EU ETS CO_2 prices [EUR'2016/tCO_2]

	2005	2010	2015	2020	2025	2030	2035	2040
Price per allowance	0	12	8	17	21	30	35	40

Source: ARE S.A. on the basis of IEA, EC, Thomson Reuters, KfW Bankengruppe

It is assumed that the price of carbon emission allowances will be gradually increasing to 40 EUR'2016/t CO_2 in 2040, working towards the EU's goal of cutting GHG emissions by 40% by 2030 and the ambitious long-term goal of reducing GHG emissions by 80-95% in 2050 compared to the 1990 level[10]. The price of carbon emission allowances will be driven, *inter alia*, by the Market Stability Reserve (MSR). Until 2030, the assumed prices of allowances align with the recommendations of the European Commission on the use of indicators for the purposes of preparing national plans[11]. In 2030-2040, the rate of increase in the prices of CO_2 emission allowances projected by the IEA is slightly slower than that in the European Commission's Reference Scenario (this may, for example, happen following an increase in the volumes of allowances offered at auctions caused by emission reductions due to the price pressure in previous years).

4.1.10. Exchange rates

The exchange rates are adopted in correspondence to the recommendations of the European Commission regarding the preparation of the NECP. They assume stabilisation of the USD/EUR exchange rate at 1.2 and that for PLN/EUR at 4.25. The 2005-2015 historical figures come from the NBP data.

Table 12. Exchange rates

	2005	2010	2015	2020	2025	2030	2035	2040
USD/EUR	1.245	1.328	1.120	1.16	1.20	1.20	1.20	1.20
PLN/EUR	4.023	3.995	4.184	4.25	4.25	4.25	4.25	4.25

Source: NBP, European Commission recommendations.

4.1.11. Number of heating and cooling degree days

The assumptions regarding the number of degree days over the forecast period are adopted on the basis of the Commission's recommendations regarding the preparation of the NECP. The 2005-2015 historical data originate from Eurostat databases. The projections assume a gradual warming of the climate in the climate zone where Poland is located.

Table 13. Number of heating degree days (HDD)

	2005	2010	2015	2020	2025	2030	2035	2040
HDD	3,547	3,881	3,113	3,442	3,430	3,418	3,408	3,399

Source: Eurostat, European Commission recommendations

Table 14. Number of cooling degree days (CDD)

	2005	2010	2015	2020	2025	2030	2035	2040
CDD	216	197	220	223	226	229	231	233

Source: Eurostat, European Commission recommendations

4.1.12. Technology cost assumptions used in the modelling of key technologies

The parameters of new generating units presented in Table 15 are based on the latest available publications of reputable research centers. The analyses are based on the assumption that the only available electricity and heat generation technologies will be those that are currently offered commercially. Carbon capture and storage (CCS) technologies are also included.

[10] European Commission, Energy Roadmap 2050 (COM(2011) 885 final of 15 December 2011.

[11] European Commission: EU Reference Scenario 2016. Energy, transport and GHG emissions trends to 2050, July 2016.

Table 15. Technical and economic parameters of generation and transmission technologies

fuel/ technology	commissioning period	capital expenditure OVN	costs		net/total electrical efficiency	technical life time	CO_2 emission factor
			fixed	variable			
		'000 EUR/MW$_{net}$	'000 EUR/MW$_{net}$	EUR/MWh$_{net}$	%	years	kg/GJ
1.1 Lignite – PL	2016-2040	1,800	48	3.4	44	40	110
1.2 Lignite – PL+CCS	2030-2040	3,250	72	8.6*	38	40	14
1.3 Lignite – FBC	2020-2040	2,050	50	3.4	40	40	106
2.1 Coal – PC	2016-2040	1,650	44	3.2	46	40	94
2.2 Coal – IGCC	2025-2040	2,250	58	5.0	48	40	12
2.3 Coal – IGCC+CCS	2030-2040	3,250	78	7.2*	40	40	12
2.4 Coal – CHP	2016-2040	2,250	48	3.2	30/80	40	94
2.5 Coal – CHP+CCS	2030-2040	3,500	76	10*	22/75	40	12
3.1 Natural gas – GTCC	2016-2040	750	18	1.8	58-62	30	56
3.2 Natural gas – GTCC+CCS	2030-2040	1,350	38	4.0*	50-52	30	6
3.3 Natural gas – TG	2025-2040	500	16	1.4	40	30	56
3.4 Gas Micro CHP	2016-2040	2350	97	-	20/90	25	56
4.1 Nuclear – PWR	2030-2040	4,500	85	0.8	36	60	0
5.1 Onshore wind	2016-2020	1,350	50	-	-	25	0
5.2 Onshore wind	2021-2040	1,350↓1,250	50	-	-	25	0
5.3 Offshore wind	2020-2030	2,450↓2,250	90	-	-	25	0
5.4 Offshore wind	2031-2040	2,250↓2,075	90	-	-	25	0
5.5 Large hydropower	2020-2040	2,500	35	-	-	60	0
5.5 Small hydropower	2016-2040	2,000	75	-	-	60	0
5.6 Geothermal	2020-2040	7,000	160	-	0.12	30	0
5.7 Photovoltaics	2016-2020	1,100↓900	16	-	-	25	0
5.8 Photovoltaics	2021-2040	900↓700	16	-	-	25	0
5.9 Roof photovoltaics	2016-2020	1,250↓1,150	20	-	-	25	0
5.10 Roof photovoltaics	2021-2040	1,100↓800	20	-	-	25	0
5.11 Agricultural biogas – CHP	2016-2040	3,250↓2,750	220	-	36/85	25	0
5.12 Wastewater treatment biogas – CHP	2016-2040	3,500	135	-	34/85	25	0
5.13 Landfill biogas – CHP	2016-2040	1,800	80	-	40/85	25	0
5.14 Solid biomass – CHP	2021-2040	2,950↓2,750	120	-	30/80	30	0
5.15. Heating boiler – coal	2016-2040	350	1	1.4	0.9	30	94
5.16. Heating boiler – natural gas	2016-2040	150	1	0.4	0.96	30	56
5.18. Heating boiler – fuel oil	2016-2040	200	1	0.5	0.95	30	74
5.19. Heating boiler – biomass	2016-2040	500	1	1.4	0.9	30	0
5.20 Power transmission network HV	2016-2040	190					
5.21 Power	2016-2040	250					

transmission network MV							
5.22 Power distribution network LV	2016-2040	500					

** Including carbon transportation and storage*

CHP – cogeneration, combined heat and power generation;
PC – condensing power plants with pulverised coal boilers
PL – condensing power plants with pulverised lignite boilers
CCS – sequestration (carbon capture and storage)
GTCC – gas turbine combined cycle power plants
IGCC – integrated gasification combined cycle power plants
FBC – fluidised bed combustion power plants
PWR – pressurised water reactor MV – medium voltage
EHV – extra high voltage
HV – high voltage

Source: ARE S.A. based on:
World Energy Outlook, International Energy Agency, Paris 2016;
WEIO 2014-Power Generation Investment Assumptions, International Energy Agency, Paris 2014;
The Power to Change: Solar and Wind Cost Reduction Potential to 2025, International Renewable Energy Agency, Bonn 2016; Energy and Environmental Economics – Recommendations for WECC's 10- and 20-Year Studies, San Francisco 2014;
World Energy Perspective Cost of Energy Technologies, World Energy Council, Project Partner: Bloomberg New Energy Finance, 2013;
Lazard's Levelized Cost of Energy Analysis - Version 9.0, Lazard, New York 2015;
Scenarios for the Dutch electricity supply system, Frontier Economics, London 2015;
Energy Technology Reference Indicator projections for 2010-2050, European Commission JRC Institute for Energy and Transport, Brussels 2014;
Projected Cost of Generating Electricity 2015 Edition, International Energy Agency, Nuclear Energy Agency, Organization for Economic Co-operation and Deployment, Paris, 2015;
Cost and Performance Characteristics of New Generating Technologies, Annual Energy Outlook 2016, U.S. Energy Information Administration, Washington 2016.

Table 16 presents the technical and economic parameters of central heating (CH) and sanitary hot water (SHW) technologies used by households and small service enterprises, adopted for calculation purposes. The data come from a range of different sources, including official websites of manufacturers and distributors of the devices concerned in Poland.

Table 16. Technical and economic parameters of CH and SHW technologies

	Purchase cost [EUR'2016]	Purchase cost of additional installations [EUR'2016/kW]	Description of additional installations	Efficiency [%]
Electric boilers or heaters – permanently installed	24	none	not applicable	100
Electric boilers or heaters – movable	12	none	not applicable	100
Electric underfloor heating	143	48	control and automation	100
Electric water heater (boiler, flow-through heater)	17	none	not applicable	100
Central heating natural gas-fired boiler	48	179	water heaters + connection	90-97
Natural gas water heater (boiler, flow-through water heater)	18	60	connection	90
Natural gas-fired combi boiler (central heating + hot water)	72	179	water heaters + connection	90-97

LPG central heating boiler (propane-butane)	48	239	water heaters + tank	90-97
LPG water heater (propane-butane)	18	2	cylinder	90
Liquid gas (propane-butane) combi boiler (central heating + hot water)	72	239	water heaters + tank	90-97
CH fuel oil-fired boiler	48	131	water heaters + tank	90-95
Fuel oil-fired combi boiler (central heating + hot water)	72	131	water heaters + tank	90-95
CH solid fuel-fired boiler	48	119	water heaters	60-80
Solid fuel-fired water heater (boiler, flow-through water heater)	18	48	solid fuel-fired boiler	60-80
Solid fuel-fired combi boiler (central heating + hot water)	66	119	water heaters	60-80
Solid fuel space heaters	24	none	not applicable	40-80
Open solid fuel fireplace	24	72	mantel	40-80
Solid fuel fireplace with a closed insert	24	72	mantel	50-80
Solid fuel fireplace with a water jacket	96	191	mantel + water heaters	60-80
Solid fuel cooker	24	none	not applicable	30-80
Heat pump	717	119	water heaters	3.5-5.4*

** For heat pumps, the coefficient of performance (COP) is given instead of efficiency.*
Source: ARE S.A. based on data collected from producers and distributors of devices

Due to the complexity of production processes in industry and the high diversity of industrial technologies and solutions, the industry sector is treated in a simplified manner in the energy model. The model defines five main directions of energy use: furnace heat, process steam, electric drives, space heating and lighting. The process steam is produced in industrial CHP plants, for which technical and economic parameters are listed in Table 16. On the other hand, furnace heat used in industrial processes, such as firing ceramic products, melting bituminous mass, glass, drying, etc., is produced using furnace technologies whose technical and economic parameters are presented in Table 17. In addition, the table contains data for electric motors commonly used in industry to convert electrical energy into mechanical energy.

Table 17. Technical and economic parameters of industrial technologies

technology	**fuel**	**direction of use**	**purchase cost [EUR'2016/kW]**	**O&M costs [EUR'2016/GJ]**	**technical life time**	**CO_2 emission factor [kg/GJ]**
industrial furnaces/boilers for process heat production	blast furnace gas	furnace heat	1,200	0.30	25	260
industrial furnaces/boilers for process heat production	coke oven gas	furnace heat	1,611	0.40	25	44
industrial furnaces/boilers for process heat production	coke	furnace heat	500	0.12	25	107
industrial furnaces/boilers for process heat production	electricity	furnace heat	1,200	0.30	25	0
industrial furnaces/boilers for process heat production	coal	furnace heat	1,611	0.40	25	94
industrial	heavy fuel oil	furnace	1,611	0.40	25	77

furnaces/boilers for process heat production		heat				
industrial furnaces/boilers for process heat production	light fuel oil	furnace heat	1,611	0.40	25	77
industrial furnaces/boilers for process heat production	LPG	furnace heat	1,200	0.30	25	63
industrial furnaces/boilers for process heat production	natural gas	furnace heat	1,200	0.30	25	56
electric motors	electricity	electric drives	400	0.18	10	0

Source: ARE S.A. on the basis of on input data for the MARKAL[12] model and the European Commission's guidelines on the preparation of the NECP

Table 18 lists the parameters of technologies used in transport, which are, however, limited to passenger vehicles only.

Table 18. Technical and economic parameters of technologies used in transport

	New vehicle purchase cost [EUR'2016/vehicle]	**Specific fuel/energy consumption [l/100km] 2015→2040**
Passenger vehicles (petrol<1,399 cm³)	8,200	5.4→3.6
Passenger vehicles (petrol 1,400-1,900 cm³)	10,600	6.6→4.3
Passenger vehicles (petrol >1,900 cm³)	12,900	8.5→5.5
Passenger vehicles (Diesel <1,399 cm³)	11,800	4.6→3.0
Passenger vehicles (Diesel 1,400-1,900 cm³)	15,300	5.9→3.8
Passenger vehicles (Diesel >1,900 cm³)	17,600	6.9→4.5
Passenger vehicles (LPG <1,399 cm³)	8,900	6.4→4.3
Passenger vehicles (LPG 1,400-1,900 cm³)	11,300	8.1→7.0
Passenger vehicles (LPG >1,900 cm³)	13,600	10.7→7.1
Passenger vehicles (hybrid)	17,400→12,000	3.8→2.8
	[EUR'2016/vehicle]	**[m3/100km]**
Passenger vehicles (CNG)	16,500	7.1→6.5
HGVs up to 3.5 t (CNG)	31,000	11.9→10.5
	[EUR'2016/vehicle]	**[kWh/100km]**
Passenger vehicles (electric)	20,000→14 000	23.0→21.0
HGVs up to 3.5 t (electric)	70,000→50,000	33.0→28.0
	[EUR'2016/vehicle]	**l/100km**
HGVs up to 3.5 t (petrol)	24,000	12.0→8.5
HGVs up to 3.5 t (Diesel)	31,000	9.6→7.0
HGVs up to 3.5 t (LPG)	29,000	12.1→10.6
HGVs up to 3.5 t (CNG)	31,000	11.9→8.7
HGVs above 3.5 t (Diesel)	94,000	45.0→34.0
	[EUR'2016/vehicle]	**[toe/year]**
Agricultural tractors	40,000	1.15→1.02
Forage harvesters	135,000	4.5→3.96
Combine harvester-threshers	63,500	1.42→1.25

[12] *UK MARKAL Model Documentation*, Kannan R., Strachan N., Pye S., Anandarajah G., Balta-Ozkan N. 2007, access: www.ucl.ac.uk/energy-models/models/uk-markal.

Source: ARE S.A. on the basis of EC recommendations, data obtained from producers and industry organisations (e.g. ITS, SAMAR). In agriculture: Pawlak Jan, Institute of Construction, Mechanisation and Electrification of Agriculture – Nakłady inwestycyjne i koszty energii w rolnictwie polskim [Capital expenditure and energy costs in Polish agriculture], Warsaw 2007.

4.2. Dimension decarbonisation

4.2.1. Greenhouse gas emissions and removals

Trends in greenhouse gas emissions and removals

The observed trends in greenhouse gas emissions and removals were determined on the basis of *Poland's National Inventory Report 2019. Greenhouse Gas Inventory for 1988-2017. Submission under the UN Framework Convention on Climate Change and its Kyoto Protocol*. The present document discusses general trends in emissions by sector using the UNFCCC reporting methodology and IPCC classification, and provides additional information on some of the major activities.

In 2017, total GHG emissions in Poland (excluding LULUCF – land use, land use change and forestry), converted to CO_2 equivalent, amounted to 413.78 MtCO2eq and were 28.3% lower than 1988 emissions (the base year for Poland under the Kyoto Protocol) and 2.5% higher than in 2005. 2017 emissions, including LULUCF, were 379.93 MtCO2eq, 32.37% less than in the base year and 6.48% more than in 2005.

GHG emissions from installations covered by the European Emissions Trading Scheme (EU ETS) and emissions from other activities covered by the Effort Sharing Regulation (ESD)

Emissions from ETS installations in Poland account for approx. 50% of total emissions in 2005-2017. In 2017, those emissions, excluding LULUCF, totalled 202.2 $MtCO_2eq$. The energy, industrial processes and product use sectors are the largest contributors to ETS emissions.

Non-ETS emissions totalled 211.5 $MtCO_2eq$ in 2017 and were higher than ETS emissions due to an increase in fuel consumption in the transport sector.

Domestic GHG emissions are on a downward trend, with a very mild rate of decline since 2000, including years with a slight increase in emissions. It should be noted, however, that the list of installations covered by the ETS has been extended since 2013 to include installations in the chemical sector and that additional gases have begun to be included in the overall greenhouse gas balance.

CO_2 was the dominant gas accounting for 81.34% of emissions in 2017.

The remaining gases were: CH4 – 11.94% (calculated as CO_2eq), N_2O – 5.03%, F-gases – 1.69%.

Tables 4.20 and 4.21 present the breakdown of GHG emissions in Poland by gas, expressed in tonnes of carbon dioxide equivalent.

Details of GHG emissions, by gas, calculated as carbon dioxide equivalent (CO_2eq) and broken down into ETS and non-ETS, are shown in the figure below. Table 19 presents the breakdown of GHG emissions in Poland by gas, expressed in tonnes of carbon dioxide equivalent.

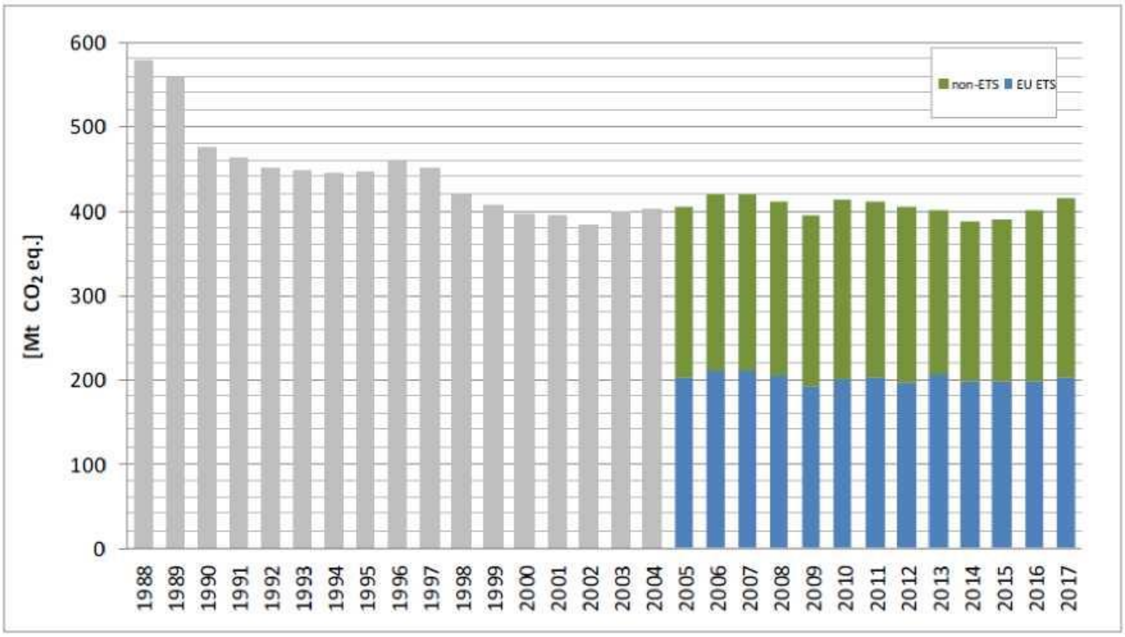

Figure 3. Trends in GHG emissions from 1988 to 2017, excluding LULUCF

Table 19. GHG emissions in 1988-2017 by gas [ktCO2eq]

GHG	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
CO_2 (incl. LULUCF)	452,009.34	427,659.20	345,109.66	349,996.26	361,756.76	356,252.01	351,033.10	342,138.18	337,758.79	329,286.14	294,031.06	288,016.40	280,849.33	285,739.12	268,259.34
CO_2 (excl. LULUCF)	471,978.71	452,353.09	376,959.60	374,274.37	364,681.59	365,106.95	360,746.15	362,428.12	376,447.49	367,768.47	338,542.58	328,855.51	318,209.19	314,602.34	306,731.15
CH4 (incl. LULUCF)	75,771.37	75,437.15	69,886.38	64,982.81	63,175.71	61,285.35	60,534.72	59,041.76	58,162.76	57,890.17	55,769.87	54,533.42	53,146.15	54,915.81	53,313.01
CH4 (excl. LULUCF)	75,727.24	75,393.12	69,842.33	64,937.82	63,131.20	61,243.14	60,493.79	58,995.85	58,126.36	57,852.23	55,735.53	54,496.32	53,113.60	54,883.23	53,278.29
N_2O (incl. LULUCF)	33,626.27	34,933.14	32,021.29	27,192.16	25,678.87	26,973.62	26,605.72	23,518.14	23,625.28	23,531.64	27,353.49	26,658.23	27,013.99	23,150.84	22,041.74
N_2O (excl. LULUCF)	29,404.57	30,671.15	27,406.31	22,936.71	21,368.33	22,334.55	22,239.90	23,173.87	23,295.31	23,202.95	22,945.85	22,235.06	22,583.39	22,739.63	21,640.32
HFC	NA, NO	NA, NO	NA, NO	NA, NO	NA, NO	NA, NO	NA, NO	164.31	335.49	481.02	569.32	780.47	1,366.50	1,925.34	2,505.93
PFC	147.26	147.51	141.87	141.31	134.63	144.86	152.78	171.97	161.07	173.36	174.86	168.71	176.68	197.34	207.33
Mix of HFCs and PFCs	NA, NO	NA, NO	NA, NO	NA, NO	NA, NO	NA, NO	NA, NO	NA, NO	NA, NO	NA, NO	NA, NO	NA, NO	NA, NO	NA, NO	NA, NO
SF6	NA, NO	NA, NO	NA, NO	NA, NO	NA, NO	NA, NO	13.27	29.12	23.80	22.91	23.94	23.50	23.07	22.86	23.29
NF3	NA, NO	NA, NO	NA, NO	NA, NO	NA, NO	NA, NO	NA, NO	NA, NO	NA, NO	NA, NO	NA, NO	NA, NO	NA, NO	NA, NO	NA, NO
Total emission (incl. LULU	**561,554.23**	**538,177.00**	**447,159.20**	**442,312.55**	**450,745.97**	**444,655.84**	**438,339.59**	**425,063.49**	**420,067.19**	**411,385.23**	**377,922.53**	**370,180.73**	**362,575.71**	**365,951.32**	**346,350.64**

CF)															
Total emission (excl. LULUCF)	**577,257.78**	**558,564.86**	**474,350.11**	**462,290.21**	**449,315.75**	**448,829.50**	**443,654.88**	**444,963.25**	**458,389.54**	**449,500.94**	**417,992.08**	**406,559.57**	**395,472.42**	**394,370.74**	**384,386.31**

GHG	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
CO_2 (incl. LULUCF)	278,535.18	271,383.94	271,331.36	291,037.81	297,288.07	290,822.03	279,578.92	298,727.57	291,554.74	284,370.62	278,067.70	274,087.76	280,636.39	290,441.13	299,116.92
CO_2 (excl. LULUCF)	319,481.21	323,644.72	322,545.79	335,658.25	335,610.49	328,822.02	315,452.05	333,457.41	333,013.09	325,488.27	321,169.32	308,729.39	312,320.56	323,021.90	336,556.77
CH4 (incl. LULUCF)	53,420.88	53,127.48	53,523.18	53,793.38	52,972.71	52,832.68	51,554.07	51,411.63	50,245.40	49,974.61	50,119.22	49,494.14	50,049.94	49,528.88	49,450.36
CH4 (excl. LULUCF)	53,383.96	53,093.21	53,489.69	53,754.30	52,942.99	52,798.04	51,524.23	51,379.98	50,214.32	49,942.83	50,082.23	49,458.93	50,015.99	49,486.83	49,412.83
N_2O (incl. LULUCF)	22,253.79	22,771.51	27,191.60	27,609.46	28,432.00	28,275.74	24,747.95	24,450.18	24,822.28	24,966.39	25,097.52	24,989.92	20,124.32	26,287.43	24,380.35
N_2O (excl. LULUCF)	21,839.65	22,341.57	22,618.00	23,090.14	23,854.09	23,244.71	20,121.67	19,772.53	20,128.37	20,119.94	20,304.37	19,854.46	19,030.58	19,792.08	20,824.17
HFC	3,078.00	3,733.23	4,556.73	5,408.05	6,009.80	6,334.89	6,289.67	7,006.36	7,622.60	7,959.91	8,356.09	8,978.00	8,987.24	6,730.80	6,893.27
PFC	201.08	205.07	187.41	193.58	184.63	163.12	17.97	17.07	16.22	15.41	14.64	13.90	13.21	12.55	11.92
Mix of HFCs and	NA, NO	NA, NO	NA, NO	NA, NO	NA, NO	NA, NO	NA, NO	NA, NO	NA, NO	NA, NO	NA, NO	NA, NO	NA, NO	NA, NO	NA, NO

PFCs															
SF6	20.72	22.36	26.80	33.20	31.16	32.87	37.60	35.37	39.02	41.92	47.54	52.79	77.03	78.38	82.43
NF3	NA, NO	NA, NO	NA, NO	NA, NO	NA, NO	NA, NO	NA, NO	NA, NO	NA, NO	NA, NO	NA, NO	NA, NO	NA, NO	NA, NO	NA, NO
Total emission (incl. LULUCF)	**357,509.64**	**351,243.59**	**356,817.09**	**378,075.48**	**384,918.37**	**378,461.33**	**362,226.18**	**381,648.18**	**374,300.27**	**367,328.86**	**361,702.70**	**357,616.51**	**359,888.13**	**373,079.17**	**379,935.26**
Total emission (excl. LULUCF)	**398,004.61**	**403,040.15**	**403,424.42**	**418,137.52**	**418,633.15**	**411,395.64**	**393,443.18**	**411,668.71**	**411,033.61**	**403,648.28**	**399,974.18**	**387,087.47**	**390,444.60**	**399,122.53**	**413,781.40**

Source: National Centre for Emissions Management (KOBiZE)

GHG emissions and removals by sector

The overall trends in emissions from the main sectors (according to IPCC) are shown in Figure 4 and Table 20.

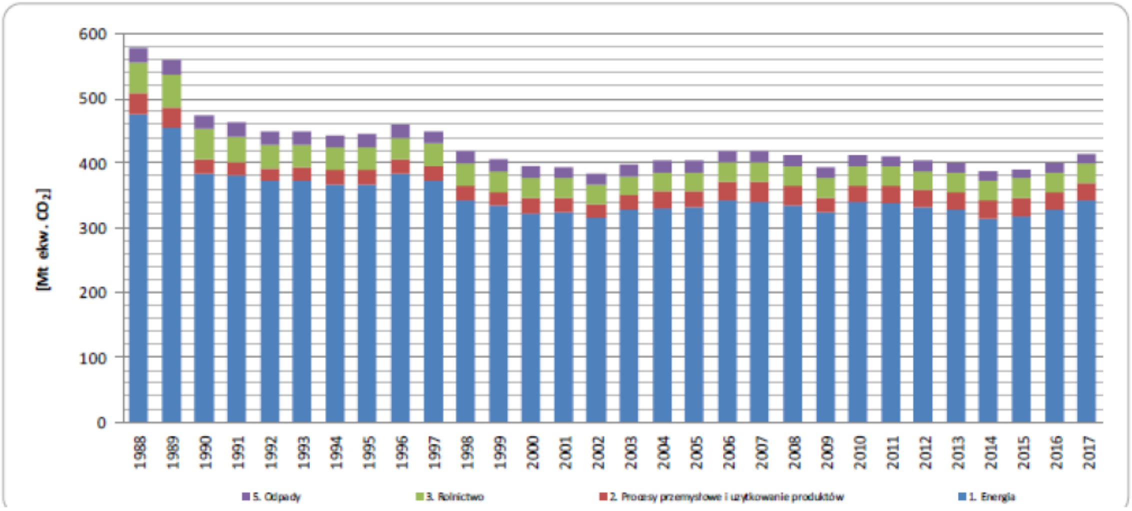

Figure 4. Trends in GHG emissions from 1988 to 2017, by sector (excluding LULUCF). Source: KOBiZE

[Mt ekw.CO_2]	**[MtCO2eq]**
5. Odpady	5. Waste
3. Rolnictwo	3. Agriculture
2. Procesy przemysłowe i użytkowanie produktów	2. Industrial processes and product use
1. Energia	1. Energy

Waste management Agriculture Industrial processes Energy

The energy sector is the largest contributor to GHG emissions. Agriculture, industrial processes and waste management have a much smaller share in emissions.

Table 20. GHG emissions in 1988-2017 by sector [kt CO_2eq]

IPCC sector	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
1. Energy	476,219.67	455,827.71	382,821.05	380,884.64	372,178.41	373,802.81	367,497.72	367,832.29	383,036.35	372,991.82	343,513.83	334,874.00	322,170.47	323,174.53	315,763.38
2. Industrial processes	31,198.21	30,235.92	22,701.35	20,099.25	19,701.64	19,316.79	21,307.17	22,727.00	22,046.66	22,962.82	21,386.60	20,589.43	23,796.89	22,468.63	20,817.90
3. Agriculture	47,908.81	50,620.63	47,244.30	40,192.79	36,587.85	35,272.74	34,852.81	34,776.64	34,044.50	34,631.23	34,379.22	32,649.91	31,049.14	30,653.18	29,977.79
4. Land use, land-use change	-15,703.55	-20,387.87	-27,190.91	-19,977.66	-1,430.23	-4,173.66	-5,306.29	-19,899.76	-38,322.34	-38,115.71	-40,069.55	-36,378.83	-32,896.71	-28,419.43	-38,035.67
5. Waste	21,931.10	21,880.60	21,583.41	21,113.54	20,847.85	20,437.16	19,988.18	19,627.31	19,262.03	18,915.07	18,712.42	18,446.22	18,455.91	18,074.40	17,827.25
6. Other	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
TOTAL (incl. LULUCF)	**561,554.23**	**538,177.00**	**447,159.20**	**442,312.55**	**450,745.97**	**444,655.84**	**438,339.59**	**425,063.49**	**420,067.19**	**411,385.23**	**377,922.53**	**370,180.73**	**362,575.71**	**365,951.32**	**346,350.64**
TOTAL (excl. LULUCF)	**577,257.78**	**558,564.86**	**474,350.11**	**462,290.21**	**449,315.75**	**448,829.50**	**443,645.88**	**444,963.25**	**458,389.54**	**449,500.94**	**417,992.08**	**406,559.57**	**395,472.42**	**394,370.74**	**384,386.31**

IPCC sector	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
1. Energy	327,240.06	330,922.34	331,239.12	343,045.78	340,513.84	334,912.06	323,791.27	340,898.85	337,601.73	331,678.57	327,958.19	314,089.59	318,446.48	328,953.87	342,088.54
2. Industrial process	23,692.37	25,490.79	25,467.11	27,997.58	30,553.23	29,128.36	23,092.39	25,000.46	27,851.08	26,797.56	26,471.15	28,111.23	28,508.35	26,415.56	26,998.20

es															
3. Agriculture	29,393.51	29,378.23	29,656.05	30,332.52	30,953.25	30,967.78	30,302.04	29,727.52	30,126.13	29,991.62	30,556.32	30,455.71	29,612.74	30,293.26	31,739.73
4. Land use, land-use change	-40,494.97	-51,796.56	-46,607.33	-40,062.04	-33,714.78	-32,934.31	-31,217.00	-30,020.54	-36,733.35	-36,319.42	-38,271.48	-29,470.96	-30,556.47	-26,043.36	-33,846.14
5. Waste	17,678.67	17,248.78	17,061.48	16,761.64	16,612.84	16,387.45	16,257.48	16,041.89	15,454.67	15,180.53	14,988.52	14,430.93	13,877.03	13,459.84	12,954.93
6. Other	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
TOTAL (incl. LULUCF)	**357,509.64**	**351,243.59**	**356,817.09**	**378,075.48**	**384,918.37**	**378,461.33**	**362,226.18**	**381,648.18**	**374,300.27**	**367,328.86**	**361,702.70**	**357,616.51**	**359,888.13**	**373,079.17**	**379,935.26**
TOTAL (excl. LULUCF)	**398,004.61**	**403,040.15**	**403,424.42**	**418,137.52**	**418,633.15**	**411,395.64**	**393,443.18**	**411,668.71**	**411,033.61**	**403,648.28**	**399,974.18**	**387,087.47**	**390,444.60**	**399,122.53**	**413,781.40**

Source: KOBiZE

4.2.1.1. GHG emissions and removals in the energy sector – current state

The entire energy sector accounted for approx. 93% of emissions in 2017. The largest part of emissions comes from the fuel combustion sector, sub-sectors 1A and 1B, whose share in total emissions is approx. 81.53%. Total CO_2 emissions are dominated by the fuel combustion sector 1.A (92.5%), including energy 1.A.1 (48.7%), transport 1.A.3 (18.6%), manufacturing and construction 1.A.2 (9.2%), and other sectors 1.A.4 (16.0%).

Trends in emissions from the energy sector and the breakdown of emissions by sub-sector are shown in the figures below.

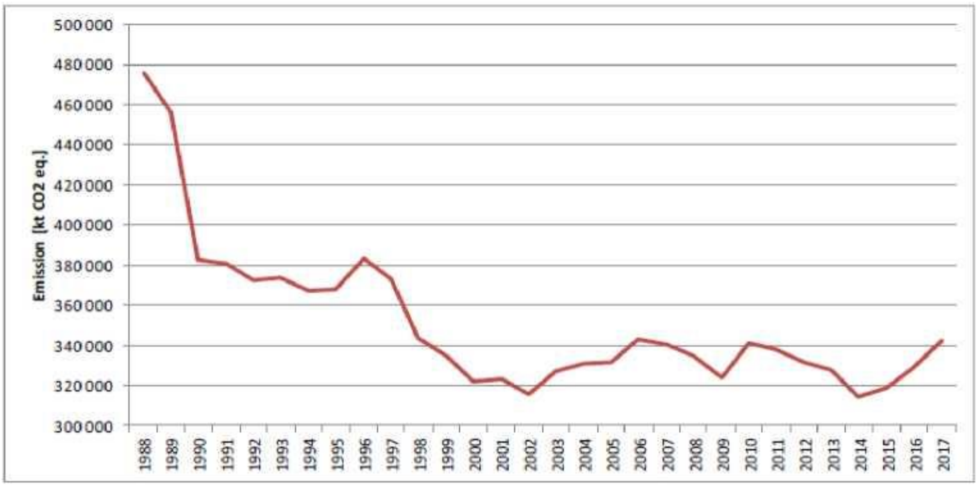

Figure 5. Trends in GHG emissions in the energy sector. Source: KOBiZE

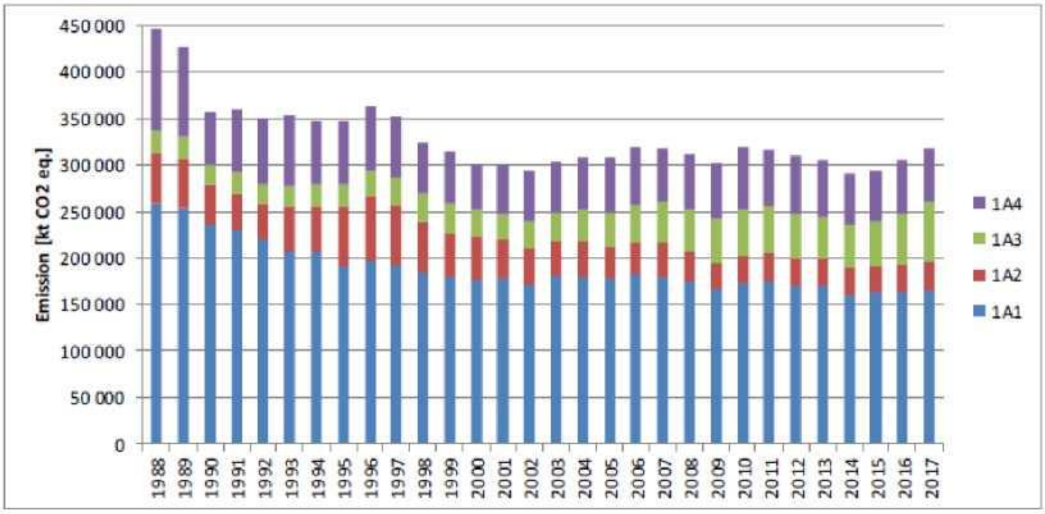

Figure 6. Emission trends in the energy sector by sub-sector: 1A1 – Energy, 1A2 – Industry and construction, 1A3 – Transport, 1A4 – Other (including trade, housing and agriculture)

- ***Transport***

The share of transport in total GHG emissions in 2017 was approx. 15.31%. These emissions came mainly from road transport (approx. 97%) and from rail, air and water transport. The chart below shows the breakdown of total greenhouse gas emissions by mode of transport and change patterns.

Following a significant increase until 2011, transport emissions stabilised by 2015. The years 2015-2107 saw a surge in emissions caused by an increase in fuel consumption by 37.1%. Apart from the successful combating of illegal trade in liquid fuels, this growth was driven by strong performance of the economy and an increase in the number of cars in use in the country.

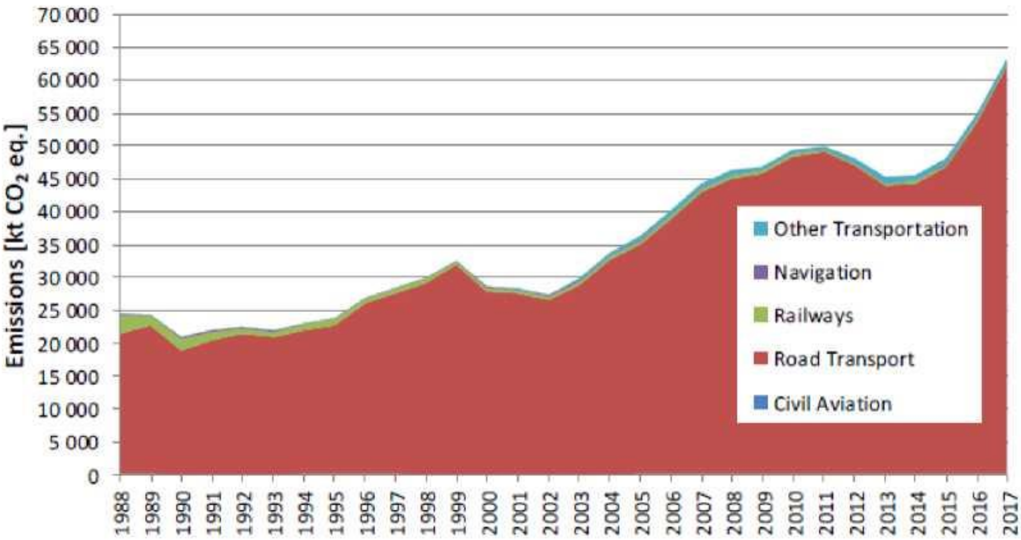

Figure 7. GHG emissions from transport in 1988-2017. Source: KOBiZE

- ***Other sectors (including housing)***

GHG emissions from housing have been steadily decreasing since 2010. This is largely due to measures to improve the energy efficiency of buildings and reduce air pollution. It should be noted, however, that emissions from this sub-sector depend, to a large extent, on the existing climatic conditions.

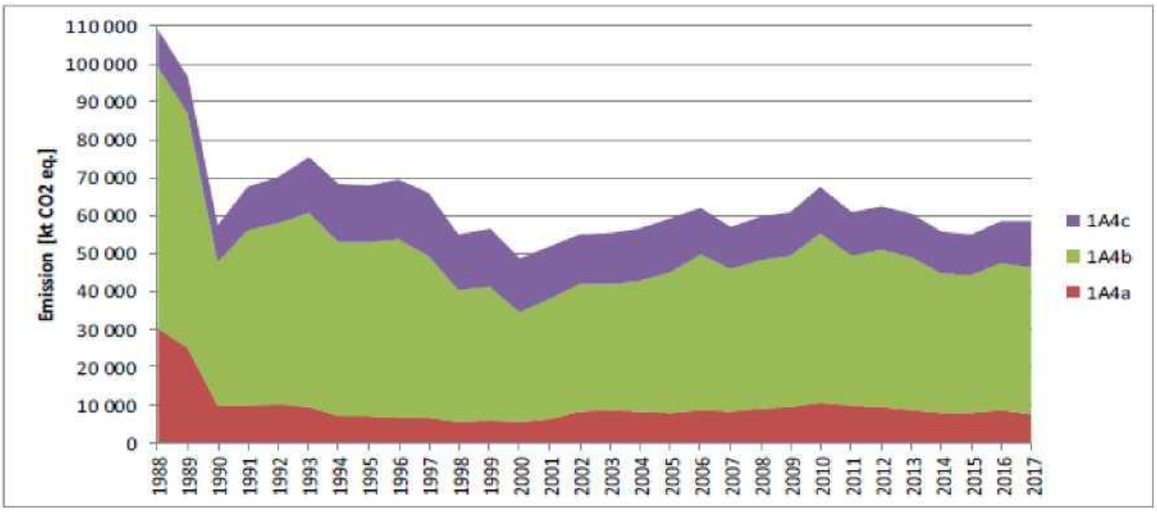

Figure 8. Emission trends in the energy sector by sub-sector: 1A4a – trade and services, 1A4b – housing and 1A4c – agriculture, forestry, fisheries. Source: KOBiZE

- ***Industrial processes and product use***

Total GHG emissions from this sector are shown in the chart below (Figure 4.11).

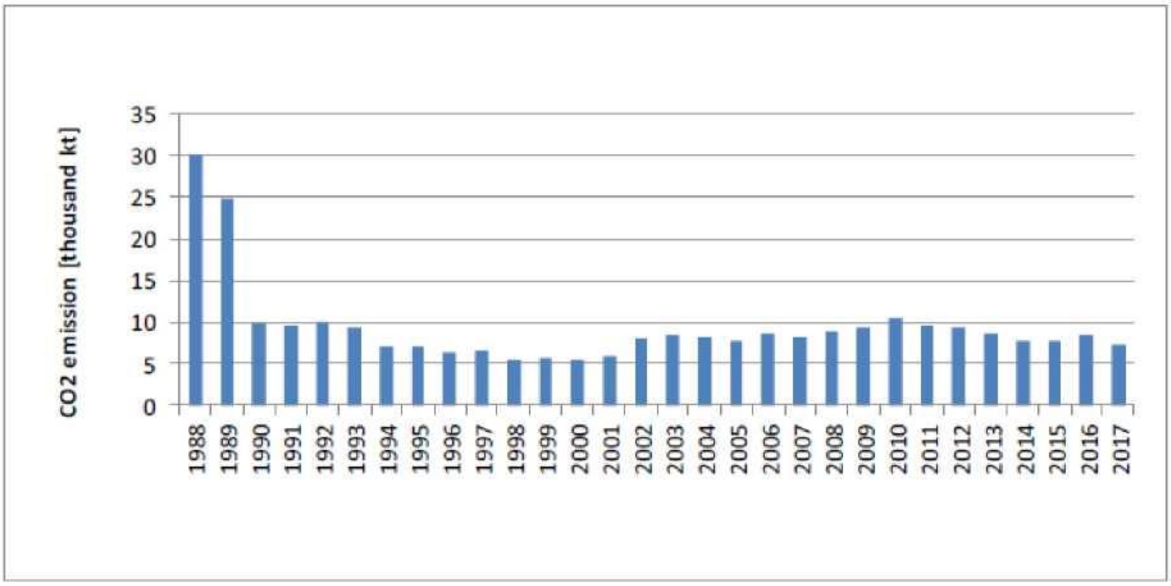

Figure 9 GHG emissions from industrial processes and product use

- ***Agriculture***

Emissions from agriculture totalled approx. 31.74 $MtCO_2eq$ in 2017, accounting for approx. 7.7% of total GHG emissions. Trends in emissions from this sector are presented in the chart below.
Nitrous oxide emissions are dominated by soil emissions, which generally demonstrate a slight upward trend with peaks in 2008 and 2013, whereas emissions from manure management show a weak downward trend. These trends are attributable to fertiliser management.
The chart below shows the breakdown of 2017 emissions by sub-sector and by gas.

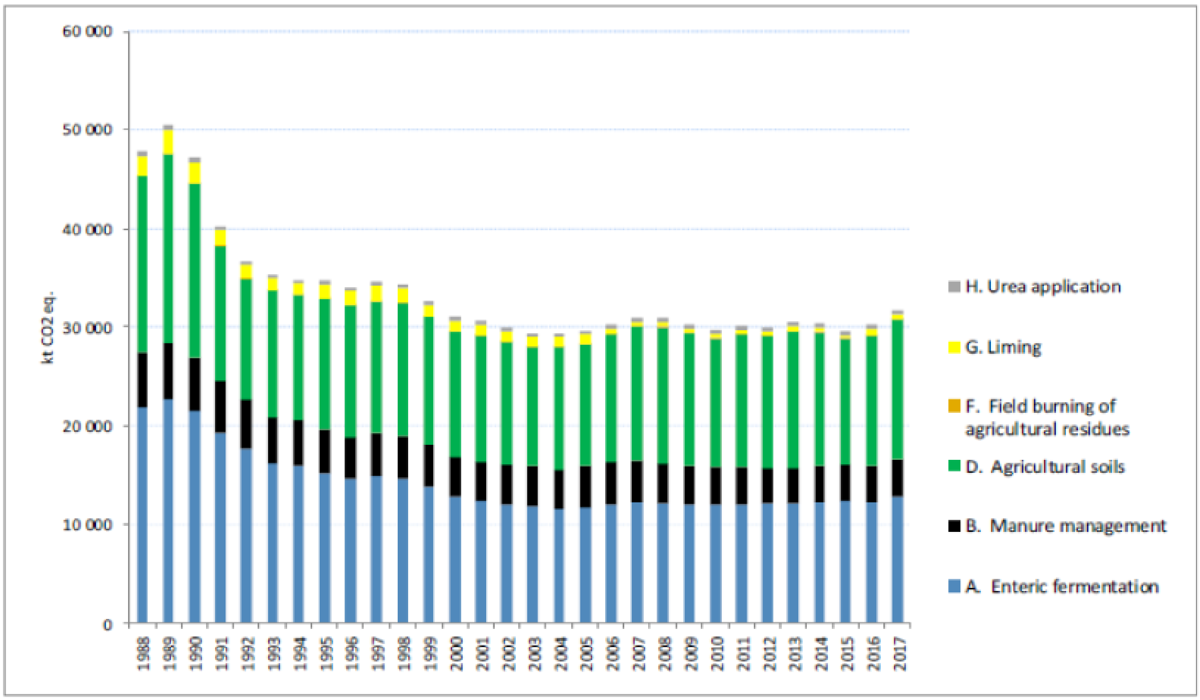

Figure 10. Trends in GHG emissions from agriculture by sub-sector: A – enteric fermentation, B – manure, D - agricultural soils, F – burning of plant waste, G – liming, H – urea application

- Land use, land-use change and forestry (LULUCF)

Activity in the analysed sector resulted in net emission reductions of approx. 29.2 $MtCO_2eq$ in 2017. Trends in this respect, by sub-sector, are shown in the chart below. One can notice a trend towards lower absorptivity resulting mainly from the use of woodland and agricultural land for housing development.

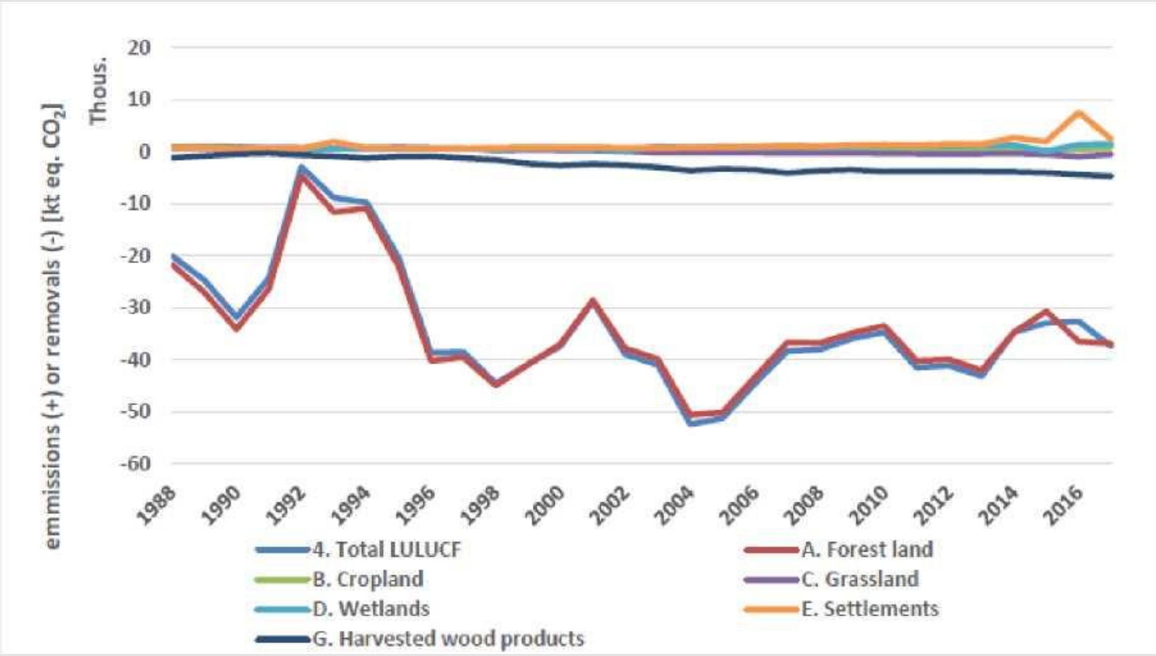

Figure 11. GHG emissions and removals from LULUCF by sub-sector: A – forest land, B – cropland, C – grassland, D – wetlands, E – built-up areas, G – wood products[22]

- ***Waste***

Emissions from the waste sector totalled 10.56 $MtCO_2eq$ in 2017. Trends in those emissions and their breakdown by sub-sector are shown in the chart below (Figure 12).

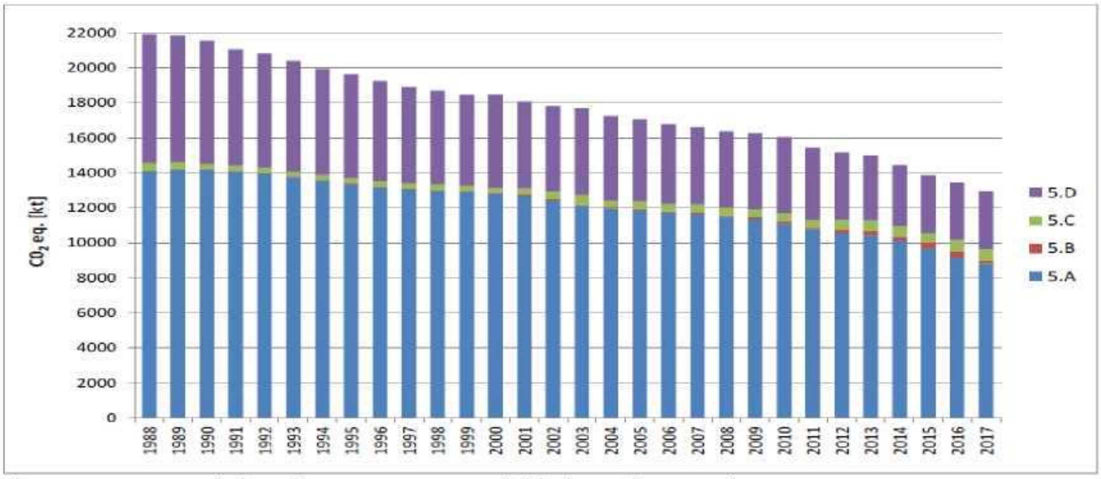

Figure 12. GHG emissions from waste by sub-sector: 5.A – solid waste disposal on land, 5.B – biological treatment of waste, 5.C – waste incineration, including open-burning of waste, 5.D – wastewater handling[22]

The presented data show declining trends in GHG emissions in all the sub-sectors except for waste incineration. These trends are most evident in solid waste disposal, which is associated with a decrease in waste discharged to landfills and with wastewater handling. Waste incineration shows an upward trend, which is related to an increasing thermal utilisation of waste.

[22] Ibidem.
[22] Ibidem.

Emission forecasts based on projected changes in sectors

The 2040 projections of GHG emissions are based on the following data sources:

1) Activity forecasts prepared by ARE S.A. for the purposes of the NECP, presented in sections 4.3 and 4.4 of the report. 2015 is the base year for forecasts;

2) Draft Fourth Biennial Report for the UNFCCC (BR4), Institute of Environmental Protection (Instytut Ochrony Środowiska) – National Research Institute, KOBiZE, 2019.

The forecasts take into account the implementation of current policies and regulations in the following areas: improvement of energy efficiency, improvement of the security of fuel and energy supply, diversification of the fuel mix in the energy industry, development of the use of renewable energy sources, development of competitive fuel and energy markets, reduction in the environmental impact of power generation.

The forecasts were prepared for the following sectors according to the IPCC classification of sources and taking into account the following methodological assumptions:

- *Energy (including Transport) – GHG emissions were calculated on the basis of ARE S.A.'s forecasts of domestic demand for fuels and energy until 2040 (with respect to transport – calculations and forecasts presented in the Draft Fourth Biennial Report for the UNFCCC (BR4), Institute of Environmental Protection (Instytut Ochrony Środowiska) – National Research Institute, KOBiZE, 2019);*

- *Industrial processes and product use, Agriculture and Waste, as well as Land use, land-use change and forestry – calculations and projections of emissions were based on the results of projections presented in the Draft Fourth Biennial Report for the UNFCCC (BR4), Institute of Environmental Protection (Instytut Ochrony Środowiska) – National Research Institute, KOBiZE, 2019.*

Below are the synthetic results of the 2020-2040 greenhouse gas emissions forecasts for Poland by IPCC sector, compared with 2005-2015 emissions (Tables 23 and 24).

Table 21. Projections of GHG emissions by sector

Source category	**GHG emission [kt CO_2 eq]**							
	2005	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**
Total excluding LULUCF	**403,424.42**	**411,668.71**	**390,444.60**	**397,810.50**	**403,635.22**	**404,739.60**	**370,476.24**	**333,869.76**
Total including LULUCF	**356,817.09**	**381,648.18**	**359,888.13**	**366,032.83**	**376,297.59**	**383,046.67**	**352,733.59**	**319,848.48**
1. Energy	331,239.12	340,898.85	318,446.48	328,559.44	334,754.34	336,041.69	301,769.43	265,070.74
2. Industrial processes and product use	25,467.77	25,000.46	28,508.35	24,419.97	24,039.81	23,941.76	23,985.41	24,245.59
3. Agriculture	29,656.05	29,727.52	29,612.74	31,751.72	32,452.22	32,880.91	33,169.74	33,249.44
4. Land use, land-use change and forestry (LULUCF)	-46,607.33	-30,020.54	-30,556.47	-31,777.68	-27,337.63	-21,692.93	-17,742.64	-14,021.28
5. Waste	17,061.48	16,041.89	13,877.03	13,079.37	12,388.85	11,875.23	11,551.66	11,303.98

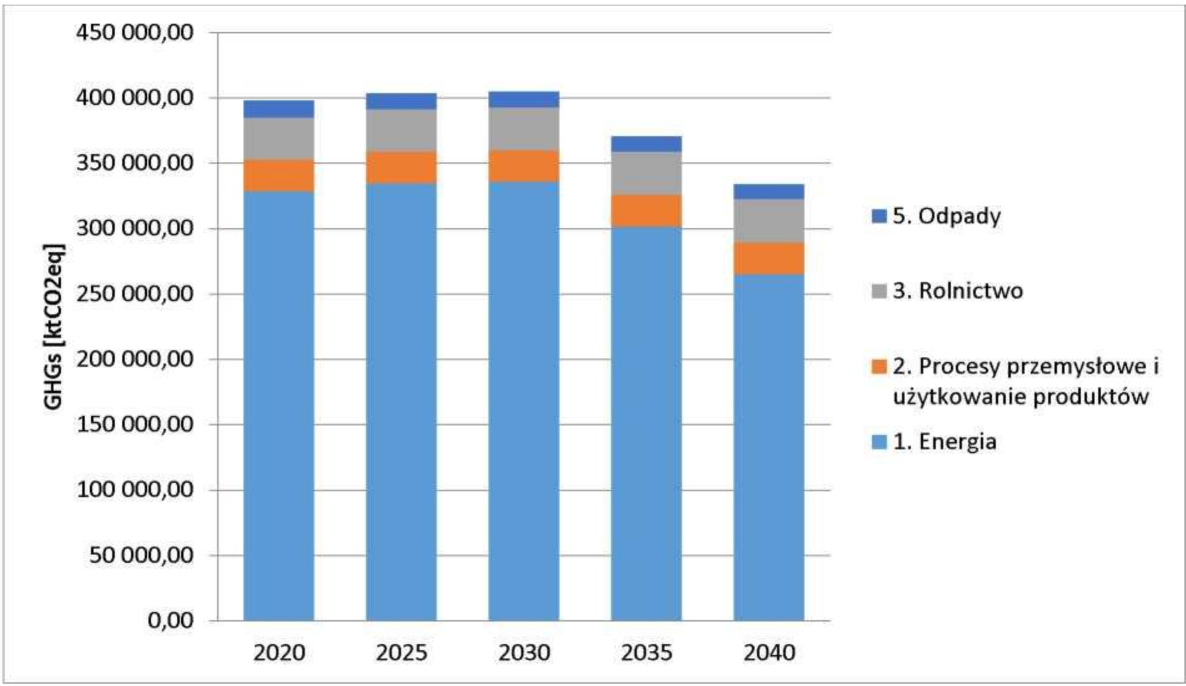

Figure 13. GHG emission projections by sector, excluding LULUCF. Source: KOBiZE

5. Odpady	5. Waste
3. Rolnictwo	3. Agriculture
2. Procesy przemysłowe i użytkowanie produktów	2. Industrial processes and product use
1. Energia	1. Energy
GHGs [ktCO2eq]	**GHGs [ktCO$_2$eq]**

Looking forward to 2030, total GHG emissions are projected to increase slightly by approx. 0.3% in relation to 2005. Emissions will then start to fall to reach approx. 334 million tonnes in 2040, a reduction of approx. 17% between 2005 and 2040.
In 2040, the largest emission volumes will continue to come from the energy sector, notably the combustion of fuels, but emissions in this sector will gradually decrease. A slight upward trend is expected in the industrial process and product use sector.
In agriculture, GHG emissions will be increasing slightly until 2040. On the other hand, there has been a steady decrease in emissions from waste since 2005. The largest emission reductions are expected in the energy sector.

The anticipated trends in the evolution of ETS and non-ETS (ESD) emissions are shown in the chart below.

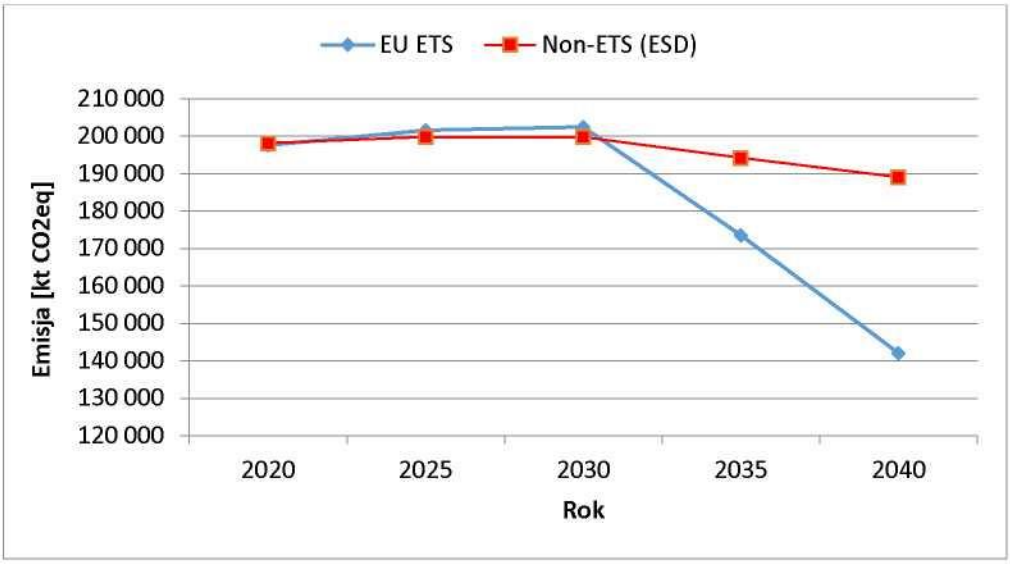

Figure 14. Projections of ETS and non-ETS emissions

EU ETS	EU ETS
Non-ETS (ESD)	Non-ETS (ESD)
Emisja [kt CO2eq]	**Emissions [kt CO_2eq]**
Rok	**Year**

GHG emissions will decrease after 2030 both in ETS and non-ETS sectors, with the decrease being more pronounced for the ETS sector.

Table 22. Projected CO_2 emissions by sector

	CO_2 [kt]							
Source category	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**
Total excluding LULUCF	**322,545.79**	**333,457.41**	**312,320.56**	**320,891.78**	**327,460.66**	**329,096.36**	**297,857.60**	**263,494.32**
Total including LULUCF	**271,331.36**	**298,727.57**	**280,636.39**	**287,197.08**	**298,153.48**	**305,492.03**	**278,194.34**	**247,678.42**
1. Energy	**304,748.07**	**315,601.31**	**292,619.07**	**299,811.62**	**306,048.20**	**307,374.60**	**275,888.63**	**241,262.11**
A. Fuel combustion	301,576.50	312,796.48	288,368.88	296,255.06	302,596.82	304,014.46	272,608.13	238,052.14
1. Energy industries	177,290.03	172,262.80	162,622.03	153,952.81	158,627.24	160,216.23	131,813.73	100,712.41
2. Manufacturing industries and construction	33,790.32	29,455.75	27,738.32	28,866.51	28,026.75	27,134.12	26,233.60	25,352.32
3. Transport	35,613.78	48,659.65	47,367.83	61,281.97	64,538.07	66,296.70	65,494.01	64,409.44
4. Other sectors	54,882.37	62,418.29	50,640.71	52,153.77	51,404.77	50,367.41	49,066.80	47,577.97
B. Fugitive emissions from fuels	3,171.57	2,804.83	4,250.19	3,556.56	3,451.38	3,360.15	3,280.50	3,209.97
1. Solid fuels	2,019.08	1,747.97	2,221.01	1,812.22	1,707.03	1,615.81	1,536.16	1,465.62
2. Crude oil and natural gas	1,152.49	1,056.85	2,029.18	1,744.34	1,744.34	1,744.34	1,744.34	1,744.34
2. Industrial processes and product use	**16,091.78**	**16,642.81**	**18,484.19**	**19,327.17**	**19,622.99**	**19,909.94**	**20,129.36**	**20,344.52**
A. Mineral products	8,355.79	9,849.54	10,088.59	10,554.14	11,061.04	11,569.50	11,899.01	12,393.28
B. Chemical industry	4,886.78	4,335.42	5,141.13	5,473.54	5,894.83	5,872.39	5,872.39	5,872.39

	CO_2 [kt]							
Source category	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**
C. Metal production	2,216.99	1,784.33	2,576.81	3,261.14	3,393.12	3,536.29	3,531.73	3,521.05
D. Non-energy products from fuels and solvent use	632.22	673.53	677.66	696.92	696.92	696.92	696.92	696.92
3. Agriculture	**1,291.94**	**790.01**	**736.36**	**1,013.16**	**1,041.93**	**1,064.27**	**1,092.06**	**1,140.15**
G. Liming	944.90	391.55	373.84	420.43	420.43	420.43	420.43	420.43
H. Urea application	347.04	398.46	362.52	423.41	450.44	468.46	468.46	468.46
4. Land use, land-use change and forestry (LULUCF)	**-51,214.43**	**-34,729.84**	**-31,684.16**	**-33,694.70**	**-29,307.18**	**-23,604.33**	**-19,663.26**	**-15,815.90**
5. Waste	**414.00**	**423.27**	**480.95**	**739.83**	**747.54**	**747.54**	**747.54**	**747.54**
C. Ashing and open burning of waste	414.00	423.27	480.95	1,811.08	1,863.68	1,863.68	1,860.21	1,856.65
CO_2 emissions from biomass	**19,803.98**	**30,442.05**	**34,962.70**	**41,228.70**	**42,222.21**	**45,167.75**	**47,522.40**	**50,028.71**

The largest CO_2 emissions will be produced by the energy sector. However, a steady decline is expected after 2030. Emissions from industrial processes and product use rank second and are bound to increase, driven by economic development.

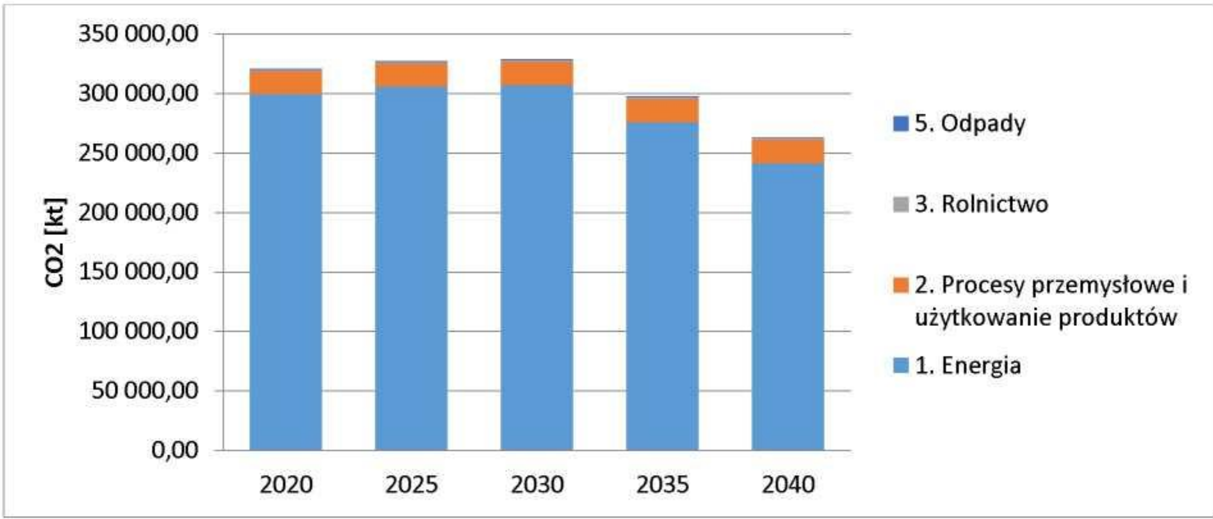

Figure 15. CO_2 emissions by sector

CO2 [kt]	CO_2 [kt]
5. Odpady	5. Waste
3. Rolnictwo	3. Agriculture
2. Procesy przemysłowe i użytkowanie produktów	2. Industrial processes and product use
1. Energia	1. Energy

The projected N_2O emissions are presented in Table 25. The largest emissions of nitrous oxide are produced by agriculture, followed by the energy and waste sectors, on a much smaller scale though. In the agricultural sector, a continued gradual increase in emissions is expected until 2040.

Table 23. Projected N_2O emissions by sector

	N_2O [kt]							
Source category	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**
Total excluding LULUCF	**75.90**	**66.35**	**63.86**	**67.97**	**69.18**	**70.42**	**70.99**	**70.52**
Total including LULUCF	**91.25**	**82.05**	**67.53**	**74.31**	**75.69**	**76.73**	**77.34**	**76.44**
1. Energy	**8.80**	**8.46**	**8.05**	**6.61**	**6.85**	**7.10**	**6.70**	**6.29**
A. Fuel combustion	8.80	8.46	8.05	6.61	6.85	7.10	6.70	6.29
1. Energy industries	2.61	2.68	2.60	2.48	2.50	2.59	2.13	1.69
2. Manufacturing industries and construction	0.48	0.50	0.60	0.59	0.59	0.58	0.57	0.57
3. Transport	1.57	1.97	1.83	2.39	2.62	2.81	2.87	2.92
4. Other sectors	4.13	3.31	3.02	1.15	1.14	1.13	1.12	1.11
B. Fugitive emissions from fuels	0.0016	0.0015	0.0018	0.0017	0.0017	0.0017	0.0017	0.0017
2. Crude oil and natural gas	0.0016	0.0015	0.0018	0.00	0.00	0.00	0.00	0.00
2. Industrial processes and product use	**15.29**	**4.15**	**2.96**	**3.04**	**3.05**	**3.07**	**3.08**	**3.09**
B. Chemical industry	14.87	3.71	2.51	2.82	3.30	3.29	3.29	3.29
G. Production and use of other products	0.43	0.44	0.44	0.44	0.44	0.44	0.44	0.44
3. Agriculture	**49.18**	**50.92**	**49.68**	**55.07**	**56.02**	**57.02**	**58.03**	**58.00**
B. Animal faeces	7.57	7.26	6.97	6.96	7.01	7.02	6.90	6.81
D. Agricultural soils	41.58	43.63	42.67	46.12	47.50	48.43	48.18	47.87
F. Burning of plant waste	0.03	0.03	0.04	0.04	0.04	0.04	0.04	0.04
4. Land use, land-use change and forestry (LULUCF)	**15.35**	**15.70**	**3.67**	**6.34**	**6.51**	**6.31**	**6.35**	**5.92**
5. Waste	**2.63**	**2.82**	**3.17**	**3.25**	**3.26**	**3.23**	**3.18**	**3.13**
B. Biological neutralisation of solid waste	0.13	0.19	0.44	0.46	0.50	0.50	0.50	0.50
C. Ashing and open burning of waste	0.06	0.09	0.18	0.21	0.21	0.21	0.21	0.21
D. Wastewater management	2.43	2.54	2.55	2.56	2.54	2.50	2.46	2.40

The projected CH_4 emission trends are presented in Table 26 below. The highest CH_4 emissions come from the energy sector, and smaller from the agriculture and waste sectors. Emissions are expected to decline in the energy and waste sectors, while agriculture is bound to see a steady slight growth.

Table 24. Projected CH_4 emissions by sector

	CH_4 [kt]							
Source category	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**
Total excluding LULUCF	**2,139.59**	**2,055.20**	**2,000.64**	**2,018.26**	**1,991.31**	**1,964.06**	**1,836.77**	**1,746.71**
Total including LULUCF	**2,140.93**	**2,056.47**	**2,002.00**	**2,019.39**	**1,992.49**	**1,965.24**	**1,837.96**	**1,747.89**
1. Energy	**954.77**	**911.02**	**937.14**	**987.30**	**972.80**	**961.27**	**848.03**	**765.59**
A. Fuel combustion	141.08	172.69	145.89	148.09	143.53	139.52	135.86	132.58
1. Energy industries	2.51	3.92	4.70	4.81	4.74	5.22	5.40	5.60

	CH_4 [kt]							
Source category	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**
2. Manufacturing industries and construction	3.37	3.52	4.27	4.29	4.28	4.24	4.20	4.18
3. Transport	6.87	6.24	4.58	3.52	3.09	2.90	2.75	2.51
4. Other sectors	128.33	159.01	132.34	135.46	131.43	127.16	123.52	120.30
B. Fugitive emissions from fuels	813.69	738.33	791.25	839.21	829.28	821.75	712.17	633.01
1. Solid fuels	719.82	651.44	690.01	741.37	731.44	723.91	614.33	535.17
2. Crude oil and natural gas	93.87	86.89	101.24	97.84	97.84	97.84	97.84	97.84
2. Industrial processes and product use	**1.89**	**2.50**	**2.62**	**2.97**	**3.04**	**3.10**	**3.15**	**3.20**
B. Chemical industry	1.39	2.03	2.02	1.97	2.93	2.91	2.91	2.91
C. Metal production	0.50	0.46	0.60	0.75	0.75	0.75	0.75	0.75
3. Agriculture	**548.33**	**550.50**	**562.87**	**573.15**	**588.70**	**593.03**	**591.34**	**592.96**
A. Enteric fermentation	471.12	479.57	496.78	499.30	492.19	482.67	478.08	481.19
B. Animal faeces	76.43	70.08	65.14	74.09	102.86	112.25	113.95	116.25
F. Burning of plant waste	0.77	0.85	0.95	0.94	0.97	1.00	1.03	1.06
4. Land use, land-use change and forestry (LULUCF)	1.34	1.27	1.36	1.13	1.18	1.18	1.18	1.18
5. Waste	**634.60**	**591.18**	**498.00**	**454.84**	**426.77**	**406.65**	**394.25**	**384.96**
A. Landfill of solid waste	474.16	444.05	387.76	329.58	329.88	327.66	327.69	329.58
B. Biological neutralisation of solid waste	2.15	3.13	7.34	7.73	8.34	8.34	8.34	8.34
C. Ashing and open burning of waste	0.000005	0.000002	0.000006	0.00062	0.00065	0.00065	0.00065	0.00065
D. Wastewater management	158.30	143.99	102.90	28.61	26.40	23.31	19.40	15.01

4.2.2. Renewable energy

- Renewable energy sources - current state

In accordance with the targets for the share of renewable energy in gross final energy consumption set out in Directive 2009/28/EC, the 2020 target for Poland was set at 15%. To meet this commitment, the National Action Plan for Renewable Energy (NAP) was adopted in 2010 that sets a 15.5% target for RES share of the national economy's gross energy consumption in 2020. The 2018 data are preliminary and subject to change.

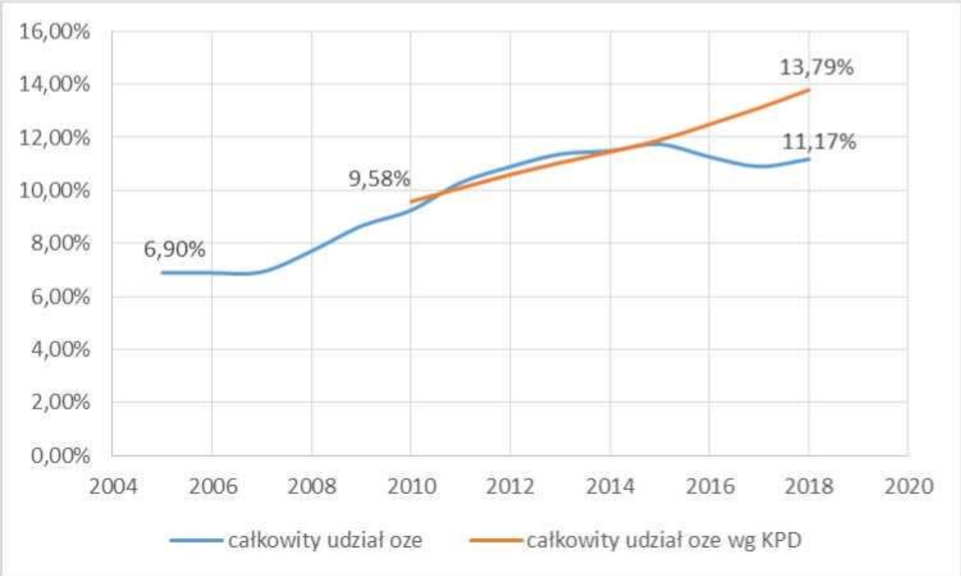

Figure 16. Comparison of RES share in the national economy with the trajectory of RES development presented in the NAP. Source: ARE S.A., NAP

całkowity udział oze	total RES share
całkowity udział oze wg KPD	total RES share – NAP

The total share of renewable energy was 6.9% in 2005. As a result of policies to promote renewable energy, the share of RES in gross inland energy consumption totalled 9.25% in 2010, i.e. 0.33% below the ceiling adopted in the NAP. A year later, the use of RES began to exceed the target set in the NAP and continued to do so until 2014 when renewable energy reached a 11.5% share in final gross energy consumption (compared to the target of 11.45%). 2016 and 2017 saw a significant decrease in the share of RES in gross energy consumption. This is due to two main factors: changes in the support system for RES-based power generation and a significant decrease in the use of biofuels in transport. The former significantly reduced the rate at which RES investments were brought into operation in 2016-2017. In turn, a reduced use of biofuels is the result of an increase in biofuel exports, which has translated into a decreased availability of biofuel on the domestic market.

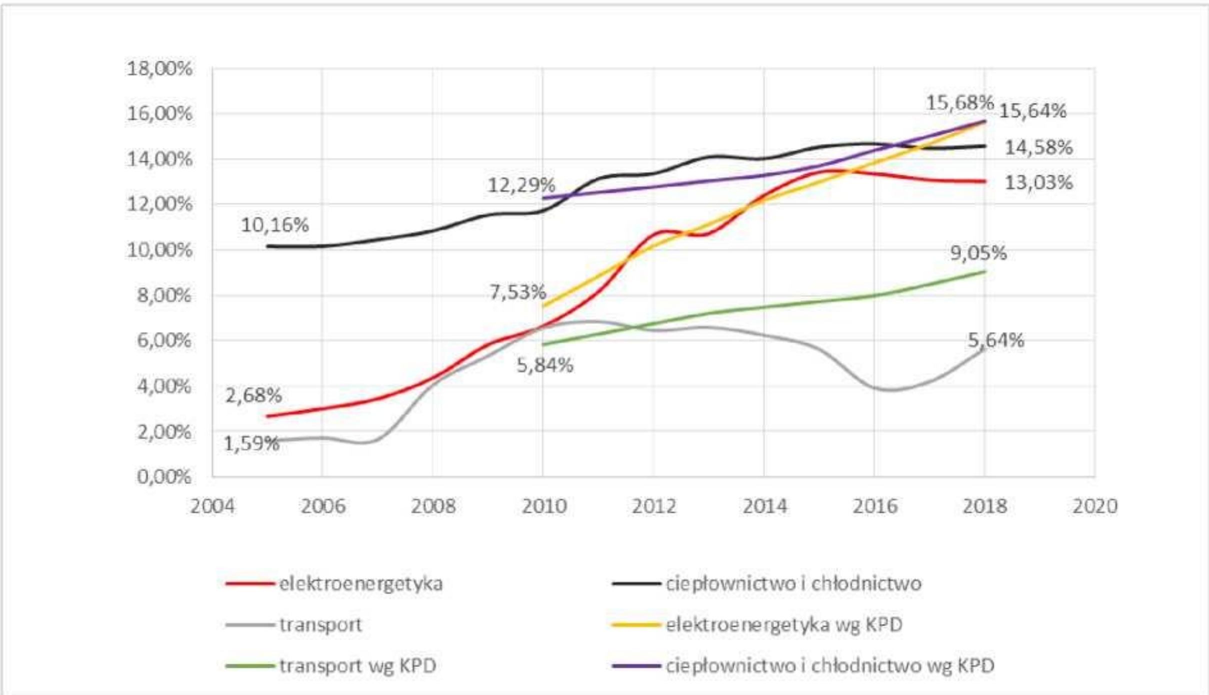

Figure 17. Comparison of RES shares in the particular sectors of the national economy with the trajectory of RES development presented in the NAP. Source: ARE S.A., NAP

elektroenergetyka	electric power
transport	transport
transport wg KPD	transport – NAP
ciepłownictwo i chłodnictwo	heating and cooling
elektroenergetyka wg KPD	electric power – NAP
ciepłownictwo i chłodnictwo wg KPD	heating and cooling – NAP

By sector, the target set in NAP was exceeded in 2010 only in the transport sector. In the heating and cooling sector, 11.73% of energy consumed came from renewable sources in 2010. In 2015, RES accounted for 14.54% of energy consumed in the heating and cooling sector, and this is the only sector in which the use of RES in 2016 was higher than the target set in the NAP. This is a result of the popularization of biomass as an environmentally friendly heating fuel. 2017 and 2018 saw a decrease in the RES share in the heating and cooling sector down to 14.49% and 14.58% respectively, a difference of 0.53% and 1.1% compared to the NAP. In the transport sector, 6.57% of energy consumed came from renewable sources in 2010. The RES share in transport peaked in 2011 and then reached 4.20% in 2017. In the electric power sector, RES accounted for 6.65%, in 2010, 13.43%, in 2015, 13.09% in 2017 and 13.03% in 2018. Following the aforementioned change in the support system in 2016 and 2017, the commissioning of new investment projects slowed down, which resulted in arresting the rate of increase in use of RES in the electric power industry.

- Forecasts of energy generation and consumption from renewable sources

The trajectories of national and sectoral RES shares presented in this subchapter assume the continuation of current trends and, consequently, do not factor in any exceptional measures to increase those shares, beyond those already defined in national legislation. A ‘business as usual’ approach does not take into account the possibility of the government administration stepping up efforts to achieve the 2020 target required by EU regulations in relation to the share of RES in final gross demand. It is assumed that the following basic mechanisms will be operated in the period under consideration to support electricity generation from RES: certificates of origin (this system is being gradually phased-out) and auctioning (expected to be in place by the end of 2035 for all RES technologies listed in the Act[13] except for offshore wind farms, for which support is expected to continue until the end of 2040). Both systems have a maximum technology subsidy period of 15 years.
It is also assumed that sources characterised by a stable mode of operation and those which may constitute a valuable addition to the existing generation units will mainly be given preference in future auctions for the supply of energy from renewable sources. The calculations are based on the data presented in the Eurostat SHARES forms used for reporting by Member States on the achievement of the 2020 RES targets. 2015 was selected as the base year, although the statistical data for 2016 and partly 2017, available at the time of preparation of this document, relating to the level of gross final energy demand and production from the particular RES generation units, were also taken into account. In the transport sector, the RES share was calculated as recommended in the RES Directive.

The calculations were based on the assumption that the share of energy from renewable sources equals the amount of RES energy consumed in transport divided by the total amount of energy consumed in transport[14].

[13] The Act of 20 February 2015 on renewable energy sources (Journal of Laws 2017, item 1148 and 1213, as amended).

[14] **numerator** – all types of energy from renewable sources consumed in transport. For the calculation of the share of electricity produced from renewable sources and consumed in all types of vehicles and for the production of renewable liquid and gaseous transport fuels, Member States may choose to use either the average share of electricity from renewable energy sources in the EU28 or the share of electricity from renewable energy sources in their own country (the former option was selected as it was considered to be more favourable). Furthermore, for the calculation of the electricity from renewable energy sources consumed by electrified rail transport, that consumption is considered to be 2.5 times the energy content of the input of electricity from renewable energy sources. For the calculation of the electricity from renewable energy sources consumed by road transport, that consumption is considered to be five times the energy content of the input of electricity from renewable energy sources. For the calculation of biofuels in the numerator, the share of energy from biofuels produced from cereal and other starch-rich crops, sugars, oil crops and energy crops cannot be more than 7% of the final consumption of energy in transport. A factor of 2 is applied to the calculations of

The anticipated national gross final energy demand and production from the particular generating units classified as RES was determined for the purposes of the study. A detailed description of the projection of an increase in energy demand for the calculation purposes is provided further in the document. For hydroelectric and wind power plants, the production figures presented in Table xx are normalised values according to the methodology recommended by Eurostat[15].

- **Wind power plants** – the maximum average annual rate of construction of new capacity in 2017-2020 was assumed at 100 MW, reflecting changes in preferences for subsidising RES technologies, in line with the auction volumes announced and proposed to date. In 2020-2025, the rate of growth of newly commissioned units (both on-shore and off-shore) was capped at 200 MW and increased to 500 MW in 2026-2030, 750 MW in 2031-2035 and 1000 MW in 2036-2040. It should be stressed that a large number of wind power units currently in operation will reach the end of their anticipated lifetime in 2031-2040 and will be replaced by new units, as a result of which the assumed maximum rate of net capacity growth is much lower (500 MW in 2031-2035 and 250 MW in 2036-2040). With regard to offshore wind power plants, it was assumed that no such units would be constructed in the coming years due to legal and technical restrictions. It was assumed that the first offshore wind farms with a total installed capacity of 400 MW would be launched through auctions by 2025. The total installed capacity of wind power plants is the result of the cost optimisation process (being competitive to alternative sources), assuming that this technology is subsidised at a level ensuring the rates of return expected by investors.

- **Hydroelectric power plants** – a maximum average annual power growth rate of 10 MW was assumed in relation to small hydroelectric power plants (below 10 MW) for the whole period under consideration. In addition, a minimum construction rate was set at 7 MW/year. No increase was envisaged for hydroelectric power plants above 10 MW, except for the construction of the 80 MW hydroelectric power plant in Siarzewo on the Vistula (to be commissioned in 2028[16]).

- **Biomass** – the trends observed in relation to all technologies using biomass in combustion processes for both electricity and heat production are assumed to continue. It is primarily expected that power plants and CHP plants with dedicated boilers of less than 50 MW_{el} and 150 MW_t (which will be supported by an auction system and will be treated preferentially in this system due to the stability of their operation), as well as distributed generation units using local resources will continue to develop. The maximum combined rate of construction of biomass-fired power plants and CHP plants is assumed to be 30 MW by 2020 and 75 MW/year in the following years, while the minimum rate is half of that.
  However, the assumption of continuing trends results in a limited increase in the use of biomass in district heating plants, where there is a significant untapped potential. In addition, the analysis assumes an increase in biomass consumption by home furnaces, consistent with the trend observed in recent years, which is attributable to, amongst others, replacement of outdated coal-fired boilers with new ones that are designed for pellet burning (as part of anti-smog measures). The results of the biomass projections are based on an analysis of the potential of this raw material and on numerous industry studies[17]. However, they lead to a conclusion that a significant increase in biomass use is unlikely unless additional incentives are provided.

- **Biomass and coal co-firing** – the analysis assumes that co-firing will take place only in existing coal units, with the production volume being the result of optimisation under the MESSAGE model. As the current formula of the support scheme for co-firing does not generate sufficient incentives for generators to return to this form of electricity production, the analysis assumed that co-firing could again be made profitable under existing support schemes with the aim of increasing the share of RES in 2020. It is assumed that support for co-firing will not continue after that year.

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second-generation biofuels.
denominator – the total amount of energy consumed in transport (petrol, diesel and biofuels, as well as electricity, including electricity used for the production of renewable liquid and gaseous transport fuels).

[15] In the case of hydroelectric power plants, normalisation consists in correcting production levels with the use of the gross capacity factor averaged over the last 15 years. A similar method was applied to wind power plants, except that a 5-years' average was used.

[16] The investment is considered a priority water project on a national scale.

[17] *Biomass Energy Europe. Executive Summary, Evaluation and Recommendations*, Chalmers University of Technology, 2011.

- **Biogas installations** – the assumed growth of this technology (a minimum of 30 MW/year, a maximum of 50 MW/year) is based on historical data and on the auction volumes proposed to date. It is primarily expected that the use of agricultural biogas will increase, given the limited potential of undeveloped organic waste from landfills and sewage treatment plants.

- **Photovoltaic installations** – the minimum rate of growth of new capacity assumed in the analysis, i.e. 75 MW/year for large installations connected to the power grid and 50 MW/year for small prosumer installations (rooftop installations), is based on the analysis of the rate of construction observed in recent years and takes into account the auction volumes announced and proposed to date.

- **Solar collectors** – the development trend observed in the country in 2012-2016 in relation to this technology is expected to continue. Further support is assumed for individual installations in the form of credit subsidies.

- **Heat pumps** – an increased average rate of development of this technology is assumed in relation to the one observed in the last six years (an average annual increase of approx. 15%) due to the expected increase in technical and economic efficiency of heat pumps, as well as their growing popularity and support in the form of subsidies.

- **Biofuels** – it is assumed that biofuel consumption will be driven by the need to achieve the targets set in the Polish legislation in terms of percentage shares in fuel sales, taking into account technical limitations related to the doping of conventional fuels and the EU requirements regarding the maximum share of biofuels derived from food crops. EU legislation sets the required minimum share of energy from renewable sources in 2020 at 10% of final energy consumption in transport in each Member State. This resulted in the introduction into national legislation [18] of requirements concerning the minimum contribution of biocomponents and other renewable fuels consumed in all modes of transport to the total volume of liquid fuels and liquid biofuels consumed during the calendar year in road and rail transport, calculated according to the calorific value. The 2020 National Indicative Target is 8.5%, and it is assumed that the target will be met and will remain unchanged until 2040.

- **Electricity from RES** – the consumption of electricity in rail, road and pipeline transport was determined using the STEAM-PL simulation model.

The forecast assumes that there will be approx. 870,000 electric vehicles on Polish roads by 2030 and approx. 2,400,000 by 2040, consuming respectively 1.2 TWh and 3.0 TWh. Estimates of the pace and extent of e-Mobility development are based on the assumption that excise tax exemptions will be the only type of support available to potential buyers. The rate at which the technology's costs are reduced will be the main factor driving an increase in vehicles of this type, but its estimation is subject to a significant level of uncertainty.

Tables 27-30 present national and sectoral projections of RES share based on the assumptions discussed above. These projections show that the continuation of RES support policies (as at the end of 2017) does not guarantee the fulfilment of the 2020 obligation set in the EU Directive. Due to the limited potential (relatively low levels of windiness, low levels of sunshine, unfavourable hydrological conditions - a lowland country with relatively low precipitation), the process of increasing Poland's share would require the deployment of expensive support mechanisms (RES become competitive only when the prices of CO_2 emission allowances are high and the technology costs are significantly reduced, a process slower than originally expected). The current contribution of RES to gross final consumption (2015) is 11.9%.

Cost optimisation, as well as an analysis of development opportunities based on existing trends and in the absence of extraordinary measures going beyond the existing legal and regulatory framework (as assumed in the scenario), suggest an achievable level of RES share in gross final energy consumption at 13.2% in 2020, 15.2% in 2030 and 18% in 2040. Electric power is the sector in which the RES share is growing at a fastest rate. The RES share is increasing in this sector from 15% in 2020 to 19.4% in 2030 and 25.9% in 2040. In the heating and cooling sector, where there is a relatively high potential, the increase is insignificant due to the limited scope of support. Moderate increase in the transport sector is a consequence of the assumption that the National Indicative Target for 2020-2040 will be maintained at 8.5%.

[18] Act of 25 August 2006 on bio-components and liquid biofuels (Journal of Laws 2014, item 1643, as amended).

Table 25. Projected total and sectoral gross final renewable energy consumption from renewable sources [ktoe] and the share of RES consumption – total and by sector [%]

[ktoe]	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**
gross final energy consumption (RES-OS denominator)	**61573.8**	**69,156.4**	**64,596.0**	**75,021**	**78,057**	**80,329**	**81,138**	**81,464**
gross final renewable energy consumption	4,245.4	6,399.3	7,664.4	9,882	10,876	12,232	13,707	14,651
consumption of RES in electric power	331.7	890.3	1,894.3	2,322	2,736	3,412	4,378	4,911
consumption of RES in heating and cooling	3,867.6	4,641.6	5,116.7	5,880	6,320	6,885	7,367	7,776
consumption of RES in transport	95.2	916.2	721.2	1,680	1,820	1,936	1,961	1,965

[%]	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**
share of RES in gross final energy consumption	6.9%	9.3%	11.9%	**13.2%**	**13.9%**	**15.2%**	**16.9%**	**18.0%**
share of RES energy in electric power	3.1%	7.0%	13.4%	15.0%	16.5%	19.4%	23.9%	25.9%
share of RES in heating and cooling	10.2%	11.7%	14.5%	15.6%	16.5%	17.7%	18.8%	19.7%
share of renewable energy in transport (with multipliers)	1.6%	6.6%	6.4%	10.0%	10.4%	11.2%	12.1%	13.0%

Source: Own study by ARE S.A., Eurostat

*Table 26. Projected gross final energy generation from renewable sources in the **electric power sector** by technology [ktoe] and the share of particular technologies in renewable energy consumption [%]*

renewable energy production by technology [ktoe]	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**
gross final electricity consumption (RES-E denominator)	12,396.7	13,390.8	14,102.1	15,466	16,584	17,620	18,308	18,993
hydropower*	184.3	202.0	202.4	210.1	223.9	251.2	265.9	280.7
wind farms*	17.5	146.2	833.0	1,182.7	1,538.0	1,999.3	2,769.8	3,093.1
photovoltaics	0.0	0.0	4.9	41.5	95.4	148.3	200.9	248.7
biomass	120.4	507.8	776.2	806.5	767.0	900.9	1,044.6	1,203.9
biogas	9.6	34.3	77.9	138.3	199.1	258.3	291.4	322.2
renewable municipal waste	0.0	0.0	0.0	44.9	52.5	51.3	52.6	54.5

share of technologies in renewable energy consumption in the electric power sector [%]	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**
hydropower	55.6%	22.7%	10.7%	9.0%	8.2%	7.4%	6.1%	5.7%
wind farms	5.3%	16.4%	44.0%	50.9%	56.2%	58.6%	63.3%	63.0%
photovoltaics	0.0%	0.0%	0.3%	1.8%	3.5%	4.3%	4.6%	5.1%
biomass	36.3%	57.0%	41.0%	34.7%	28.0%	26.4%	23.9%	24.5%
biogas	2.9%	3.9%	4.1%	6.0%	7.3%	7.6%	6.7%	6.6%
renewable municipal waste	0.0%	0.0%	0.0%	1.9%	1.9%	1.5%	1.2%	1.1%

Source: Own study by ARE S.A., Eurostat

*Table 27. Projected gross final renewable energy consumption in **heating and cooling** by source [ktoe] and the share of particular sources in renewable energy consumption in heating and cooling [%]*

gross final renewable energy consumption in heating and cooling by source [ktoe]	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**
gross final energy consumption in heating and cooling (RES-H&C denominator)	**38,064.0**	**39,558.3**	**35,202.3**	**37,656**	**38,376**	**38,944**	**39,282**	**39,377**
geothermal	11.4	13.4	21.7	28.6	30.3	31.5	32.4	33.1
solar	0.1	10.0	45.0	90.4	244.3	425.8	540.5	564.1

solid biomass	3,814.5	4,554.6	4,896.0	5,464.8	5,632.7	5,847.5	6,041.2	6,252.1
biogas	40.9	50.8	88.4	110.1	133.6	160.3	187.3	220.0
heat pumps	0.0	9.9	25.6	104.9	184.5	309.0	441.2	563.7
renewable municipal waste	0.7	2.9	39.9	81.4	94.3	110.5	124.5	142.6

share of technology in renewable energy consumption in heating and cooling [%]	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**
geothermal	0.3%	0.3%	0.4%	0.5%	0.5%	0.5%	0.4%	0.4%
solar	0.0%	0.2%	0.9%	1.5%	3.9%	6.2%	7.3%	7.3%
solid biomass	98.6%	98.1%	95.7%	92.9%	89.1%	84.9%	82.0%	80.4%
biogas	1.1%	1.1%	1.7%	1.9%	2.1%	2.3%	2.5%	2.8%
heat pumps	0.0%	0.2%	0.5%	1.8%	2.9%	4.5%	6.0%	7.3%
renewable municipal waste	0.0%	0.1%	0.8%	1.4%	1.5%	1.6%	1.7%	1.8%

Source: Own study by ARE S.A., Eurostat

Table 28. Projected gross final renewable energy consumption in the transport sector by technology [ktoe] and the share of technologies in renewable energy consumption in transport [%]

gross final renewable energy consumption in the transport sector by technology [ktoe]	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**
gross final energy consumption in transport (RES-T denominator)	**10,178.7**	**14,951.0**	**14,488.0**	**20,523**	**21,881**	**22,770**	**22,787**	**22,419**
electricity	49.1	48.8	67.8	101.9	140.1	197.4	246.9	292.3
first-generation biofuels/first-generation HVO/CHVO	46.1	867.4	653.4	1358.3	1460.1	1518.2	1494.1	1452.6
second-generation biofuels or second-generation HVO/COHVO	0.0	0.0	0.0	220.0	220.0	220.0	220.0	220.0

consumption of electricity for road transport purposes classified as RES	0.3	0.3	0.5	3.2	14.6	43.9	81.6	116.2
consumption of electricity for rail transport purposes classified as RES	43.7	43.3	61.1	90.1	114.9	141.7	152.9	163.5
consumption of electricity in pipeline transport classified as RES	5.2	5.1	6.3	8.7	10.5	11.9	12.4	12.6

total consumption of electricity in transport	343.0	289.0	267.1	307.2	369.3	480.7	573.6	646.8
including: for road transport purposes	1.8	2.0	1.9	9.6	38.5	106.8	189.6	257.1
for rail transport purposes	305.2	256.8	240.6	271.5	302.9	345.0	355.3	361.8
in pipeline transport	36.0	30.2	24.7	26.1	27.8	28.9	28.7	27.8

[%]	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**
share of electricity in renewable energy consumption in transport	51.6%	5.3%	9.4%	6.1%	7.7%	10.2%	12.6%	14.9%
share of biofuels in renewable energy consumption in transport	48.4%	94.7%	90.6%	93.9%	92.3%	89.8%	87.4%	85.1%

share of electricity used for road transport purposes	0.5%	0.7%	0.7%	3.1%	10.4%	22.2%	33.1%	39.8%
share of electricity used for rail transport purposes	89.0%	88.8%	90.1%	88.4%	82.0%	71.8%	61.9%	55.9%
share of electricity used in other types of transport	10.5%	10.5%	9.2%	8.5%	7.5%	6.0%	5.0%	4.3%

Source: Own study by ARE S.A., Eurostat

- Projected generation of electricity and heat in buildings

Projections concerning the production of electricity in buildings[19] stem from the cost optimisation carried out with the use of the MESSAGE model, which takes into account existing legislation on the development of distributed RES-based energy and the anticipated potential decrease in the cost of associated technologies. Under this model, distributed sources are competitive in relation to the retail price of electricity. The fact that energy can be used on the site where it is produced, without having to transmit it over long distances, is an important advantage of technological solutions of this type. Prosumer energy generation is undoubtedly an element of the system that can contribute to the improvement of local energy security and further diversification of energy supplies. Prosumerism is only just beginning to develop in Poland and, similarly as in western countries, is expected to play an increasingly important role in the future. The results of analysis regarding the possible production potential of RES-based small installations and microinstallations, as presented below, are based on the assumption of a gradual decrease in technology costs, an increase in retail prices of electricity (mainly as a result of the rising costs of CO_2 emission allowances for units relying on fossil fuels), as well as the methods of support involving mainly the co-funding of investment costs, the availability of preferential loans, and the possibility of feeding excess energy generated by prosumers into the grid subject to the rules applicable to the system of discounts provided for by the RES Act. It is apparent from the results obtained that photovoltaics will be the fastest growing technology among small installations and microinstallations in buildings (and the one with the highest rate of cost reduction).
The tables below show projections of electricity and heat generation from renewable energy sources by small installations and microinstallations in buildings, including data on electricity self-consumed and fed into the grid. The share of energy fed into the grid in the respective periods is determined on the basis of an analysis of historical data provided by the Energy Regulatory Office (URE)[20]. The projections on the generation of heat by microinstallations are based on the STEAM-PL simulation model which takes into account elements such as the level of demand for useful energy output, existing potential, technology costs, subsidies, user preferences, existing pace of development, forecasts from industry organisations and reputable Polish and foreign research institutions.

Table 29. Generation of electricity through renewable energy sources in buildings [GWh]

Total gross production [GWh]				
	Biogas plants	Photovoltaics	Wind farms	Small hydropower
2015	230	157	50	69
2020	694	401	111	155
2025	1,159	653	166	242
2030	1,488	885	211	328
2035	1,851	1,102	255	414
2040	230	157	50	69
Self-consumption [GWh]				
	Biogas plants	Photovoltaics	Wind farms	Small hydropower
2015	0	5	0	0
2020	0	5	0	0
2025	184	92	13	7
2030	556	235	30	15
2035	928	382	45	23
2040	1,191	518	57	32
Energy fed into the grid [MWh]				
	Biogas plants	Photovoltaics	Wind farms	Small hydropower
2015	0	4	0	0
2020	46	65	36	62
2025	138	166	81	140
2030	231	271	122	218

[19] Within the meaning of Article 2(1) of Directive 2010/31/EU.

[20] *Zbiorcze informacje dotyczące wytwarzania energii elektrycznej z odnawialnych źródeł energii w mikroinstalacji lub małej instalacji za 2016 r. (art. 17 ustawy OZE)* [Summary information on renewable electricity generation by microinstallations and small installations in 2016 (Article 17 of the RES Act)] – URE Report. Warsaw, April 2017.

2035	296	367	154	296
2040	369	457	186	374

Source: ARE S.A. own study (STEAM-PL, MESSAGE-PL)

Table 30. Generation of heat through renewable energy sources in buildings [ktoe]

Total gross production [ktoe]					
	Biogas plants	Solar collectors	Biomass-fired boiler heaters	Heat pumps	Geothermal
2015	0	45	1,069	26	0
2020	105	90	1,236	105	0
2025	381	244	1,348	185	0
2030	657	426	1,460	309	0
2035	822	541	1,583	441	0
2040	1,098	564	1,716	564	0
Self-consumption [ktoe]					
	Biogas plants	Solar collectors	Biomass-fired boiler heaters	Heat pumps	Geothermal
2015	0	45	1,069	26	0
2020	105	90	1,236	105	0
2025	381	244	1,348	185	0
2030	657	426	1,460	309	0
2035	822	541	1,583	441	0
2040	1,098	564	1,716	564	0
Energy injected into the grid [ktoe]					
	Biogas plants	Solar collectors	Biomass-fired boiler heaters	Heat pumps	Geothermal
2015	0	0	0	0	0
2020	0	0	0	0	0
2025	0	0	0	0	0
2030	0	0	0	0	0
2035	0	0	0	0	0
2040	0	0	0	0	0

Source: ARE S.A. own study (STEAM-PL, MESSAGE-PL)

4.3. Dimension energy efficiency

Poland overachieved its national energy efficiency target understood as realising by 2016 final energy savings of at least 9% of the average inland consumption of such energy in 2001-2005. Poland has seen a steady decrease in the energy intensity, and 2010 was the only year when energy intensity showed an upward trend. The decreasing primary and final energy intensity is due to the rate of energy consumption being outpaced by the GDP growth rate. In 2006-2015, the average annual rate of improvement in energy intensity exceeded 3%. When adjusted for climate conditions, the rate was slightly lower.
The years 2005-2015 saw an increase in the share of the transport and service sectors in the final energy consumption, and a drop in the share of industry, households and agriculture. The share of transport grew from 22% to 28%, and that of services from 12% to 13%. Households remained the largest consumer despite a drop in their share from 35% to 31%. The share of industry declined from 26% to 24%, and that of agriculture from 8% to 5%. The above changes reflect the prevailing trends in the development of the Polish economy (e.g. rising foreign trade), as well as measures taken by the industrial sector (rationalisation of energy consumption in response to growing prices of energy carriers). The most noticeable change was observed in the transport sector, where the increased demand for energy resulted from a high growth in the volumes of both goods transport (as a result of growth in economic activity) and passenger transport (increased prosperity of the population and growing saturation of the passenger car market). The gap between Poland and the European average as regards the key energy performance indicators has decreased to a dozen or so percent, but the most efficient economies remain well ahead.

4.3.1. Primary and final energy consumption

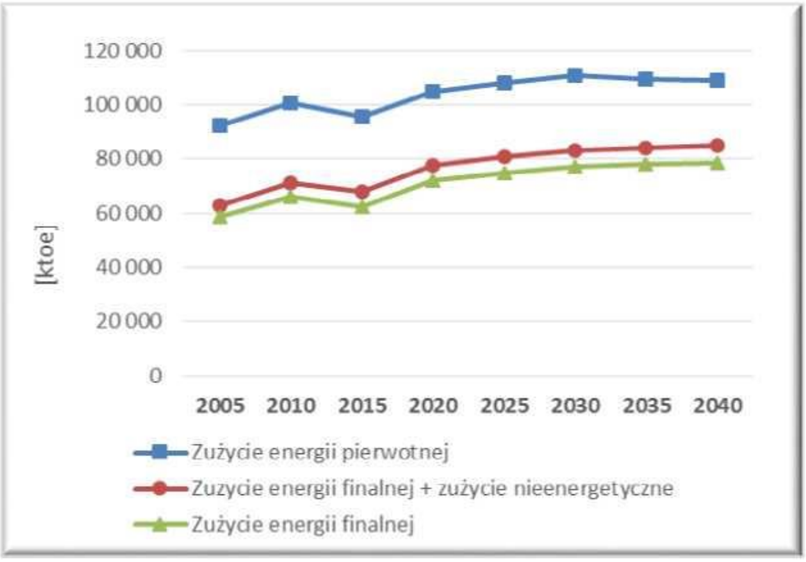
The table and figure below summarise the historical and projected primary and final energy consumption in

Poland. The data obtained show a moderate increase in demand for primary energy in the country from 95.7 Mtoe to 110.0 Mtoe in 2030 (an increase of less than 15%) and then a slight decrease to 108.1 Mtoe in 2040. On the other hand, final energy consumption increases in the period under consideration from 66.4 Mtoe to 83.2 Mtoe in 2030 and 84.9 Mtoe in 2040. The demand projections are based on the number of heating and cooling degree days as given in Tables 13 and 14.

Table 31. Total primary and final energy consumption [ktoe]

	2005	2010	2015	2020	2025	2030	2035	2040
primary energy consumption*	92,560	101,558	95,739	103,929	107,328	110,098	108,538	108,134
final energy consumption including non-energy use	62,080	70,199	66,409	77,719	80,808	83,185	84,280	84,889
final energy consumption	57,472	65,230	60,775	72,117	75,078	77,327	78,300	78,784

**including non-energy use*
Source: Own study by ARE S.A., Eurostat



** including non-energy use*
Figure 18. Total primary and final energy consumption [ktoe]

[ktoe]	[ktoe]
Zużycie energii pierwotnej	Primary energy consumption
Zużycie energii finalnej + zużycie nieenergetyczne	Final energy consumption + non-energy use
Zużycie energii finalnej	Final energy consumption

4.3.2. Final energy consumption by sector

In sectoral terms, an increase in final energy demand is mainly associated with transport. A significant impact was exerted by the introduction in July 2016 of a legislative package restricting the ‘grey market’ in transport fuels, which resulted in the disclosure in national statistics of additional volumes of fuel sales and consumption, the records of which could not be kept before 2016. The rapidly growing trade and services sector is another sector where a significant increase in energy consumption is to be expected. In 2015-2030, energy consumption in this sector is expected to increase by approx. 35%. Consumption in industry and households will grow at a much slower, albeit more constant, rate (an increase of 16.8% and 14%, respectively, between 2015 and 2030). In agriculture, consumption will basically remain stable at 3.3-3.6 Mtoe.

Table 32. Final energy consumption by sectors (excluding non-energy use) [ktoe]

	2005	2010	2015	2020	2025	2030	2035	2040
Industry	14,616	13,498	14,096	16,088	16,271	16,462	16,645	16,831
Transport	12,221	17,187	16,559	23,495	24,897	25,790	25,744	25,434
including: passenger	No data	No data	8,985	10,996	11,215	11,144	11,063	10,949
freight	No data	No data	7,494	12,417	13,598	14,560	14,594	14,398
Special purpose vehicles	No data	No data	79	82	84	86	87	87

Households	19,467	21,981	18,948	20,267	20,989	21,615	22,071	22,415
Services	6,730	8,833	7,842	8,811	9,431	9,936	10,286	10,518
Agriculture	4,438	3,730	3,330	3,457	3,491	3,523	3,555	3,585
TOTAL	57,472	65,230	60,775	**72,117**	**75,078**	**77,327**	**78,300**	**78,784**

Source: ARE S.A. own study (STEAM-PL), Eurostat

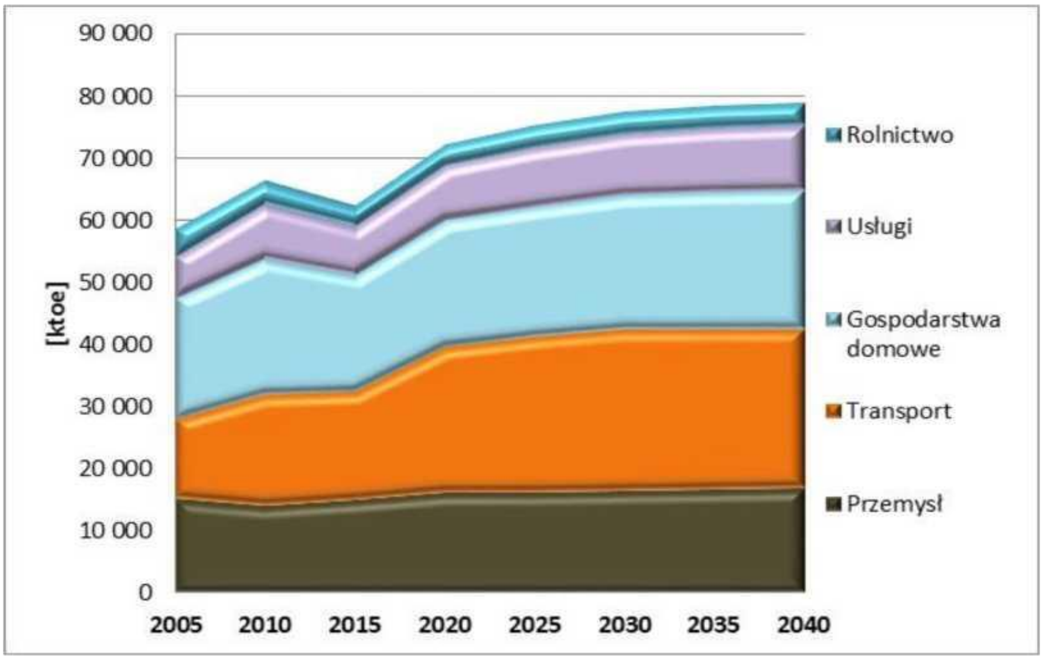


Figure 19. Final energy consumption by sectors (excluding non-energy use)

[ktoe]	**[ktoe]**
Rolnictwo	Agriculture
Usługi	Services
Gospodarstwa domowe	Households
Transport	Transport
Przemysł	Industry

4.3.3. Final energy consumption by fuel

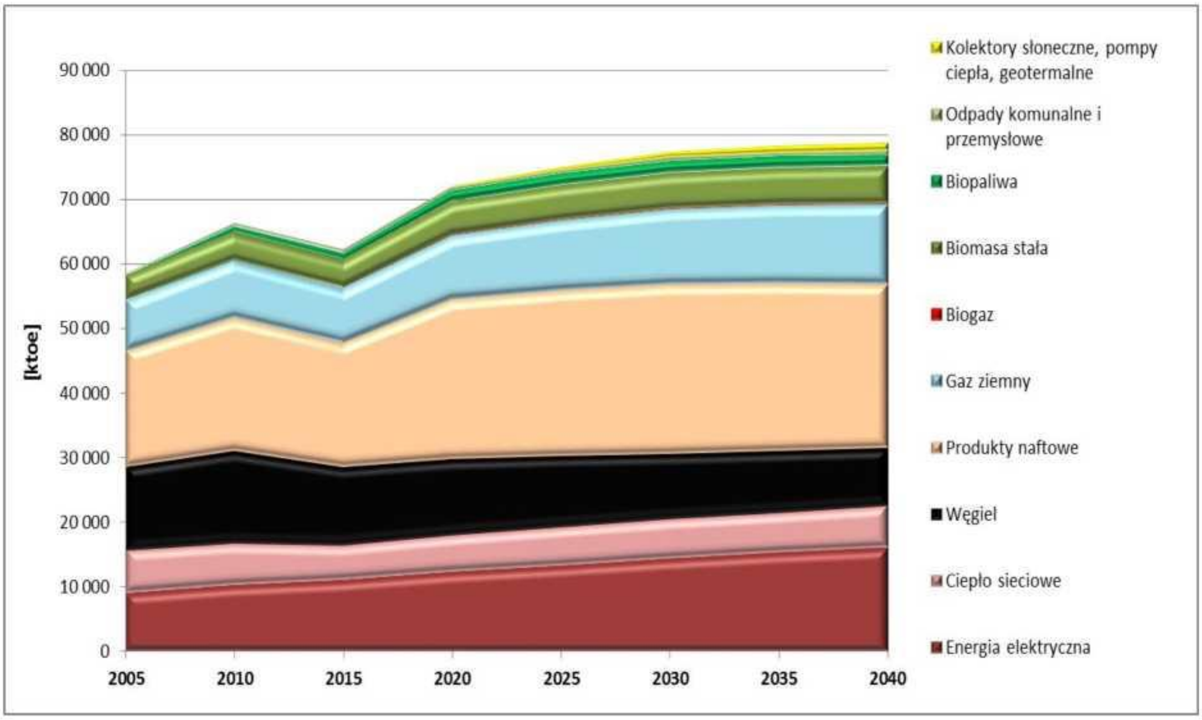
As far as final energy consumption is concerned, gradual changes can be observed in the fuel mix. Coal consumption is falling significantly (from 18% in 2015 to approx. 13% in 2030), while the consumption of electricity, natural gas and energy from renewable sources is gradually increasing. Based on the adopted assumptions, a relatively small increase is expected in demand for district heating, which would mean the reversal of the long-term downward trend as a result of intensified efforts to promote new connections to the grid as part of anti-smog measures and support for high-efficiency cogeneration. The decrease in hard coal consumption is mainly associated with the slow but steady process of retrofitting production plants (in the industry sector), partly as a result of the operation of the ETS, which involves the switch to fuels and carriers such as gas or electricity. It will also be driven by the replacement of old, inefficient manually fed boilers in households, supported by subsidies. Moreover, the Regulation on the requirements for solid fuel boilers[21], which took effect in 2017, introduced the obligation to comply with standards applicable to boilers manufactured and installed in Poland with a capacity below 500 kW. The projection assumes that all new boilers meet the criteria set forth by the Regulation.

Table 33. Final energy consumption by fuels and carriers [ktoe]

	2005	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**
Electricity	9,028	10,206	10,990	12,241	13,247	14,255	15,151	16,019

[21] Regulation of the Minister for Development and Finance of 1 August 2017 on the requirements for solid fuel boilers.

District heating	6,634	6,547	5,462	5,759	6,013	6,202	6,376	6,558
Coal	12,340	13,733	11,218	11,936	11,081	10,291	9,591	8,969
Petroleum products	17,563	20,213	18,646	24,621	25,656	26,178	25,890	25,407
Natural gas	7,917	8,884	8,487	9,877	10,819	11,583	12,053	12,293
Biogas	40	48	78	90	104	121	142	170
Solid biomass	3,755	4,306	4,639	5,146	5,324	5,469	5,610	5,744
Biofuels	46	867	653	1,579	1,681	1,739	1,715	1,673
Municipal and industrial waste	136	378	486	666	704	714	725	738
Solar collectors, heat pumps, geothermal	12	48	116	203	450	777	1,047	1,213
TOTAL	**57,472**	**65,230**	**60,775**	**72,117**	**75,078**	**77,327**	**78,300**	**78,784**



Source: ARE S.A. own study (STEAM-PL), Eurostat
Figure 20. Final energy consumption by fuel and carrier

[ktoe]	**[ktoe]**
Kolektory słoneczne, pompy ciepła, geotermalne	Solar collectors, heat pumps, geothermal
Odpady komunalne i przemysłowe	Municipal and industrial waste
Biopaliwa	Biofuels
Biomasa stała	Solid biomass
Biogaz	Biogas
Gaz ziemny	Natural gas
Produkty naftowe	Petroleum products
Węgiel	Coal
Ciepło sieciowe	District heating
Energia elektryczna	Electricity

4.3.4. Non-energy use

Non-energy use is the quantity of energy carriers used for the production of certain products (e.g. consumption of gas for the production of mineral fertilisers or of hard coal for the production of electrodes). The forecast assumes a moderate increase in the consumption of all energy carriers used to date for non-energy purposes in line with the observed historical trend. This increase is highly correlated with economic growth.

Table 34. Non-energy use by fuels [ktoe]

	2005	2010	2015	2020	2025	2030	2035	2040
Coal	52	54	102	118	119	119	120	121
Coke	39	1	0	0	0	0	0	0
Peat	90	30	0	0	0	0	0	0
Kerosene	672	986	1,048	1,085	1,131	1,173	1,212	1,249
LPG	73	81	144	103	103	107	115	124
Other petroleum products	1,664	2,156	2,222	2,146	2,201	2,256	2,309	2,365
Natural gas	2,017	1,661	2,120	2,151	2,176	2,202	2,223	2,245
TOTAL	**4,608**	**4,969**	**5,635**	**5,602**	**5,729**	**5,858**	**5,979**	**6,106**

Source: ARE S.A. own study (STEAM-PL), Eurostat

4.3.5. Primary energy intensity

The table below presents the rate of primary energy intensity to GDP. This rate is gradually decreasing throughout the considered timespan, which reflects energy efficiency improvements in the Polish economy and is to a large extent a result of the market transformation that has been progressing in the country since the 1990s. As demonstrated by comparisons, energy intensity per unit of GDP has been decreasing in Poland over the past years at a rate more than twice faster than the EU average (it dropped by approx. 30% relative to 2005). The primary energy intensity of GDP calculated for 2015, which amounts to 206 toe/EUR'2016 million, is almost twice as high as the EU average (by approx. 89% according to EUROSAT data). This leads to a conclusion that there is still a significant untapped potential for further efficiency improvements, although it is certain that this potential is not excessively big and not easy to tap. Another point is that the energy intensity index calculated by reference to the purchasing power parity (PPP), which was only 17% higher than the EU average in 2014, would be a much better indicator.

Table 35. Primary energy intensity in relation to GDP [toe/EUR'2016 million]

	2005	2010	2015	2020	2025	2030	2035	2040
Country total	292	254	207	190	167	148	130	116

Source: Own study of ARE S.A.

4.3.6. Final energy intensity by sector

The table below presents the rates of final energy intensity by sectors. Those rates improve gradually over the considered timescale across all sectors of the national economy. Some exception is the transport sector, where fuel consumption was adjusted following the introduction of what is known as the 'fuel package' as of 1 July 2016 (a surge in legal fuel consumption resulting from the eradication of the 'grey market' makes the intensity indicator for 2015-2020 more realistic).

Table 36. Final energy intensity by sectors [toe/EUR'2016 million]

	2005	2010	2015	2020	2025	2030	2035	2040
Country total	**196**	**175**	**144**	141	124	111	100	90
Industry	225	156	139	138	123	110	103	97
Transport	677	930	644	757	738	711	664	621
including: passenger	no data	no data	347	352	331	306	284	266
freight	no data	no data	289	398	401	399	375	350
Services	41	43	34	32	29	26	24	21
Agriculture	431	363	349	355	351	347	343	339
Households [toe/household]	1,524	1,632	1,357	1,375	1,359	1,347	1,335	1,325

Source: Own study of ARE S.A.

4.3.7. Fuel input in electricity and heat generation

The table below presents projections of the consumption of fuels for the purposes of electricity and heat generation. The 2020-2040 consumption figures are a derivative of the optimal structure of electricity and heat production and capacity in the country, as determined under the dedicated model (MESSAGE-PL) and further described in Sections 4.4.5 and 4.4.6 of this elaboration. The key conclusion that can be drawn from the obtained results is the anticipated phasing-out of coal and lignite use in the power and heating sectors, mainly due to the rising cost of CO_2 emission allowances, the need to put out of service units that are usually not able to meet environmental requirements, and the generally adverse regulatory and market environment for high-carbon plants. This is done at the cost of increasing the share of fuels and technologies that are less burdensome for the natural environment (RES, gas, nuclear power). Thanks to the introduction of a capacity market and the operation of certain mechanisms mitigating the effects of the sector's transformation (which is factored in the model), a major decrease in the consumption of coal by the electric power sector is noticeable only after 2030. The prices of CO_2 emission allowances assumed in the forecasting model in accordance with the Commission's recommendations rise in this period to 30-40 EUR/tCO_2, pushing coal-fired plants out of the merit order curve. However, the prices of CO_2 emission allowances are a key element of uncertainty in relation to the obtained results.

Table 37. Fuel input for electricity and heat generation [ktoe]

	2005	2010	2015	2020	2025	2030	2035	2040
Power plants								
Coal	2,265	1,118	507	5,096	6,248	6,201	6,201	5,684
Petroleum products	10	4	1	2	2	2	2	1
Gas	1	0	0	0	0	0	0	0
RES, waste	6	61	441	438	436	397	397	289
CHP plants								
Coal	34,392	33,935	32,375	25,232	24,926	25,347	17,197	9,418
Petroleum products	555	558	403	139	147	142	112	87
Gas	1,182	1,093	1,347	2,666	3,241	3,462	6,484	8,624
RES, waste	435	1,547	2,021	2,275	2,296	2,817	3,208	3,745
Nuclear fuel	0	0	0	0	0	0	2,668	8,003
Heat plants								
Coal	3,060	3,337	2,394	2,196	2,045	1,960	1,788	1,875
Petroleum products	51	36	16	19	17	15	13	12
Gas	295	277	209	185	174	171	160	188
RES, waste	40	47	42	47	56	72	81	92

Source: ARE S.A. own study (MESSAGE-PL)

4.3.8. Fuel input in other conversion processes

The transformation sector comprises industrial plants that use technological processes where one form of energy (usually primary energy carriers, e.g. coal) is converted into another, derivative form of energy (e.g. electricity, heat, coke, gas from technological processes, etc.). In addition to power plants, combined heat and power plants and heating plants, which are discussed in the previous section, the transformation sector includes refineries, petrochemical plants, gas works, coking plants, patent fuel plants and blast furnaces. The table below illustrates the total fuel consumption in these units. The presented data show a gradual increase in fuel consumption associated with the growing needs of the developing economy. An increase is expected in the consumption of all fuel categories defined in the table, used as fuel input in conversion processes.

Table 38. Fuel input in other conversion processes [ktoe]

	2005	2010	2015	2020	2025	2030	2035	2040
Crude oil	18,432	23,188	26,537	28,078	29,683	30,825	31,237	31,403
Coal	9,519	10,559	11,063	10,887	11,078	11,236	11,380	11,515
Petroleum products	1,085	1,703	1,906	1,969	2,086	2,176	2,229	2,268
Gas	204	308	638	709	754	782	774	760
RES, waste	0	0	0	0	0	0	0	0

Source: ARE S.A. own study (STEAM-PL)

4.3.9. Share of cogeneration in electricity and heat production

An indisputable advantage of cogeneration systems is their high energy efficiency, which significantly reduces the consumption of primary fuels, which in turn reduces emissions of CO_2 and other pollutants. In cogeneration plants, most energy savings are derived from a more comprehensive use of energy supplied in the fuel thanks to the utilisation of residual heat that accompanies separate production of useful heat and electricity. Currently, approx. 66%[22] of useful heat comes from cogeneration, while the remaining portion is produced in water boilers (heating plants and heating boiler units of public power plants). Consequently, Poland has a considerable potential that can be tapped through the conversion of water boilers that do not meet the environmental requirements into cogeneration units. It is also technically possible to utilise waste heat generated by waste incineration plants, industrial installations or other installations generating waste heat. Micro-cogeneration and prosumer energy offer further opportunities. It follows from analyses, *inter alia* those carried out by ARE S.A., that Poland has the potential to install another 7.5 to 10 GW of cogeneration capacity[23][24].

In the model simulations, the rate of cogeneration development in Poland is determined on the basis of projected useful heat demand, taking into account economic factors, and assuming continued support for high-efficiency cogeneration. The results of model calculations (Table 41) show the possibility of increasing the share of electricity from high-efficiency cogeneration from 16.0% in 2015 to 20.5% in 2030 and 26.5% in 2040. Based on the adopted assumptions, large gas-fired CHP plants are the fastest-growing technology (their environmentally-friendly nature, the availability of fuel and competitiveness in the face of the rising prices of CO_2 emission allowances are the factors weighting in favour of this solution).

Table 39. Percentage share of cogeneration in electricity and heat production

	2005	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**
Share of cogeneration	12.9%	17.6%	16.2%	19.7%	20.6%	20.8%	25.9%	26.7%

Source: ARE S.A. own study (MESSAGE-PL)

4.3.10. Production of heat in power plants, combined heat and power plants and heating plants

Projections concerning the production of heat by CHP plants are the result of cost optimisation under the MESSAGE-PL model. The production of district heating will increase, driven in particular by combined heat and power generation.

Table 40. Production of heat in power plants, combined heat and power plants and heating plants [TJ]

	2005	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**
combined heat and power plants	219,883	205,851	186,626	200,060	218,230	230,000	244,539	247,396
heating plants	116,508	129,980	94,767	93,662	62,828	53,635	43,070	46,404
TOTAL	**336,391**	**335,831**	**281,393**	**293,722**	**281,058**	**283,635**	**287,609**	**293,800**

Source: ARE S.A. own study (MESSAGE-PL)

4.3.11. Potential for high-efficiency cogeneration and efficient district heating and cooling

Below is an assessment of the potential for the application of high-efficiency cogeneration and efficient heating and cooling systems carried out in 2017 by the research team of the Warsaw University of Technology[25].

The potential for development of cogeneration in the country is relative to the size of demand for useful heat.

The following levels of potential are distinguished in assessments:

- total potential, equal to total demand for useful heat,
- technical potential = the part of the total potential that can actually be used, taking into account the current technical and technological progress,
- economic potential = the part of the technical potential whose actual use is economically justified.

[22] *Gospodarka paliwowo-energetyczna* [Fuel and Energy Economy], GUS, Warsaw 2016.

[23] *Raport o stanie kogeneracji w Polsce w latach 2007-2014* [Report on the state of cogeneration in Poland in 2007-2014], ARE S.A., Warsaw 2015.

[24] *Kogeneracja - wczoraj, dziś, jutro* [Cogeneration – yesterday, today, tomorrow], ARE S.A., Warsaw 2016.

[25] *Analiza krajowego potencjału ciepłownictwa i chłodnictwa. Aktualizacja na rok 2017* [Analysis of the national heating and cooling potential. A 2017 update], Warsaw University of Technology, Warsaw 2017.

According to another criterion, the total potential is divided into:
- potential already used = the part of the useful heat which is currently generated by cogeneration units,
- additional potential = the part of the useful heat which is currently generated by other techniques.

Poland's current total annual demand for useful heat (total cogeneration potential) is estimated at 973 PJ (weather fluctuations may cause upward or downward changes in annual demand by 10%), of which:
- 256 PJ is the heat obtained by all sectors from district heating networks;
- 402 PJ are the needs of the household sector, met from own sources – currently from solid fuels (approx. 70%), natural gas (approx. 25%) and other sources (approx. 5%), including liquid fuels and electric heating; this represents a total additional potential for the application of cogeneration in this sector;
- 315 PJs are the needs of economic sectors (industry, services, agriculture), met from own sources – largely industrial plants' own cogeneration units. The additional potential is relatively small; in particular, approx. 60 PJ of heat is recovered from industry and coking plants, which is a very cheap form of waste heat generation.

In technical terms, the cogeneration technologies are currently available over a complete power range from several kilowatts (small residential houses) to hundreds of kilowatts (large thermal power plants). For this reason, the technical potential of cogeneration is taken to be the country's total annual useful heat demand, less only heat recovery in industry and coking plants, as it would be pointless to replace recovery with any cogeneration technology. The country's technical potential for cogeneration is, therefore, estimated at 973 – 60 = 913 PJ.

The additional economic potential, i.e. the amount of useful heat which is not currently produced by cogeneration, yet which is considered, after a detailed analysis, to be economically justified, is the relevant category for a realistic planning of future cogeneration developments. In practice, the development of cogeneration will be conditional on tapping the additional technical potential, which is 191 PJ (after adjustments). The technical potential is adjusted by subtracting two categories of heat produced without cogeneration that form part of the additional technical potential:

- heat generated in CHP plants outside the cogeneration process (56 PJ), since this heat is usually only generated in periods of very low air temperatures and the time span for use of the heating capacity is very short;
- heat generated from biomass (11 PJ).

The additional economic potential of cogeneration development was calculated on the basis of an economic analysis of the effects of implementing cogeneration instead of separate electricity and heat generation. The effectiveness of cogeneration investments was assessed using the sum of discounted cash flows (NPV). External costs of electricity and heat generation, i.e. social costs not passed on to prices of energy carriers, were also factored in.

The calculations were carried out for the following technologies, which are considered to be representative for the future development of cogeneration:
- technologies for large and medium-sized district heating systems (capacity ≥ 20 MW):
  - 50 MW steam-gas unit,
  - 100 MW steam unit with a fluidised bed boiler,
- technologies for small heating systems (1 MW ≤ capacity < 20 MW):
  - 5 MW gas turbine,
  - 5 MW steam power unit,
  - 5 MW gas engine,
- micro-cogeneration technologies (capacity < 1 MW):
  - 0.5 MW gas engine,
  - 0.3 MW gas turbine.

The results concerning the additional economic potential indicate that cogeneration investments are socially viable (NPV > 0) with relatively short periods of capacity use (even less than 2,700 hours per year). For the purposes of rationalising profitability, the typical periods of use of the installed capacity were adopted: 4,600 hours per year for CHP plants generating heat for heating buildings and hot water and 6,000 hours per year for industrial CHP plants.

The total additional economic potential for CHP is estimated at 185 PJ, a negligible difference compared to the adjusted additional technical potential of 191 PJ. To fully exploit this potential, cogeneration units would need to be built with a total electrical capacity of 10,243 MW and a total thermal capacity of 11,112 MW. They would produce 185 PJ of heat and 47 TWh of electricity per year, which would save 253 PJ of primary energy and reduce CO_2 emissions by 26 million tonnes per year. The total capital expenditure on the construction of cogeneration units meeting these characteristics would amount to PLN 41.5 billion.

The conducted analysis also enabled recommending specific cogeneration technologies that are the most cost-effective at current price ratios:

- for large district heating systems – gas/steam systems or coal-fired steam blocks,
- for smaller systems – internal combustion engines or gas turbines,
- for residential micro-cogeneration systems – microturbines, internal combustion engines or Stirling engines.

In addition to heat from cogeneration, the production of district cooling is also assessed as a promising prospect from an energy efficiency point of view. Existing air conditioning units are usually local and powered by electricity, whereas the centralised distribution of cooling energy is rare or at the testing stage in Poland. In this respect, the situation of air-conditioned buildings is similar to that of buildings heated by their own thermal energy sources. The total national potential for the production of cooling energy, limited to its primary application, i.e. the services sector, is estimated at 19 PJ, which is twice as low as the heating needs of buildings in this sector.

Tables 43-45 show the current state of application of high-efficiency cogeneration in Poland in three aspects: the production volume in organisational terms, the production volume in technical terms as set out in Article 9l of the Energy Law, and the contribution of the production volume to total inland production.

Table 41. Electricity production from high-efficiency cogeneration in organisational terms

breakdown	2007	2010	2015	2018
	GWh			
Country total	24,930	26,885	26,183	28,180
Public condensing power plants	2,174	2,255	1,896	1,643
Public CHP plants	16,975	17,449	16,080	17,201
Independent CHP plants	536	795	978	1,203
CHP plants operated by heating companies	68	345	568	826
Industrial CHP plants	5,177	6,041	6,513	7,307

Source: ARE S.A.

Table 42. Electricity production from high-efficiency cogeneration in technical terms

breakdown			2007	2010	2015	2018
			GWh			
Country total			24,930	26,885	26,183	28,180
including	units with a capacity of < 1 MW		7	166	161	301
	gas-fired		2,511	4,050	2,492	6,287
	methane or biogas-fired		-	556	377	923
	other units		22,413	21,411	19,894	20,669
	including	condensing power plants	1,896	2,255	1,663	1,643
		combined heat and power plants	19,515	21,483	18,232	19,027

Source: ARE S.A.

Table 43. Electricity production from high-efficiency cogeneration in technical terms

Breakdown	Year			
	2007	2010	2015	2018
	GWh			
Domestic electricity production	159,348	157,658	164,944	170,039
Gross domestic electricity production from high-efficiency cogeneration	24,930	26,885	26,183	28,180
Share in total inland production	%			
	15.65	17.05	15.87	16.6
Share in inland production – units with a capacity of < 1 MW and gas-fired	1.58	1.91	2.56	3.9
Share in inland production – methane or biogas-fired units	-	0.09	0.34	0.54

Share in inland production – other units	14.07	15.06	12.98	12.3

Source: ARE S.A.

There are three main factors influencing the production volume in each year: (1) a long-term decreasing trend in heat demand associated with thermal modernisation of buildings and rationalisation of heating, (2) weather conditions in heating seasons, causing deviations from the trend (3) operation of the cogeneration support system.

Steam condensing extraction turbines are the predominant cogeneration technology in Poland, although back-pressure steam turbines, combined cycle gas turbines and internal combustion engines are also used. There are also gas turbines with heat recovery and organic Rankine cycles, but their market share does not exceed 1%.

4.3.12. Cost-optimal minimum requirements for energy performance

As buildings account for nearly 40% of final energy consumption and almost 36% of greenhouse gas emissions in the European Union, they are essential for the Union's policy on improving energy efficiency, in particular with regard to meeting the long-term objectives of the European framework for climate and energy policy from 2020 to 2030 and beyond.

Directive 2010/31/EC of the European Parliament and of the Council of 19 May 2010 promotes the improvement of the energy performance of buildings requires Member States to calculate cost-optimal levels of minimum energy performance requirements using a comparative methodology and relevant parameters, such as climatic conditions and the practical accessibility of energy infrastructure.

Cost-optimal level is defined in Article 2(14) of the Directive and means the energy performance of the building (expressed in kWh/m^2 of primary energy) which leads to the lowest cost over the estimated economic lifecycle (30 years for residential buildings and 20 years for non-residential buildings).

The lowest cost is determined taking into account energy-related investment costs, maintenance and operating costs (including energy costs and savings, the category of building concerned, earnings from energy produced, where applicable), and disposal costs, where applicable. The estimated economic lifecycle is determined by each Member State and refers to the remaining estimated economic lifecycle of a building.

In Poland, cost-optimal levels of minimum energy performance requirements are set out in the Regulation of the Minister for Infrastructure of 12 April 2002 regarding the technical conditions to be met by buildings and their location (Journal of Laws 2015, item 1422).

The above regulation requires that the building and its installations (heating, ventilation, air-conditioning, hot water and, in the case of public buildings, collective housing, production, commercial and storage buildings, also built-in lighting) should be designed and constructed in such a way as to meet the minimum values of the EP indicator [kWh/(m2 • year)], which measures the annual calculated demand for non-renewable primary energy for heating, ventilation, cooling, sanitary hot water preparation, and in the case of public buildings, collective housing, production, commercial and storage buildings, also for built-in lighting public, calculated according to the provisions establishing the methodology for calculating the energy performance of buildings.

Partitions and technical equipment of the building should meet at least the thermal insulation requirements specified in Annex 2 to the above-mentioned regulation. Similarly, the surface of windows, balcony doors and external doors should comply with the values of the heat transfer coefficient set out in Annex 2.

The graphs below compare the cost-optimal levels reported by countries with the minimum energy performance requirements for major renovations of existing buildings, new buildings and building elements.

The minimum energy performance requirements for existing/renovated buildings were set no more than 15% above the cost-optimal level in the case of 9 countries. In Poland, the average gap was significantly above the 15% threshold.

In the case of new buildings, the minimum performance requirements were set no more than 15% above the cost-optimal level in 13 cases. In this case, Poland was slightly above the 15% threshold.

As regards the replacement of building elements (e.g. wall, roof, floor, window), the minimum performance requirements were set no more than 15% above the cost-optimal level in 11 countries (out of 22). In Poland, the average gap in relation to replacement of building elements was above the 15% threshold (nearly 40%).

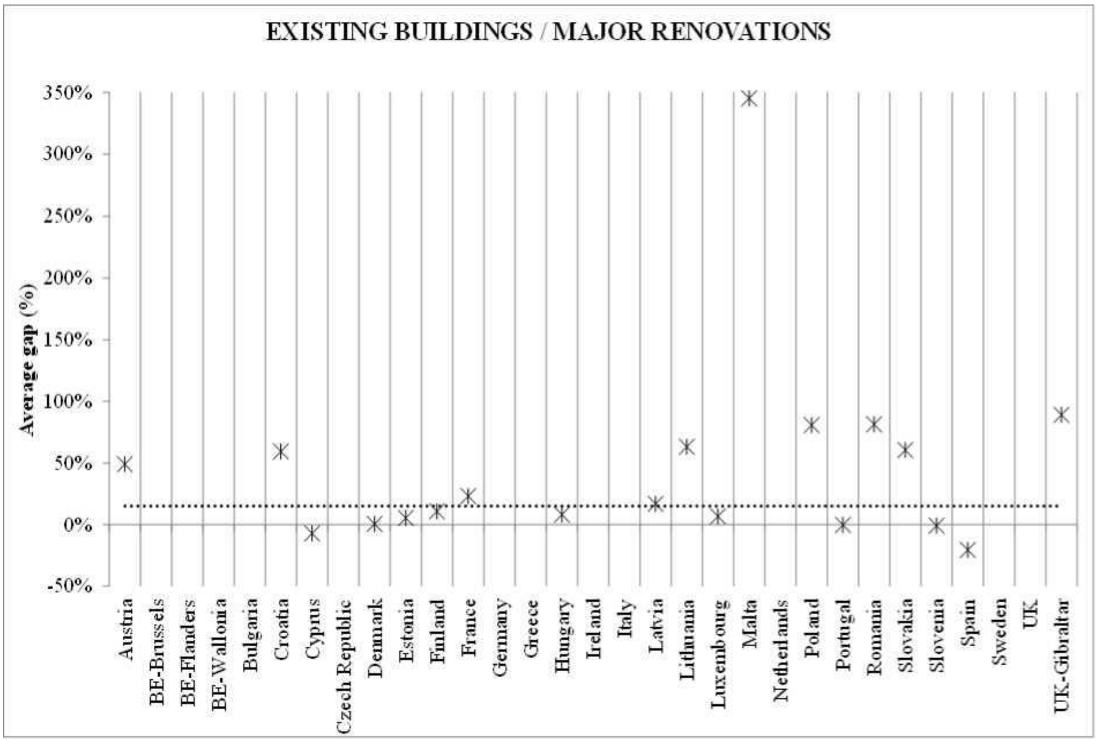


Figure 21. Average gap between minimum energy performance requirements and cost-optimal levels: major renovations

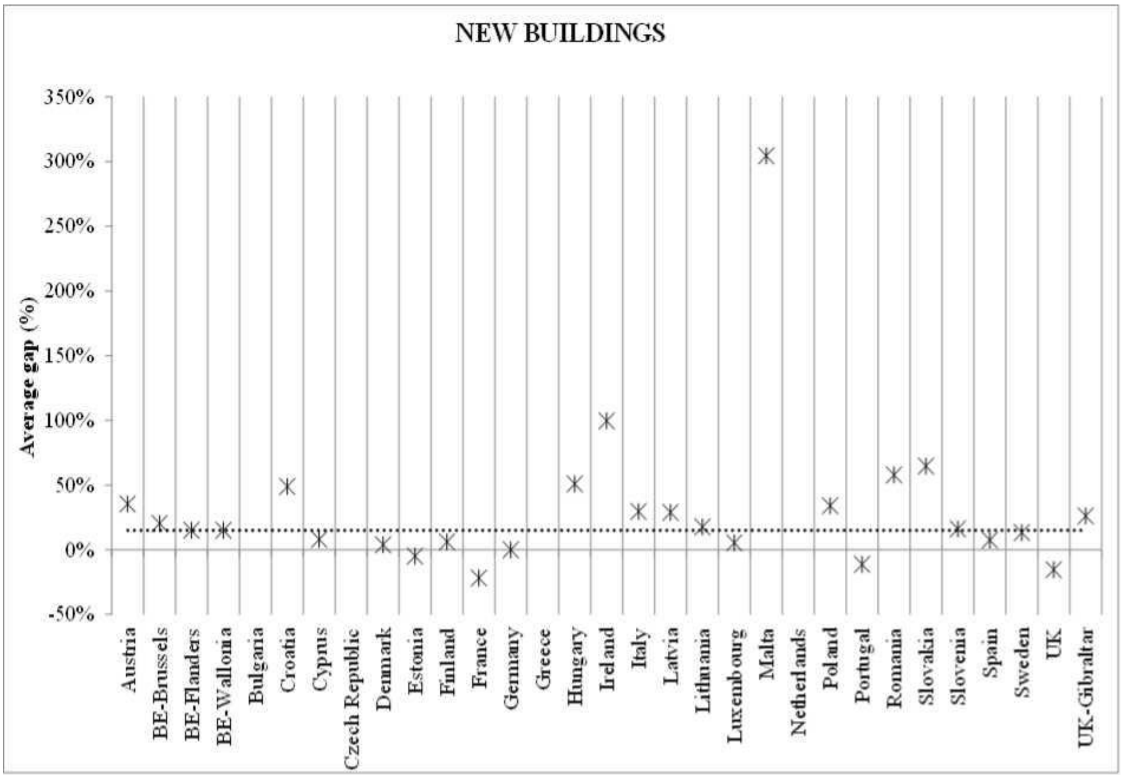


Figure 22. Average gap between minimum energy performance requirements and cost-optimal levels: new buildings

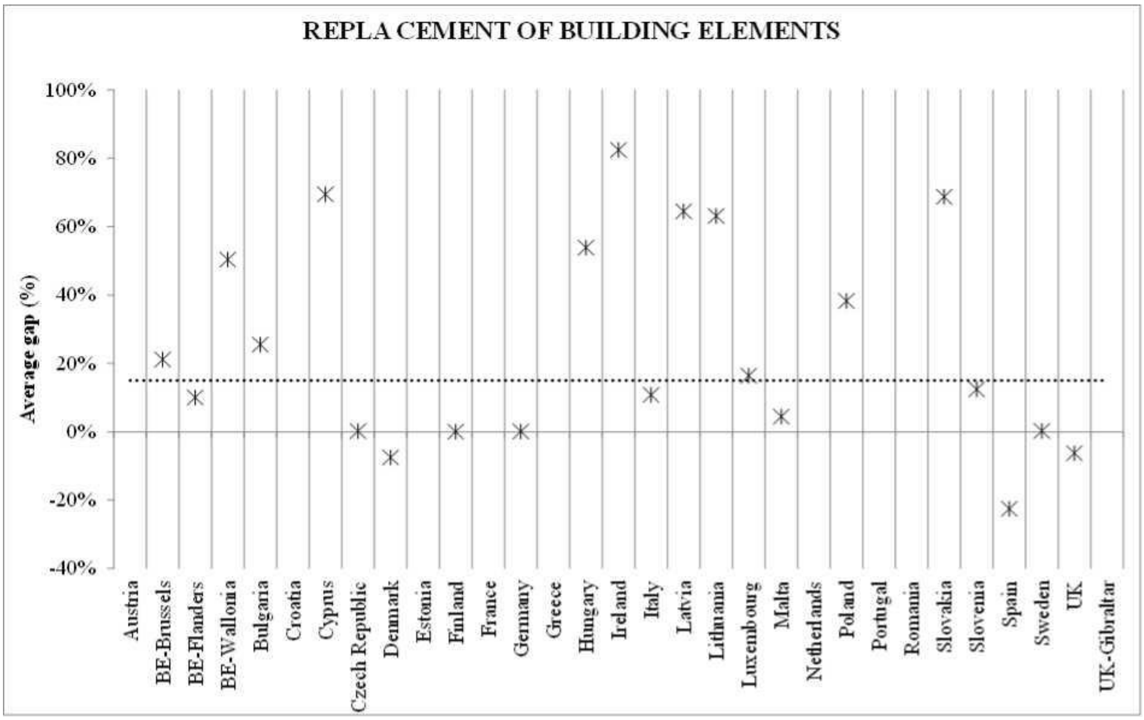


Figure 23. *Average gap between minimum energy performance requirements and cost-optimal levels: replacement of building elements*

Some of the provisions of the above-mentioned directive were transposed to the national legislation by the Act of 29 August 2014 on energy performance of buildings (Journal of Laws, item 1200 and of 2015, item 151). Article 39(3) of the Act was the basis for the preparation of the *National Plan to increase the number of low energy consuming buildings.*

The National Plan includes, in particular, a definition of low-energy buildings and their specific characteristics; government measures to promote low-energy buildings, including the design, construction and conversion of buildings in a manner ensuring energy efficiency, and to increase the uptake of renewable energy in new and existing buildings; as well as a timetable for achieving the targets.
The establishment of the National Plan is linked to the pursuit of the headline target set out in Article 9(1) of Directive 2010/31/EU, which provides that:

- all new buildings are to be nearly zero-energy buildings by 31 December 2020,
- new buildings occupied and owned by public authorities are to be nearly zero-energy buildings after 31 December 2018.

The most important element of the National Plan is to define low energy consuming buildings in Poland, taking into account the condition of existing buildings and the viable and economically justified measures for energy efficiency improvement.

The Ministry of Infrastructure and Construction periodically reviews the legislation specifying the minimum energy performance requirements for buildings. The reviews are carried out on the basis of, amongst others, expert opinions from the Institute of Building Technology and the Krakow University of Technology, as well as inputs from construction market actors.

4.4. Dimension energy security

4.4.1. National energy resources

Hard coal

The documented anticipated economic resources (Polish *zasoby bilansowe*) of hard coal totalled 58,578 million tonnes as at 31 December 2016. Nearly three-fourths of all resources are formed by thermal coals, one-fourth by coking coal, with other types of coal accounting for approx. 2% of all coal resources. At 22,222 million tonnes, exploited deposits currently account for 37.9% of anticipated economic resources. Economic resources (Polish *zasoby przemysłowe*) totalled 2,983 million tonnes. According to data from the Polish Geological Institute, hard coal production amounted to 66.5 million tonnes in 2016[26].

Despite the fact that hard coal mining has been declining since the beginning of the 1990s (figure below), no restrictions in the supply of this raw material are expected in the present analysis. At the 2016 production level, economic resources will last for approx. 40 years. It is assumed that future demand will, insofar as possible, be met by domestic coal production and supplemented by imports. Due to the location of resources in areas free of armed and political conflicts, high efficiency of the logistic network, options for opening new deposits and the availability of highly developed mining technologies, hard coal appears set to remain available in the long term and its price is expected to be stable.

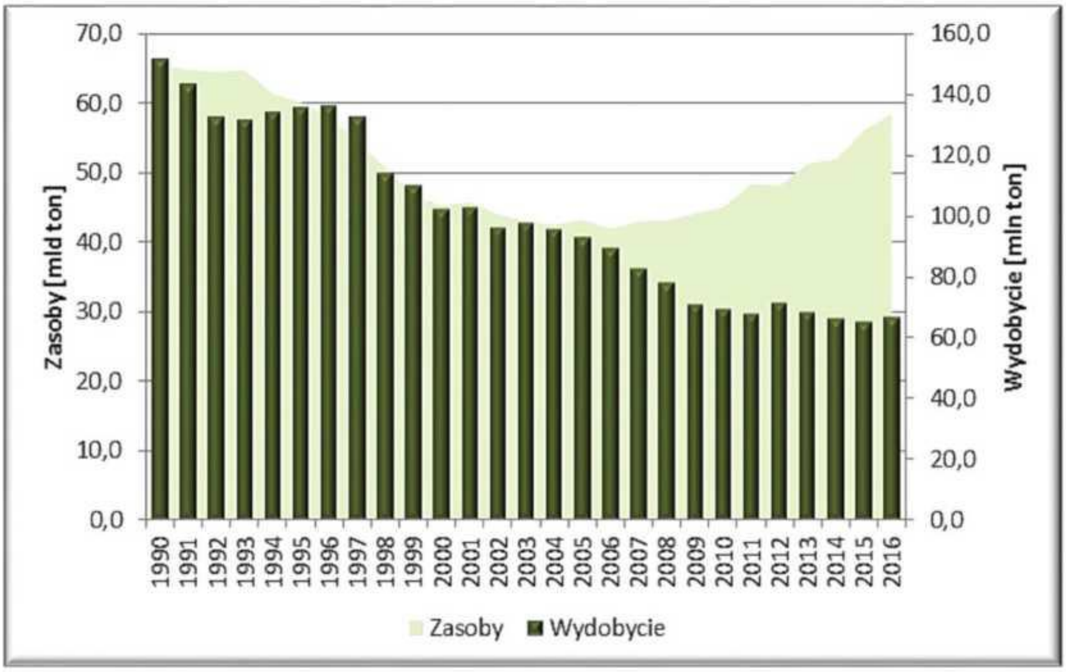


Figure 24. Hard coal deposits and production in Poland in 1990-2016. Source: Polish Geological Institute

Zasoby [mld ton]	**Resources [billion tonnes]**
Wydobycie [mln ton]	**Production [billion tonnes]**
Zasoby	Resources
Wydobycie	Production

Lignite

Anticipated economic resources of lignite totalled 23,451 million tonnes as at 31 December 2016. At 1,354 million tonnes, exploited deposits currently account for 6% of anticipated economic resources (Polish *zasoby bilansowe*). Economic resources (Polish *zasoby przemysłowe*) of lignite totalled 1,065 million tonnes as at the end of 2016. Compared to 2015, economic resources decreased by 64.49 million tonnes as a result of production and operating losses. According to data provided by the Polish Geological Institute, coal production totalled 60 million tonnes in 2016.

[26] *Bilans zasobów złóż kopalin w Polsce wg stanu na 31.XII.2016* [Balance of mineral resources in Poland as of 31 December 2016], Polish Geological Institute, Warsaw 2017.

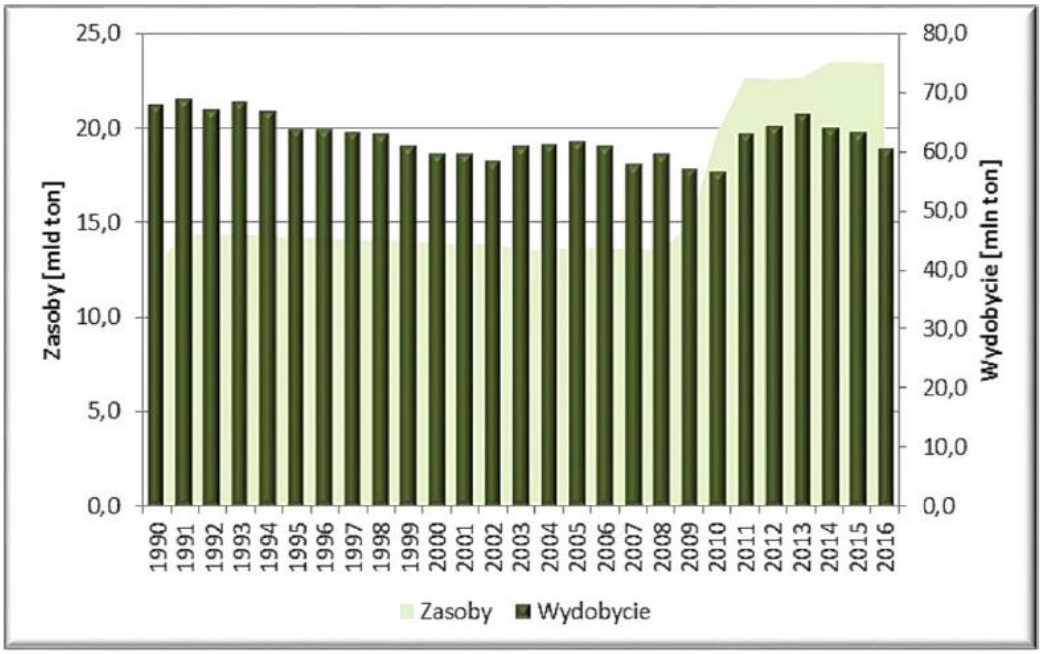


Figure 25. Lignite deposits and production in Poland in 1990-2016. Source: Polish Geological Institute

Zasoby [mld ton]	**Resources [billion tonnes]**
Wydobycie [mln ton]	**Production [billion tonnes]**
Zasoby	Resources
Wydobycie	Production

If electricity generation from lignite is considered, it would be necessary to explore new lignite reserves due to the limited resources in the currently operated mining fields (a sharp drop in the supply of this raw material from existing open-pits is expected after 2030).

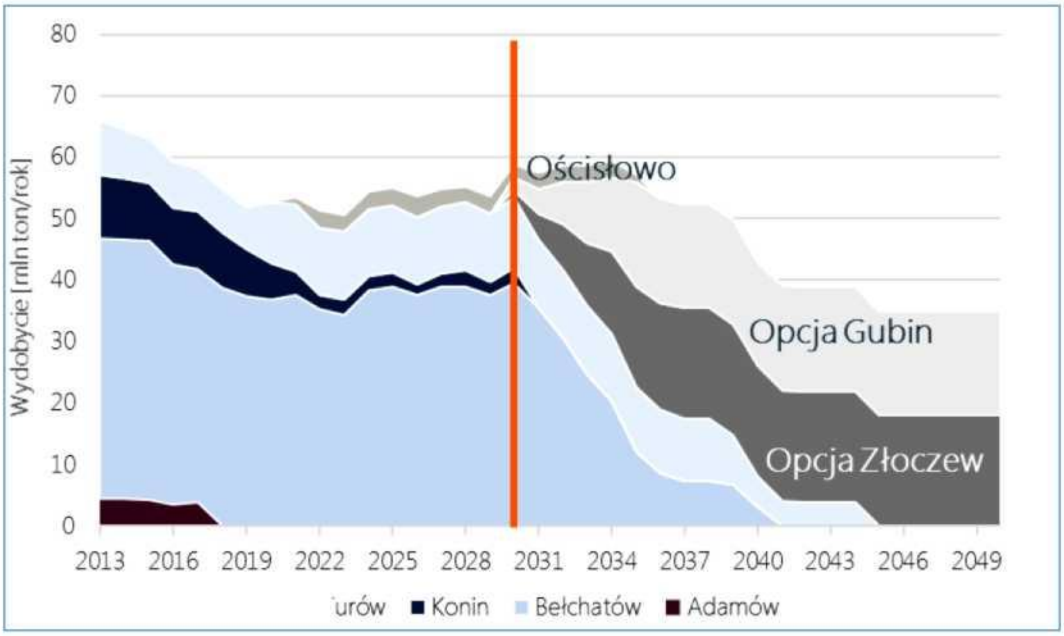


Figure 26. Currently available options for construction of new lignite-based fuel and energy complexes. Source: Węgiel brunatny - oferta dla polskiej energetyki. Możliwości rozwoju działalności węgla brunatnego w Polsce do 2050 r. [Lignite – an offer for the Polish power industry. Opportunities for the development of lignite operations in Poland until 2050], ed. Tajduś A., Krakow, 2014.

Wydobycie [mln ton/rok]	Production [million tonnes/year]
Turów	Turów

Konin	Konin
Bełchatów	Bełchatów
Adamów	Adamów
Ościsłowo	Ościsłowo
Opcja Gubin	Gubin option
Opcja Złoczew	Złoczew option

The analysis assumes that the Złoczew open-pit mine will be commissioned, ensuring continuity of raw material supplies for unit 14 of the Bełchatów Power Plant and continued operation of some of the units of the Bełchatów Power Plant beyond 2040 (no assumptions are made regarding the construction of new units). The commissioning of the Ościsłowo open-pit mine has also been factored in, even though no decision has yet been made in this regard. This will ensure that the upgraded units of the Pątnów Power Plant will continue to operate until 2030. The paper also assumes that new large open-pits (most likely in Gubin and Legnica) will become operational only after 2030.

Natural gas

According to data from the Polish Geological Institute, the recoverable resources of natural gas totalled 120 bcm as at 31 December 2016. Total recoverable resources of developed natural gas fields amounted to 98 bcm, or 82% of the total volume of recoverable resources. Economic resources of natural gas amounted to 52 bcm in 2016.

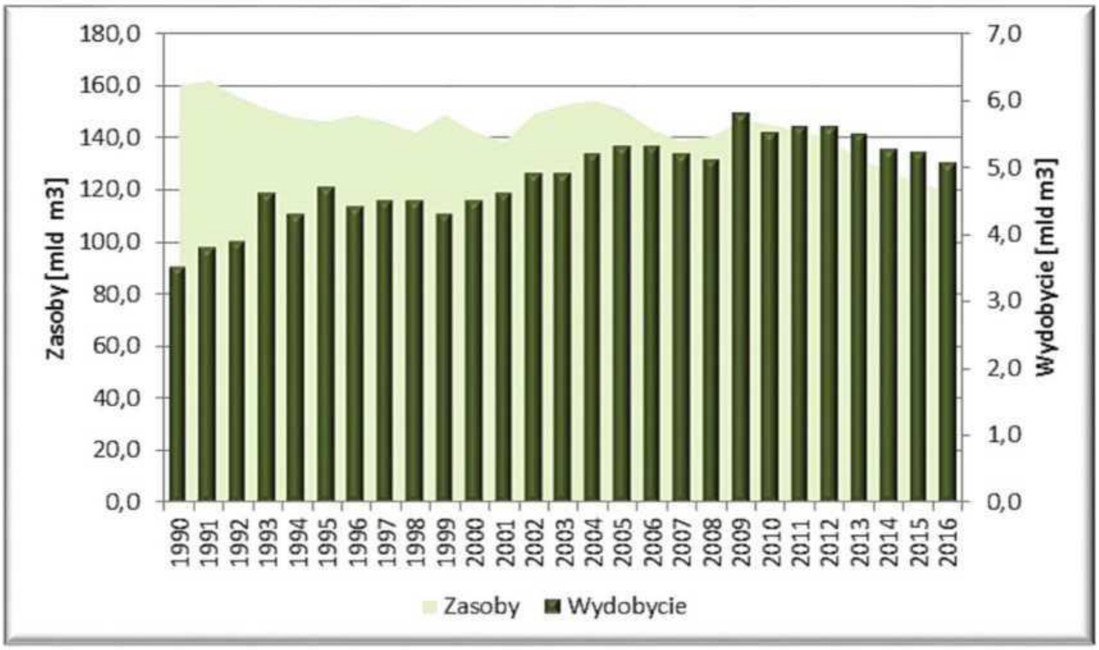


Figure 27. Natural gas deposits and production in Poland in 1990-2016. Source: Polish Geological Institute

Zasoby [mld m3]	**Resources [bcm]**
Wydobycie [mld m3]	**Mining [bcm]**
Zasoby	Resources
Wydobycie	Production

Domestic natural gas resources are an important complement to gas imports from the point of view of security of supply, but their significance is limited for the economy as a whole. The domestic demand for natural gas is largely met by supplies from abroad. The total imports of natural gas to Poland in 2016 amounted to 13.9 bcm [157,086 GWh], including:

- imports of natural gas from the East (including through the Yamal-Europe pipeline) – 10.3 bcm [116,671 GWh] (74.3% of total imports);
- intra-Community acquisition of natural gas from Germany – 2.5 bcm [28,299 GWh] (18% of total imports);

- intracommunity acquisition of natural gas from the Czech Republic – 0.049 bcm [55.5 GWh] (0.00035% of total imports);
- imports of natural gas from Qatar – 0.963 mcm [11,134 GWh] (7.1% of total imports);
- gas imports from Norway – 0.078 bcm [927 GWh] (0.59% of total imports).

Exports of natural gas from Poland in 2016 totalled 839.3 mcm [9,248 GWh].
Due to the unpromising results of the exploration of unconventional gas deposits, the broader use of unconventional gas is not included in the forecast. The analysis prepared by the Polish Geological Institute considers the range of 346-768 bcm to be the most likely for shale gas resources in Poland. At the current stage of development of shale gas production technology, economic considerations are a limiting factor.

Nuclear fuel

Poland's uranium ore deposits are not sufficient to make mining currently profitable, although development of these deposits is not excluded in the future. On the global market, nuclear fuel is widely available (this includes both uranium ore and uranium hexafluoride conversion capacity, as well as the capacity of plants specialising in the enrichment and production of reactor fuel elements). Therefore, it is assumed that nuclear fuel resources would not limit the pace of development of nuclear power over the timescale of the forecast and that the price of nuclear fuel would remain relatively stable.

Biomass

It is assumed that the supply of this raw material will not limit the development of technologies based on biomass fuels, although in reality such a situation cannot be entirely ruled out, as the development of this sector in the country is conditioned by, and closely linked to, the operation of a specific support system.

Biomass in Poland has the greatest technical potential from among all domestic renewable energy sources. The annual technical potential comprising forest solid biomass, biomass from agriculture (energy crops and plant waste) and food processing, and biogas is estimated at approx. 610 PJ in 2020 and 910 PJ in 2030[27]. The actual economic potential of biomass in Poland is estimated at over 600 PJ in 2020 and the market potential at 533.1 PJ (according to data from the Renewable Energy Institute)[28]. The market potential consists of the following types of biomass:

- solid waste 149,338 TJ,
- wet waste (for biogas) 72,609 TJ,
- firewood 24,452 TJ,
- energy crops 286,718 TJ.

Agricultural biogas

The domestic wet waste biomass resources of agricultural origin, which can be used locally for electricity production in agricultural biogas plants, will support production of approx. 4.4 TWh in 2030 and up to 5.1 TWh in 2040. The domestic wet biomass resources are also sufficient to enable a significant development of agricultural biogas plants producing thermal energy in cogeneration. The capacity for heat production towards 2030 is estimated at 45 PJ and at 105 PJ in 2040[29].

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[27] *Ocena zasobów odnawialnych źródeł energii możliwych technicznie i ekonomicznie do wykorzystania w celu produkcji energii elektrycznej* [Assessment of the renewable energy resources technically and economically feasible for electricity production]. A report for the Polish Electricity Committee by System Tests of EnergSys sp. z o.o., Warsaw 2008.

[28] *Możliwości wykorzystania OZE w Polsce do roku 2020* [Options for RES use in Poland until 2020], Renewable Energy Institute, Warsaw 2007.

[29] *Opracowanie prognoz zapotrzebowania na energię końcową, rozwoju OZE i poprawy efektywności energetycznej na lata 2021-2030* [Forecasting final energy demand, RES development and energy efficiency improvement for 2021-2030], EY, Warsaw, November 2017.

Other biogas

The potential for the use of biogas from landfills and sewage treatment plants in electricity production is estimated at approx. 1.3 TWh by 2030 and 1.7 TWh by 2040. The potential of other biogas for heat cogeneration is estimated at 6.2 PJ by 2030 and 8.2 PJ by 2040[38].

Geothermal energy

Theoretically, geothermal energy resources in Poland are unlimited, but there are relatively few locations where the use of geothermal energy makes economic sense. The capacity for production of heat from installations other than heat pumps using deep rock heat was assessed taking into account significant economic limitations in their use. This capacity was determined at 45 PJ in 2030 and 105 PJ in 2040.

Heat pumps

As with geothermal energy, the use of heat pumps for thermal production is primarily limited by economic considerations. This study assumes that the potential for use of heat pumps is high at 45 PJ in 2030 and 105 PJ in 2040. However, it will be very difficult and, above all, costly to exploit this potential, and subsidies will be the main driver of the development of this technology in the country[30].

Water

Hydropower resources in Poland are estimated at approx. 12 TWh[31] per year (technical resources), of which only 2.1 TWh per year is currently used. The utilisation rate of these resources is much lower than in a country with a similar geomorphological structure such as Germany, which uses 19 TWh of its annual capacity of 25 TWh.

Wind

According to EY's estimates, Poland’s wind resources offer an economic potential to install up to approx. 30 GW of onshore wind farm capacity. However, the assessment of actual potential must take into account the existence of systemic, social, environmental, infrastructure and regulatory constraints. The actual potential for the construction of offshore wind farms, as determined by EY, is based on the opportunities existing at the Polish Baltic coast and the analysis of the pace of and prospects for the development of wind technology in other countries. According to these data, the actual potential of wind units will be approx. 5 GW by 2030 and 10 GW by 2040[32].

Solar

On the basis of an analysis of the development of large PV installations in other European countries and the observed cost trends, the actual potential for the development of this technology is estimated at 5 GW by 2030 and 10 GW by 2040. A larger potential for PV technologies exists in relation to small rooftop installations. According to EY's estimates, it is approx. 7 GW by 2030 and 12.5 GW in 2040[33].

National energy mix 2005-2016

Primary energy production has remained at approx. 66-67 Mtoe since 2010. A significant drop in production, by over 10%, occurred in 2005-2010. Primary energy production is dominated by coal, but its output is decreasing faster than total primary energy production. The share of coal in total primary energy production fell from 88% in 2005 to 78% in 2016. Renewable energy is the only group of energy carriers where production increased

[30] Ibidem.

[31] Data from the Polish Association for Small Hydropower Development.

[32] Ibidem.

[33] Ibidem.

significantly between 2005 and 2016. RES production doubled in that period, and its share in total primary energy production increased from 6% in 2005 to 14% in 2016.

Net energy imports doubled between 2005 and 2010 and remained stable, at approx. 30 Mtoe, between 2010 and 2016. Its increase was significantly influenced both by an increase in imports of oil and liquid fuels (by over 15%) and natural gas (by 35%) and by a decrease in hard coal exports. The import/export balance of hard coal has been close to zero after 2010, but Poland remains a net exporter of solid fuels thanks to high coke exports.

Gross inland energy consumption varied between 92 and 101 Mtoe from 2005 to 2016, the main reasons for this volatility being: the uneven GDP growth, energy efficiency improvements and changing weather conditions. As far as the breakdown of gross inland energy consumption in 2005-2016 is concerned, there was an increase in the share of liquid fuels (from 24% to 27%), natural gas (from 13 to 15%) and renewable energy (from 5 to 9%). On the other hand, the share of solid fuels fell from 59% to 49% over that period. Final energy consumption fluctuated in the period of 2005-2016, similarly to gross inland consumption, and its share in gross consumption has been approx. 66% in recent years.

Poland's dependency on energy imports increased significantly between 2005 and 2010, with net imports doubling, and has remained at a level close to 30% since 2010. Import dependency is highest for liquid fuels (approx. 97% – stable over multiple years) and high for natural gas (over 70% – a mildly growing trend). Overall import dependency is reduced by significant net exports of solid fuels, mainly coke.

Table 44. National energy balance 2005-2016 (Mtoe)

	2005	**2010**	**2015**	**2016**
Total primary energy production	77.9	66.7	67.3	66.4
of which: coal and lignite	68.4	55.1	53.6	52.1
crude oil	0.9	0.7	0.9	1.0
natural gas	3.9	3.7	3.7	3.6
renewable energy	4.5	6.8	8.6	9.0
other	0.2	0.4	0.5	0.7
Net energy imports	15.9	31.5	28.0	30.3
including: solid fuels	-13.0	-2.8	-5.6	-5.9
liquid fuels	21.5	25.2	23.3	24.8
natural gas	8.5	8.9	9.9	11.5
renewable energy	0.0	0.4	0.4	-0.3
other	0.0	0.0	0.0	0.0
Gross inland energy consumption	92.2	100.7	95.4	99.9
including: solid fuels	54.6	54.6	48.3	49.1
liquid fuels	21.7	25.7	23.9	26.5
natural gas	12.2	12.8	13.8	14.6
renewable energy	4.5	7.3	9.0	8.8
other	0.2	0.4	0.5	0.7
Final energy consumption	58.5	66.3	62.3	66.7
Import dependency – total	17.2%	31.3%	29.3%	30.3%
solid fuels	-23.9%	-5.2%	-11.6%	-12.0%
liquid fuels	97.5%	97.0%	96.8%	92.9%
natural gas	69.7%	69.3%	72.2%	78.8%
Share of renewable energy in gross final energy consumption	6.9%	9.3%	11.8%	11.3%

Source: Eurostat, ARE S.A.

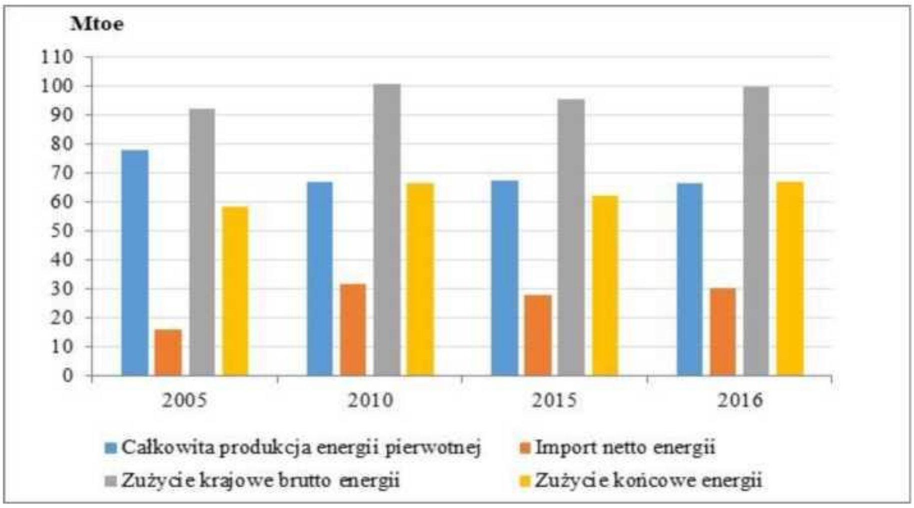


Figure 28. National energy balance 2005-2016. Source: ARE S.A.

Mtoe	**Mtoe**
Całkowita produkcja energii pierwotnej	Total primary energy production
Zużycie krajowe brutto energii	Gross inland energy consumption
Import netto energii	Net energy imports
Zużycie końcowe energii	Final energy consumption

4.4.2. Inland production by fuel type

The table below illustrates the volume of domestic supply of the particular fuels and energy carriers until 2040. The following conclusions can be drawn from the obtained results:

- **Hard coal** production (excluding coking coal) declines moderately between 2015 and 2030 from 32.1 Mtoe to 30.6 Mtoe (or 59.2 million tonnes and 56.4 million tonnes, respectively, in natural units). Between 2030 and 2040, the expected level of hard coal production is significantly reduced to 21.8 Mtoe (40.1 million tonnes). The downward trend is associated with the decreased demand across the sectors of the national economy. The decommissioning of end-of-life generation units is expected to accelerate after 2030. The construction of new coal-fired units (except for those in relation to which the investment decision has already been made) is not economically justified in view of the increasing prices of CO_2 emission allowances, ever tighter environmental requirements and the directions of the EU's energy and climate policy. Installations fitted with CCS can only be competitive if prices of CO_2 emission allowances are high, i.e. over EUR 50/t.

  The decrease in demand for coal in industry will be mainly due to the modernisation of production processes. In the household and services sectors, as part of anti-smog efforts, inefficient manually fed boilers will gradually be replaced by boilers meeting higher environmental standards (high energy conversion efficiency) and coal-based technologies will be replaced by more environmentally friendly ones (RES, gas, district heating).

- **Coking coal** production will remain stable at approx. 10 Mtoe (and is closely related to coke production). In view of the volatility of the coke market, the actual level of production may deviate considerably from the forecasts.

- The supply of **lignite** will decrease considerably after 2030. It is assumed that open-pit mines in Złoczew and Ościsłowo will be commissioned for use by existing power plants and that no new units will be built other than the one already under construction in Turów (450 MW). The development of new lignite open-pit mines that enable the commissioning of new units before 2040 (similarly to hard coal) does not turn out to be competitive in relation to other sources, such as nuclear power, RES or gas.

- The level of **crude oil** production will remain stable (relatively low – at approx. 1 Mtoe), as will domestic **natural gas** production (approx. 3.6 Mtoe or 5-5.3 bcm).

- The inland production of **biofuels** (mainly first-generation HVO/COHVO) is expected to increase, driven by the growing demand in the transport sector and the fact that, thanks to their properties, these substances can replace conventional fuels without any significant technical constraints.

- In 2015-2040, **solid biomass** production is expected to increase by approx. 34%, a moderate growth that builds to a limited extent on the domestic potential. The demand for biomass is bound to grow in all sectors. Along with an increase in prices of CO_2 emission allowances, the profitability of biomass utilisation in dedicated boilers, hybrid systems and installations co-firing coal will be increasing in the power and heating sectors. In the household and services sectors, intensified use of biomass will be associated with the replacement of outmoded coal-burning boilers with modern pellet-fired ones.

- Uranium ore mining and processing into nuclear fuel is not expected.

Table 45. Inland production by fuel type [ktoe]

	2005	2010	2015	2020	2025	2030	2035	2040
Coal	45,736	35,302	32,136	31,868	31,082	30,605	25,000	21,768
Coking coal	9,948	8,216	9,155	10,089	10,183	10,261	10,336	10,410
Coke	5,721	6,701	6,666	7,198	7,358	7,491	7,610	7,722
Lignite	12,736	11,559	12,299	10,336	10,915	10,906	8,106	2,829
Crude oil	840	681	922	1,000	1,000	1,000	1,000	1,000
Natural gas	3,884	3,693	3,683	3,595	3,627	3,653	3,675	3,694
Nuclear fuel	0	0	0	0	0	0	0	0
Biofuels	117	446	936	1,100	1,171	1,212	1,195	1,167
Solid biomass	4,166	5,866	6,268	7,022	7,078	7,535	7,951	8,400

Source: ARE S.A. own study (STEAM-PL)

4.4.3. Net imports by fuel type

The import-export balance plays an important role in determining the ways of meeting demand and selecting the electricity production mix, as well as influencing the price of this carrier on the wholesale market.

Since 2014, a clear upward trend in the share of electricity imports has been observable in the National Power System (NPS). This is a result of the growing import and export capacities and intensive subsidisation of RES, which are unstable energy sources, in neighbouring countries.

By around 2023, Poland is expected to become a net importer of electricity, unless extraordinary circumstances arise that will change the current price relationships at interconnections. The analysis shows that net imports will total approx. 129 ktoe (1.5 TWh) in or around 2020. The planned completion of the decommissioning of German nuclear power plants in 2023 and the general reduction in overcapacity in Central and Western Europe as a result of the shutdown and replacement of conventional energy sources will drive up prices on European energy markets. Poland's energy security will be improved by the launch of a capacity market and the commissioning of new investment projects (Opole, Jaworzno, Turów, and Ostrołęka). For this reason, the balance of electricity imports and exports is close to zero in the remaining period of the forecast.

However, it must be emphasised that the accurate determination of future volumes of exchange at existing and planned interconnections is bound to be characterised by high uncertainty, especially as regards the anticipated electricity prices on wholesale markets in neighbouring countries, which determine the directions and volume of transboundary trade, given that they are largely dependent on weather conditions, the legislative and regulatory environment, and many other fortuitous factors.

Table 46. Net electricity import-export balance [ktoe]

	2005	2010	2015	2020	2025	2030	2035	2040
Electricity	-962	-116	-29	129	0	0	0	0

"-" before the figure stands for exports
"+" before the figure stands for imports
Source: ARE S.A. own study (MESSAGE-PL), Eurostat

The table below summarises the current situation and forecasts for net imports of other energy carriers. The presented data show that imports of crude oil and natural gas will need to increase significantly in the future. Deterioration of energy self-sufficiency will be a negative consequence of increasing the share of gas in the national structure of energy consumption under the pursued climate and energy policy. The challenge in the coming years will be to diversify the sources of supply of this raw material in order to reduce dependence on supplies from a single direction. The situation is similar for oil, where almost 100% of imports comes from a single supplier (from outside the EU). Options for the diversification of oil supplies are much more limited. The reference scenario takes into account the expansion of the Crude Oil Terminal in Gdańsk, which will involve the construction of five additional crude oil storage tanks together with the necessary technological with a capacity of 362,000 m^3 (the project is expected to be completed by the end of 2020) and the construction of the second line of the Pomeranian Oil Pipeline.

Table 47. Net import-export balance [ktoe]

	2005	2010	2015	2020	2025	2030	2035	2040
Coal	-8,161	489	-1,588	-382	-315	-240	-755	-1,019
Coking coal	-1,801	944	275	57	148	223	286	342
Coke	-3,068	-4,227	-4,333	-4,597	-4,759	-4,893	-5,006	-5,105
Lignite	-2	-19	16	14	14	14	11	4
Crude oil	17,741	22,484	26,311	27,363	28,971	30,115	30,529	30,697
Natural gas	8,531	8,874	9,947	13,053	14,612	15,584	19,008	21,371
Nuclear fuel	0	0	0	0	0	0	2,668	8,003
Biofuels	-65	427	-144	480	511	529	522	509
Solid biomass	0	0	506	517	522	567	607	651

Source: ARE S.A. own study (STEAM-PL, MESSAGE-PL), Eurostat

Import dependency from third countries is defined as the total volume of energy imports from non-EU countries to gross inland energy consumption.

Table 48. Import dependency from third countries

	2005	2010	2015	2020	2025	2030	2035	2040
Electricity	1.4%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Coal	4.2%	13.1%	8.6%	9.2%	9.2%	9.2%	9.2%	9.2%
Coking coal	0.3%	18.3%	17.0%	14.5%	15.3%	15.9%	16.5%	16.9%
Coke	0.5%	1.2%	2.1%	3.4%	3.7%	3.9%	4.1%	4.2%
Lignite	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Crude oil	95.7%	95.9%	99.0%	97.3%	97.4%	97.5%	97.5%	97.6%
Natural gas	67.7%	61.8%	52.6%	58.6%	56.1%	53.5%	52.3%	50.7%
Nuclear fuel	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%	100.0%
Biofuels	0.0%	0.0%	6.5%	5.6%	5.6%	5.6%	5.6%	5.6%
Solid biomass	0.0%	0.0%	8.5%	7.9%	7.9%	7.9%	7.9%	7.9%

Source: Own study of ARE S.A.

4.4.4. Main sources of imports (countries)

With respect to the main sources of imports, use is made of an expert approach that is based on an analysis of current directions of supply and prospects for the emergence of new sources. Therefore, no significant changes in the key sources of imports are expected in relation to the majority of fuels and energy carriers under analysis (directions of imports are largely determined by global developments, which are difficult to predict). The exception is the supply of natural gas, which has been dominated by a single supplier. The government's strategy seeks to diversify gas supplies through the completion of an investment project facilitating the transport of gas from Norway and the intensification of purchases of liquefied gas from the United States.

Table 49. Main sources of imports (countries)

	2005	2010	2015	2020	2025	2030	2035	2040
Electricity	Germany	Germany	Germany	Germany	Germany	Germany	Germany	Germany
	Ukraine	Sweden	Sweden	Sweden	Sweden	Sweden	Sweden	Sweden
	Belarus	Czech Republic	Czech Republic	Lithuania	Lithuania	Lithuania	Lithuania	Lithuania
Hard coal	Russia	Russia	Russia	Russia	Russia	Russia	Russia	Russia
	Ukraine	Czech Republic	Czech Republic					

		Ukraine	Colombia					
		Kazakhstan						
Coking coal	Czech Republic	US	Australia	Australia	Australia	Australia	Australia	Australia
	Australia	Czech Republic	Czech Republic	US	US	US	US	US
	Germany	Australia	US	Russia	Russia	Russia	Russia	Russia
Coke	Czech Republic	Czech Republic	Russia	Russia	Russia	Russia	Russia	Russia
		Russia						
Lignite	-	Germany	Czech Republic	Germany	Germany	Germany	Germany	Germany
			Germany					
Crude oil	Russia	Russia	Russia	Russia	Russia	Russia	Russia	Russia
		Norway	Iraq					
Natural gas	Russia	Russia	Russia	Russia	Norway	Norway	Norway	Norway
	Uzbekistan	Germany	Germany	Germany	Russia	Russia	Russia	Russia
	Kazakhstan				Germany	Germany	Germany	Germany
Nuclear fuel	-	-	-	-	-	-	No data	No data
Biofuels	-	No data	Germany	Germany	Germany	Germany	Germany	Germany
	-	-	Netherlands					
	-	-	Switzerland					
Solid biomass	-	No data	No data	No data	No data	No data	No data	No data

Source: Own study of ARE S.A.

4.4.5. Gross inland fuel and energy consumption

The gross inland consumption of the particular fuels and energy carriers are presented in the table below[34]. The following conclusions can be drawn from the presented data:

- Inland electricity consumption will increase by 29% between 2015-2030 and by 34% between 2015-2040. The average annual growth rate for this category is 1.2% over the entire forecast period. Electricity consumption will increase in all sectors. Services, as the fastest growing sector of the economy, will be characterised by the highest rate of growth of electricity consumption. Saturation with appliances, including air conditioning units, will be increasing along with the development of commercial services.

- The moderate increase in the consumption of electricity by households is a consequence of the growing level of welfare of the society (as measured by disposable income), the growing number of dwellings and the increasing saturation and usage of appliances, although the fact that appliances use less and less electricity will slow down the pace at which energy consumption is increasing.

- The increase in electricity consumption in industry will be mainly driven by the growth in production of industrial products, and by the modernisation and mechanisation of manufacturing plants.

- More electricity is also expected to be utilised in transport. In rail transport, this will be mainly driven by improvements in the quality of rail passenger transport and its growing popularity, while in road transport by the development of e-mobility. The forecast assumes that there will be approx. 870,000 electric vehicles on

[34] Gross inland fuel and energy consumption is calculated according to the following algorithm:

(+) Final consumption
(+) Consumption in the electricity sector
(+) Consumption in the energy transformation sector
(-) Transmission and distribution losses
(+/-) Statistical differences
(=) Gross inland energy consumption

Polish roads by 2030 and approx. 2,400,000 by 2040, consuming respectively 1.2 TWh and 3.0 TWh. Estimates of the pace and extent of e-Mobility development are based on the assumption that excise tax exemptions will be the only type of support available to potential buyers. The rate at which the technology's costs are reduced will be the main factor driving an increase in vehicles of this type, but its estimation is subject to a significant level of uncertainty.

- A slight increase is expected in the consumption of district heat that will depend on the rate at which new customers are connected and at which the thermal upgrading process progresses. The projection assumes that measures taken to mitigate 'low-stack' emissions will provide incentives for district heating investments.

- The consumption of coal and lignite is expected to decrease as a result of the pursued energy and climate policy and a reduction in the use of coal in buildings. The decline in coal consumption in the power and heating sectors will accelerate considerably in 2030-2040.

- The consumption of oil and petroleum products is expected to increase further. Economic growth is the driving force behind the growth of demand in this sector. On the other hand, this growth is hampered by efficiency improvements resulting from technological progress, measures taken to improve the organisation of transport services (implementation of integrated traffic management systems, intermodality, collective transport), and the development of transport infrastructure (motorway and expressway networks).

- A further gradual increase is anticipated in demand for renewable energy carriers, such as biomass, biogas, biofuels and renewable municipal and industrial waste.

Table 50. Gross inland fuel and energy consumption [ktoe] – Reference scenario

	2005	2010	2015	2020	2025	2030	2035	2040
Electricity	12,532	13,440	14,154	15,466	16,584	17,620	18,308	18,993
District heating	8,032	8,021	6,721	7,015	7,298	7,497	7,682	7,872
Coal	37,651	39,774	31,248	31,486	30,767	30,365	24,245	20,749
Coking coal	7,891	8,700	9,489	10,146	10,331	10,484	10,622	10,752
Coke	2,318	2,074	2,228	2,601	2,599	2,598	2,604	2,617
Lignite	12,726	11,576	12,283	10,349	10,929	10,920	8,117	2,833
Crude oil	18,459	23,184	26,506	28,078	29,683	30,825	31,237	31,403
Petroleum products	21,987	25,956	24,074	30,773	32,035	32,752	32,611	32,261
Natural gas	12,235	12,805	13,776	16,648	18,239	19,237	22,683	25,066
Coke oven gas	1,447	1,707	1,704	1,741	1,760	1,776	1,788	1,798
Blast furnace gas	560	526	632	668	661	649	632	614
Other gaseous fuels	161	149	163	172	151	145	144	139
Solid biomass	4,166	5,866	6,884	7,539	7,600	8,102	8,558	9,051
Biogas	54	115	229	268	282	299	320	347
Biofuels	54	868	664	1,580	1,682	1,741	1,717	1,676
Nuclear fuel	0	0	0	0	0	0	2,668	8,003
Municipal and industrial waste	157	400	564	717	759	773	789	806

Source: ARE S.A. own study (STEAM-PL, MESSAGE-PL), Eurostat

4.4.6. Electricity and heat production

Table 53 and Figure 29 show data on the gross electricity and district heat production in Poland. As shown by the results of projections, domestic electricity production is expected to grow from 164.9 TWh in 2015 to 204.9 TWh in 2030 and to 220.9 TWh in 2040. The percentage increase is 24% in 2015-2030 and 34% in 2015-2040.

On the other hand, the domestic production of district heating will increase from 281.4 PJ in 2015 to 329.6 PJ in 2040, a growth of 17% in the period under consideration. The results of projections are based on the assumption that measures to connect new customers to district heating will be stepped up and that the thermal upgrading of buildings will proceed at a moderate pace.

Table 51. Gross electricity and district heat production

	2005	2010	2015	2020	2025	2030	2035	2040

Electricity [GWh]	156,935	157,658	164,944	178,374	192,875	204,915	212,924	220,887
District heat [TJ]	336,292	335,831	281,393	293,722	305,532	313,902	321,635	329,578

Source: ARE S.A. own study (STEAM-PL, MESSAGE-PL), Eurostat

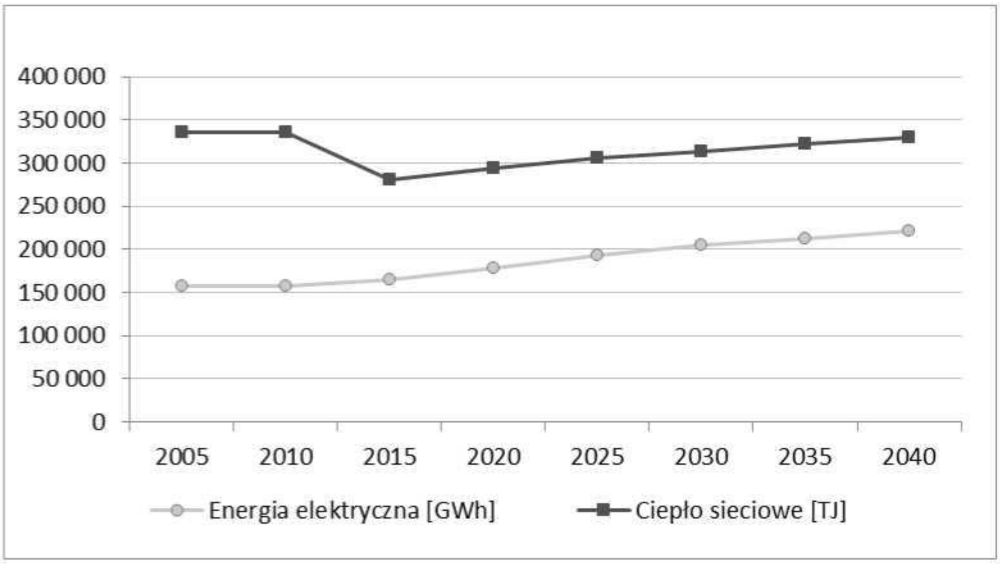


Figure 29. Gross electricity and district heat production

Energia elektryczna [GWh]	Electricity [GWh]
Ciepło sieciowe [TJ]	District heat [TJ]

4.4.7. Gross electricity generation by fuel

Electricity generation by fuel is presented in Table 55 and Figure 30. An analysis of the directions of development of the national electric power sector suggests gradual shifts in the energy mix as a result of legislative and market developments that will be driven mainly by the EU's climate and energy policies. The development of renewable energy sources (enforced by administrative measures) and the obligation of operators of coal-fired plants to purchase CO_2 emission allowances under the ETS will result in steadily decreasing the share of coal-fired plants in the energy mix. The share of coal-based units in the generation structure is expected to decrease from approx. 80% in 2015 to approx. 69% in 2030 and approx. 31% in 2040. Between 2030 and 2040, the share of coal-fired units in total electricity generation will, therefore, be rapidly decreasing. This process will be mainly driven by the decommissioning of coal-fired units (determined on the basis of declarations of electricity undertakings) and the decreasing operating time of coal-fired units, amongst others as a result of an expected increase in the popularity of low-carbon sources over the period. Nevertheless, despite the high decline in their share, coal-fired power plants will remain an important producer of electricity in the country. This can be attributed, to a large extent, to the production units currently under construction in Kozienice, Opole and Jaworzno and the planned unit in Ostrołęka. The share of gas units (the new units are mainly high-efficiency steam-gas units) in the production structure will increase from 3.9% in 2015 to approx. 9% in 2030 and then will almost triple in 2040 (up to approx. 24%). The country's climate and energy policy will enforce the implementation of new low-carbon sources, a large proportion of which will be non-controllable intermittent renewable sources (wind farms and solar farms). The anticipated existence of such generation sources will necessitate investments in flexible (e.g. gas) sources, energy storage, etc., that will be necessary for the sources to be integrated with the power system. The share of RES in net electricity generation will double during the analysed period. The development of nuclear power in Poland plays a central role in the decarbonisation policy. The first nuclear power plant unit is expected to be put into operation between 2031 and 2035 and another two between 2036 and 2040.

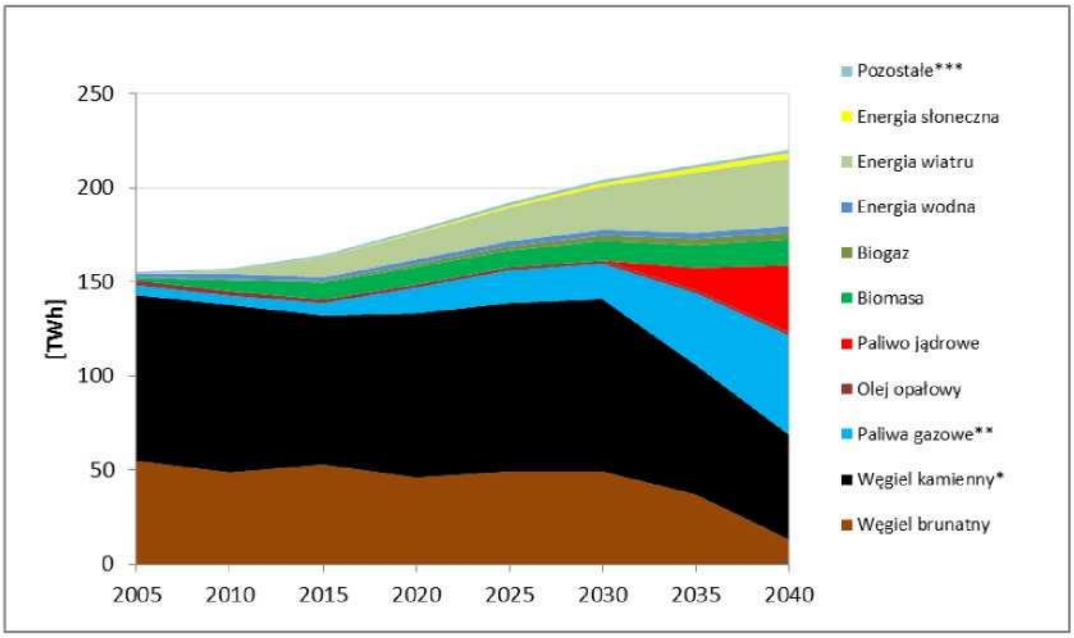
Decarbonisation of the Polish energy sector will be a long-lasting and very costly process that will have to be spread over time in such a way as to mitigate the resulting economic and social impacts, including a risk of deepening the problem of energy poverty in the country.

It should be emphasised that the strong development of nuclear, gas and RES power generation anticipated in 2030-2040 is to a large extent dependent on the cost of CO_2 emission allowances, not only in a given period, but most of all during the unit's lifetime remaining after 2040. For this reason, in order to avoid the distortion of analysis results in relation to investment decisions made towards the end of the modelling period, the horizon analysed under the MESSAGE model was extended to 2050[35].

Table 52. Gross electricity production [TWh]

	2005	2010	2015	2020	2025	2030	2035	2040
Lignite	54.8	48.7	52.8	46.0	49.2	49.2	36.9	13.0
Hard coal*	88.2	89.2	79.4	87.3	89.6	91.6	69.0	55.8
Gaseous fuels**	5.2	4.8	6.4	13.6	17.3	18.8	38.1	52.8
Fuel oil	2.6	2.5	2.0	1.7	1.7	1.7	1.7	1.7
Nuclear fuel	0.0	0.0	0.0	0.0	0.0	0.0	11.8	35.5
Biomass	1.4	5.9	9.0	9.4	8.9	10.5	12.2	14.0
Biogas	0.1	0.4	0.9	1.6	2.3	3.0	3.4	3.8
Hydropower	2.2	2.9	1.8	2.4	2.6	2.9	3.1	3.3
Pumped storage	1.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Wind power	0.1	1.7	10.9	13.8	17.9	23.3	32.2	36.0
Solar power	0.0	0.0	0.1	0.5	1.1	1.7	2.3	2.9
Other***	0.7	1.1	1.0	1.6	1.7	1.6	1.7	1.7
Total	156.9	157.7	164.9	**178.4**	**192.9**	**204.9**	**212.9**	**220.9**

** Including coke oven gas and blast furnace gas*
*** High-methane and nitrogen-rich natural gas, mine demethylation gas, oil field gas*
**** Inorganic industrial and municipal waste*
Source: ARE S.A. own study (MESSAGE-PL), Eurostat



** Including coke oven gas and blast furnace gas*
*** High-methane and nitrogen-rich natural gas, mine demethylation gas, oil field gas*
**** Inorganic industrial and municipal waste*

Figure 30. Gross electricity production in Poland by fuel

[TWh]	[TWh]
Pozostałe***	Other***
Energia słoneczna	Solar power
Energia wiatru	Wind power
Energia wodna	Hydropower
Biogaz	Biogas

[35] As regards fuel prices after 2040, they are assumed to increase in line with the 2030-2040 trend, while the price of CO_2 emission allowances is projected to increase gradually to EUR 50'2017 per tonne in 2050.

Biomasa	Biomass
Paliwo jądrowe	Nuclear fuel
Olej opałowy	Fuel oil
Paliwa gazowe**	Gaseous fuels**
Węgiel kamienny*	Hard coal*
Węgiel brunatny	Lignite

4.4.8. Electricity generation capacity by source

The results of the analyses demonstrate that far-reaching changes in the structure of electricity generation in Poland should be expected in 2040. (Table 55 and Figure 31). The net generating power of electricity sources will increase from 37.3 GW in 2015 to approx. 51 GW in 2040 (an increase of approx. 37%). The role of coal-fueled utility power plants will be significantly diminished, as reflected by their reduced share in net installed capacity. The share of renewable sources and natural gas-fueled units will increase significantly. The first nuclear power unit with a capacity of approx. 1,500 MW will be added to the production capacity structure between 2030 and 2035. A further two units with a total capacity of 3,000 MW_{net} will be constructed between 2035 and 2040.

Table 53. Net generating power of electricity sources by technology [MW]

	2005	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**
lignite-fired pp – old	8,197	8,145	8,643	7,669	7,060	7,060	4,827	2,492
lignite-fired pp – new	0	0	0	455	455	455	455	455
coal-fired pp – old	14,613	14,655	13,617	11,975	11,672	9,408	5,005	2,450
coal-fired pp – new	0	0	0	3,497	4,422	4,422	4,422	4,422
gas-fired pp	0	0	0	0	0	0	700	1,989
nuclear pp	0	0	0	0	0	0	1,500	4,500
hydroelectric power stations	1,064	935	964	1,002	1,049	1,175	1,225	1,275
pumped-storage hydro	1,256	1,405	1,405	1,405	1,405	1,405	1,405	1,405
industrial CHP	6,140	6,126	1,925	1,975	1,879	1,745	1,810	1,836
coal-fired cp			4,046	4,291	4,169	3,876	3,232	2,426
gas-fired cp	760	807	928	2,687	3,137	3,297	5,481	6,319
biomass pp and cp	102	140	553	649	873	1,146	1,416	1,763
biogas cp			216	319	439	556	649	707
wind farms	121	1,108	4,886	6,088	7,625	10,004	12,688	13,910
photovoltaics	0	0	108	613	1,238	1,863	2,488	3,037
gas turbine/cold reserve/ import	0	0	0	0	0	0	1,116	1,965
total	32,253	33,320	37,290	**42,624**	**45,424**	**46,412**	**48,419**	**50,950**

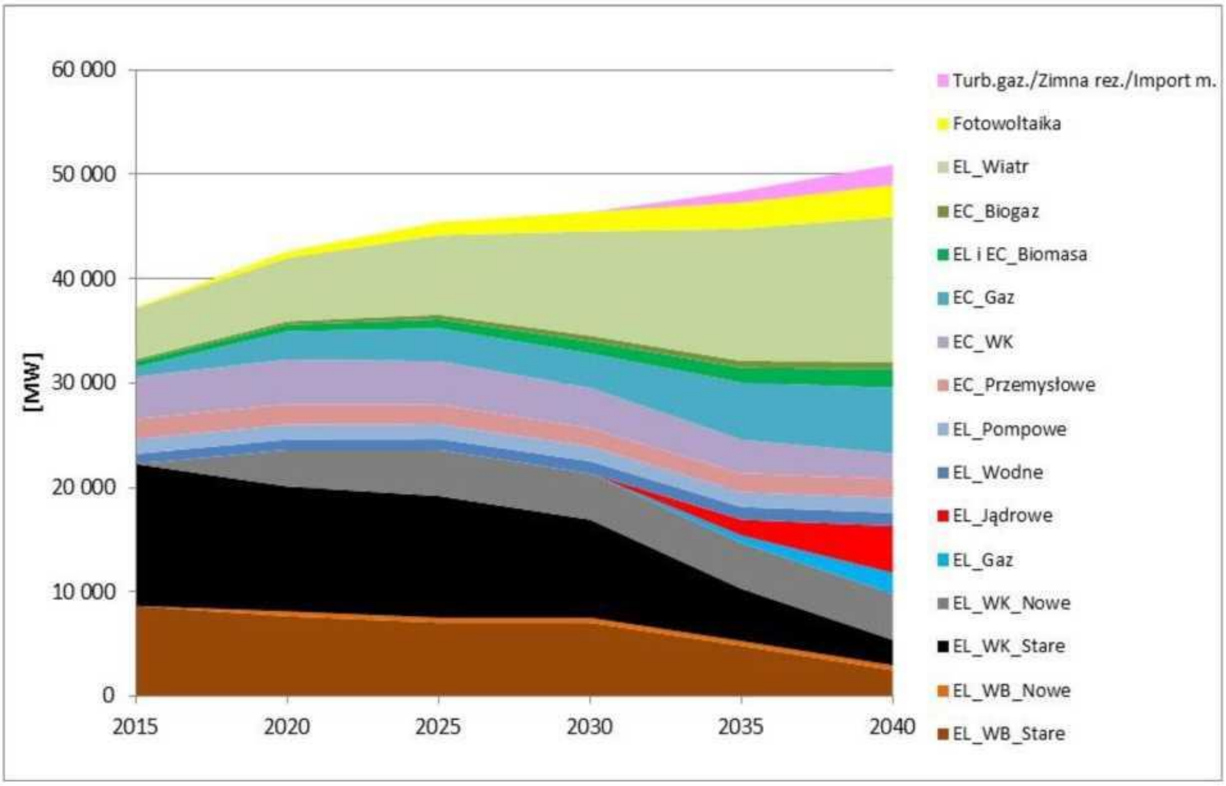


Figure 31. Generating power of electricity sources by technology

[MW]	[MW]
Turb.gaz./Zimna rez./Import m.	Gas turbine/cold reserve/import
Fotowoltaika	Photovoltaics
EL_Wiatr	Wind energy
EC_Biogaz	Biogas
EL i EC_Biomasa	Biomass power plants and CHP
EC_Gaz	Gas CHP
EC_WK	Hard coal CHP
EC_Przemysłowe	Industrial CHP
EL_Pompowe	Pumped-storage power plants
EL_Wodne	Hydroelectric power plants
EL_Jądrowe	Nuclear power plants
EL_Gaz	Gas power plants
EL_WK_Nowe	Hard coal power plants – new
EL_WK_Stare	Hard coal power plants – old
EL_WB_Nowe	Lignite power plants – new
EL_WB_Stare	Lignite power plants – old

4.5 Dimension internal energy market

4.5.1. Interconnections

As pointed out in the introductory part, the reference scenario concerns the situation and forecasts as at the end of 2017. Poland has decided not to publish forecasts concerning interconnections, in relation to both electricity and gas, as they are not up-to-date and may be misleading. For updated information, see Chapter 5 in Annex 2 to the NECP.

4.5.2. Energy transmission infrastructure

- ***Electricity – key parameters of existing transmission infrastructure***

The transmission system operator (TSO), defined in the Energy Law as an energy enterprise dealing with electricity transmission, is Polskie Sieci Elektroenergetyczne S.A. based on the licence issued by the President of the Energy Regulatory Office (URE) on 16 June 2014 for the period of 2 July 2014 to 31 December 2030.

PSE S.A. owns and manages the extra-high voltage transmission network which comprised the following components as at the beginning of 2017:

- 256 lines of a total length of 14,126 km, including 1 line of 750 kV with a length of 114 km, 90 lines of 400 kV with a total length of 6,139 km, and 165 lines of 220 kV with a total length of 7,873 km,

- 106 extra-high voltage (EHV) substations,

- a 450 kV DC submarine connection between Poland and Sweden with a total length of 254 km,

of which 127 km is owned by PSE S.A.

The characteristics of the main items of technical infrastructure of the national electricity transmission and distribution sub-sector are presented in the table below. The current diagram of the extra-high voltage grid is shown in the figure below.

Table 54. Characteristics of national transmission and distribution networks

Breakdown	Unit of measurement	2005	2010	2016	2018
LENGTH OF OVERHEAD POWER LINES					
- high voltage (EHV + HV)	km	45,378	46,112	47,432	48,187
750 kV	km	114	114	114	114
400 kV	km	4,831	5,303	6,139	6,813
220 kV	km	8,123	8,088	7,873	7,831
110 kV	km	32,310	32,607	33,229	33,429
- medium voltage (MV)	km	233,855	234,741	230,743	229,218
- low voltage (LV)	km	286,994	289,977	311,044	312,755
All voltages in total	**km**	**566,227**	**570,830**	**589,142**	**590,160**
LENGTH OF CABLE LINES:					
- high voltage (EHV + HV)	km	79	164	528	648
- medium voltage (MV)	km	61,988	68,998	80,861	86,185
- low voltage (LV)	km	125,776	140,320	159,098	171,193
All voltages in total	**km**	**187,843**	**209,482**	**240,487**	**258,026**
NUMBER OF UPPER VOLTAGE STATIONS:					
- 400 and 750 kV	pc	31	35	44	45
- 220 kV	pc	67	67	64	63
- 110 kV	pc	1,356	1,405	1,537	1,556
- medium voltage (MV)	pc	236,067	246,562	261,169	265,690
All voltages in total	**pc**	**237,521**	**248,069**	**262,814**	**267,354**
NUMBER OF MAINS TRANSFORMERS WITH THE TURNS RATIO:					
- EHV/(EHV + HV)	pc	168	185	211	214
- HV / MV	pc	2,527	2,553	2,791	2,832
- MV / MV	pc	264	1,215	1,179	1,185
- MV / LV	pc	237,595	247,479	261,079	264,622
Total	**pc**	**240,554**	**251,432**	**265,260**	**268,853**
CAPACITY OF MAINS TRANSFORMERS WITH THE TURNS RATIO:					
- EHV/(EHV + HV)	MVA	37,812	42,302	56,470	58,360
including DSO	MVA	640	730	1,710	2,040
- HV / MV	MVA	46,904	49,700	57,923	60,259
- MV / MV	MVA	1,055	5,280	5,346	5,396
- MV / LV	MVA	40,858	44,135	49,521	51,006
Total	**MVA**	**126,629**	**141,417**	**169,260**	**175,021**
NUMBER OF CONNECTIONS:					

- overhead	'000 pc	5,633	5,635	5,462	5,460
- cable	'000 pc	719	989	1,347	1,534
Total	**'000 pc**	**6,352**	**6,624**	**6,810**	**6,994**
LENGTH OF CONNECTIONS:					
- overhead	km	119,829	120,595	114,387	113,674
- cable	km	23,837	32,320	47,640	54,657
Total	**km**	**143,666**	**152,915**	**162,027**	**168,331**

Source: ARE S.A. based on the results of the study 1.44.02.

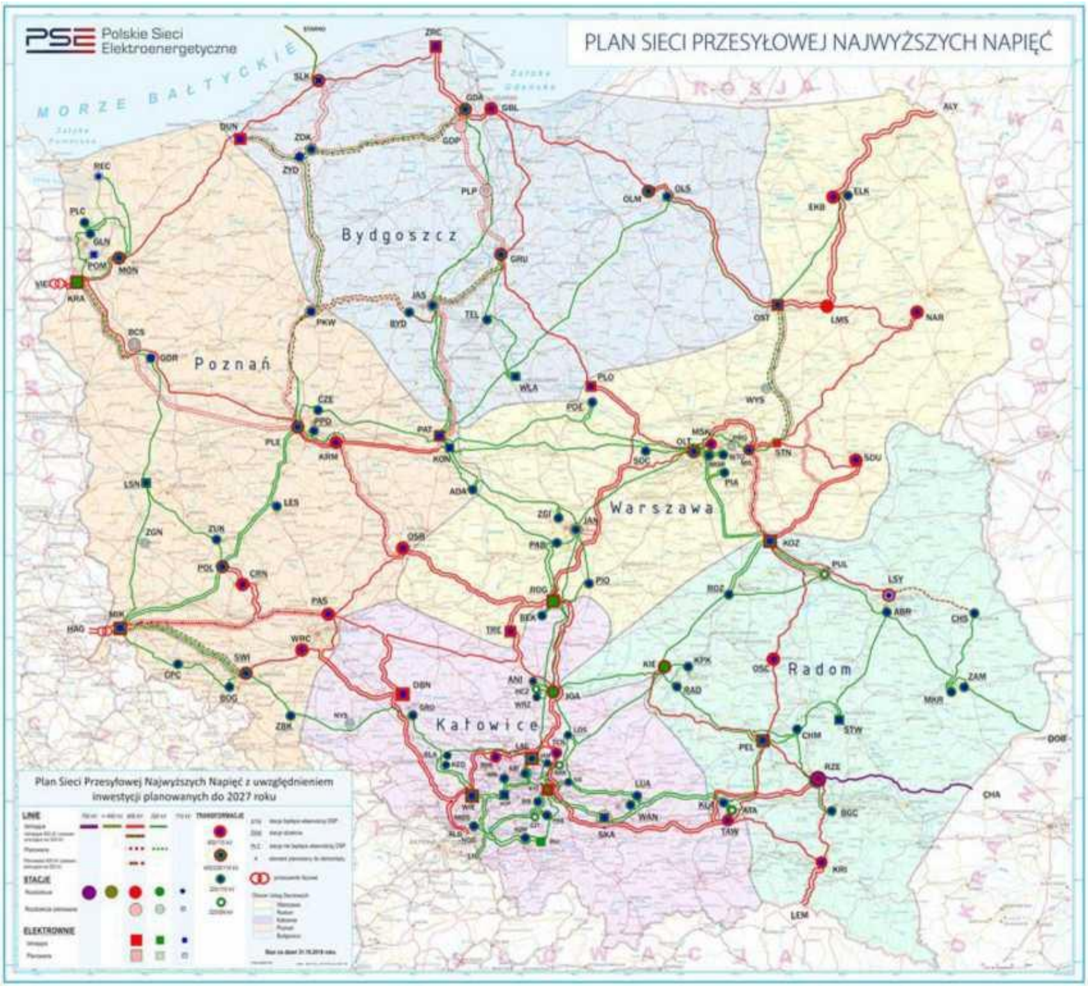


Figure 32. Diagram of the transmission grid with marked areas of operation of PSE S.A. Branches (as at 31 December 2018)

PLAN SIECI PRZESYŁOWEJ NAJWYŻSZYCH NAPIĘĆ	EXTRA-HIGH VOLTAGE TRANSMISSION GRID PLAN
Plan Sieci Przesyłowej Najwyższych Napięć z uwzględnieniem inwestycji planowanych do 2027 roku	The extra-high voltage transmission grid plan including investments planned until 2027
LINIE	LINES
STACJE	SUB-STATIONS
ELEKTROWNIE	POWER PLANTS
TRANSFORMACJE	TRANSFORMATIONS

In 2016, Polskie Sieci Elektroenergetyczne incurred capital expenditures of PLN 1,216.9 million to implement its investment tasks and plans. Thus, between 2005 and 2016, the nominal capital expenditures on the National Transmission Grid (KSE) increased over 2.5 times from PLN 481.9 million spent by the TSO on grid development and modernisation in 2005. Key expenditures in 2016 were PLN 1,024,300 on the construction and development of substations and power lines, and PLN 136.5 million on their modernisation. These investments increased the reliability of the power system and adapted the sub-stations to new operating conditions (remote supervision, control and monitoring, unmanned operation). The additionally installed autotransformers will contribute to meeting demand for electricity and increasing reliability of power supply for consumers. Newly built or extended facilities will increase the capacity of the National Transmission System, as well as improving reactive power compensation and voltage regulation in the NTS. Thanks to the investment activities undertaken in 2016, nearly 78 km of new 400 kV lines and 10 km of 220 kV lines were built and nearly 240 km of 400 kV lines and 400 km of 220 kV lines were modernised. In addition, 270 km of optical fibre routes and 3,186.8 m^2 of technological buildings were built by PSE. The construction of phase shifters at the Mikułowa sub-station was a very important investment completed in 2016. The aim of the project was to improve conditions for intersystem power exchange in the synchronous area with Germany and to avoid loop flows from the German system through the Polish system. The applied shifter technology is unique on a global scale. These are the first such shifters in Europe.

2018 was a record year for PSE in terms of the value of investments. In 2018, capital expenditure s totalled PLN 1.8 billion, approx. PLN 1.7 billion of which was allocated to the upgrading and construction of network infrastructure. 16 out of over 140 investment projects planned for the coming years were also completed: two related to the construction of new lines and 14 consisting in the extension and upgrading of existing infrastructure.

Table 55. Total TSO capital expenditure [PLN million]

Capital expenditure	2005	2010	2015	2016	2018
TSO	481.9	492.6	1,536.1	1,216.9	1,810.2

Source: ARE S.A.

- ***Natural gas – key parameters of existing transmission infrastructure***

The natural gas transmission system in Poland is operated by GAZ-SYSTEM S.A. The transmission pipeline operator was designated by a decision of the President of the Energy Regulatory Office in 2006. Its main tasks are to manage the national transmission network and ensure continuous and reliable gas transmission between sources and customers in Poland. GAZ-SYSTEM S.A. is licensed as the transmission system operator until 6 December 2068.

In 2017, GAZ-SYSTEM S.A. had nearly 12,000 kilometers of gas transmission pipelines under its management. The transmission system operated 67 points of entry (both import and domestic entry points, i.e. points of gas supply from mines or compressor stations) and 983 points of exit from the system (mainly connections with distribution systems and points of gas off-take by final customers). In terms of age, more than 53% of the pipelines are older than 30 years. Only 10% of the total length of the transmission pipelines has been put into operation in the last 5 years.

Table 56. Technical characteristics of the National Transmission System

Transmission system element	Unit	2011	2018
System pipelines	km	9,853	10,743
System nodes	pc	57	34
Gas stations		869	848
Compression stations		14	15

Source: GAZ-SYSTEM S.A.

The National Transmission System is composed of two natural gas subsystems: high-methane natural gas (L) and nitrogen-rich natural gas (Lw).

The high-methane natural gas system has the form of a trunk line system consisting of:
- Transit Gas Pipeline System;
- the Eastern trunk line: Jarosław – Wronów – Rembelszczyzna;
- the Southern trunk line: Jarosław – Pogórska Wola – Tworzeń – Odolanów;
- the new North-Western trunk line: Lwówek – Szczecin – Świnoujście LNG Terminal – Szczecin – Gdańsk;
- the Central Poland supply system on the Hołowczyce – Rembelszczyzna route, strengthened on the Gustorzyn – Odolanów route;
- the Northern Poland supply system on the Gustorzyn – Gdańsk route;

- the transmission system in Lower Silesia.

The nitrogen-rich natural gas transmission system covers three provinces in western Poland: Lubuskie, Wielkopolskie and Dolnośląskie. The system is supplied with gas from mines located in the Polish Lowlands: Kościan-Brońsko, Radlin, Białcz, Roszków and Kaleje. In addition, gas from the Wielichowo mine is mixed with high-methane gas at the gas mixing plant in Grodzisk Wielkopolski and is then fed into the nitrogen-rich gas system. The layout of the systems is shown in the figure below.

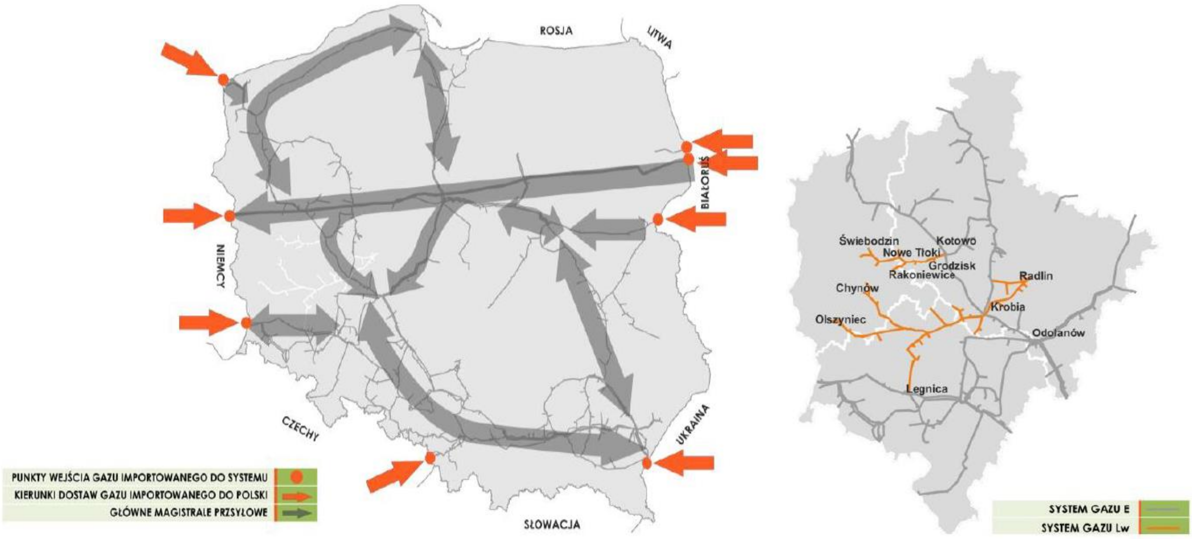


Figure 33. Main E-gas trunk lines (left) and Lw-gas trunk lines (right). Source: 2020-2029 National Ten-Year Transmission System Development Plan, GAZ-SYSTEM S.A.

PUNKTY WEJŚCIA GAZU IMPORTOWANEGO DO SYSTEMU	**SYSTEM ENTRY POINTS FOR IMPORTED GAS**
KIERUNKI DOSTAW GAZU IMPORTOWANEGO DO POLSKI	**DIRECTIONS OF DELIVERIES OF GAS IMPORTED TO POLAND**
GŁÓWNE MAGISTRALE PRZSYŁOWE	**TRANSMISSION MAINS**
SYSTEM GAZU E	**HIGH-METHANE GAS (E) SYSTEM**
SYSTEM GAZU Lw	**NITROGEN-RICH GAS (Lw) SYSTEM**

High-methane gas storage facilities are an important component of gas infrastructure. By storing gas to offset periodic shortfalls of gas imports and/or production, they contribute to increasing the country's energy security. Currently there are seven natural gas storage facilities in Poland. Their technical parameters are shown in the table below.

Table 57. Maximum capacity of storage facilities in the 2018/2019 season

Storage facility	Working gas volume		Maximum injection capacity		Maximum off-take capacity	
	mcm	GWh	mcm/d	GWh/d	mcm/d	GWh/d
Underground gas storage facilities in depleted natural gas fields						
Wierzchowice	1,200	13,200	6	67.2	9.6	105.6
Husów	500	5,625	4.15	46.7	5.76	64.6
Strachocina	360	4,050	2.64	29.7	3.36	37.9
Swarzów	90	1,008	1	11.2	0.93	10.4
Brzeźnica	100	1,125	1.44	16.2	1.44	16.1
Total	2,250	14,325	15.23	171	21.09	234.6
Cavern underground gas storage in leached caverns in salt deposits						
Mogilno	589.85	6,570.9	9.6	106.9	18	200.5
Kosakowo*	145.5	1,622.3	2.4	26.8	9.6	107
Total	735.35	8,193.2	12	133.7	27.6	307.5
Overall	**2,985.35**	**33,201.2**	**27.23**	**304.7**	**48.69**	**542.1**

**under expansion, a planned working capacity of 250 mcm*
Source: 2020-2029 National Ten-Year Transmission System Development Plan, GAZ-SYSTEM S.A.

The total storage capacity amounted to nearly 3 bcm, an almost twofold increase compared to 2010. The total capacity was then 1.6 bcm. This change is due to a number of factors:

- Increase in the working capacity of the Wierzchowice storage facility from 575 mcm to 1,200 mcm;
- Increase in the working capacity of the Strachocina storage facility from 150 mcm to 360 mcm;
- Increase in the working capacity of the Husów storage facility from 350 mcm to 500 mcm;
- Increase in the working capacity of the Mogilno storage facility from 370 mcm to 589.85 mcm;
- Commissioning of the Kosakowo storage facility towards the end of 2014. In 2018, it had the capacity of 145.5 mcm and its target capacity is 250 mcm.

- ***Crude oil and liquid fuels – key parameters of existing infrastructure***

Poland is dependent on external supplies of crude oil due to the fact that its own resources are limited and sufficient only to meet 4% of domestic demand. With a share of approx. 80% in the current supply structure, Russia is a key importer of crude oil to Polish refineries. Despite this unfavourable dependence, Poland's fuel security is ensured from a technical viewpoint, particularly thanks to its extensive transmission infrastructure ('Friendship' and 'Pomeranian' pipelines) and the oil terminal in Gdańsk, whose capacity is sufficient to fully cover the demand of Polish refineries.

The system of emergency oil and fuel stocks is essential to ensuring continuity of supply, as it guarantees an effective government response when a crisis situation occurs. Approx. 6 million tonnes of crude oil and fuels are kept as emergency stocks, a volume sufficient to meet domestic demand for more than three months at a normal consumption level.

At over 13 mcm, Poland's oil and fuel storage capacity is sufficient to hold emergency stocks, as well as to meet the commercial and operational needs of market operators. However, it is necessary to ensure full physical availability of stocks in a crisis situation, which necessitates additional investments (which are currently underway).

The fuel market in Poland is fully competitive. There is an extensive retail fuel sales network, which is diversified in terms of ownership structure. Dominated by two refineries, the wholesale market is more concentrated. The majority of fuel consumption is met by domestic production, with imports playing a complementary role. In order to secure the continuity of fuel supply to the market, it is necessary to ensure that domestic fuel demand is covered to the maximum extent by domestic production. The difficulties with which the refining sector in Europe has been coping for several years (low refining margin), caused by both internal factors (e.g. decrease in fuel consumption) and external factors (e.g. extraction of crude oil from unconventional deposits in the United States of America, increased fuel exports to EU countries from outside Europe, lower environmental costs of non-EU refineries), will be increasingly affecting Polish refineries as well.

In view of the limited domestic oil resources, Poland's energy security in the oil sector depends in particular on the existing oil infrastructure, processing capacities of domestic refineries and storage capacities. Their reliability, modernisation and possible further expansion will have a key impact on maintaining energy security in the future. In this respect, it is important to maintain State control over key oil companies, and thus the government's ability to actively influence the oil sector. It is, therefore, advisable to maintain the State's share in key enterprises in the sector at least at the current level.

Over the last two years, steps have been taken to make the structure of oil supply more geographically balanced. The main limitations in this regard have so far stemmed from economic considerations. This is evidenced, amongst others, by the difficulties related to the construction of the third oil supply route to Poland (the Odessa-Brody-Płock oil pipeline project)[36].

The Polish system of pipelines for liquid fuels is based on the installations operated by PERN S.A., a company wholly owned by the State Treasury, located in Płock. The company specialises in the operation of a network

[36] The 675 km long Odessa-Brody pipeline connects the Black Sea with the Druzhba oil pipeline and ends up near the Polish border. Built between 1996 and 2001, the pipeline connects the Ukrainian cities of Odessa and Brody and has been planned as the first stage of construction of a pipeline supplying oil from the Black Sea to the Baltic Sea. To this end, an extension from Brody to Płock, and from there to Gdańsk, has been planned. The pipeline extension project is to be co-financed by the European Union.

of pipelines (the Druzhba pipeline) transporting crude oil from Russia to fuel producers in Poland and Germany, as well as oil storage.

Russian oil is transported through two lines of the Druzhba pipeline, running from Adamowo, located at the Polish border with Belarus, to Płock, and then to the German border town of Schwedt. The company also has a network of product pipelines that are used to transport liquid fuels produced by refineries. This network spreads radially from Płock towards Warsaw, Poznań and Częstochowa. The oil pipeline network operated by PERN consists of three sections: Eastern, Western and Pomeranian.

The Eastern Section connects Adamowo near the border with Belarus with Miszewek Strzałkowski near Płock via three lines. It is used to transport crude oil to PKN Orlen and indirectly to the Lotos Group and German refineries.

The pipeline has a length of 233 km and a maximum capacity of 56 million tonnes of crude oil per year (following the completion of the third line in October 2016).

The Western Section connects Miszewko Strzałkowskie with the German refineries TRM Spergau and PCK Schwedt via two lines. The length of the route in Poland is 416 km and the nominal capacity is 27 million tonnes of crude oil per year.

On the section of Miszewko Strzałkowskie to Żółwieniec, the first line of the pipeline operates in a reverse mode, allowing crude oil to be pumped in two directions, i.e. to Germany and to Płock. The section connecting Żółwieniec with the Underground Oil and Fuel Storage Facility in Góra operated by Inowrocław Salt Mines (IKS Solino) is owned by PKN Orlen.

The Western section also connects PERN's pipeline system with PGNiG's mines in Wierzbno and Dębno. The Company transports the Polish raw material extracted near these locations.

The third section of the pipeline, i.e. the Pomeranian Section, connects Miszewko Strzałkowskie with Gdańsk. This route is used to transport Russian crude oil intended for the Lotos Group's refinery in Gdańsk and oil imported by sea for the PKN Orlen refinery. The Pomeranian Section operates in a reverse mode, a solution which enables pumping oil in both directions (the reverse direction is used to pump crude oil to PKN Orlen and, if necessary, to German refineries). Moreover, in combination with the infrastructure of the Naftopol liquid fuel terminal in Gdańsk, this arrangement facilitates exports of crude oil transported through the Druzhba pipeline, as well as its imports by sea and further pumping through PERN's pipeline system. The length of the Pomeranian Section is 235 km and the nominal capacity is 27 and 30 million tonnes of crude oil per year (in the northern and southern direction, respectively).

PERN operates also a network of product pipelines for transporting petroleum products (petrol, diesel and heating oil) in three directions:
- Płock – Nowa Wieś Wielka – Rejowiec. The length of the route is approx. 208 km and the nominal capacity is 2.1 and 1.4 million tonnes per year (in the direction of Płock – Nowa Wielka Wieś and Nowa Wielka Wieś – Rejowiec, respectively).
- Płock – Mościska – Emilianów. The length of the route is approx. 163 km and the nominal capacity is 1.15 million tonnes per year.
- Płock – Koluszki – Boronów. The length of the route is approx. 265 km and the nominal capacity is 3.8 and 1 million tonnes per year (in the direction of Płock – Koluszki and Koluszki – Boronów, respectively).

Oil storage tanks form an integral part of PERN's pipeline system. The Company has four crude oil storage facilities (including the Oil Terminal in Gdańsk): Adamowo (15 storage tanks with a total capacity of approx. 770 tcm); Miszewko Strzałkowskie (29 storage tanks with a total capacity of approx. 1.464 mcm); Gdańsk (18 storage tanks with a total capacity of approx. 900 tcm); Gdańsk Oil Terminal (6 storage tanks with a total capacity of approx. 375 tcm).

In 2016, in the Port of Gdańsk, PERN commissioned the Crude Oil Terminal for transshipment and storage of crude oil, which plays a major role in the energy security of Poland. Its advantages include a very good location, i.e. near Naftoport liquid fuel terminal, the availability of space for building an additional jetty, and the proximity of rail and road transport infrastructure.

Crude oil is delivered to the Oil Terminal from the Pomeranian pipeline via the Gdańsk Base. It is then transmitted from the Oil Terminal by pipelines to the Gdańsk Base and from there to the Pomeranian pipeline and the Lotos S.A.'s refinery. The Naftoport liquid fuel terminal is also served. The map below shows the current system of oil pipelines in Poland.

Figure 34. The current system of oil pipelines in Poland. Source: PERN

Naftport	Naftport
Terminal Naftowy	Oil Terminal
Baza PERN S.A.	PERN S.A. Base
Baza Paliw Nr 2	Fuel Base No 2
Baza Paliw OLPP Nr 1	OLPP Fuel Base No 1
Baza PKN Orlen	PKN Orlen Base

PERN's long-term strategy until 2020 focuses on investments in the area of, amongst others, oil transport and storage. The Company is expanding its storage capacity, including at the Crude Oil Terminal in Gdańsk, and is working on a project of oil reverse flow via the Eastern Section pipeline, i.e. transport of crude oil in the opposite direction from the base near Płock to Adamowo. The reverse construction plans are divided into two parts to be completed by 2020 and 2022. The reverse capacity is planned at 15 million tonnes per year in the first phase and approx. 22 million tonnes in the second phase.

The reverse use of the Eastern Section has been necessitated by the need to adapt PERN's logistic services relating to crude oil transport and storage to the new needs of refineries, which are increasingly exploring new directions of raw material supplies by sea as part of their diversification efforts.

Polish and German refineries are looking for oil from different directions. There are now tanker deliveries to Lotus and Orlen from Saudi Arabia, Iraq, Iran, Canada and the USA. Such deliveries are bound to increase. Due to the diversification of supplies by PERN's customers, free storage capacities may occasionally occur in Adamowo. In such a situation, reverse flow will enable making more use of Adamowo's capacity by using it for storage of oil supplied not only from the East.

In addition to the reverse flow project concerning the Eastern Section, PERN is planning a nearly 10% increase in capacity of the reversible pipeline of the Pomeranian Section connecting the company's storage facilities near Płock and in Gdańsk. Aimed at increasing the transported volumes of crude oil by changing the parameters of pumping stations, the project is scheduled to be completed by 2020. On the other hand, the expansion of the Gdańsk Oil Terminal through construction of new tanks, which will double the storage capacity there, is planned by 2022 at the latest.

The production of liquid fuels for the purposes of crude oil processing is carried out mainly in refineries owned by Polski Koncern Naftowy ORLEN S.A. and Grupa Lotos S.A.

Polski Koncern Naftowy ORLEN S.A., together with companies forming ORLEN Group, is the leader of the refinery and petrochemical industry in Central and Eastern Europe. ORLEN Group comprises PKN ORLEN as the parent company, as well as companies located in Poland, Germany, the Czech Republic, Lithuania, Malta, Sweden, the Netherlands, Slovakia, Hungary, Estonia, Latvia, the USA and Canada. As at 31 December 2018, ORLEN Group comprised 67 companies, including 57 subsidiaries.

In 2018, the crude oil processed by PKN ORLEN totalled 33.4 million tonnes a year. The Group's refinery and processing structure comprises refineries in Poland, the Czech Republic and Lithuania with a total crude oil processing capacity of 35.2 million tonnes a year, as well as crude oil processing plants, including

- PKN ORLEN Refinery in Płock, which is one of the most modern integrated production plants in Central and Eastern Europe with a capacity of 16.3 million tonnes a year. In the area of petrochemical production, the key Olefin unit has a maximum capacity of about 700,000 tonnes of ethylene and approx. 380,000 tonnes of propylene.

- Other Polish refineries of ORLEN Południe located in Trzebinia and Jedlicze specialising in production of biocomponents, base oils, heating oils, hydro refined paraffins and regeneration of used oils.

- ORLEN Lietuva's refinery in Mažeikiai with a production capacity of 10.2 million tonnes a year is the only plant of this type in the Baltic states (Lithuania, Latvia and Estonia).

- The Unipetrol Group's refineries located in Kralupy and Litvinov have a total production capacity of 8.7 million tonnes a year. The Unipetrol Group also has petrochemical assets with a production capacity of approx. 600,000 tonnes a year (320,000 tonnes of polyethylene and approximately 280,000 tonnes of polypropylene). A new Polyethylene 3 unit with a capacity of approximately 270,000 tonnes a year is also under construction, which will enable higher utilisation of the Olefins unit and deeper integration of petrochemical and refinery production.

- Anwil in Włocławek is the only producer of polyvinyl chloride (PVC) in Poland and one of the largest producers of fertilisers and sodium hydroxide in the country. The production capacity is approximately 1.0 million tonnes a year of nitrogenous fertilisers, 0.4 million tonnes a year of PVC and granulates and 0.2 million tonnes a year of sodium hydroxide. Thanks to the planned construction of the third nitrogenous fertiliser production facility, ANWIL's production capacity after 2021 will increase to approximately 1.5 million tonnes a year.

- Basell ORLEN Polyolefins in Płock – the largest plastic plant in Poland and the only domestic manufacturer of polyolefins; it has installations with a total production capacity of 900,000 tonnes (420,000 tonnes of polyethylene and 480,000 tonnes of polypropylene), and products are distributed both in Poland and on foreign markets.

- Petrol stations operate under the ORLEN brand in the premium segment and the Bliska brand in the economy segment (only 3% of the network) in Poland, mainly under the Benzina and Benzina Plus brands in the Czech Republic (mainly the premium segment), and under the ORLEN brand (premium segment) in Lithuania. On the German market, ORLEN Deutschland manages economy stations under the star brand, and the network is supplemented by a dozen or so Famila stations attached to hypermarkets or supermarkets.

The LOTOS Capital Group is the second largest fuel producer in Poland. It is the only operator to engage in hydrocarbon extraction in the Polish Exclusive Economic Zone of the Baltic Sea. Oil exploitation is also carried out by the LOTOS Capital Group in the area of the Norwegian Continental Shelf and in onshore oil fields in Lithuania. The Group's refinery in Gdańsk is one of the youngest and most technologically advanced refinery complexes in Europe with an annual capacity of approx. 10.5 million tonnes of crude oil.

The LOTOS Capital Group focuses its operations on the extraction and processing of crude oil and the wholesale and retail sale of petroleum products, including fuels (unleaded petrol, diesel and light fuel oil), heavy fuel oil, asphalts, aviation fuel, pyrolytic petrol, propane-butane (LPG) and base oils. As at 31 December 2018, the Capital Group of Grupa LOTOS S.A. was composed of Grupa LOTOS S.A. as the parent company and 18 companies under the LOTOS brand. Three of them are based outside Poland: in Lithuania, Norway and the United Kingdom.

In 2018, the average daily production of oil and gas by the LOTOS Group was 20,400 boe/day (barrels of oil equivalent), which means an annual capacity of nearly 1 million toe (tons of oil equivalent).74% of the total volume, i.e. 15,200 boe/day, came from Norwegian deposits. As at the end of 2018, the LOTOS Group had total proved and probable oil and gas reserves of 89.8 million boe, including 69.8 million boe of oil (78% of total 2P reserves) and 20.1 million boe of gas (22% of total 2P reserves).

As in previous years, Russian Ural oil was the dominant type of oil processed. At approx. 73.1%, its share was slightly lower than in previous years. Crude oil imported from other directions, including approx. 197,000 tonnes of oil supplied by LOTOS Petrobaltic Capital Group, complemented the mix.

4.5.3. Electricity and gas markets, energy prices

- ***Current situation on the electricity market***

During the period of analysis, domestic electricity production shows an upward trend, reaching 170.5 TWh in 2017 and 170.0 TWh in 2018, the highest result in the history of the Polish energy industry. An increase in electricity consumption is also visible in the same period, after a decrease resulting from the economic slowdown in 2009, and this increase has been outpacing production since 2016. The growing consumption of electricity in 2018 was supplemented by imports of 5.7 TWh, i.e. 3.3% of domestic consumption (see the figure below).

The structure of the wholesale electricity market is presented on the basis of an analysis of directions of energy sales.

In 2016, public power generators sold a total of 144.1 TWh of energy, i.e. approx. 1.8% less than in 2015 (146.6 TWh), and the wholesale of electricity by commercial power plants and CHP plants took place primarily through regulated markets where, similarly to the previous year, the dominant role was played by the power exchange and sales to trading companies. The increase in the popularity of electricity exchange trade in Poland was primarily influenced by the 2010 amendment to the Energy Law that introduced what is known as ‘exchange obligation’. Namely, electricity generators are obliged to sell 15% of generated electricity via a commodity exchange. With regard to generators receiving compensation for the premature termination of long-term electricity purchase contracts, the exchange obligation applies to all generated electricity with the exception of, amongst others, electricity generated through cogeneration, electricity generated for own use and electricity generated in units with an installed capacity of not more than 50 MWe.

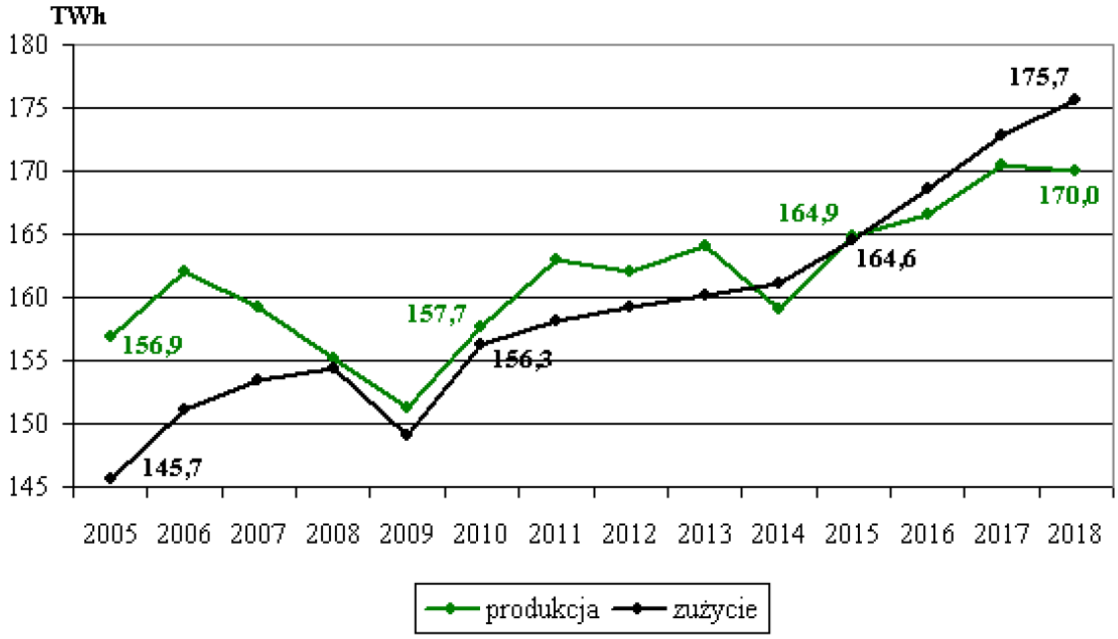


Figure 35. Total electricity production in 2005-2018. Source: ARE S.A.

produkcja	production
zużycie	consumption
TWh	**TWh**

The volume of electricity coming from hard coal remained at a similar level both in 2005 and 2010, but has decreased quite significantly in recent years.

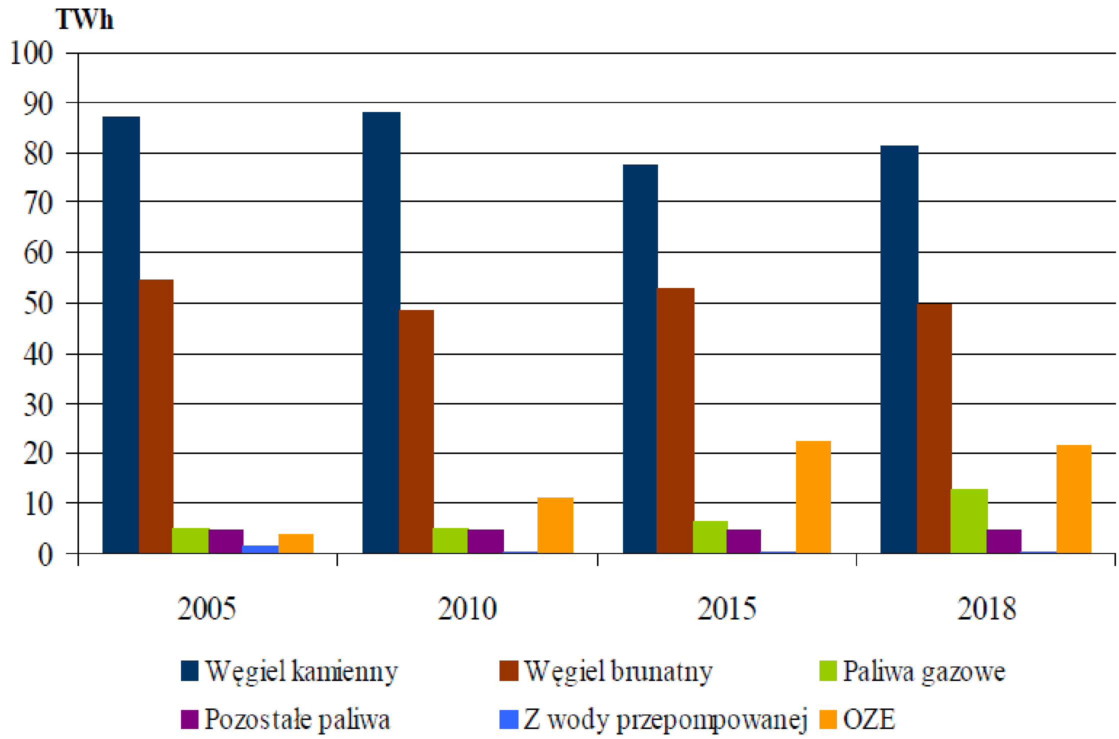


Figure 36. Electricity production by energy carrier in 2005, 2010, 2015 and 2016. Source: ARE S.A.

TWh	**TWh**
Węgiel kamienny	Coal
Pozostałe paliwa	Other fuels

Węgiel brunatny	Lignite
Z wody przepompowanej	Pumped storage
Paliwa gazowe	Gaseous fuels
OZE	RES

In 2018, sales to trading companies were the main channel for the sale of electricity by generators, accounting for over 66% of total sales, a 22.7 percentage points increase compared to 2015. Under bilateral contracts, sales to other entities of the capital group accounted for over 90% of trading volume. The Polish Power Exchange (Towarowa Giełda Energii S.A.) sold 24.3% of electricity. For comparison, the exchange's market share was 0.7% in 2005, 4.2% in 2010 and 48.2% in 2015. The remaining sales were mainly made on the balancing market (6%), which included sales for the purpose of ensuring the security of operation of the national power system, and only to a small extent to final customers and for export.
The structure of electricity sales is presented in Table 68 and sales of electricity to final customers[37] in Table 69.

Table 58. Structure of electricity sales of public CHP plants

Years	Sales of electricity						
	Total	including:					
		trading companies[1)]	exchange market – Polish Power Exchange	of which: forwards market	of which: SPOT	final customers	balancing market
	GWh	%					
2005	145,031.0	87.32	0.72	.	.	3.59	8.37
2010	141,253.1	88.05	4.21	1.12	3.10	1.85	5.87
2015	146,588.5	43.65	48.17	45.21	2.94	2.41	5.39
2018	144,017.0	66.36	24.30	21.80	2.49	2.14	5.99

[1)] this includes sales to PSE S.A. in 2005. Source: ARE S.A.

Table 59. Sales of electricity to final customers

Breakdown	2005		2010		2015		2016	
	volume	av. price	volume	av. price	volume	av. price	volume	av. price
	GWh	EUR2016/MWh	GWh	EUR2016/MWh	GWh	EUR2016/MWh	GWh	EUR2016/MWh
Public thermal plants[1)]	5,359	35.6	1,363	60.7	2,856	49.9	2,692	56.8
including: customers under comprehensive contracts	1,025	42.6	388	62.5	2,232	50.7	2,243	56.9
Independent CHP plants	-	-	1,501	60.2	1,057	51.1	1,089	47.5
including: customers under comprehensive contracts	-	-	-	-	836	50.4	1,001	46.1
Trading companies	3,969	34.4	6,308	57.6	13,907	49.6	14,539	51.7
customers under comprehensive contracts	-	-	-	-	10	52.5	91	59.1
customers under sales contracts	3,969	34.4	6,308	57.6	13,898	49.6	14,448	51.5

[37] A customer purchasing fuels or energy for own use; own use does not include electricity purchased for the purpose of electricity generation, transmission or distribution.

including: - HV/LV	2,752	34.5	2,218	55.9	2,073	42.5	1,604	49.9
- MV	1,213	34.1	3,764	58.0	7,874	50.2	11,961	50.2
- LV	3	100.6	325	63.9	3,950	52.1	4,392	54.7
Retail trading companies	98,705	37.7	108,954	63.8	107,517	55.2	111,833	52.3
customers under comprehensive contracts	95,531	37.7	86,802	65.3	60,512	60.9	59,037	58.0
- HV+EHV	14,311	34.3	7,588	58.0	3,629	47.4	2,312	45.6
- MV	33,392	35.7	27,439	65.1	16,400	55.3	14,775	51.6
- LV	47,796	40.3	51,775	66.5	40,484	64.3	40,924	61.1
customers under sales contracts	3174	33.9	22,152	57.9	47,005	47.8	52,796	46.7
- HV+EHV	3139	33.9	12,965	55.5	16,849	41.0	23,185	41.6
- MV	35	34.2	7,328	60.7	21,080	50.2	24,878	48.7
- LV	-	-	1,858	63.0	9,076	55.0	10,529	53.0
TOTAL 2)	**108,036**	**37.5**	**118,126**	**63.4**	**125,339**	**54.4**	**138,548**	**52.3**

1) including independent power plants in 2005.
2) – including public hydropower plants
Source: ARE S.A. based on the results of the study 1.44.02.

Sales of electricity to final customers is gradually increasing. An increase of over 28% is recorded within the discussed timeframe (2005 to 2018). 'Incumbent' trading companies that came into operation following the spin-off of the distribution system operator from the former distribution companies continue to be the main sellers of energy, accounting for 84% of all trades. Other independent companies engaged in electricity trading are gaining an increasing share of sales to final customers. Electricity is sold under comprehensive contracts (Polish *umowa kompleksowa*) and sales contracts. In the period under discussion, there is a significant increase in the share of TPA customers in the energy market. The number of TPA customers and the share of TPA sales are presented below.

- ***Current situation on the electricity market***

In December 2012, an important step was taken towards the liberalisation of the Polish gas market by launching the gas exchange on the Polish Power Exchange. This was the implementation of Article 49b of the Energy Law, which requires that a certain volume of high-methane natural gas fed into the transmission network in a given year be mandatorily sold by electricity undertakings on commodity exchanges. In 2013, this volume equalled 30% of gas fed into the transmission network and has been as high as 55% from 2015. In 2015, TGE S.A. operated the following gas fuel markets: Intra Day Market, Day-Ahead Market, Commodity Forward Instruments Market, and the auctioning of natural gas.

The gas market in Poland operates on two levels:

- **wholesale market** – sale of gas to large customers connected to the transmission network or to distribution or trading companies (as at the end of 2018, 197 operators were licensed to trade in gaseous fuels on the wholesale market, 102 of which were actively engaged in natural gas trade),
- **retail market** – sale of gas to final customers connected to the distribution network.

In 2015, gas sales to final customers continued to be dominated by PGNiG Group companies. Following the distinction introduced in 2014, wholesale customers and final customers with an annual natural gas consumption of over 25 mcm began to be supplied by PGNiG S.A. and the remaining final customers by PGNiG Obrót

Detaliczny Sp. z o.o. 2015 saw an increase in the share of alternative vendors in the retail market. The PGNiG Group's share in gas sales to final customers was over 88% in 2015. The remaining gas sales to final customers were carried out by other trading companies operating in Poland and by companies selling gas mainly on the German market directly to large final customers, who imported gas to Poland on their own. Gas companies sold 150,192 GWh of natural gas to final customers in 2015 and 157,211 GWh in 2010.

Table 60. Sales of natural gas (GWh)

	2005	2010	2015
Total sales	153,200	157,211	150,192
Industrial customers	93,504	95,816	95,390
Households	41,698	45,788	40,783

Source: ARE S.A.

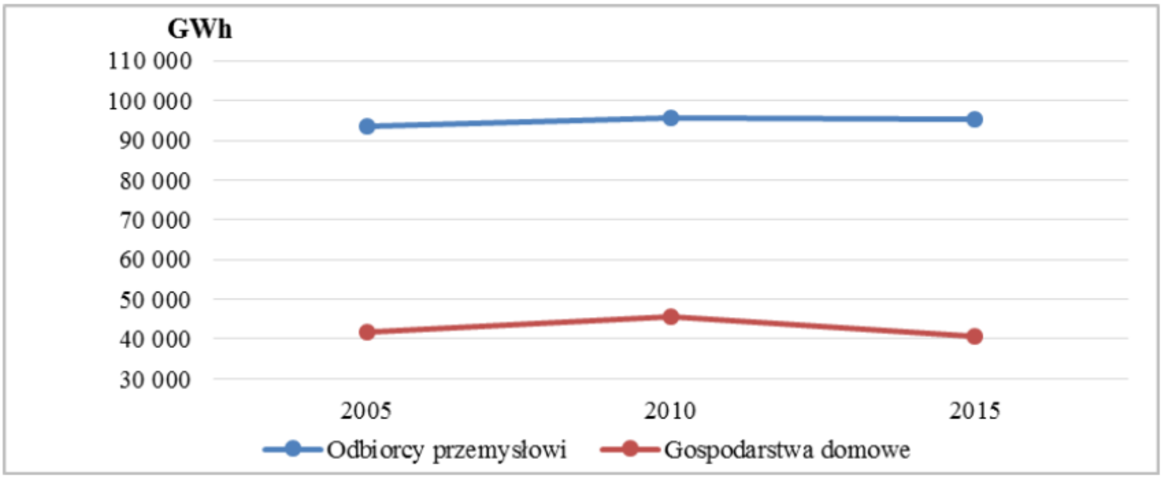
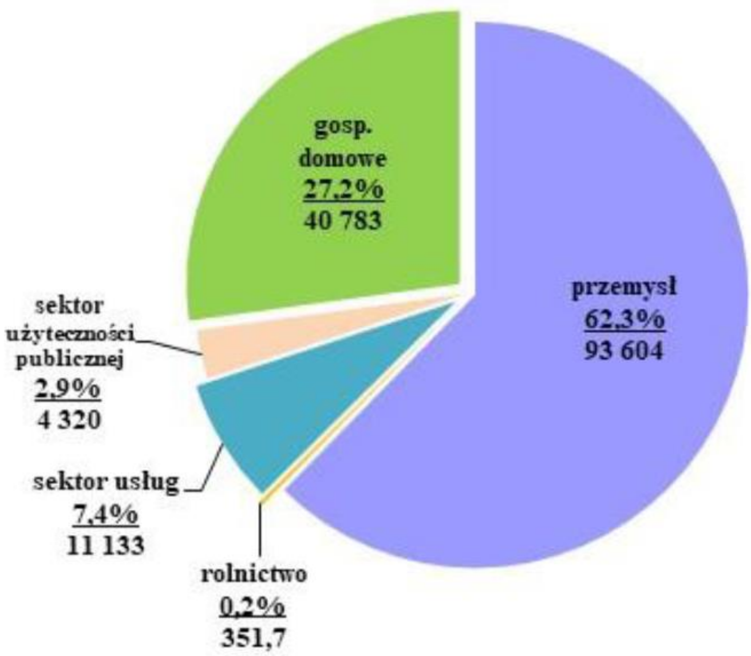


Figure 37. Sales of natural gas to industrial and household customers in 2005, 2010, 2015 (GWh). Source: ARE S.A.

GWh	**GWh**
Odbiorcy przemysłowi	Industrial customers
Gospodarstwa domowe	Households



gosp. domowe	**households**
przemysł	**industry**
rolnictwo	**agriculture**
sektor usług	**service sector**
sektor użyteczności publicznej	**utilities**

Figure 38. Breakdown of gas sales to final customers by sector (GWh) – as at the end of 2015. Source: ARE S.A.

Domestic natural gas production was 47,591 GWh in 2015 (47,414 GWh in 2010). Total natural gas imports, i.e. the sum of imports and intra-Community acquisitions, amounted to 128,762 GWh in 2015 (115,136 GWh in 2010).

Imports of natural gas from the East totalled 93,432 GWh in 2015 (103,174 GWh in 2010). Intra-Community acquisition of gas totalled 33,950 GWh in 2015 (11,962 GWh in 2010). In December 2015, liquefied natural gas from Qatar was imported for the first time to Poland by sea to the Świnoujście terminal under PGNiG's contract with Qatargas.

Table 61. Natural gas production and imports in 2005, 2010, 2015

	2005	2010	2015
	GWh		
National production	50,194	47,414	47,591
Total imports	110,708	115,162	129,123
Imports from the East	101,382	103,204	93,731
Intra-Community acquisition	3,929	11,958	34,013

Source: ARE S.A.

On 1 January 2017, the provisions of the Energy Law came into force, abolishing the supervision of the President of the Energy Regulatory Office over tariffs for the sale of gas to wholesale customers, the sale of LNG and CNG, the sale of gas to final customers purchasing it at a virtual point and through tenders, auctions and public procurement. The obligation to obtain approval of the President of the Energy Regulatory Office for price lists of high-methane and nitrogen-rich natural gas sold to final customers other than households was lifted on 1 October 2017. The ERO President will supervise tariffs (i.e. maximum prices) for network gas sold to households until the end of 2023.

Following the amendment of the Act on stocks of crude oil, petroleum products and natural gas in 2017, natural gas stocks will have to be stored physically, in specifically designated installations and in a manner that meets strictly defined conditions. The discharge of this obligation through the use of 'virtual storehouses' by Obliged Entities is excluded. The amended Act also provides the cancellation or expiry of a licence or discontinuation of natural gas imports during a given gas year does not release the Obliged Entity from maintaining mandatory stocks of natural gas until the end of the year.

- *Electricity prices by sector*

Price projections for final customers are based on projections of averaged system costs, taking into account estimates of costs related to the operation of the particular support systems in Poland, the level of taxation and transmission and distribution charges. The presented electricity price projections include the full cost associated with the operation of support systems for energy produced from renewable energy sources and in cogeneration, as well as for energy efficiency improvement projects. The analysis also factors in the introduction of a capacity payment mechanism.

The calculations of final customer prices and their components are based on data collected using the G-11e statistical form, the aim of which is to obtain information on electricity prices by categories of standard household and non-household (including industrial) final customers, defined in accordance with the new data collection methodology developed and recommended by the European Commission. A final customer means a customer consuming electricity for his own use.

Categories of standard final customers are determined by annual electricity consumption. The reporting form contains 12 categories of final customers: 5 categories of standard household customers and 7 categories of standard industrial and service customers.

The table below presents projections of electricity prices for the three defined groups of final customers. The presented figures are average prices offered under comprehensive contracts (Polish *umowa kompleksowa*) and separate contracts (Polish *umowa rozdzielona*), inclusive of taxes (the calculations are based on an excise duty of PLN 0.02/MWh at current prices and 23% VAT throughout the forecast horizon). As is shown by the results obtained, a gradual increase in electricity prices is expected for all the three groups of final customers. The increase in prices is evenly distributed across the sectors, which is a consequence of the assumption of proportional distribution of the costs of all support schemes, with the exception of support for renewable energy (currently industry is partially exempted from the RES charge). The main factors behind the projected increase include the costs of CO_2 emission allowances, which increase over time, and the development costs of zero-emission technologies.

VAT for industrial customers is reimbursed by the State Treasury, and therefore electricity prices inclusive of VAT are given for industrial consumers for reference only.

Table 62. Electricity prices by sector [EUR'2016/kWh] – Reference scenario

	2005	2010	2015	2020	2025	2030	2035	2040
Households	0.1142	0.1453	0.1504	0.160	0.179	0.180	0.188	0.189
Services	No data	No data	0.1346	0.142	0.160	0.162	0.169	0.170
Industry	0.066	0.1001	0.0823	0.101	0.115	0.116	0.122	0.118

- *National retail prices of fuels*

The model simulations distinguish between ex-mine/ex-yard coal prices by groups of consumers – energy sector, industry and small-scale consumers based on the domestic structure of prices taken from 2005-2015 statistics. Also for natural gas, the simulations take into account the costs and share of gas produced in Poland, the average costs of transport within the network, and costs associated with infrastructure investments (network projects and construction of the Świnoujście LNG terminal). The projected prices of natural gas, coal and petroleum products are based on trends in global prices of these energy carriers.

Table 63. National retail prices of fuels [EUR'2016/ktoe]

Years	Natural gas								Steam coal					Cooking coal
	Industry (Total price)	Industry (excise tax)	Industry (VAT)	Electricity generation (Average price)	Electricity generation (Nitrogenrich gas)*	Households (Total price)	Households (Excise tax)	Households (VAT)	Industry (Total price)	Electricity generation (Total price)	Households (Total price)	Households (Excise tax)	Households (VAT)	Industry (Total price)
	EUR'2016/ktoe													
2005	212,271	0	0	175,216	-	418,771	0	75,428	96,360	87,981	222,767	0	40,154	154,630
2010	379,524	0	0	243,484	-	645,043	0	116,229	147,186	129,740	299,987	0	54,089	224,466
2015	339,968	2,832	0	238,394	332,803	636,686	567	119,527	117,657	106,019	318,345	0	59,532	138,406
2020	291,002	2,666	0	215,286	304,723	621,916	0	116,293	106,616	97,046	318,830	0	59,619	142,442
2025	327,425	2,666	0	242,481	343,215	700,476	0	130,983	118,462	107,829	354,256	0	66,243	158,269
2030	350,711	2,666	0	259,868	367,815	750,703	0	140,375	125,231	113,990	374,499	0	70,028	167,313
2035	373,211	2,666	0	276,667	391,598	799,232	0	149,450	127,770	116,301	382,090	0	71,448	170,704
2040	382,210	2,666	0	283,386	401,114	818,643	0	153,080	130,308	118,611	389,681	0	72,867	174,096

Years	Light fuel oil					Diesel					Gasoline			LPG			
	Industry (Total price)	Industry (Excise tax)	Households (Total price)	Households (Excise tax)	Households (VAT)	Commercial use (Total price)	Commercial use (Excise tax)	Non-comm use (Total price)	Non-comm use (Excise tax)	Non-comm use (VAT)	Non-comm use (Total price)	Non-comm use (Excise tax)	Non-comm use (VAT)	Commercial use (Total price)	Non-comm use (Total price)	Non-comm use (Excise tax)	Non-comm use (VAT)
	EUR'2016/ktoe																
2005	613,425	79,188	796,974	79,188	143,761	1,031,865	406,181	1,258,889	406,181	227,024	1,457,052	573,547	262,861	704,947	860,478	206,607	155,070
2010	730,719	74,717	929,669	74,717	167,791	1,130,529	415,357	1,379,244	415,357	248,825	1,573,408	573,598	283,685	792,309	966,616	199,271	174,417
2015	671,381	65,730	860,111	65,730	160,925	1,037,404	415,847	1,276,007	415,847	238,563	1,408,693	507,954	269,651	612,179	752,980	178,755	140,779
2020	745,110	61,857	739,697	61,857	138,278	1,120,631	391,342	1,378,376	391,342	257,745	1,479,352	478,021	276,627	716,135	834,678	168,221	156,078
2025	832,689	61,857	783,969	61,857	146,554	1,194,244	391,342	1,468,920	391,342	274,676	1,557,631	478,021	291,264	779,024	889,807	168,221	166,387
2030	907,442	61,857	831,194	61,857	155,382	1,257,075	391,342	1,546,203	391,342	289,127	1,624,446	478,021	303,758	832,702	936,862	168,221	175,186
2035	942,429	61,857	881,569	61,857	164,799	1,286,483	391,342	1,582,374	391,342	295,891	1,655,717	478,021	309,606	857,826	958,885	168,221	179,304
2040	992,172	61,857	935,305	61,857	174,845	1,328,292	391,342	1,633,800	391,342	305,507	1,700,177	478,021	317,919	893,545	990,196	168,221	185,159

Source: Own study by ARE S.A., Eurostat – Energy prices and taxes

Energy-related investment costs

- Capital expenditure on infrastructure development in the gas sector

Only 11 of the strategic projects placed on the OPI&E list will cost **PLN 4.4 billion.** In addition to these projects, GAZ-SYSTEM S.A. has included another 20 transmission infrastructure projects in the National Ten-year Gas Transmission System Development Plan.

The PGNiG Group's 2017-2022 strategy with an outlook until 2026 sets out capital expenditure of **PLN 10 billion** for the development of distribution networks in 2017-2022. As a result of these investments, the Group expects to connect over 300,000 new natural gas customers to the distribution network and increase the volume of gas distribution by 16%. Moreover, the PGNiG Capital Group expects to invest approx. PLN 300 million in trade and storage. The expansion of KPMG Kosakowo to reach the capacity of 250 mcm is the largest such investment project in the near future.

Companies operating on the gas market have revised many of their projects and it is, therefore, pointless to provide detailed data that are not up-to-date. Current data are provided in Annex 2 to the NECP.

- Capital expenditure on infrastructure development in the electric power sector

Forecasted capital expenditure on the replacement of end-of-life generation units and the construction of new and retrofitting of existing units, as required by the Industrial Emissions Directive and contained in the BAT Conclusions of 17 August 2017, is shown in the table below. Capital expenditure on sources in the electric power industry were determined on the basis of the results of the MESSAGE model, taking into account the unit capital expenditures discussed earlier. The amount of expenditure on the adaptation of the public energy sector to the requirements of the BAT Conclusions was adopted on the basis of EY's analysis[38].

The estimated total investment needs in the generation sector (table below), necessary to ensure the security of electricity supply while meeting the stricter environmental requirements, amount to approx. EUR'2016 79 billion by 2040. This translates into an average annual capital expenditure of approx. EUR 3.2 billion by 2040.[*]
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Table 64. Projected capital expenditure in manufacturing in 2016-2040 [EUR'2016 billion]

Generation sector	**2016-2020**	**2021-2025**	**2025-2030**	**2031-2035**	**2036-2040**	**2016-2040**
Total	**14.3**	**7.7**	**6.8**	**20.7**	**29.5**	**79.0**
Power plants	9.8	5.1	3.9	15.4	25.0	**59.2**
CHP plants	4.5	2.6	2.9	5.3	4.5	**19.8**
Adaptation to IED (new BAT)	1.15	0.55	0	0	0	0
By fuel						
Coal-derived	9.4	2.7	0.7	0.0	0.0	**12.7**
Gaseous	2.1	0.5	0.4	4.3	2.4	**9.8**
Nuclear	0.0	0.0	0.0	8.3	16.5	**24.8**
Other fuels	0.0	0.0	0.3	0.1	0.0	**0.5**
Renewable sources	2.8	4.5	5.5	8.1	10.5	**31.2**
- Water	0.1	0.1	0.4	0.1	0.1	**1.0**
- Wind	1.4	2.6	2.9	5.7	6.5	**19.1**
- Photovoltaic	0.6	0.6	0.6	0.5	0.5	**2.7**
- Biomass	0.3	0.5	0.6	0.6	1.1	**3.1**
- Biogas	0.4	0.7	0.9	1.1	2.3	**5.3**

The bulk of the capital expenditure (over 60%) occurs in the period of 2030-2040 period (averaging approx. EUR'2016 5 billion per year) when most of the existing coal-fired units will be decommissioned and replaced by

[38] *Koszty dostosowania sektora energetycznego do wymagań Konkluzji BAT oraz metodyka oceny odstępstw* [Costs of adapting the energy sector to the requirements of the BAT Conclusions and the methodology for assessing deviations], EY, Warsaw, 12 July 2017.

nuclear, gas and renewable units. Approx. 5,000 MW of the current renewable energy units will have to be replaced[39]. The required capital expenditure on renewable sources for the whole period 2016-2040 is estimated at approx. 40% of the total capital expenditure.

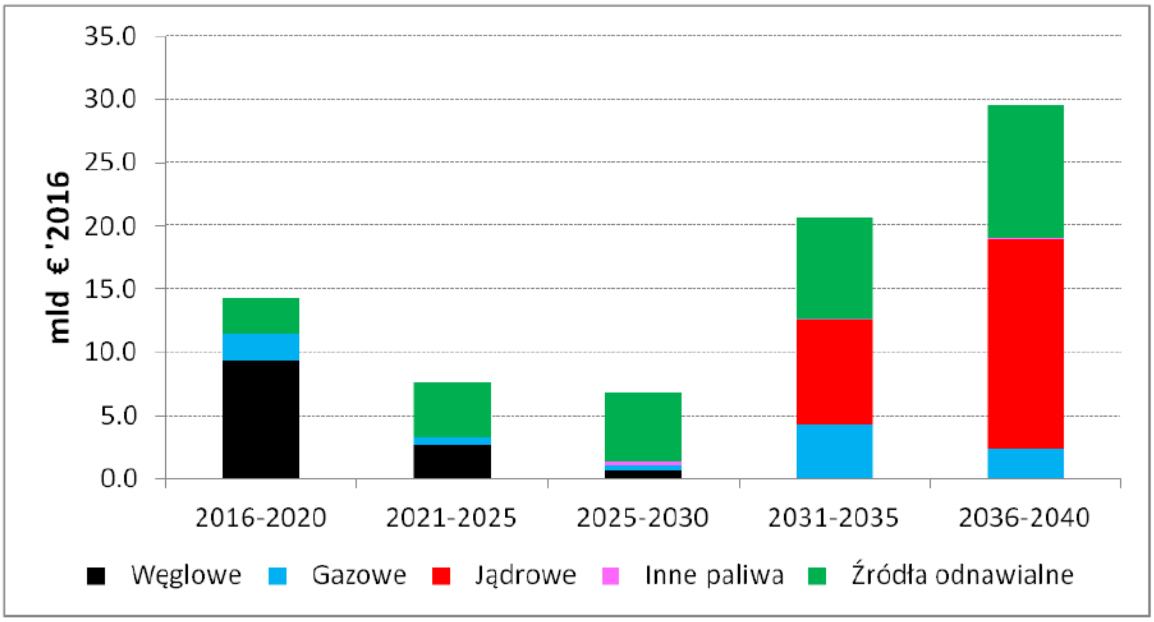

Figure 39. Capital expenditure on the projected structure of generation sources by fuel

mld €'2016	**EUR'2016 billion**
Węglowe	Coal-derived
Gazowe	Gaseous
Jądrowe	Nuclear
Inne paliwa	Other fuels
Źródła odnawialne	Renewable sources

Projected capital expenditure in the electricity transmission and distribution sub-sector comprises the costs of network expansion or strengthening related to the introduction of new capacities into the system. The assessment of these costs is an extremely difficult task, as upgrading costs depend on the condition of the existing infrastructure, location of sources and type of technology, area, length and rated power of power lines. In general, the more decentralised the power system is, the greater the need for strengthening of the distribution network and thus the higher the costs involved.

This analysis employs an estimation based on the adopted unit investment costs for the transmission network (HV) and for the distribution networks (MV and EHV), expressed in million EUR/MW of additional capacity of generation units connected to the respective network. Unit investment costs were assumed according to the PRIMES model (Table 4.15), with the exception of network costs for offshore wind farms, which were assumed to be 0.7 million EUR/MW of installed capacity. Projected capital expenditure in the electricity transmission and distribution sub-sector in 2016-2040 is presented below.

Table 65. Projected capital expenditure in the electricity transmission and distribution sub-sector [EUR'2016 billion]

Transmission and distribution	**2016-2020**	**2021-2025**	**2025-2030**	**2031-2035**	**2036-2040**	**2016-2040**
Total	**1.8**	**1.4**	**1.2**	**3.3**	**3.4**	**11.1**
Transmission network	1.2	0.8	0.2	2.3	1.9	**6.3**
Distribution network	0.6	0.6	1.0	1.0	1.5	**4.8**

[39] The analysis assumes that existing units will be replaced by new ones once they reach end of life, although it is probable that some of them will remain in operation beyond 2040 following their extensive retrofitting.

The estimated demand for capital expenditure on the development of the national power grid in 2016-2040 amounts to just over EUR'2016 11 billion, approx. 43% of which will be allocated to the development of the distribution network.

4.6. Dimension Research, innovation and competitiveness

4.6.1. Current situation of the low-carbon-technologies sector and its position on the global market

In Poland, emission abatement actions are carried out mainly in the energy sector[40], which accounts for 42% of national emissions. This is due to the domination of coal in the fuel structure of energy sources and the low efficiency of generation units. As this coal-dominated structure cannot be changed quickly, efforts are primarily focused on developing technologies that increase the efficiency of primary energy conversion in coal-fired power and heat generation units. In addition to gas sources, coal-fired power plants are a necessary system component by guaranteeing a stable operation of the system, especially in view of the increasing share of renewable energy sources that are characterised by unstable operation (wind and photovoltaic power plants). Nuclear power plants may also be used as system sources, but their rate of development is limited.

Clean coal technologies

4.6.1.1 High-efficiency coal and lignite-fired power plants

The basic way to reduce pollutant emissions in new coal-fired power generation units is to increase generation efficiency and reduce specific pollutant emissions by increasing fresh steam parameters (temperature and pressure). The 900-1,000 MW coal-fired units in Opole and Jaworzno were built using a supercritical parameter technology, where the steam temperature is 580-600°C and the pressure is 260-300 bar. In December 2017, a unit was commissioned at the Kozienice power plant with a capacity of 1,075 MW and an efficiency of 45.6%. Preparations are underway to construct super-supercritical units in which the steam temperature is approx. 620°C, the pressure is 315 bar and the net efficiency is in the range of 43% to 46%. New steel grades are required to reach ultra-supercritical parameters, i.e. the pressure of 350 bar and the steam temperature of approx. 700°C, which enable a power plant to reach a net efficiency above 48%. Such steel grades are currently being developed in global technological centres. The electrical capacity of coal-fired units under construction typically ranges from 850 to 1000 MWe.

4.6.1.2 Integrated gasification combined cycle coal-fired power plants

Integrated gasification combined cycle (IGCC) plants can be an alternative to ultra-supercritical power plants. In these units, the first step is to gasify the fuel and the resulting synthesis gas is used in the gas-steam system. IGCC units can achieve an efficiency of over 50%. Only demonstration plants are currently in operation in Europe (Vresova – 400 MW, Czech Republic; Schwarze Pumpe – 200 MWt, Germany; Buggenum – 250 MW, Netherlands and Puertollano – 350 MW, Spain). Also outside Europe, IGCC technology is still at the demonstration phase. A unit in Mississippi shows why this is the case. The power plant in Kemper County was to be the largest power unit using coal gasification technologies under commercial conditions (582 MW of installed capacity). However, because of economic considerations, a decision was taken in mid-2017 to convert the plant to natural gas combustion. In a situation where easily accessible gas fuel is cheap, there is no pressure to develop new and therefore risky technologies.

4.6.1.3 Coal-fired power plants with CCS and CCUS systems

Increasing the efficiency of sources of electricity and heat generation for a low-emission economy is universal, as it reduces the specific emissions of all pollutants. Measures to reduce greenhouse gas (GHG) emissions, which form part of climate policies, are addressed separately.

The technology recommended by the European Commission for the clean use of fossil fuels in power generation involved the use of CCS (Carbon Capture and Storage) technologies. However, CCS technologies have proved to be very difficult to apply widely. A greater potential is seen in the development of carbon processing

[40] *Narodowy program rozwoju gospodarki niskoemisyjnej* [National programme for the development of low-emission economy], Ministry of Energy, Warsaw 2015.

technologies, the use of CO_2 in carbochemistry and the production of fuels from carbon, including biofuels. Taking this into account, the development of Carbon Capture Utilization and Storage (CCUS) technology is recommended[41]. The use of this technology in the combustion of fossil fuels is considered, especially by European Union bodies, as the best – and in the future the only acceptable – form of energy generation from fossil fuels. It is not a foregone conclusion when these technologies will be commercially available, given that the last 10 years have not brought any significant progress, especially in terms of cost reduction. According to the International Energy Agency, the costs of carbon capture range from 20 to 80 USD/t CO_2, the costs of transport over 100 km from 1 to 10 USD/t CO_2, and the costs of gas injection and injected gas monitoring from 2 to 5 USD /t CO_2. Their verification is not possible, as no industrial installation of this type has yet been put into operation. However, the European Union requires that new fossil-fuel power units be built to 'CCS ready' or 'CCU ready' to enable the launching of the technology as soon as it reaches commercial maturity. This is expected to happen in 2030 at the earliest and only if prices of GHG emission allowances reach a minimum level of 50 EUR/t CO_2. Despite a wide-ranging research effort, it will be extremely difficult for CCS technologies to become commercially mature.

CCS and CCUS research and development are focused on:

- technologies for carbon capture from gases from air combustion of primary energy carriers, especially coal. Such systems may be added to existing power plants and included in newly built ones;
- pre-combustion carbon capture technologies, where fuels are in the form of synthesis gas or natural gas with the separation of carbon and hydrogen streams. Hydrogen can then be used for electricity generation or as a fuel in fuel cells and the carbon stream is converted to a form suitable for storage or sequestration;
- oxy-fuel combustion technologies, in which oxygen is used instead of air in the combustion process. The result is exhaust fumes containing mainly H_2O and CO_2, which can be easily captured after steam condensation;

Carbon capture from air combustion fumes involves the process of chemical absorption of carbon dioxide. This technology is the closest to full commercial maturity. However, in order for this technology to be used in the power industry, it is necessary to increase the efficiency of the currently tested installations by about 50 times[42] and to solve several technical problems with the reduction in concentration of other gaseous pollutants (SO_2 and NO_x). This can significantly increase the cost of CCS installations and affect their cost-effectiveness. Recent evaluations of the profitability of industrial use of CCS technology in power generation are not optimistic[43].

Pre-combustion carbon capture technologies require prior gasification of solid fuel. The gasification of fossil fuels is a process well known and available on an industrial scale for many years, but not very widely used for energy purposes. IGCC installations require further development to tackle many of the remaining technical problems. The market also lacks high-efficiency hydrogen turbines that would be adapted to the needs of CCS.

The technology of combustion in an oxygen-enriched atmosphere consists in the removal of nitrogen from the air using the traditional air separation technology. The fuel is then burned in a mixture of oxygen and carbon oxide. Such combustion results in exhaust gases consisting mainly of CO_2 and water vapour. These flue gases can be thickened to produce a stream of highly concentrated CO_2. Combustion in a pure oxygen atmosphere, mixed with CO_2, is well understood on a small scale, and there are also many industrial plants with oxygen combustion. However, in cases where coal is the fuel and very large installations are used, such combustion is not yet sufficiently well researched in terms of the required scale of the process.

Demonstration facilities which have been set up in several European countries (Italy, the Netherlands, Germany) have not been successful. In Poland, an attempt was made to implement CCS technology as part of the construction of a 858 MW lignite-fired unit in Bełchatów. 16.6 million tonnes of CO_2 was planned to be injected into storage over a period of 10 years. The capacity of the installation was to correspond to 260 MW of electric

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[41] *Nowe technologie i przyszłość energetyki* [New technologies and the future of the energy sector], Prof. dr hab. inż. Wojciech Nowak, the AGH University of Science and Technology Centre of Energy.

[42] *Możliwości redukcji emisji CO_2 i jej wpływ na efektywność, koszty wytwarzania energii z węgla* [Options for reducing carbon emissions and their impact on effectiveness and costs of energy production from coal], Krzysztof Stańczyk, Marek Bieniecki, the Górnictwo i Geoinżynieria Journal, Volume 2, 2007.

[43] *Polska energetyka wczoraj i dziś, prezentacja na Kongresie innowacji w energetyce* [Polish power industry yesterday and today, a paper presented at the Energy Innovation Congress], Chmielniak, 2017.

capacity (30% of the unit's installed capacity). Capture efficiency was planned at 85% and the reduction of the unit's capacity due to the use of steam for CCS was planned at 28.6 MWe. However, the project was shown not to be economically viable and it was abandoned.

Gas turbine combined cycle power plants

Gas turbine combined cycle (GTCC) power plants are becoming increasingly important in the Polish power system and are the most typical electricity generation technology based on gaseous fuels. High efficiency of such units, currently exceeding 61%, is achieved by combining two cycles: an open-cycle gas turbine system and a closed-cycle steam system. In the former cycle, natural gas is burned in a gas turbine which drives an electricity generator. Exhaust fumes entering the gas section cools down from the temperature of 1600°C at the inlet (1700°C behind the combustion chamber) to approx. 500-650°C. They are then directed to a recovery boiler where their energy is used to produce steam, which is the operating medium of the second cycle. The produced steam feeds the steam turbine that drives the electricity generator. This system enables recovering, through the steam cycle, some of the exhaust gas from the gas turbine which is lost in the open gas turbine cycle.

Compared to coal-fired units, gas-steam units are characterised by higher efficiency, lower investment and operating costs, a relatively short construction time and low emissions. The main factor affecting the cost of electricity generation in gas-steam units is the cost of fuel, whose share may amount to up to 80% of the total cost of generation, while unit capital expenditures are low (up to EUR 850,000/MW). Given the significant investments in the gas transmission infrastructure, as well as Poland's efforts to diversify its supply sources (e.g. through the Baltic Pipe and LNG Terminal projects), we can expect an increase in the supply of raw material on the Polish market.

Cogeneration

Cogeneration is a very effective way of increasing the efficiency of primary-to-final energy conversion, while reducing specific emissions of pollutants. For this reason, Poland should be increasing the share of cogeneration in electricity generation, while promoting the development of indigenous technologies in this area. The potential for innovation concerns in particular the development of technologies for electricity and heat cogeneration, as well as district cooling combined with technologies for the production of gaseous and liquid fuels using methods of fermentation or gasification of biomass, or agricultural, animal or municipal waste, sewage, etc., i.e. low or even cost-free raw materials.

The expansion of the district heating network combined with the liquidation of individual heat sources should guarantee compliance with Article 7b of the Energy Law, which requires that buildings with a capacity of not less than 50 kW must be connected to the district heating network, unless an energy undertaking has refused to do so due to economic unprofitability. Appropriate mechanisms of financial support for the development of the district heating network may change the economic calculation of network investments and thus contribute to the reduction of pollutant emissions.

It is also important to support the development of innovative technologies for generating cooling from district heating (adsorption chillers, installations in buildings) and to put in place appropriate mechanisms for the commercialisation of this solution which, in addition to reducing the load on the power grid on hot days and enabling the operation of cogeneration units in summer, will contribute to improving the economic efficiency of investments in district heating networks.

Systemic support for such solutions should cover both heating companies (with regard to the construction of district heating substations) and final customers. The development of a system of investment support for tri-generation technology is important in view of the potential for the generation of cooling from district heat in large district heating systems, the result of which would be to reduce demand for peak capacity of the power system during the summer season and increase the annual utilisation of the capacity of power units operating in cogeneration and tri-generation modes (which would improve their profitability).

Methane for energy purposes

The following measures are necessary to increase the use of methane for energy purposes:

- Identification of existing methane resources that can be recovered for energy purposes.

- Large-scale implementation of deposit demethylation technology by increasing the effectiveness of the support system for electricity generation from methane.
- Large-scale implementation of the technology of capturing methane from ventilation air and recovering methane by fracking coal-seams prior to extraction.

Methane recovery from coal deposits by fracking is in particular a method of choice for companies responsible for the extraction of raw materials. According to PGNiG S.A.'s estimates, between 150 and 200 bcm of natural gas can be extracted from the Upper Silesian Coal Basin. Under the INGA Innovative Gas Industry programme, approx. PLN 60 million will be allocated to innovative technologies in the area of coal demethylation.

Biomass

Biomass is the most popular source of renewable energy in Poland and is used mainly for heating. No additional carbon dioxide is emitted to the atmosphere during the combustion and co-combustion of biomass, as the volume of carbon dioxide produced is balanced with the volume absorbed by burnt plants at the time of their growth. However, in the short term, biomass combustion causes carbon dioxide emissions to the atmosphere.

For a more sustainable use of biomass for energy purposes it is important to:

- abandon co-firing as an inefficient way of generating electricity;
- further increase local biomass use and reduce biomass imports;
- adopt a new approach to the management of land for biomass production, taking into account the balance of emissions and carbon recovery from green areas.

Biogas plants

Biogas plants are an important technology in the field of RES. However, due to high investment costs, they require incentives to stimulate their development. The promotion of biogas plants in Poland requires:

- removing social barriers to investment in agricultural biogas plants;
- organic recycling of biodegradable waste to obtain raw material for energy generation;
- promoting the use of micro- and small biogas installations in agriculture and agri-food processing;
- using existing water and sewage facilities as municipal biogas plants;
- reviewing and adjusting financial instruments for small biogas plants.

Germany is currently the largest market for biogas plants. In 2015, a total of over 4 GW of power was installed in fewer than 9,000 units. However, a slowdown in biogas investments is expected due to the high costs of this technology, combined with a slow decline in costs (compared to other renewable technologies).

Wind energy

The onshore wind energy sector in Poland exhibited the highest rate of development thanks to a favourable support system based on green certificates. The potential of onshore wind energy, as estimated by the International Renewable Energy Agency, is such as to enable, in theory, the installation of up to 15,000 MW of capacity by 2030. Offshore wind energy is a promising area of RES development. Its theoretical potential based on the availability of locations for offshore wind farms, wind conditions and the maximum productivity of offshore wind farms is estimated at 8 GW of installed capacity and 48-56 TWh of energy per year.

Taking into account systemic, economic, legal and social conditions as well as realistic investment plans, the market potential of onshore wind energy is estimated at approx. 10 GW of installed capacity by 2030, compared to less than 5 GW installed in 2015.

According to data provided by Wind Europe, wind energy is the fastest growing renewable energy sector. In 2000, wind power accounted for only 2.4% (12.9 GW) of the capacity of the European power system. By 2015, this figure increased already to 15.6% (141.6 GW), 0.1% more than the share of hydroelectric power. According to the forecasts of the aforementioned organisation, the installed capacity of onshore wind farms is likely to double by 2030.

Photovoltaics

Photovoltaics is the second area of significant RES development in Poland after wind power. Photovoltaic panels/modules are the most important element of the system responsible for power generation by home solar power plants. They are built of solar cells made of semiconductors. Their task is to convert solar energy into direct current. A photovoltaic system uses at least a few panels so as to obtain a number sufficient to produce enough current to power electrical devices. Photovoltaic panels are usually installed on rooftops or mounted on posts in the ground. The location must be such as to protect the surface of the panels from factors that may damage or contaminate them in a way that reduces efficiency.

Energy storage

Apart from adapting the power system to an increased share of unstable RES, it is necessary to develop energy storage technologies[44]. Electricity storage forms an important element of a market-based approach to balancing energy demand and supply, while ensuring reliability, efficiency and security of electricity supply. As part of the smart grid, it will also complement distributed generation from renewable sources, which is particularly vulnerable to generation instability due to changing weather conditions. The International Electrotechnical Commission (IEC), a global organisation for the preparation and publication of international standards for all electrical, electronic and related technologies., published *Electrical Energy Storage – White Paper* in December 2011. The document addresses the topic of energy storage, with particular emphasis on available systems and the most popular trends in their application.

Currently, pumped-storage power plants account for more than 99% of the world's energy storage. The total capacity of these power plants exceeds 100 GW, while the total capacity of all other energy storage facilities is not higher than 1 GW. Efficiency of energy recovery in such a process is approx. 80%. The response time to changes in demand does not typically exceed one minute. On the minus side, such power plants require the use of two water tanks at significantly different heights, which is usually not viable in lowland areas.

Large water reservoirs created by dams at hydroelectric power plants are another type of water-based energy storage. Water can be trapped in the reservoir when the demand is low and released when it is high. The overall effect is then the same as with pumped-storage power plants, except that no energy needs to be spent on pumping.

Technically, batteries are the simplest form of energy storage. Batteries enable energy to be stored in an electrochemical form that lends itself easily to recovery. They are a convenient energy store, as charging and discharging does not require any additional infrastructure. Up to 85% of energy input can be recovered. High price and limited service life are, however, the disadvantages.

The growing popularity of electric vehicles would enable the application of batteries as dispersed energy stores. Since an average car spends 95% of its time idle, the owner could use the car's battery as an energy store during that time, charging it at night when energy is cheap and using it during the day. A car battery can store 20-50 kWh of electricity, which is sufficient to meet 2-5 days of average household demand.

Hydrogen systems are a modern form of storage technology. Hydrogen can potentially be used for large-scale energy storage. It can be produced in large quantities from methane and steam by steam reforming or by water electrolysis. The hydrogen obtained in this way is used as a high-energy fuel in combustion engines or fuel cells.

Solar thermal collectors

In addition to economic benefits, the widespread use of solar collectors has a positive impact on the environment and public health. This is due to the fact that collectors are an economically interesting alternative for households that are not connected to district heating and obtain heat energy from domestic installations fuelled by low-quality coal or burnt waste.

The use of solar collectors is developing quite robustly in Poland, although in 2013 fewer collectors were installed (274,000 m^2) than a year before (over 300,000 m^2). This has been the first instance where the rate of development of the Polish collector market dropped since 2000, i.e. the year when the Institute of Renewable

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[44] *Magazynowanie energii elektrycznej* [Electrical energy storage], Hajdrowski K., Enea Operator (*Energia Elektryczna*, issue No 11/2012).

Energy commenced to research that market. The development of the collector market has so far been driven by the subsidy programme implemented in 2010-2014 by the National Fund for Environmental Protection and Water Management (NFOŚiGW).

In the case of households which obtain heat from electricity, the installation of a collector on the building will involve a significant reduction in demand for electricity, which will contribute to improving the security of the power system on a nationwide scale and reducing pollutant emissions.

Heat pumps

As in the case of solar collectors, the growth of the heat pump market will stimulate the development of modern lines of industries and services in Poland and will contribute to reducing the use of dirty fuels for space heating and hot water production. Wider use of heat pumps and ground source heat exchangers for heating purposes requires:

- Monitoring the quality of existing heat pumps.
- Raising awareness of the benefits of installing heat pumps and providing information on how to properly operate pumps.
- Reviewing the existing legislation on heat pumps in order to create a stable legal framework for the development of this market.
- Reviewing support instruments (other than those resulting from the RES Act).
- Creating a scientific environment involved in the development of heat pumps.

Geothermal energy

Poland has good geothermal conditions for the construction and operation of installations providing hot water for heating and for use in, for example, geothermal centres. As much as 80% of the country's territory is covered by 3 geothermal provinces: Central European, Pre-Carpathian and Carpathian. However, geothermal waters can be used only in relation to 40% of the country's territory (extraction is profitable when the temperature reaches 65°C up to a depth of 2 km, the salinity does not exceed 30 g/l and the capacity of the source is adequate). The water in these areas has a temperature of 30-130°C and is found in sedimentary rocks at a depth of 1-10 km. Natural outflows are very rare (the Sudetes – Cieplice, Lądek Zdrój). The first Polish Geothermal Plant in Bańska-Biały Dunajec was established in 1989-1993. Since 2001, the wells and installations have been used by PEC Geotermia Podhalańska SA, which covers 35% of the heat demand in Zakopane. The cost of building an installation with a capacity of approx. 10 MW, which is sufficient to connect 1,000 single-dwelling houses, totalled PLN 20 million for one of the wells in Podhale.

Use of waste

Low-carbon transformation will not be possible without using residual waste fractions in low-carbon energy processes in order to supplement the recycling-based system of waste management. Reuse is an economically efficient method of waste management. The use of waste as fuel in waste incineration or co-incineration plants is a way of managing the residual fraction of municipal waste (not suitable for recycling), especially in the context of EU regulations limiting landfilling. However, valuable raw materials should primarily be recovered from waste in order to meet the EU's reuse and recycling targets for municipal and packaging waste and to reduce the use of primary resources, which will contribute to a closed-loop economy.

Electromobility

Regardless of the low-carbon sources of power generation, it is essential to create an electromobility ecosystem that will comprise vehicle manufacturers and users and the energy sector operators providing electromobility services. This will contribute to reducing emissions from transport, which account for 12% of total greenhouse gas emissions. This requires action on several levels: from awareness-building among potential users through the introduction of a system of benefits for electric vehicle users, the stimulation of development of manufacturers in the electromobility segment and the adoption of regulations conditioning the development of electromobility to the adaptation of power networks to the needs of vehicles.

In response to these challenges, the Ministry of Energy has developed the Clean Transport Package consisting of the Electromobility Development Plan (setting out the conditions for the development of electric vehicles), the National Policy Framework for the Development of Alternative Fuel Infrastructure (setting out targets and tools for the development of infrastructure necessary for the use of alternative-fuel vehicles) and the Act establishing the Low-Emission Transport Fund tasked with supporting the development of alternative fuel infrastructure and the creation of a market for alternative-fuel vehicles.

Electromobility is treated as a priority in the Clean Transport Package due to the fact that, in addition to reducing greenhouse gas emissions from combustion vehicles, it can be used for electricity storage. The prerequisite will be the creation of an appropriate infrastructure for charging car batteries and feeding accumulated energy into the power grid.

The concentration of public financial resources will be an important tool for the development of electromobility: in addition to the establishment of the Low-Emission Transport Fund, an important role will be played by research programmes of the National Centre for Research and Development (NCBiR) dedicated to electromobility and the creation of a programme supporting the demand for electric vehicles within NFOŚiGW. The role of the Fund may also be to create future consumers of electric vehicles by launching pilot projects.

Nuclear energy

Construction of nuclear power plants

All countries where nuclear power plants are operated or built recognise nuclear power as an economic and sufficiently safe power generation technology. For the same reasons, other countries are continuing their plans to develop nuclear power in the future.

Notwithstanding the above, there are developments in nuclear power plant technology, relating in particular to reactors, aimed at increasing the use of uranium fuel and improving operational safety in order to overcome fears of nuclear power, even those irrational ones. These measures are all the more so justified in view of the fact that nuclear power is a universally accepted direction of development of low-emission energy generation.

Development is focused primarily on light water reactors (LWRs), pressurised water reactors (PWRs) and boiling water reactors (BWRs), which are the most common types of reactors used in nuclear power plants operated and built worldwide (over 80%). Generation III+ LWRs have passive emergency core cooling systems that do not require an external power supply for at least 72 hours after the most severe failure.

One of the priority directions for the development of nuclear power technology is to construct units of smaller capacity (below 700 MW) that would offer competitive energy generation costs while complying with all nuclear safety requirements. Modular reactors are a forward-looking solution, offering the option to assemble the required capacity from 150-300 MW modular units. Modular high temperature gas reactors (HTGRs), which can be used not only to produce electricity but also process heat for the chemical industry, are another promising technology.

The disposal of low- and intermediate-level waste is controlled worldwide and does not pose a major problem. In Europe, almost all countries operate landfills for such waste. In Poland, the National Landfill Site for Radioactive Waste is in operation in Różan nad Narwią, but it is slowly filling up and is not adapted to receive highly radioactive waste. For this reason, the construction of a new landfill for low- and intermediate-level waste is expected. A greater problem, albeit one that is also successfully tackled on a global scale, is the storage of spent fuel and highly radioactive waste, especially from spent fuel reprocessing plants. The planned landfill site for high-level waste will be put into operation at a time appropriate to the fuel cycle and fuel post-processing.

The supply of reactors and entire nuclear steam generation systems in nuclear power plants is dominated by large companies, which traditionally compete with each other on the global market. They will also compete for nuclear power contracts in Poland. These are first of all:

- Framatome, which offers power plants with EPR reactors with a gross capacity of 1,650 MW;
- General Electric, which offers, via its subsidiary GE Hitachi, ABWR power plants of 1,350 MW and ESBWR power plants of 1,535 MW;
- Korean KHNP, which offers PWR power plants of 1,400 MW.

As a member of the European Union, Poland must comply with Community requirements. In the field of nuclear power, these are the provisions of the Euratom Treaty and Euratom normative documents. According to Euroatom requirements, all nuclear installations under construction in the EU must be notified and receive a favourable opinion from the European Commission.

Despite the tighter safety requirements, nuclear power plants are competitive in relation to organic fuel sources, especially when the costs of purchasing carbon emission allowances are factored in.

The Polish Nuclear Power Programme has been developed and adopted by the government[45]. This is the first comprehensive document on nuclear power in Poland. The main objective of the Polish Nuclear Power Programme is to implement nuclear power in Poland, which will contribute to ensuring the supply of appropriate volumes of electricity at prices acceptable to the economy and the society, while complying with environmental protection requirements, especially those regarding zero carbon emissions.

The overall objective will be implemented through the following specific targets:

1. Establishing and updating the legal framework for the development and operation of nuclear power.
2. Ensuring the highest achievable level of safety of nuclear power plants.
3. Implementing a rational and effective system of radioactive waste and spent fuel management, including the construction of a new landfill site for low- and intermediate-level waste.
4. Developing institutional support for nuclear power.
5. Increasing and maintaining public support for the development of nuclear power by, amongst others, raising public awareness.
6. Strengthening the national system for responding to radiological incidents with respect to nuclear power operation, including strengthening the national radiation monitoring system.
7. Ensuring qualified personnel for the development and operation of nuclear power.
8. Creating a robust, effective scientific and research support for nuclear power.
9. Increasing the innovation and technological advancement of Polish industry.
10. Ensuring conditions for a stable fuel supply to nuclear power plants.
11. Preparing the National Power System (NPS) for the development of nuclear power.
12. Creating stable economic and financial conditions for the development of nuclear power.

The Polish Nuclear Power Programme provides an opportunity to develop new technologies through associated research and development projects. Similarly to the UK, such projects have a dual purpose. On the one hand, they respond to future energy needs, and on the other hand, they are aimed at developing indigenous competences, technologies and products.

Production and use of tight gas

Tight gas, which is locked in low-permeability sandstones, is a promising alternative to conventional coal and natural gas. It can be used to produce electricity and heat with low atmospheric emissions. The Polish Geological Service estimates its deposits in Poland at 1.5-1.9 bcm (based on geological surveys in the regions of Poznań-Kalisz, Wielkopolska-Silesia and the western part of the Baltic Basin).

4.6.2. Current level of public and private investment in research and innovation in low-carbon technologies, current number of patents and current number of researchers

Data on investment in innovation are provided by the International Energy Agency, which periodically publishes data on public spending (defined as funds from state budgets and companies controlled by central government) in the area defined as Research, Development and Demonstration (RD&D) of new energy technologies. Total investment in RD&D is divided into seven main areas: energy efficiency, fossil fuels, renewable energy sources, nuclear power, hydrogen and fuel cells, other power and storage technologies, other cross-cutting energy technologies. This classification is different from the one used by the European Commission in its reporting, which is why the reported spending differs between the two sources even in relation to similarly characterised research areas, such as for example nuclear power.

[45] Resolution 15/2014 of the Council of Ministers of 28 January 2014 on the multi-annual programme referred to as the Polish Nuclear Power Programme (Polish Monitor [M. P.] of 2014 item 502).

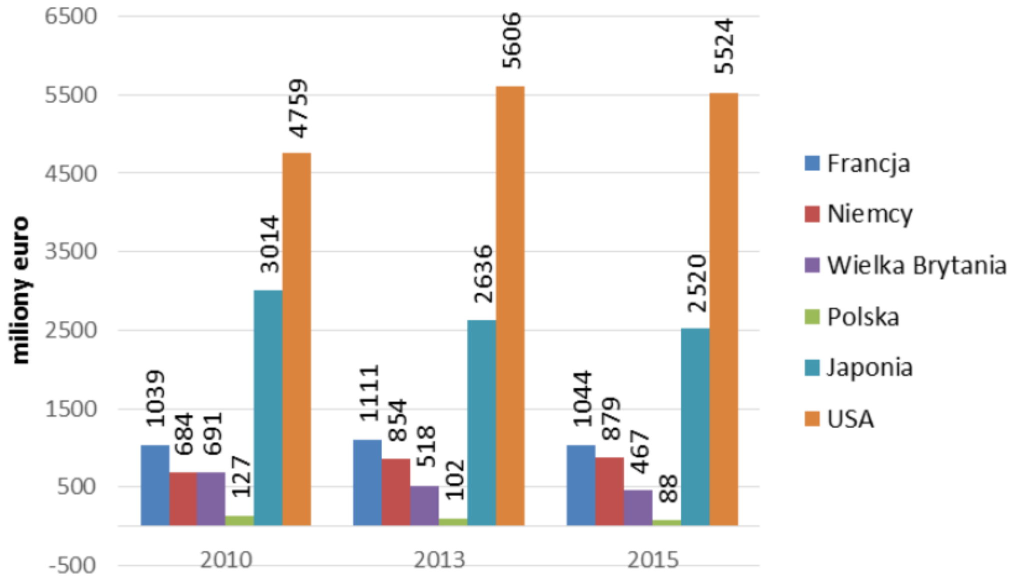

Figure 40. Total Research, Development and Demonstration budget in selected countries in 2005, 2010, 2015. Source: IEA

miliony euro	**EUR million**
Francja	France
Niemcy	Germany
Wielka Brytania	United Kingdom
Polska	Poland
Japonia	Japan
USA	US

The above figure presents public spending on RD&D in selected global economies. No significant changes in innovation investments are observed over 2010-2015. According to the IEA's report, energy innovation budgets in Japan and the USA remained at a similar level in 2013-2015. The distribution of financial resources between RD&D sectors also differs from country to country.

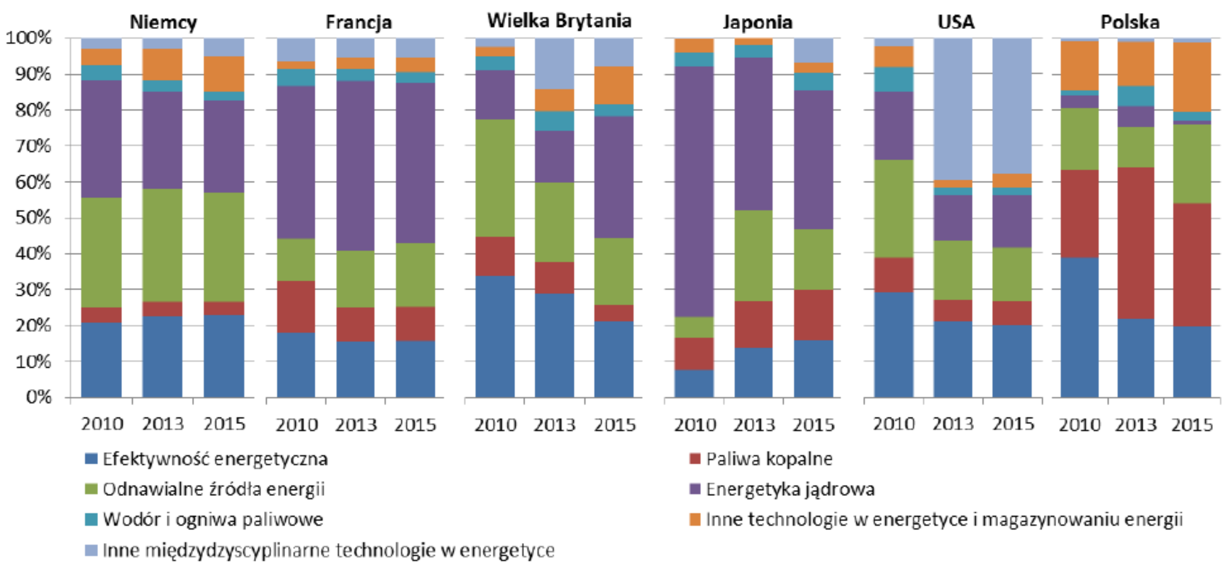

Figure 41. Total Research, Development and Demonstration budget in selected countries in 2005, 2010, 2015. Source: IEA

Efektywność energetyczna	Energy efficiency
Odnawialne źródła energii	Renewable energy sources
Wodór i ogniwa paliwowe	Hydrogen and fuel cells

Inne międzydzyscyplinarne technologie w energetyce	Cross-cutting
Paliwa kopalne	Fossil fuels
Energetyka jądrowa	Nuclear
Inne technologie w energetyce i magazynowaniu energii	Other power and storage technologies
Niemcy	**Germany**
Francja	**France**
Wielka Brytania	**United Kingdom**
Japonia	**Japan**
USA	**US**
Polska	**Poland**

It can be seen from the figure above, as well as from data presented by the European Commission, that individual countries are investing in areas of particular strategic importance. For example, countries with developed nuclear power allocate a significant share of their RD&D budgets to power (in 2015: 44% – France, 39% – Japan, 33% – Great Britain, 26% – Germany). The US spends only 14.5% of its energy RD&D outlays on nuclear power projects, but since its budget is the largest among the countries compared, it ranks second (after Japan) in the above comparison. At 34%, the fossil fuel sector has a significant share of the RD&D budget in Poland. This reflects a significant share of coal in Poland's fuel mix.

The chart below presents a comparison between the RD&D budgets of the countries that are members of both the EU and the IEA and the outlays incurred by the European Commission, understood as the expenditure from the European Commission's budget for research and development under programmes, grants and projects, such as for example Horizon 2020. The biggest differences can be seen between nuclear power investments. However, this is related to the investment priorities adopted by the European Commission, which puts more emphasis on modern, renewable and sustainable energy sources.

National R&D investment[46]

The Europe 2020 strategy sets out a target for increased R&D investment which is tailored to implementation capacities of the individual Member States. As part of this strategy, Poland is required to allocate 1.7% of its GDP to R&D in 2020. (2010 – 0.72% of GDP, 2015 – 1% of GDP)[47]. The European Union has committed itself to allocating a total of 3% of the GDP for R&D in 2020 compared to 1.93% in 2010[48].

National statistics provide information on total research and development expenditure, without showing specific data for low-carbon technologies or priority areas of the Energy Union.

According to the data of Statistics Poland, capital expenditure on Science and Technology totalled PLN 18.06 billion in 2015, an increase of 54.5% compared to 2011.

According to *Energy R&I financing and patenting trends in the EU,* a publication by the Joint Research Centre (JRC) on the monitoring of progress in Member States in the area under consideration, Poland has allocated EUR 88 million to research and innovation, of which as much as EUR 42.6 million has been allocated to investments in integrated energy systems. Renewable energy sources and bioenergy ranked second, with EUR 16.4 million invested in research and innovation. Capital expenditure in both these areas has significantly decreased since 2011 (by 19% and 57%, respectively). In other analysed areas, such as energy efficiency in industry or CCUS, a relatively similar level of capital expenditure has been maintained. In Poland, as elsewhere in the Community, private spending is higher than public spending. The greatest difference between public and private sector investments can be seen in the area of renewable energy sources, were private spending is ten times public spending. The same is true for investment in renewable fuel innovation (private sector spending is three times higher) and energy efficiency technologies in industry (six times higher).

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[46] *Nauka i technika w 2015 r.* [Science and technology in 2015], Statistics Poland.

[47] Research and development activities in Poland, Statistics Poland.

[48] Operational Programme Smart Growth 2014-2020

According to IEA statistics, Poland allocated EUR 88.2 million to RD&D. This figure is similar to that presented by the JRC, but both of these institutions have different research priorities. For example, according to the IEA, 34% of the funds were invested in fossil fuels, a category that is not monitored by the JRC. According to IEA data, 22% of public spending, i.e. approx. EUR 19 million, has been allocated to innovation in renewable sources.

National innovation investments Energy Union priorities

According to data of Statistics Poland (GUS), innovation expenditure of Polish industrial enterprises totalled PLN 31.1 billion in 2015, in which large undertakings[49] (representing 27.2% of the total number surveyed) had a 93% share. The estimated innovation expenditure of the surveyed service sector enterprises totalled PLN 12.6 billion, in which large enterprises (representing 16.7% of the total number surveyed) had a 93.8% share.

Industrial enterprises invested primarily in fixed assets (77.3% of total innovation expenditure), with a majority of funds being allocated to the purchase of technical machines and equipment, means of transport, tools, instruments, movables and fittings (51.2%) and in research and development (PLN 5.1 billion or 16.5% of total innovation expenditure). Services sector enterprises invested primarily in fixed assets (38.5% of total innovation expenditure), and in research and development (PLN 4.1 billion or 32.7% of total innovation expenditure).

Innovation spending on research and development in large enterprises in 2015 totalled 16.7% in industry, and 32.1% in the surveyed sections of the services sector (G-U sections) (compared to 19.6% and 24.2%, respectively, in 2014). Enterprises financed their innovation activities in 2015 from their own resources. Innovation spending accounted for 62.0% of all outlays in industrial enterprises and 73.0% in services enterprises.

R&D personnel

157,900 persons were employed in research and development (R&D) in Poland in 2015, including 118,500 researchers. Employment in R&D totalled 109,200 full-time equivalents, of which researchers accounted for 82,600 FTE. Research and development intensity, i.e. the share of internal R&D expenditure in the GDP, stood at 1.00% in 2015, an increase from 0.75% in 2011. 6.8 out of 1,000 persons employed in general (in FTE) were employed in R&D in 2015. This figure was almost twice as low as the EU average in 2014 (13.0).

In 2014, Poland ranked 23rd among the Union countries in terms of employment in research and development (in FTE) per 1,000 persons employed in general and 22nd in terms of employment of researchers (in FTE) per 1,000 persons employed in general. In 2014, Poland ranked 20th among the EU countries in terms of R&D intensity, which was twice as low for Poland as for the Union as a whole.

Patents in Poland

4,815 applications for the protection of an invention were filed with the Patent Office of the Republic of Poland in 2015, an increase of 17.6% compared to the previous year. In 2000-2005, the total number of invention applications ranged from 6,000 to 8,000 per year. Since 2006, there has been a change in the structure of applications compared 2000-2005 in favour of those filed by national applicants. In 2015, national applicants filed 4,676 invention applications with the Patent Office of the Republic of Poland, i.e. 18.7% more than in the previous year.

According to the aforementioned Joint Research Centre study, most patents in Poland are filed in the area of energy efficiency and renewable energy sources (40 and 39 respectively in 2013). These two areas were most active in terms of the number of patents in 2008-2013. Innovation in renewable fuels was the third area of patent activity. A total of 146 patents were filed in 2013 in the priority areas of the Energy Union (16 fewer than in 2012 and almost four times more than in 2008).

4.6.3. Current level of energy costs taking into account the international context

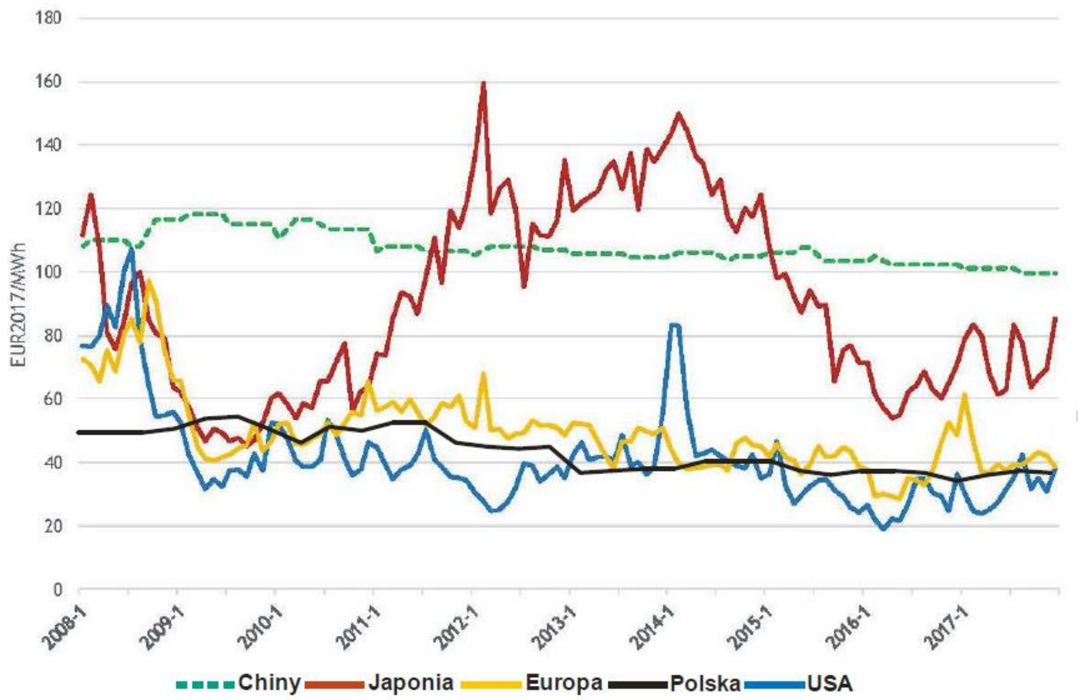
Given the role that energy plays in production processes and in broadly understood services, energy costs are

[49] Employing over 49 persons.

a key factor in terms of competitiveness. When analysing energy costs, both energy price levels and energy intensity must be taken into account. In 2014, energy purchases accounted for 2.1% of the total value of goods produced in the manufacturing sector. However, this value varies greatly between different sectors of the economy.

Since 2010, barring some short periods, wholesale electricity prices in the US have been lower than in Europe. In the first half of 2016, US prices were 35% lower than the EU average. The difference is mainly due to low energy production costs in the US. Over the past few years, low prices of natural gas have led to an increase in the production of electricity from this fuel, partially displacing coal from energy generation. Due to an increasing dependence on gas-based generation, energy prices in the US are more volatile than in Europe. In recent years, the costs of electricity generation have also fallen in the EU, a development that has been driven by reduced demand, falling fossil fuel prices and the gradual penetration of renewable energy into the energy mix. Over the last few years, Japanese wholesale electricity prices have been significantly higher than in the EU. The price difference reached its peak after the Fukushima nuclear accident when cheap nuclear power plants were temporarily replaced by gas-fired ones. However, after 2014, due to falling prices of imported LNG and the restarting of some nuclear reactors, energy generation costs decreased, putting pressure on wholesale electricity prices. By 2016, Japanese wholesale electricity prices returned to pre-Fukushima levels, but remained well above European prices.

In the first half of 2016 prices in Japan were almost twice as high as in the EU. Wholesale electricity prices in Poland remained slightly below the European average from the end of 2010 until early 2014. In the first half of 2016, the average European price fell to around 30 EUR/MWh, while wholesale prices in Poland remained relatively stable at around 39 EUR/MWh. This price level was maintained in Poland in 2017, whereas the years 2018 and 2019 brought an increase in electricity prices on the wholesale market.



**Electricity prices for Poland are presented on a quarterly basis*
Source: Trinomix et altri study (2018); ARE S.A. databases
Figure 42. Wholesale electricity prices in the EU and selected countries in 2010-2018

EUR2017/MWh	EUR2017/MWh
Chiny	China
Japonia	Japan
Europa	Europe
Polska	Poland
USA	US

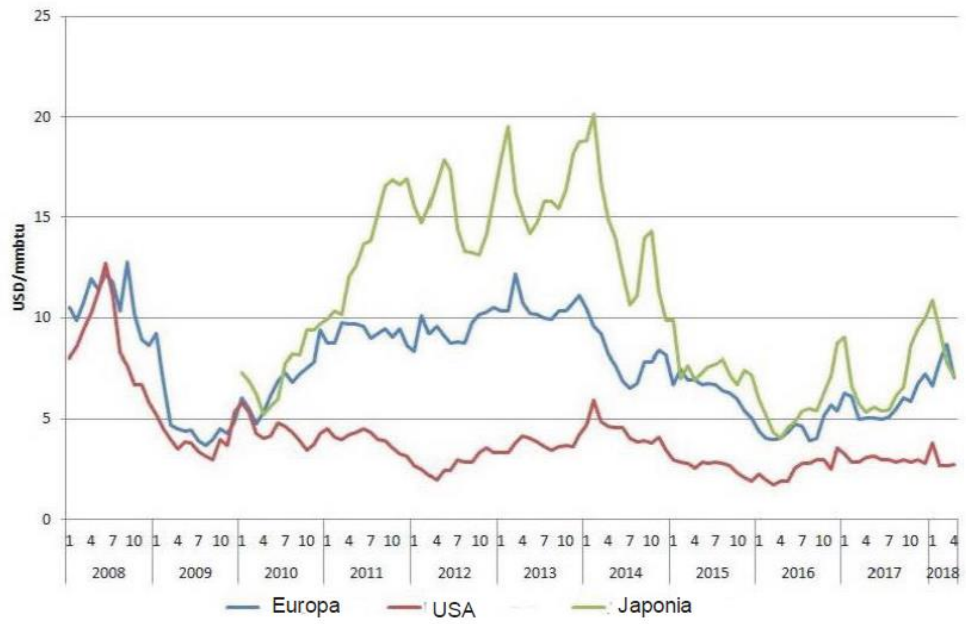


Figure 43. Wholesale prices of natural gas in selected countries worldwide, 2008-2016. Source: Platts, Thomson Reuters

Europa	Europe
USA	US
Japonia	Japan
USD/mmbtu	**USD/mmbtu**

The above figure shows wholesale gas prices in three points: United States (Henry Hub), United Kingdom (NBP hub) and Japan (JKM spot price). A clear price divergence occurred between 2010 and 2013. On the other hand, wholesale prices have fallen significantly in all regions since 2014, leading to a convergence of regional price levels.

As mentioned earlier, demand for gas in Japan increased after the Fukushima accident, causing LNG prices to rise. However, after 2014, LNG prices fell significantly and prices in Japan decreased by almost 80% between February 2014 and April 2016. Since 2010, with the advent of the shale gas boom, US gas prices have been consistently lower than those in Europe and Asia. Since January 2015, the Henry Hub average monthly price has remained below 3 USD/mmbtu and even temporarily dropped below 2 USD/mmbtu. Gas prices in this hub exceeded 3 USD/mmbtu only in the period of December 2016 to January 2017 and April to May 2017. On the other hand, the fall in the price of oil brought down the production of oil-related gas, which affected the competitiveness of shale gas. European prices have also fallen significantly since 2014 as a result of a combination of several factors: low demand, continued LNG imports and falling oil prices are putting pressure on hub prices. The devaluation of the euro against the US dollar has also contributed to this trend, lowering European prices expressed in US dollars. As a result, the difference between the NBP price and the Henry Hub price fell to an average of 2 USD/mmbtu in the first nine months of 2016. However, both electricity and fossil energy prices vary considerably between EU countries. This is mainly due to differences in production capacities and the availability of fuels for energy needs.

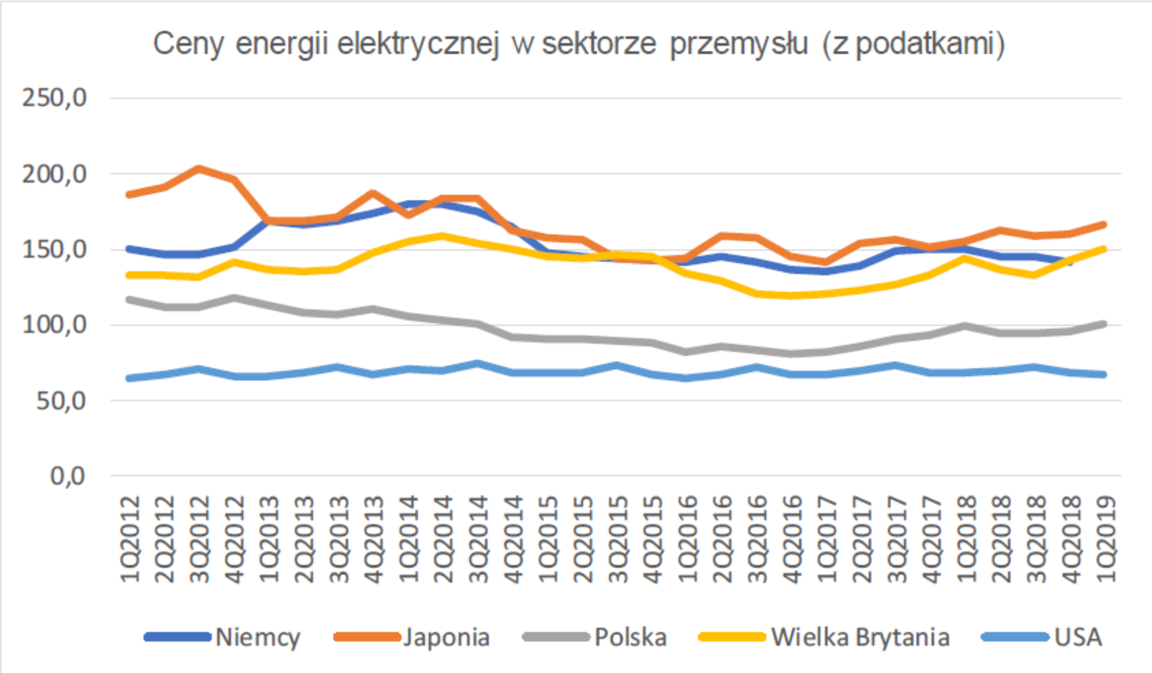


Figure 44. Final electricity prices in the industry sector, excluding taxes, in selected countries from 2012 to the first half of 2019 (data according to the IEA)

Ceny energii elektrycznej w sektorze przemysłu (z podatkami)	Electricity prices in the industrial sector (including taxes)
Niemcy	Germany
Japonia	Japan
Polska	Poland
Wielka Brytania	United Kingdom
USA	US

Prices for industrial customers (excluding taxes) in Poland and Germany show a high convergence. This is mainly due to the proximity of the two countries and the resultant electricity interconnections which cause interactions between the two markets. Factoring in the tax burden in the above table, the energy price in Germany is also higher than in the UK, while the price for the industrial sector in Poland remains at a similar level (the average tax according to IEA data in the analysed period was less than 5 EUR/MWh). Clear differences can be seen in electricity prices among countries that are not interconnected, such as the US, Germany and Japan. Such comparisons are driven mainly by factors such as the costs of energy carriers and energy transmission. However, the competitiveness of the economy is affected not only by the energy cost alone, but also by energy intensity.

Real Unit Energy Cost (RUEC) is an indicator that combines energy cost and energy intensity and measures the amount of money spent on energy needed to obtain 1 unit of value added in the generation sector (excluding refineries). The higher the indicator, the higher the share of energy cost in the overall cost structure of the generation sector in a given country.

RUEC is calculated as the ratio of energy costs in current prices (energy input consists of the sum of four product categories (1) coal and lignite, (2) peat, crude oil and natural gas, (3) coke, refinery products and nuclear fuels, (4) electricity, gas, steam and hot water) over value added in constant 2005 prices. This indicator can be interpreted as the product of the actual energy price and energy intensity[50].

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[50] RUEC = EC/VAb = EC/(VAs*PVA) = EC/(QE*PVA) * QE/VAs, where:

EC - energy cost in current prices,
QE - energy input expressed in energy units,
VAb - value added in current prices,

As a measure of energy costs in the industrial sector, presented as a percentage of added value, RUEC is used for international comparisons in this area. A comparison of real unit energy costs expressed as a percentage of value added in the downstream industry in individual countries of the European Union and a comparison between the EU28, the US, Japan, China and Russia for 2005, 2011 and 2014 are shown in the figure below.

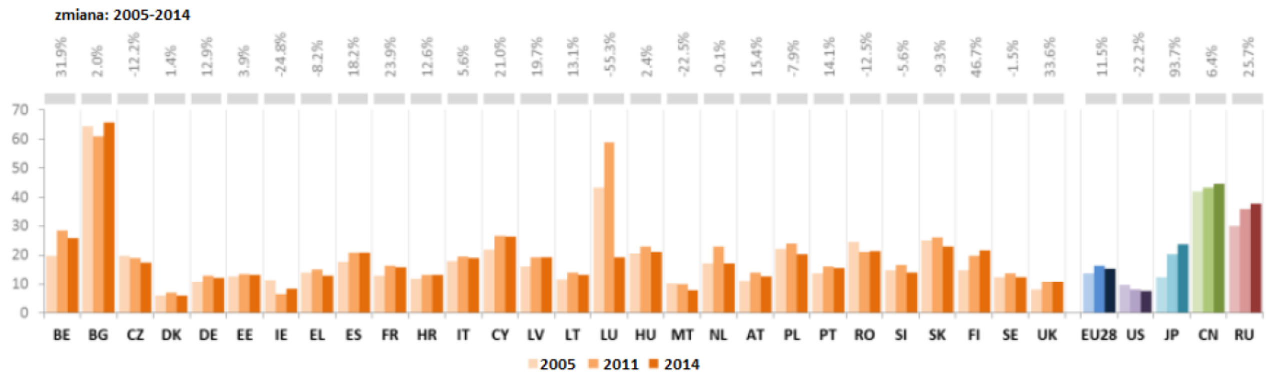


Figure 45. Comparison of real unit energy costs (RUEC) expressed as % of value added in 2005, 2011 and 2014. Source: Second Report on the State of the Energy Union, 2017.

zmiana: 2005-2014	**change: 2005-2014**

A series of conclusions and observations can be drawn from this figure. First of all, energy costs increased, in some cases significantly (Luxembourg, Belgium), between 2005 and 2011. Then energy costs (expressed by RUEC) stopped growing and decreased by 6.6% for the Union as a whole in 2011-2014. Nevertheless, the European Union’s RUEC increased by 11.5% over 2005-204. In 2014, the lowest energy costs in the downstream industry were recorded in the US, followed by the EU28, Japan, Russia and China. It must be taken into account that the prices of energy carriers paid by industrial customers in the US are lower than in most EU countries, while prices in Japan are in most cases higher than EU prices (Fig. 4.71 and 4.72). A fall in costs for the EU28 can be explained by the decreasing energy intensity of the manufacturing sector (which is linked to the increasing energy efficiency of European economies). Poland’s RUEC is higher than the EU average. However, in 2005-2014, actual unit energy costs fell by 7.9%, placing Poland among the 11 European countries where energy costs fell in the analysed period. The highest energy costs were recorded in Bulgaria, Belgium and Cyprus, which is due to the predominance of energy-intensive industries.

The figure below shows the evolution of RUEC expressed in % over the period of 2005-2014 in individual EU countries, in the EU28 and in the main economic partner countries.

VAs - value added in constant prices,
PVA - value added deflator.

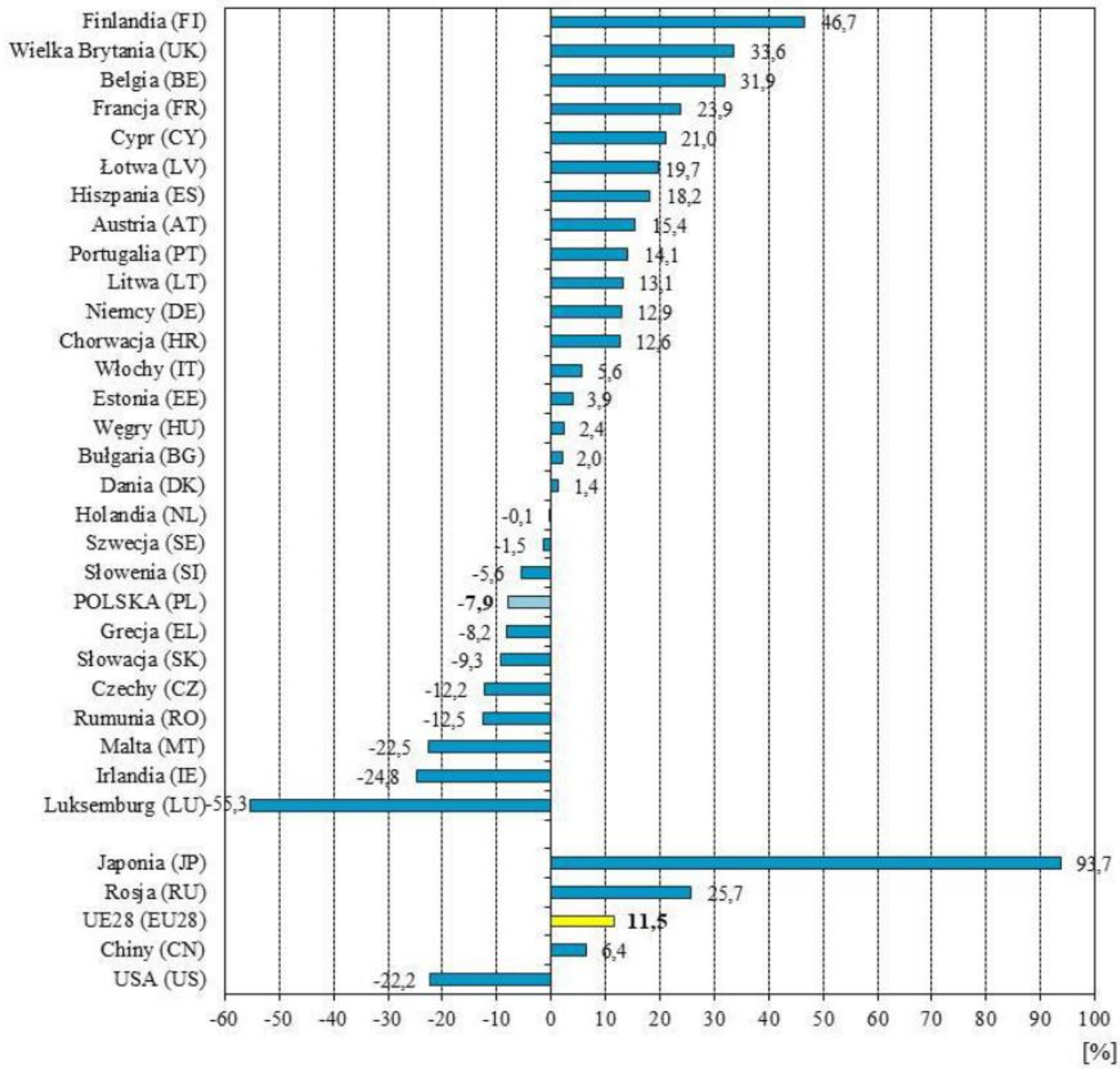


Figure 46. Percentage changes in RUEC between 2005 and 2014

Source: Second Report on the State of the Energy Union, 2017.

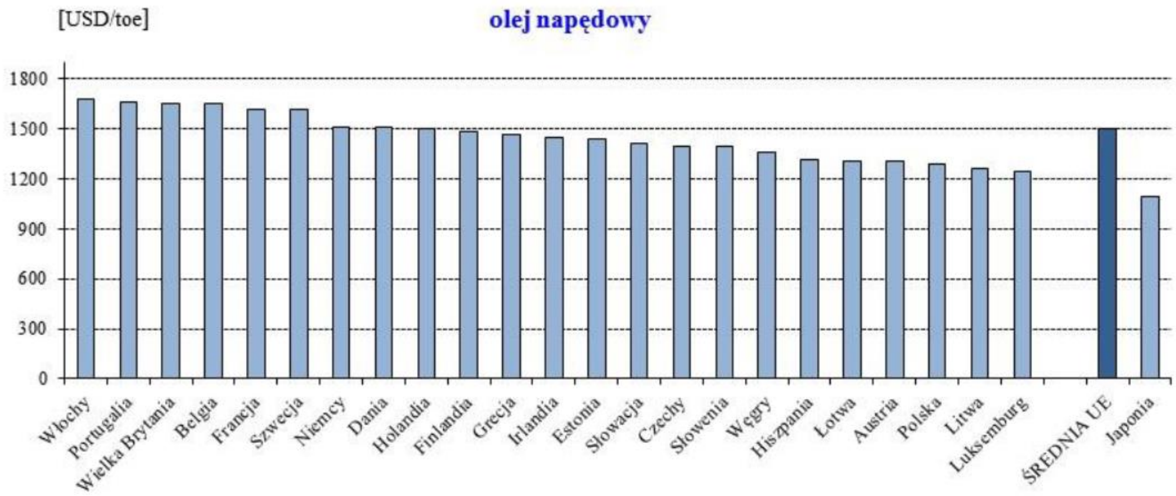
Finlandia (FI)	Finland (FI)
Wielka Brytania (UK)	United Kingdom (UK)
Belgia (BE)	Belgium (BE)
Francja (FR)	France (FR)
Cypr (CY)	Cyprus (CY)
Łotwa (LV)	Latvia (LV)
Hiszpania (ES)	Spain (ES)
Austria (AT)	Austria (AT)
Portugalia (PT)	Portugal (PT)
Litwa (LT)	Lithuania (LT)
Niemcy (DE)	Germany (DE)
Chorwacja (HR)	Croatia (HR)
Włochy (IT)	Italy (IT)
Estonia (EE)	Estonia (EE)
Węgry (HU)	Hungary (HU)
Bulgaria (BG)	Bulgaria (BG)
Dania (DK)	Denmark (DK)
Holandia (NL)	Netherlands (NL)
Szwecja (SE)	Sweden (SE)

Słowenia (SI)	Slovenia (SI)
POLSKA (PL)	POLAND (PL)
Grecja (EL)	Greece (EL)
Słowacja (SK)	Slovakia (SK)
Czechy (CZ)	Czech Republic (CZ)
Rumunia (RO)	Romania (RO)
Malta (MT)	Malta (MT)
Irlandia (IE)	Ireland (IE)
Luksemburg (LU)	Luxembourg (LU)
Japonia (JP)	Japan (JP)
Rosja (RU)	Russia (RU)
UE28 (EU28)	UE28 (EU28)
Chiny (CN)	China (CN)
USA (US)	USA (US)

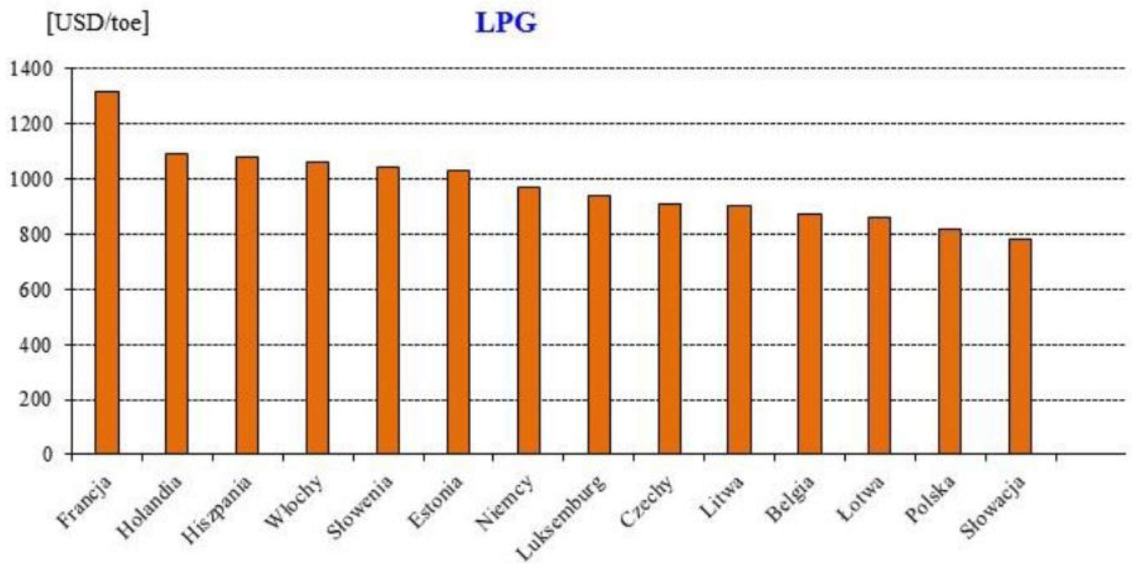
As already mentioned, energy costs depend on energy prices and energy intensity. The figures below show the average prices of selected energy carriers in individual EU countries and in the US and Japan in 2016.

lekki olej opałowy	**light fuel oil**
[USD/toe]	[USD/toe]
Włochy	Italy
Holandia	Netherlands
Szwecja	Sweden
Grecja	Greece
Finlandia	Finland
Dania	Denmark
Słowenia	Slovenia
Francja	France
Estonia	Estonia
Polska	Poland
Irlandia	Ireland
Łotwa	Latvia
Wielka Brytania	United Kingdom
Austria	Austria
Hiszpania	Spain
Luksemburg	Luxembourg
Belgia	Belgium
Czechy	Czech Republic
Litwa	Lithuania
Niemcy	Germany
ŚREDNIA UE	EU AVERAGE

Japonia	Japan
USA	US



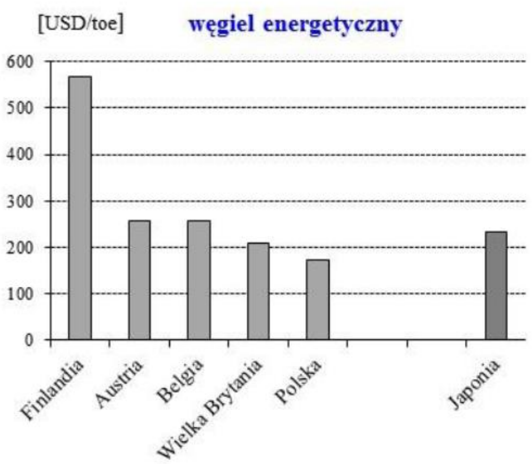
[USD/toe]	[USD/toe]
olej napędowy	**diesel**
Włochy	Italy
Portugalia	Portugal
Wielka Brytania	United Kingdom
Belgia	Belgium
Francja	France
Szwecja	Sweden
Niemcy	Germany
Dania	Denmark
Holandia	Netherlands
Finlandia	Finland
Grecja	Greece
Irlandia	Ireland
Estonia	Estonia
Słowacja	Slovakia
Czechy	Czech Republic
Słowenia	Slovenia
Węgry	Hungary
Hiszpania	Spain
Łotwa	Latvia
Austria	Austria
Polska	Poland
Litwa	Lithuania
Luksemburg	Luxembourg
ŚREDNIA UE	EU AVERAGE
Japonia	Japan

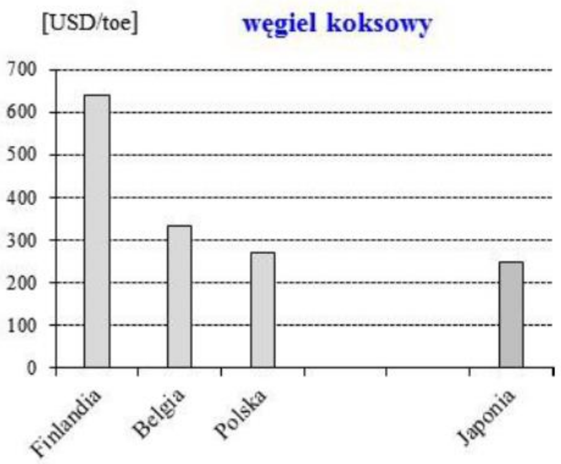


[USD toe]	[USD toe]
LPG	**LPG**
Francja	France
Holandia	Netherlands
Hiszpania	Spain
Włochy	Italy
Słowenia	Slovenia
Estonia	Estonia
Niemcy	Germany
Luksemburg	Luxembourg
Czechy	Czech Republic
Litwa	Lithuania
Begia	Belgium
Łotwa	Latvia
Polska	Poland
Słowacja	Slovakia

Figure 47. Comparison of average prices of selected energy carriers in USD/toe paid by industrial customers in EU countries and in the US and Japan in 2018.

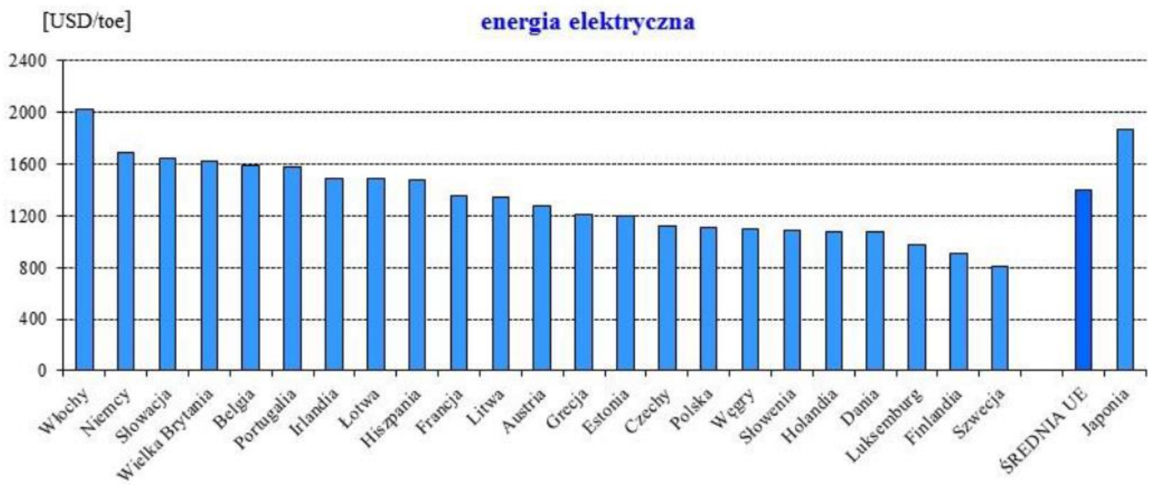
[USD toe]	[USD toe]
gaz ziemny	**natural gas**
Finlandia	Finland
Szwecja	Sweden
Litwa	Lithuania
Francja	France
Dania	Denmark
Irlandia	Ireland
Włochy	Italy
Austria	Austria
Estonia	Estonia
Łotwa	Latvia
Grecja	Greece
Słowenia	Slovenia
Słowacja	Slovakia
Portugalia	Portugal
Luksemburg	Luxembourg
Czechy	Czech Republic
Belgia	Belgium
Węgry	Hungary
Niemcy	Germany
Wielka Brytania	United Kingdom
Holandia	Netherlands
Hiszpania	Spain
Polska	Poland
ŚREDNIA UE	EU AVERAGE





[USD toe]	[USD toe]
węgiel energetyczny	**steam coal**
Finlandia	Finland
Austria	Austria
Belgia	Belgium
Wielka Brytania	United Kingdom
Polska	Poland
Japonia	Japan

[USD/toe]	[USD/toe]
węgiel koksowy	**coking coal**
Finlandia	Finland
Belgia	Belgium
Polska	Poland
Japonia	Japan



[USD/toe]	[USD/toe]
energia elektryczna	**electricity**
Włochy	Italy
Niemcy	Germany
Słowacja	Slovakia
Wielka Brytania	United Kingdom
Belgia	Belgium
Portugalia	Portugal
Irlandia	Ireland
Łotwa	Latvia
Hiszpania	Spain
Francja	France
Litwa	Lithuania
Austria	Austria
Grecja	Greece
Estonia	Estonia
Czechy	Czech Republic
Polska	Poland
Węgry	Hungary
Słowenia	Slovenia
Holandia	Netherlands
Dania	Denmark
Luksemburg	Luxembourg
Finlandia	Finland
Szwecja	Sweden
ŚREDNIA UE	EU AVERAGE
Japonia	Japan

Source: IEA/OECD

Note: the selection of countries and the presence of the European average price in the graph were dependent on the availability of data.

Figure 48. Comparison of average prices of selected energy carriers in USD/toe paid by industrial customers in EU countries and in the US and Japan in 2018 (cont.)

As can be seen in the graphs above, energy carriers in Poland are amongst the lowest priced in Europe. This is mainly due to the nature of fuel demand by the national economy. Most of the Polish power industry uses cheap domestic coal while liquid fuels are not widely used (unlike in, for example, Italy).

On the other hand, Figures 62-64 show the ranking of EU countries in terms of electricity prices expressed in EUR/MWh in the second half of 2016 for three categories of industrial customers, differing in their annual consumption levels. These figures illustrate the large variation in energy prices both between countries and between industrial consumers within one country depending on the level of consumption. Electricity prices in

Poland are lower than the average EU price for each consumption range.

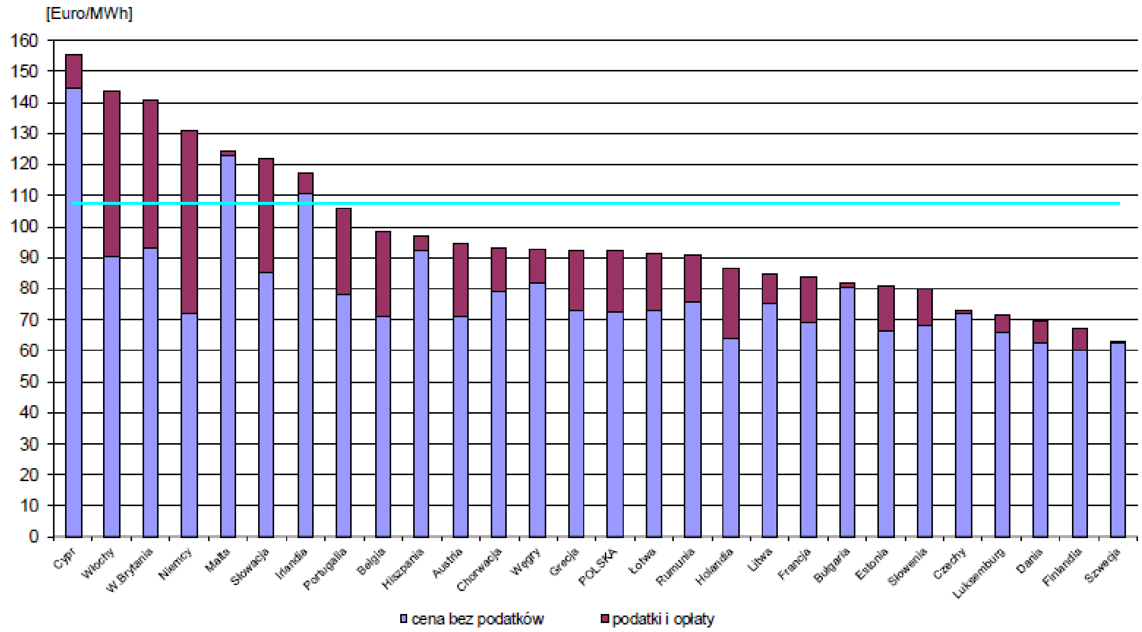


Figure 49. Electricity prices for industrial customers for the first half of 2019 – IC category (500–2,000 MWh). Source: Eurostat

[Euro/MWh]	[Euro/MWh]
cena bez podatków	price net of taxes
podatki i opłaty	taxes and fees
Włochy	Italy
Cypr	Cyprus
Niemcy	Germany
W. Brytania	UK
Irlandia	Ireland
Malta	Malta
Słowacja	Slovakia
Portugalia	Portugal
Hiszpania	Spain
Belgia	Belgium
Austria	Austria
Grecja	Greece
Łotwa	Latvia
Chorwacja	Croatia
Francja	France
POLSKA	POLAND
Rumunia	Romania
Węgry	Hungary
Słowenia	Slovenia
Holandia	Netherlands
Litwa	Lithuania
Estonia	Estonia
Luksemburg	Luxembourg
Bułgaria	Bulgaria
Czechy	Czech Republic
Szwecja	Sweden
Finlandia	Finland
Dania	Denmark

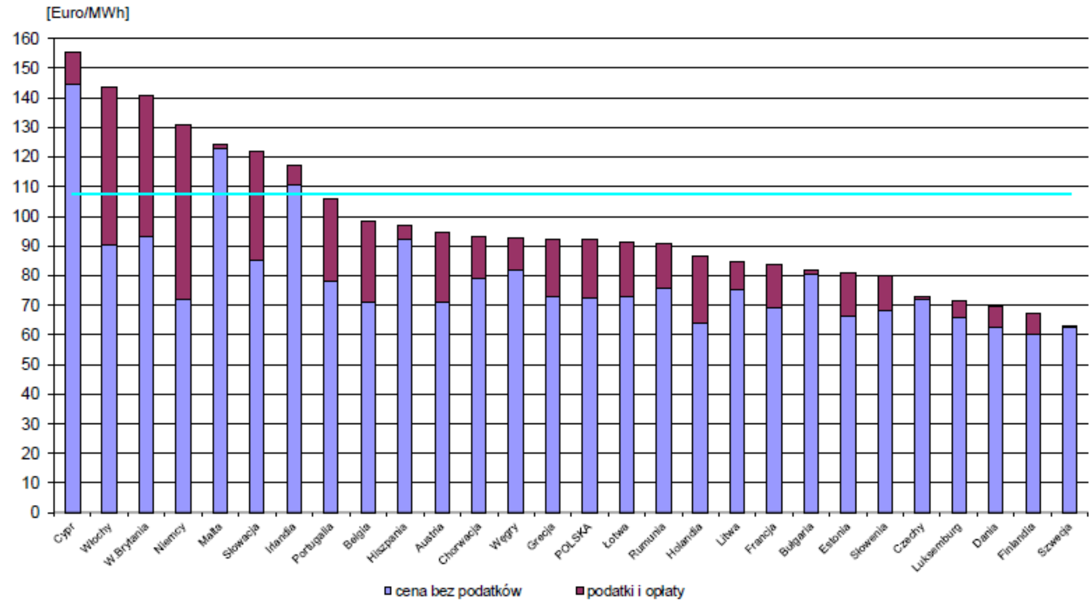


Figure 50. Electricity prices for industrial customers for the first half of 2019 – ID category (2,000-20,000 MWh). Source: Eurostat

[Euro/MWh]	[Euro/MWh]
cena bez podatków	price net of taxes
podatki i opłaty	taxes and fees
Cypr	Cyprus
Włochy	Italy
W. Brytania	UK
Niemcy	Germany
Malta	Malta
Słowacja	Slovakia
Irlandia	Ireland
Portugalia	Portugal
Belgia	Belgium
Hiszpania	Spain
Austria	Austria
Chorwacja	Croatia
Węgry	Hungary
Grecja	Greece
POLSKA	POLAND
Łotwa	Latvia
Rumunia	Romania
Holandia	Netherlands
Litwa	Lithuania
Francja	France
Bułgaria	Bulgaria
Estonia	Estonia
Słowenia	Slovenia
Czechy	Czech Republic
Luksemburg	Luxembourg
Dania	Denmark
Finlandia	Finland
Szwecja	Sweden

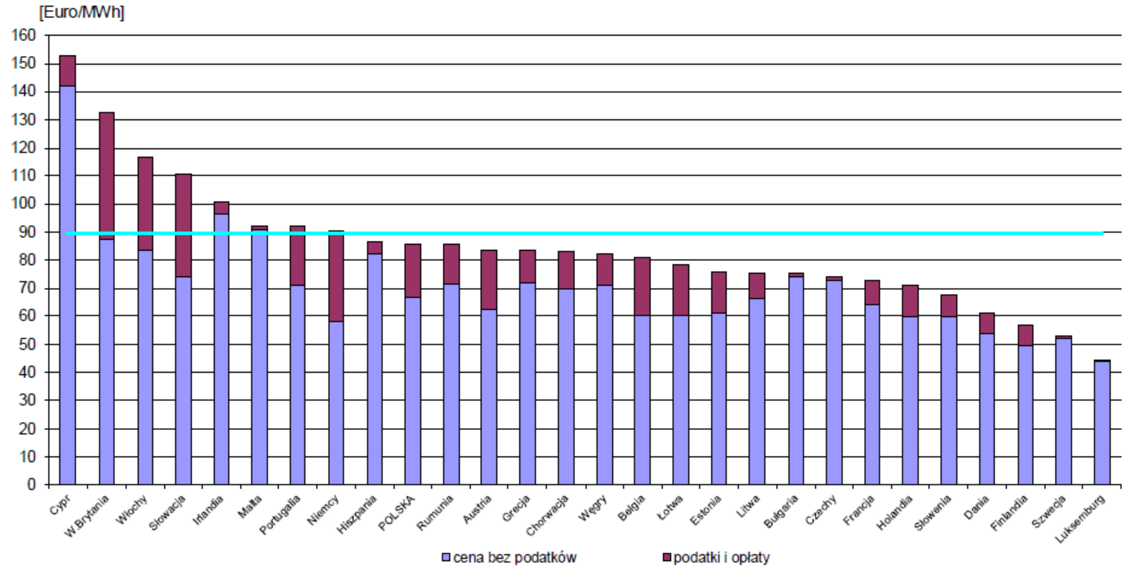


Figure 51. Electricity prices for industrial customers for the first half of 2019 – IE category. Source: Eurostat

[Euro/MWh]	[Euro/MWh]
cena bez podatków	price net of taxes
podatki i opłaty	taxes and fees
Cypr	Cyprus
W. Brytania	UK
Włochy	Italy
Słowacja	Slovakia
Irlandia	Ireland
Malta	Malta
Portugalia	Portugal
Niemcy	Germany
Hiszpania	Spain
POLSKA	POLAND
Rumunia	Romania
Austria	Austria
Grecja	Greece
Chorwacja	Croatia
Węgry	Hungary
Belgia	Belgium
Łotwa	Latvia
Estonia	Estonia
Litwa	Lithuania
Bułgaria	Bulgaria
Czechy	Czech Republic
Francja	France
Holandia	Netherlands
Słowenia	Slovenia
Dania	Denmark
Finlandia	Finland
Szwecja	Sweden
Luksemburg	Luxembourg

As shown in Figure 65, prices of particular energy carriers in Poland, expressed in EUR'2016/ktoe, fluctuated over the years 2005-2018, although a clear downward trend began in 2012 that lasted until 2016. An increase in prices of all energy carriers has been observed in the last two years. In percentage terms, this increase is as follows: 6.5% – natural gas, 16.6% – steam coal, 28.8% – coking coal, 1.3% – electricity, 11.6% – light heating oil, 7.5% – diesel, 4.9% – petrol and 9.5% – LPG.

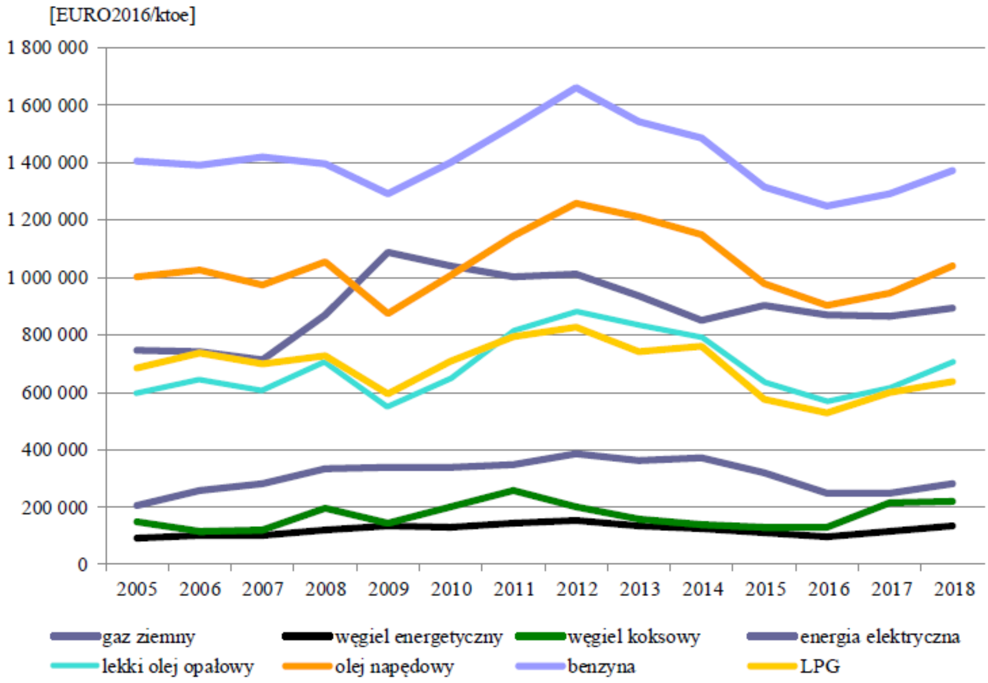


Figure 52. Prices of energy carriers for industrial customers in Poland in 2005-2018, expressed in EUR'2016/ktoe. Source: OECD

[EURO2016/ktoe]	[EUR'2016/ktoe]
gaz ziemny	natural gas
węgiel energetyczny	steam coal
węgiel koksowy	coking coal
energia elektryczna	electricity
lekki olej opałowy	light fuel oil
olej napędowy	diesel
benzyna	petrol
LPG	LPG

The energy intensity of the Polish downstream industry in 2005-2015 was higher than the EU average but it decreased at an annual rate of 7.2% whereas the energy intensity of the EU28 was characterised by an annual increase of 3.9% (Fig. 4.78). Most of the differences resulting from different industrial structures in individual EU countries were eliminated in the calculation of the average EU energy intensity. The rate of improvement in Poland is a result of both greater specialisation in less energy-intensive industries and of improved energy efficiency.

In recent years, the rate of improvement of energy intensity has slowed down both in EU countries and in Poland. In 2010-2017, this figure stood at 2.2% in Poland and 2.6% in the EU28.

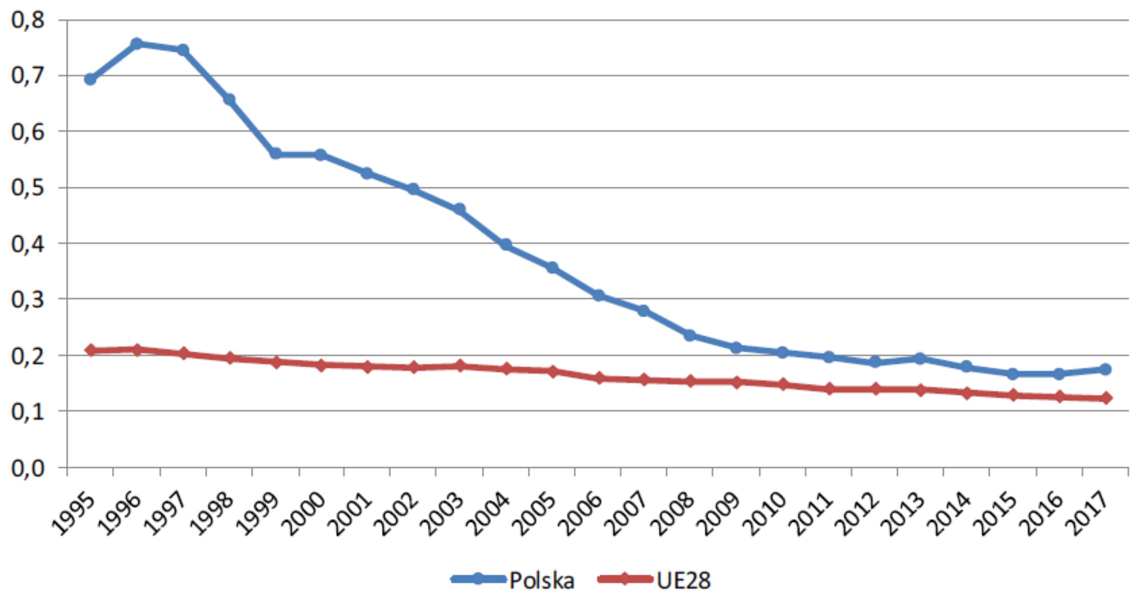


Figure 53. Comparison of energy intensity of the downstream industry in the EU28 and Poland expressed in EUR'2005/koe in 1995-2017.
Source: GUS

Polska	Poland
UE28	UE28

4.6.4. Current research and innovation policies and measures.

Objectives, policies and measures established at national level to ensure an adequate contribution to the new European approach to research and innovation.

In the current conditions of globalised economy, economic growth based on, amongst others, innovation and knowledge is the path leading towards the country's sustainably successful development.

Adopted by the Council of Ministers on 14 February 2017, the *Strategy for Responsible Development* is currently the principal state document in the area of medium and long-term economic policy.

The *Strategy for Responsible Development* aims to coordinate actions in key sectors of the Polish economy and to use the science sector in pursuing strategic objectives. According to the document, innovative technologies are the main mechanism and source of social and economic development, and an increase in expenditure on research and development is the driving force behind the country's economic growth and the innovativeness of the economy. The strategy also refers to the challenges faced by the Polish energy sector, as the technological transformation of this sector may be a factor that will accelerate Poland's economic development.

1. The Ministry of Energy's paper *Directions for Energy Innovation Development*

Responding to the global acceleration of changes in the area of energy, the Ministry of Energy prepared a paper entitled *Directions for Energy Innovation Development*. Its aim is to stimulate innovation and target actions at key and most productive areas while enhancing indigenous technological and industrial potential.

The programme is designed to launch innovative processes in the Polish energy sector through public funding and involvement. It also gives a coherent boost to innovation activity in the private sector. At the same time, it is important to activate leading business operators in the Polish energy sector and increase their commitment, including in financial terms, to research, development and implementation.

The Directions for Energy Innovation Development are to increase the coherence and alignment of policy documents at the level of government administration and State agencies in the field of development and innovation policy for the energy sector. This will allow for an effective use of existing resources and achievement of economic and development objectives, while providing an impetus to policy-making based on the most up-to-date assessment of trends and challenges for the sector.

Detailed objectives for the **development of energy innovation** are presented in the figure below.

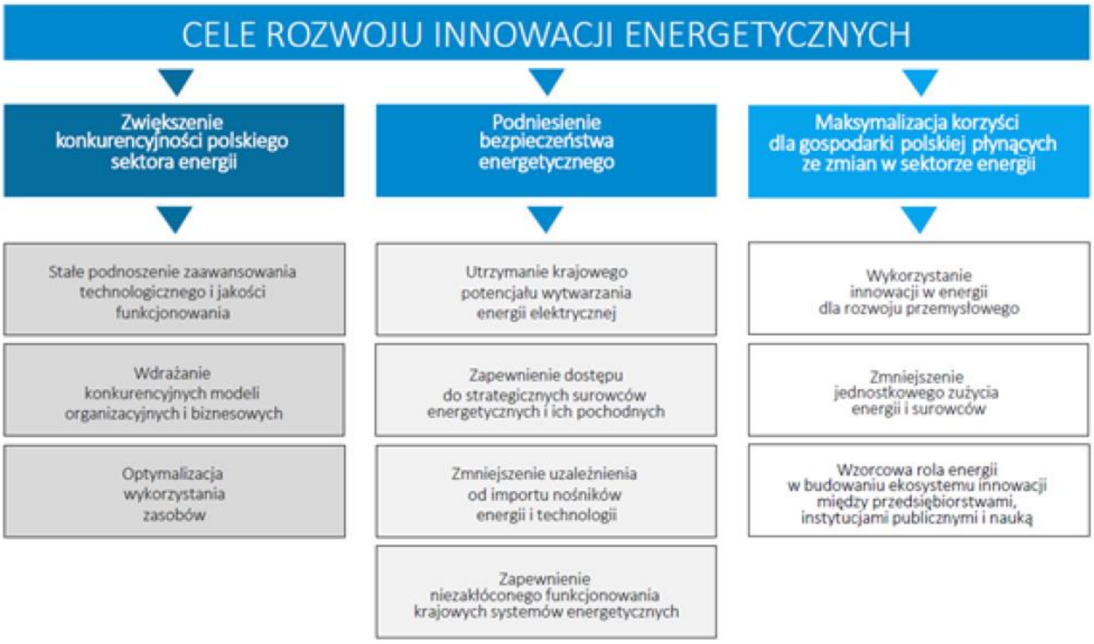


Figure 54. Objectives for the development of energy innovation. Source: Ministry of Energy

CELE ROZWOJU INNOWACJI ENERGETYCZNYCH	OBJECTIVES FOR THE DEVELOPMENT OF ENERGY INNOVATION
Zwiększenie konkurencyjności polskiego sektora energii	Increasing the competitiveness of the Polish energy sector
Podniesienie bezpieczeństwa energetycznego	Increasing energy security
Maksymalizacja korzyści dla gospodarki polskiej płynących ze zmian w sektorze energii	Maximising gains for the Polish economy from changes in the energy sector
Stałe podnoszenie zaawansowania technologicznego i jakości funkcjonowania	Continuous improvement of technological advancement and operational quality
Wdrażanie konkurencyjnych modeli organizacyjnych i biznesowych	Implementing competitive organisational and business models
Optymalizacja wykorzystania zasobów	Optimising the use of resources
Utrzymanie krajowego potencjału wytwarzania energii elektrycznej	Maintaining the national potential for electricity generation
Zapewnienie dostępu do strategicznych surowców energetycznych i ich pochodnych	Ensuring access to strategic energy resources and their derivatives
Zmniejszenie uzależnienia od importu nośników energii i technologii	Reducing dependence on imported energy carriers and technologies
Zapewnienie niezakłóconego funkcjonowania krajowych systemów energetycznych	Ensuring an uninterrupted operation of national power systems
Wykorzystanie innowacji w energii dla rozwoju przemysłowego	Utilising energy innovation for industrial development
Zmniejszenie jednostkowego zużycia energii i surowców	Reducing specific energy consumption and consumption of raw materials
Wzorcowa rola energii w budowaniu ekosystemu innowacji między przedsiębiorstwami, instytucjami publicznymi i nauką	The exemplary role of energy in building an ecosystem of innovation among businesses, public institutions and science.

To meet the above objectives, it is necessary to define the selected areas of action. It is not possible to stimulate the development of all technologies and solutions. For this reason, four main areas of development of energy innovation have been identified through an analysis of the potential of the Polish energy sector and industry, global technology trends and local resources that ensure energy security and underpin the competitiveness of the Polish energy sector. These areas will be adapted as progress is made and external conditions change.

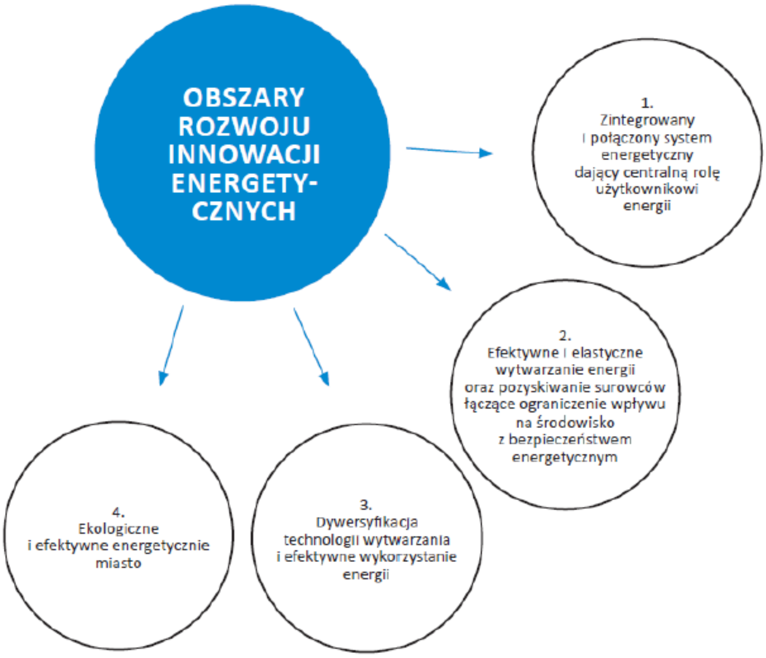


Figure 55. Areas of energy innovation development. Source: Ministry of Energy

OBSZARY ROZWOJU INNOWACJI ENERGETYCZNYCH	**AREAS OF ENERGY INNOVATION DEVELOPMENT**
1. Zintegrowany i połączony system energetyczny dający centralny rolę użytkownikowi energii	1. An integrated and interconnected power system giving a central role to the energy user
2. Efektywne i elastyczne wytwarzanie energii oraz pozyskiwanie surowców łączące ograniczenie wpływu na środowisko z bezpieczeństwem energetycznym	2. Effective and flexible energy generation and raw material sourcing combining environmental impact reduction with energy security
3. Dywersyfikacja technologu wytwarzania i efektywne wykorzystanie energii	3. Diversification of generation technologies and effective use of energy
4.Ekologiczne i efektywne energetycznie miasto	4. A green and energy-efficient city.

<u>Action Area 1</u> – An integrated and interconnected power system giving a central role to the energy user. Area 1 includes:

- Exploiting the potential of information and communication technologies (ICT) to optimise the operation of the power grid and implementation of the Internet of Things, as well as protection of energy transport networks, especially the power grids, in particular in terms of cyber security.
- Adapting power grids for optimal use of electricity by the user.
- Stability of operation of transmission and distribution networks.

<u>Action Area 2</u> – Effective and flexible energy generation and raw material sourcing combining environmental impact reduction with energy security. Area 2 includes:

- Increasing the flexibility and efficiency of coal-based power generation and alternative uses of coal.
- New ways of obtaining and using energy raw materials and energy sources.
- Perfecting hydrocarbon exploration and production technologies.

Action Area 3 – Diversification of energy generation and use technologies. Area 3 includes:

- The spread of electric transport, development of the electromobility industry and transition to a flexible energy network using energy storage systems.
- The Polish Nuclear Power Programme and the High Temperature Reactor (HTR) construction project.
- Supporting the power generation section of the circular economy.

Action Area 4 – A green and energy-efficient city. Area 4 comprises:
- Upgrading individual heating sources.
- Developing cogeneration and heat/cooling transmission networks.
- Reducing the energy intensity of buildings

2. National Action Plan on Energy Efficiency for Poland

An updated National Action Plan on Energy Efficiency for Poland is planned to be adopted in early 2018. It states, amongst others, that the objectives will be achieved by making maximum use of existing mechanisms and organisational infrastructure.

Poland's obligation to adopt the plan stems from the EU directive which requires all Member States to submit their plans to the European Commission. Plans are drawn up periodically, every 3 years. The current plan is an update of the document adopted in 2014. It contains an updated description of measures to improve energy efficiency in different sectors of the economy, adopted in connection with the implementation of the 2016 national energy efficiency target, as well as additional measures to achieve the overall energy efficiency target of 20% savings in primary energy consumption in the European Union by 2020. The plan is based on the assumption that policies aimed at increasing the energy efficiency of the economy will be continued and will translate into a reduced energy intensity of the economy. It is also planned that these actions will be based as much as possible on market mechanisms and will rely to a minimum extent on budgetary funding. The objectives will be implemented according to the principle of least cost, i.e. by making maximum use of existing mechanisms and organisational infrastructure and that the national potential will be used to improve energy efficiency.

Poland overachieved its national energy efficiency target understood as realising by 2016 final energy savings of at least 9% of the average inland consumption of such energy in 2001-2005. Poland has seen a steady decrease in the energy intensity. The decreasing energy intensity is due to the rate of energy consumption being outpaced by the GDP growth rate. In 2006-2015, the average annual rate of improvement in energy intensity exceeded 3%. When adjusted for climate conditions, the rate was slightly lower.

The most important financial instruments supporting energy efficiency investments in Poland include programmes implemented by the National Fund for Environmental Protection and Water Management (NFOŚiGW) and Regional Environmental Protection Funds, as well as funds from the Operational Programme Infrastructure and Environment (OPI&E), Regional Operational Programmes (ROPs), BOŚ Bank, and the Thermomodernisation and Repairs Fund.

3. National Action Plan on Renewable Energy

One of the priorities of the State's energy development strategy is to ensure that in 2020 Poland achieves at least 15% share of energy from renewable sources in gross final energy consumption, including at least 10% share of renewable energy in transport. The obligation to adopt the above target results directly from Directive 2009/28/EC on the promotion of the use of energy from renewable sources.

In fulfilment of the obligations set out in the directive, the Council of Ministers adopted on 6 December 2010 the *National Action Plan for Renewable Energy* (NAP), which was subsequently submitted to the European Commission. The NAP sets national targets for the share of energy from renewable sources consumed in transport, electricity, heating and cooling in 2020.

The Act of 20 February 2015 on renewable energy sources (Journal of Laws 2017, item 478, as amended) is currently the basic legal act governing renewable energy sources. The Act implements into Polish law two basic EU directives on RES, namely:

- Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC (OJ L 140, 5.6.2009, p. 16, as amended);
- Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC (OJ L 315, 14.11.2012, p. 1).

The basic assumptions of the RES Act are as follows:
- increasing energy security and environmental protection through, amongst others, efficient use of renewable

energy sources;

- rational use of renewable energy sources, having regard to the implementation of a long-term economic development policy, the fulfilment of obligations resulting from international agreements, and the improvement of innovation and competitiveness of the Polish economy;
- developing mechanisms and instruments to support the production of electricity, heat/cooling and agricultural biogas in renewable energy installations;
- developing an optimal and sustainable supply of electricity, heat/cooling and agricultural biogas from renewable energy installations to final customers;
- creating innovative solutions for the production of electricity, heat/cooling and agricultural biogas in renewable energy installations;
- creating new jobs as a result of an increase in the number of new renewable energy installations being put into operation;
- ensuring the use of by-products and residues from agriculture and the industry using agricultural raw materials for energy purposes.

4. Act on electromobility and alternative fuels

The Act of 11 January 2018 on electromobility and alternative fuels implements Directive 2014/94/EU of the European Parliament and of the Council of 22 October 2014 on the deployment of alternative fuels infrastructure (further Directive 2014/94/EU) into Polish law. The Directive requires Member States to develop alternative fuels infrastructure. States should ensure the deployment of electric vehicle recharging points, CNG and LNG refuelling points, and LNG bunkering points. The Directive also puts Member States under an obligation to adopt technical specifications, harmonised rules for recharging electric vehicles, and rules on consumer information, as provided for by Directive 2014/94/EU.

The Act on electromobility and alternative fuels is the first document that comprehensively addresses, from the regulatory viewpoint, the principles of development and operation of alternative fuel infrastructure, in particular the development of networks of electric vehicle charging points and the operation of the charging service. The Act aims to stimulate the development of electromobility and the use of alternative fuels in transport. This will enable Poland to increase its energy security and independence, as well as improving air quality in cities. Moreover, an increased use of alternative fuels in transport will translate into the development of modern technologies on the Polish market.

The Act lays down, amongst others, the rules for building core infrastructure for the distribution of alternative fuels in order to ensure favourable conditions for its creation. The expansion of the core network will enable the free movement of vehicles using alternative fuels across the country. In accordance with the *National Policy Framework for the Development of Alternative Fuel Infrastructure* adopted by the Council of Ministers in March 2017, the core network will comprise 6,400 recharging points and 70 CNG natural gas stations to be located in cities and along key express routes. The rules of operation of this infrastructure and the entities responsible for the construction and management of recharging stations and natural gas stations are also defined. This should enable the creation of a core infrastructure network for alternative fuels, thus contributing to the realisation of the objectives of the Act and of the national framework.

The Act also provides for the creation of clean transport zones in cities where entry will be restricted to vehicles powered by alternative fuels, such as electricity, natural gas or hydrogen. This solution is primarily aimed at improving air quality in large cities, where concentrations of pollutants are typically the highest.

The Act offers a number of benefits for electric vehicle users. These include the exemption from excise duty on purchase of an electric vehicle (which will bring down the prices), a more favourable rate of depreciation, the right to use bus lanes, free parking in paid parking zones.

The Act introduces new concepts, including the term ‘recharging’ understood as the intake of electricity for the purpose of powering an electric vehicle, a hybrid vehicle, a zero-emission bus, a motor vehicle other than an electric vehicle, a moped, a bicycle or a bicycle trolley within the meaning of the Act of 20 June 1997 – Road Traffic Law.

Recharging of electric vehicles is a new type of business activity. Although the recharging service consists in enabling the recharging of vehicles for a fee in a publicly available recharging station, it is not sale of electricity within the meaning of the Energy Law and as such does not require a licence.

The Act marks the second stage of transposition of the provisions of Directive 2014/94/EU of the European Parliament and of the Council of 22 October 2014 on the deployment of alternative fuels infrastructure into Polish law. It was preceded by the adoption of the aforementioned National Policy Framework for the Development of Alternative Fuel Infrastructure, which is a strategic document setting out objectives and instruments to support market and infrastructure development in relation to electricity and natural gas (CNG and LNG) used in road transport and water transport.

5. Polish Nuclear Power Programme

The Polish Nuclear Power Programme (*Program polskiej energetyki jądrowej* – PPEJ) was adopted by the Council of Ministers on 28 January 2014. It envisages the construction of two nuclear power plants with a total installed capacity of 6,000 MW.

The main objective of the Polish Nuclear Power Programme is to implement nuclear power in Poland, which will contribute to ensuring the supply of appropriate volumes of electricity at prices acceptable to the economy and the society, while complying with environmental protection requirements. The overall objective will be implemented through the following specific targets:

- establishing and updating the legal framework for the development and operation of nuclear power,
- ensuring the highest achievable level of safety of nuclear power plants,
- implementing a rational and effective system of radioactive waste and spent fuel management, including the construction of a new disposal facility for low- and intermediate-level waste,
- developing institutional support for nuclear power,
- strengthening the national system for responding to radiological incidents with respect to nuclear power operation, including strengthening the national radiation monitoring system,
- ensuring qualified personnel for the development and operation of nuclear power,
- creating a robust and effective scientific and research support for nuclear power,
- increasing the innovation and technological advancement of Polish industry,
- preparing the National Power System (NPS) for the development of nuclear power industry.

The document is being updated.

6. The Ministry of Energy's Clean Energy HUB programme

Clean Energy HUB is a new initiative of the Ministry of Energy to support the development of the Polish energy sector and thus contribute to the development of new technologies.

The aim of the project is to provide comprehensive support for innovative energy technologies and to organise a platform that will contribute to facilitating their uptake by large energy operators in Poland, as well as to their promotion abroad. Initiatives in the fields of electromobility, low-carbon technologies, clean coal technologies, recycled energy, smart urbanisation or renewable energy are eligible for participation in the project.

Clean Energy HUB will support the development of the energy sector in Poland by targeting Polish and foreign undertakings which have a direct influence on the energy market, including by adding electric cars to their fleets or using green solutions in business. This is a practical example of what public, business-friendly solutions should look like. The Ministry of Energy focuses on developing innovation, improving the qualifications of entrepreneurs and increasing their chances for development through access to foreign markets and economies of scale.

7. The national plan for increasing the number of low-energy buildings

The national plan includes a definition of a low-energy building, reflecting existing conditions and economically justifiable measures to improve the energy performance of buildings. In addition, it outlines government actions taken to promote low-energy buildings, including the design, construction and alteration of buildings in a way that ensures their energy efficiency and increases the use of renewable energy in new and existing buildings, as well as sets out a timetable for achieving the targets.

The timetable is set out in the Regulation of the Minister for Infrastructure of 12 April 2002 on the technical conditions to be met by buildings and their siting (Journal of Laws 2015, item 1422, as amended), which implements some of the provisions of Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings. According to that timetable, all new buildings occupied and owned by public authorities are to be nearly zero energy buildings from 1 January 2019 and all new buildings are to be nearly zero energy buildings from 1 January 2021.

8. Legal framework on innovation

Financing research and development in the field of innovation is subject to statutory regulation. The Act of 4 November 2016 amending certain acts determining the conditions for innovative activity (Journal of Laws 2016, item 1933), known as ‘Small Innovation Act’, which came into force towards the end of 2016, increased the tax relief to 50%, permanently abolished income tax on the in-kind contribution of intellectual and industrial property, extended the time limit for deducting costs of R&D activity from 3 to 6 years and removed time limitations on the eligibility of inventors to share in the benefits of commercialisation. The first Act on innovation has been in force from the end of 2016.

The second Act on innovation, namely the Act amending certain acts in order to improve the legal environment for innovative activity (Journal of Laws 2017, item 2201) was adopted on 9 November 2017. This Act comprehensively addresses matters related to innovation (it is commonly referred to as the ‘Large Innovation Act’). Drafted by the Ministry of Science and Higher Education in cooperation with the Ministry of Development and Finance, the Act is aimed at increasing support for research and development. The Act is in line with the assumptions underlying, amongst others, the Strategy for Responsible Development. It assumes an increase in R&D spending to 1.7% of GDP in 2020 and the establishment of 1,500 start-ups within 7 years. What draws particular attention is the high potential for employment increase in R&D: the employment rate in this sector per 1,000 economically active persons in Poland in 2013 was 5.4 compared to an average of 12.6 for the entire European Union in the same year.

The Act introduces a number of tax changes, including increasing the of tax relief for research and development activities to 100%. It also addresses proposals from the scientific community by expanding the scope of activity of special purpose vehicles established by universities and institutes of the Polish Academy of Sciences (PAN) and deregulates procedures applicable to the establishment of the Polish Roadmap for Research Infrastructure.

The most important assumptions underlying the second Act on innovation include:

- increasing the tax relief for research and development activity (R&D) to 100%[51] (150% for Research and Development Centres), clarifying and expanding a list of costs eligible for R&D relief (to include assets other than fixed assets and forms of employment other than contract of employment),
- enabling undertakings operating in special economic zones (SEZ) to benefit from R&D relief in relation to eligible costs other than costs of operation in a SEZ,
- extension of the double taxation exemption of capital companies and limited joint-stock partnerships engaged in R&D activities until 2023,
- expanding the scope of activity of special purpose vehicles established by universities and institutes of the Polish Academy of Sciences (PAN) to include economic activity,
- enabling universities and the PAN’s scientific institutes to establish companies to manage research infrastructure,
- providing the Ministry of Science and Higher Education with legal instruments to monitor the career paths of PhD students,
- deregulating procedures applicable to the establishment of the Polish Roadmap for Research Infrastructure.

The Polish Roadmap for Research Infrastructure defines measures to ensure increased efficiency in energy generation, storage and transmission (including sustainable use of raw materials, alternative and low-carbon technologies, nuclear energy, advanced materials and technologies for energy generation). To this end, dedicated centres are planned to be set up in leading Polish research institutions. This includes the Centre of Clean Coal Technologies (CCTW) at the Central Mining Institute (GIG), the Energy Centre at AGH University of Science and Technology, and the National Energy Laboratory (NLEJ) at the National Centre for Nuclear Research, which will serve as the National Research Centre and Poland’s contribution to international projects devoted to the development of high-temperature reactors. Most of these projects are either completed or in progress.

9. National Research Programme (KPB)

[51] In relation to the amount of tax reliefs under the currently applicable Act.

The Act of 30 April 2010 on the principles of financing science introduced (in Article 4) the obligation to establish the National Research Programme. The issues relating to the energy and climate matters broadly understood, which fall within the scope of Dimension 5: Research, innovation and competitiveness, as referred to in the *Regulation of the European Parliament and the Council on the Governance of the Energy Union*, are addressed in three strategic directions of scientific research and development, namely: new energy technologies, modern materials technologies, natural environment, agriculture and forestry.

These directions form the basis for the National Centre for Research and Development *(Narodowe Centrum Badań i Rozwoju* – NCBiR) to develop strategic research and development programmes.

The National Centre for Research and Development is a key State institution responsible for financing research and development in Poland. From the perspective of the Ministry of Energy, the alignment of the NCBiR's work and programmes with the strategic directions of the sector is a prerequisite for an effective innovation policy, in particular in terms of reducing pollutant emissions.

Selected NCBiR programmes in the field of energy technologies, the implementation of which is consistent with planned actions for clean energy, are presented below.

9.1. Operational Programme Smart Growth 2014-2020

The programme is approved by the European Commission and wholly financed by the European Regional Development Fund. According to the Partnership Agreement, a total of EUR 8,614,000 is allocated to the programme. The Smart Growth Programme is designed to support research, development of new innovative technologies and activities aimed at improving the competitiveness of small and medium-sized enterprises. Its main objective will be to stimulate the innovativeness of the Polish economy by increasing private spending on R&D and creating demand for innovation and R&D among enterprises.

'*From idea to market*' is the programme's main assumption. It means supporting the creation of innovation: from the conception of unprecedented products, services or technologies through the preparation of prototypes/pilot lines to their commercialisation.

The National Centre for Research and Development (NCBiR) plays the main organisational and managerial role in the programme, although contributions from the Polish Agency for Enterprise Development (PARP) or Bank Gospodarstwa Krajowego (BGK) are also important.

Support under the Smart Growth Programme is available primarily to enterprises (in particular SMEs), scientific entities, consortia of enterprises and scientific entities, and business environment institutions.

Projects financed under the programme fall into two groups. The first group are projects that contribute primarily to the development of entities that implement them. This concerns, for example, companies which enter new markets and improve their products by investing in the development and implementation of innovative products or services or by cooperating with R&D entities. The second group consists of projects in the case of which implementing bodies act only as contractors or intermediaries in delivering specific solutions to selected groups of addressees. An example are projects carried out by business environment institutions which provide free or partially subsidised advisory services or by bodies implementing financial instruments, providing support in the form of loans, guarantees or capital instruments. Projects such as Smart Growth are addressed primarily to micro, small and medium-sized enterprises and start-ups.

27 new competitions were launched under the programme in 2018, with the pool of support totalling PLN 7.44 billion. The largest amount of support was allocated to projects under Axis I: Supporting R&D carried out by enterprises. PLN 3.5 billion was available for allocation through eight competitions. Another 29 competitions are to be launched in 2019.

Five competitions with a pool of PLN 1.9 billion are also planned under Axis III: Support for innovation in enterprises.

9.2 Strategic research and development programme 'Modern Material Technologies' (TECHMATSTRATEG)

The programme covers five strategic areas stemming directly from the National Research Programme, in line with the priority directions of research currently being carried out in the European Union and worldwide. Energy storage and transmission is one of these areas. The projects implemented under the programme will result in developing and preparing the implementation of new products, techniques and technologies and a whole range of other solutions applicable in the areas covered by the programme.

9.3 Strategic research project ‘Integrated system to reduce the energy intensity of buildings'

The aim of the project is to develop technical and organisational solutions for the design, erection and operation of residential and public buildings, leading to a reduction in their energy intensity and an increase in the use of renewable energy sources in the energy balance of the building. The expected effect of this strategic project will be the development of energy efficiency in the construction sector, as well as a significant reduction of emissions of carbon dioxide and other pollutants into the atmosphere. The strategic research project ‘Integrated system to reduce the energy intensity of buildings’ consisted of seven independent, topic-related research tasks. Each of the tasks is an independent whole, and the outcome of one of them does not affect the outcome of the other. Therefore, the result of the whole project is the sum of the outcomes of individual tasks, which include the assessment of opportunities, effects and threats to the increase of energy efficiency in the construction sector and the development of energy-optimised typical structural, material and installation solutions for buildings that will contribute to the elimination of design solutions resulting in an excessive energy consumption throughout the life cycle of the building.

9.4 Strategic research project 'Technologies to support the development of safe nuclear energy'

The project is a response to the call for increasing the country's energy security in the context of nuclear power. Its implementation is closely linked to the plans to build a nuclear power plant in Poland and the EU's climate and energy policy. The strategic project will create links between research carried out by Polish scientific teams and global research and will prepare scientific and technical staff to face the needs of the Polish nuclear industry. Its implementation is intended to contribute to addressing problems related to spent fuel and radioactive waste. Furthermore, the project will enable the regulation of radiological protection, which will translate into increased public approval of nuclear power in Poland.

Task/project title:

a) Development of high temperature reactors for industrial use.
b) Research and development of controlled thermonuclear fusion technologies.
c) Basis for securing the fuel needs of Polish nuclear energy.
d) Development of techniques and technologies to support the management of spent fuel and radioactive waste.
e) Analysis of opportunities and criteria for the participation of Polish industry in the development of nuclear energy.
f) Development of methods to ensure nuclear safety and radiological security for current and future nuclear energy needs.
g) Analysis of hydrogen generation processes in a nuclear reactor under normal operating and emergency conditions, together with proposals for measures to improve nuclear safety.
h) Analysis of the processes involved in the normal operation of nuclear power plant water cycles, together with proposals for measures to improve nuclear safety.
i) Development of methods, and performance of, safety analyses in nuclear reactors in the event of heat distortion and severe accidents.
j) Development of a method and execution of an exemplary system analysis of the operation of a nuclear unit with a water reactor at partial cogeneration.

The value of projects implemented in 2011-2015 totalled approx. PLN 55 million.

9.5. GEKON Programme – Generator of Ecological Concepts, a joint venture of NCBiR and NFOŚiGW.

The GEKON programme is a joint venture carried out under an agreement between NCBiR and the National Fund for Environmental Protection and Water Management (NFOŚiGW). Under the joint project, NCBiRD finances industrial research and development related national environmental technologies in five thematic areas:

- Environmental aspects of unconventional gas production;

- Energy efficiency and energy storage;
- Protection and rational use of water;
- Clean energy generation;
- Innovative methods for production of fuels, energy and materials from waste and recycled waste.

In 2015, NCBiR carried out substantive and financial supervision over 59 research and development projects selected through competition, as well as continued the procedure for giving decisions on the second competition and signing contracts for the execution and financing of projects selected through the first and second competition. The value of 59 projects monitored in 2015 totalled approx. PLN 279.5 million.

9.6 Blue Gas – Polish Shale Gas Programme – a joint venture between NCBR and ARP S.A.

The Blue Gas Programme is a joint venture between NCRD and the Industrial Development Agency (Agencja Rozwoju Przemysłu S.A.), aimed at supporting large, integrated research and development projects, including pilot tests leading to the development and commercialisation of innovative technologies in the area of shale gas extraction in Poland. A total of 21 projects selected for funding under the first and second competition continued to be monitored in 2015. The value of financial and in-kind contributions of entrepreneurs participating in the programme totalled PLN 5.2 million in 2015.

According to own estimates of the Ministry of Science and Higher Education (MNiSW), approx. PLN 300-400 million a year has been allocated in recent years (since 2010) to energy and environmental technology projects from the science budget (MNiSW, NCBiR and NCN). These are both large programmes and strategic projects implemented by NCRD, as well as larger initiatives (joint ventures, sector programmes) and smaller projects (research, targeted, development projects, etc.) on topics selected by the applicants.

Other institutions coordinating research in low-emission energy in Poland

Coordination of work in the area of low-carbon energy is essential to achieve improvements. The following institutions are tasked with coordination in the field of research and development:

- **National Fund for Environmental Protection and Water Management (NFOŚIGW) –** an institution equipped with actual tools to implement new energy technologies, especially in the environmental aspect. For optimal use of the Fund's resources in terms of energy and environmental objectives, the Ministry of Energy submits to the Fund its proposals for strategic projects with the greatest environmental impact. Important areas of support are:

- replacement of individual heating sources with cogeneration units and their upgrading combined with the expansion of the heating network, which will lead to reducing the emission of pollutants while creating a market for domestic manufacturers of modern boilers;

- increased use of waste;

- construction of installations for methane production from coal mines;

- coal gasification technologies on an industrial scale.

Some of the above actions have already been initiated within the framework of the National Fund for Environmental Protection and Water Management. However, they require not only continuation, but also a significant extension of their scope and scale. A fast path for the most important groups of projects, selected by the Ministry of Energy, may be a good way to ensure their implementation. The Infrastructure and Environment Operational Programme 2014-2020 includes, amongst others, the following priorities:

- decarbonisation of the economy, with an amount of support of EUR 2,151,095,269;

- environmental protection, including adaptation to climate change, with a budget of EUR 4,127,263,725;

- development of low-emission public transport in cities, with an amount of support of EUR 2,704,921,948.

- **Low Emissions Transport Fund** – it is intended to support, amongst others:

- manufacturers of vehicles powered by electricity, as well as those powered by compressed natural gas (CNG) and liquefied natural gas (LNG);

- research of new technologies related to the use of electricity in transport.

4.6.5. Projection of outlays on emission reduction research

Outlays on research and development show a strong upward trend in Poland. Between 2005 and 2015 they increased from approx. 0.5% to approx. 1%. In line with the Strategy for Responsible Development and the Europe 2020 strategy, a further increase in R&D outlays is projected to reach the target of 1.7% of GDP in 2020 as set out in these documents.

An assumption is made in the present work that R&D outlays will remain at the level of 1.7% of GDP until 2040.

Table 66. Outlays on scientific research and development (EUR'2016 million)

	2005	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**
Outlays (EUR'2016 million)	1,711	2,798	4,250	9,371	11,044	12,716	14,345	15,948

Source: GUS: http://stat.gov.pl/wskazniki-makroekonomiczne/- accessed in November 2017.

Table 67. Research and development outlays by sector of emission reduction technologies (EUR'2016 million)

	2005	2010	2015
Energy efficiency	No data	49.23	17.45
Fossil fuels	No data	30.78	30.12
Renewable energy sources	No data	22.18	19.50
Nuclear	No data	4.58	1.07
Hydrogen and fuel cells	No data	1.80	1.94
Other power and storage technologies	No data	17.25	17.06
Other interdisciplinary technologies in the energy sector	No data	0.92	1.08
Total R&D budget of the emission reduction sector	No data	127	88

Source: IEA

The projection of R&D investment in emission-reducing sectors assumes that the growth rate of R&D investment between 2015 and 2040 is proportional to the growth rate of overall R&D investment.

Table 68. Projected total spending on emission reduction research by 2040 (EUR'2016 million)

	2005	2010	2015	2020	2025	2030	2035	2040
Total R&D budget of the emission reduction sector	No data	127	88	195	229	264	298	331

Source: IEA, ARE S.A.