IOP Conf. Series: Materials Science and Engineering **268** (2017) 012002 doi:10.1088/1757-899X/268/1/012002

# Access to primary energy sources - the basis of national energy security

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**Abstract**. National energy security is of fundamental importance for economic development of a country. To ensure such safety energy raw material, also called primary energy sources, are necessary. Currently in Poland primary energy sources include mainly fossil fuels, such as hard coal, brown coal, natural gas and crude oil. Other sources, e.g. renewable energy sources account for c. 15% in the energy mix. Primary energy sources are used to produce mainly electricity, which is considered as the cleanest form of energy. Poland does not have, unfortunately, sufficient energy sources and is forced to import some of them, mainly natural gas and crude oil. The article presents an insightful analysis of energy raw material reserves possessed by Poland and their structure taking account of the requirements applicable in the European Union, in particular, those related to environmental protection. The article also describes demand for electricity now and in the perspective of 2030. Primary energy sources necessary for its production have also been given. The article also includes the possibilities for the use of renewable energy sources in Poland, however, climatic conditions there are not are not particularly favourable to it. All the issues addressed in the article are summed up and ended with conclusions.

## 1. Introduction

Energy security of countries has always been a priority for each government. Since the beginning of armed conflicts in North Africa and the Middle East, in countries with rich deposits of crude oil and natural gas - the issue of energy security of many countries, including Poland, makes the front pages of newspapers.

Energy security is not clearly defined. In the in the Energy Law Act of 10 April 1997 [1], the following definition, which is also used in this article, is given:

'National energy security – the condition of the economy which enables full coverage of the customer's ongoing and prospective demand for fuels and energy in a technically and economically justified manner, with the observance of the environment protection requirements'.

Demand for final energy and quantities of primary energy sources necessary to produce it are published in a government document entitled: 'The assumptions of the Polish energy policy until...'.

The current document sets out the perspective until 2030 and demand for energy raw materials even until 2050 (draft of policy assumptions ...) [2].

The production process of final energy, which is electricity, is schematically presented in figure 1. Electricity is considered as the cleanest energy and the most refined. Therefore, economic development of a country is determined on the basis of per capita energy consumption.

In the further parts of the article the said primary energy source will be discussed. Their usefulness for further development of the Polish economy will be assessed.

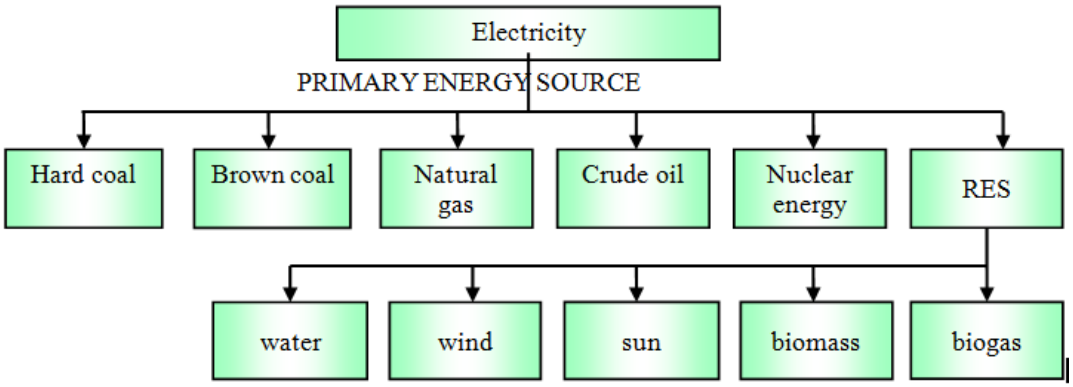


**Figure 1.** Process of electricity production.

## 2. Fossil sources of primary energy and their location in the territory of Poland

The distribution of hard coal and brown coal deposits in Poland is shown in figure 2. The following colours mean respectively:

- black - hard coal,
- brown - brown coal.


**Figure 2.** Deposits of hard coal and brown coal in Poland.

Table 1 presents the balance reserves of the said energy raw materials, the number of the developed deposits and production as at 31 December 2015. The data presented in table 1 show that the balance reserves of hard coal increased by 4.26 billion Mg, despite its production of c. 72 million Mg in 2015. The increase of reserves results, however, mainly from the reassessment of coal reserves based on new criteria.

The reserves of other raw materials do not show significant changes, except for the changes resulting from production (gas, crude oil). It is worth noting that the gas balance includes also methane extracted from hard coal deposits, which until now has not been taken into account.

**Table 1.** Summary of geological balance reserves and production of important fossil fuels in Poland in 2015 - in million metric tons; natural gas and methane in billion metric tons; crude oil and gas - deposits extracted (Source: own study based on data of Polish Geological Institute).

| Fossil fuel | Number of deposits | | | Balance reserves | | | Production | |
|---|---|---|---|---|---|---|---|---|
| | total | developed quantity | 2014 =100% | situation on: 31/12/2015 | including developed reserves | + increase - decrease | volume | 2014 =100% |
| ENERGY FOSSIL FUELS: | | | | | | | | |
| - gas | 352 | 236 | 101 | 213.59 | 138.09 | -0.73 | 5.53 | 99.64 |
| - liquid | 86 | 64 | 96 | 22.82 | 22.26 | -0.71 | 0.90 | 97.83 |
| - solid | 247 | 60 | 100 | 79 736.67 | 22.525.75 | +4265.65 | 128.20 | 98.64 |
| Natural gas | 292 | 207 | 100 | 122.82 | 101.68 | -4.70 | 5.21 | 99.05 |
| Coal deposit methane | 60 | 29 | 104 | 90.77 | 36.41 | +3.97 | 0.32 | 110.34 |
| Crude oil | 86 | 64 | 96 | 22.82 | 22.26 | -0.71 | 0.90 | 97.83 |
| *1* | *2* | *3* | *4* | *5* | *6* | *7* | *8* | *9* |
| Brown coal | 91 | 9 | 100 | 23.516.19 | 1418.70 | +5.60 | 63.13 | 98.64 |
| Hard coal | 156 | 51 | 100 | 56.220.48 | 21.107.05 | +4260.05 | 65.07 | 98.64 |

### *2.1. Hard coal*

This raw material is the main source of primary energy used for electricity production. Over 50% of electricity has been produced using coal. Of all the energy sources at the disposal of the Polish energy industry, only the resources of hard coal and brown coal are sufficient. Therefore, the Polish energy industry is based mainly on those materials.

However, the reserves of those materials are determined in years. Hard coal reserves in Poland are shown in table 2 [4].

**Table 2.** Hard coal reserves in operating deposits as at 01/01/2015 (million Mg).

| | **Balance reserves** | **Industrial reserves** | **Operable reserves** |
|---|---|---|---|
| During concession term | 14.872 | 3.230 | 1.813 |
| For entire deposit | 20.282 | 6.023 | 3.390 |

Taking account of operable reserves of 3 3.390 million Mg and current production of c. 70 million Mg annually - the reserves are sufficient to meet c. 48 years of production, i.e. to c. 2070, if decreased production in the final stage of coal deposits mining is taken into account.

Hard coal reserves in Poland compared to selected countries are shown in table 3 [5].

**Table 3.** World hard coal production between 2008 – 2016 (in thousand Mg) Source: GUS (Central Statistical Office).

| COUNTRY | 2008 | 2009 | 2010 | 2011 | 2012 | 2013[a] | 2014 | 2015 | 2016 |
|---|---|---|---|---|---|---|---|---|---|
| World | 5.688.416 | 5.789.687 | 5.877.025 | 6.235.943 | 6.454.799 | 7.240.791 | 7.212.081 | . | . |
| Australia | 431.004 | 426.996 | 449.004 | 443.700 | 488.868 | 542.832 | 571.332 | 571.284 | . |
| China | 2.585.664 | 2.983.992 | . | . | . | . | . | . | . |
| India | 483.468 | 521.376 | . | 523.488 | 560.100 | 561.276 | 600.972 | 631.788 | . |
| Indonesia | 483.468 | 521.376 | . | . | . | . | . | . | . |
| Canada[a] | 32.844 | 27.960 | 33.708 | 34.620 | 35.376 | 38.280 | 35.676 | . | . |
| Kazakhstan | 181.572 | 209.340 | . | . | . | . | . | . | . |
| Poland[b] | 84.240 | 77.916 | 76.596 | 76.212 | 79.524 | 76.452 | 73.008 | 72.228 | 70.584 |
| South Africa | 252.252 | 249.120 | 254.160 | 252.672 | 258.192 | 253.704 | . | . | . |
| Russia | 245.568 | 230.316 | 245.088 | 257.328 | 276.504 | 274.800 | 286.428 | 298.788 | 311.688 |
| United States[c] | 1.063.044 | 975.156 | 983.724 | 993.936 | 922.440 | 893.436 | 907.224 | 813.720 | 670.104 |
| Ukraine[c] | 59.268 | 54.816 | 54.444 | 61.752 | 64.692 | 63.312 | 44.688 | 28.224 | . |
| Vietnam | 39.600 | 43.752 | 44.676 | 44.496 | 42.096 | . | . | . | . |

*a including sub-bituminous coal, b* Excluding briquettes, sub-bituminous coal and similar solid fuels, *c* including brown coal

Not all countries make their recent commercial data available, therefore, there is no information in table 3 about production of such big players as China, Indonesia and Kazakhstan. However, the USA,

Russia and Australia publish their production. Global hard coal production in 2014 was over 7.2 billion Mg. Poland with production of c. 70 million Mg in 2016 is no longer a coal power. Table 3 has been included mainly as an indication from which country Poland could import coal after its own hard coal deposits have been depleted.

Table 4 shows global hard coal reserves broken down by continents. They amount to c. 411.3 billion Mg. The USA has the largest share in those reserves (108.95 billion Mg).

**Table 4.** Summary of hard coal balance reserves on individual continents.

| No. | Continent | Reserves (million Mg) | Largest share in continent reserves |
|---|---|---|---|
| 1. | Europe and Eurasia | 102.042 | Russia (49 088) |
| 2. | Asia and Oceania | 155.809 | China (62 200) |
| 3. | South and Central America | 6.964 | Columbia (6 434) |
| 4. | North America | 113.281 | USA (108 950) |
| 5. | Africa and Middle East | 33.225 | South Africa (30 408) |
| 6. | WORLD TOTAL | 411.321 | USA (108 950) |

*2.2. Brown coal*

Global production of brown coal in 2014 amounted to 810,467 thousand Mg. The largest producer of brown coal is Germany, where in 2015 production amounted to 178,068 thousand Mg. Countries with similar brown coal production of between 63 million Mg and 73 million Mg include: USA, Turkey, Poland and Russia. Brown coal production data between 2008 - 2015 are presented in table 5 [5].

A subtracting in Poland brown coal is usually transported directly to a power plant. Electricity production based on brown coal accounts for c. 31% of total production.

Balance reserves of brown coal in Poland are estimated at c. 23 billion Mg. Reserves broken down by exploration and development categories are shown in table 6. A substantial part of balance reserves (c. 3,690 million Mg) is deposited in so-called Poznań fault and cannot be mined due to protests of the local population.

**Table 5.** World's brown coal production between 2008 - 2015 in thousand Mg.
Source: GUS (Central Statistical Office).

| COUNTRY | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 |
|---|---|---|---|---|---|---|---|---|
| World | 990.528 | 856.142 | 840.249 | 890.675 | 887.187 | 834.669 | 810.467 | . |
| Australia | 69.907 | 72.037 | 72.090 | 71.000 | 71.350 | 62.845 | 60.661 | . |
| Bosnia | 5.518 | 5.628 | 5.618 | 6.289 | 5.836 | 5.711 | 6.110 | . |
| Brazil | 2.229 | 2.049 | 2.095 | 2.136 | 3.170 | 3.645 | . | . |
| Bulgaria | 28.740 | 27.180 | 29.304 | 37.080 | 33.420 | 28.620 | . | 35.856 |
| Czech Republic | 47.532 | 45.408 | 43.656 | 46.620 | 43.536 | 40.392 | 38.220 | 38.100 |
| Estonia | 16.044 | 14.928 | 17.892 | 18.732 | 18.420 | 20.508 | 20.436 | 19.716 |
| Greece | 62.460 | 61.824 | 53.628 | 56.796 | 61.740 | 52.572 | 48.024 | 45.096 |
| India | 32.124 | 35.724 | 37.733 | 40.380 | 46.524 | 44.760 | 46.164 | 44.448 |
| Indonesia | . | . | . | . | . | . | . | . |
| Canada *a* | 34.908 | 34.980 | 34.188 | 32.496 | 31.188 | 30.624 | 32.076 | . |
| Kazakhstan | 4.728 | . | . | . | . | . | . | . |
| Mecedonia | . | . | 6.724 | 8.209 | 7.310 | 6.686 | 7.128 | . |
| Mongolia | 5.903 | 7.349 | 5.723 | 6.938 | 5.936 | 6.330 | 6.330 | . |
| Germany | 175.308 | 169.680 | 169.404 | 176.508 | 185.436 | 182.700 | 178.512 | 178.068 |
| Poland | 59.668 | 57.108 | 56.510 | 62.841 | 64.280 | 65.849 | 63.877 | 63.060 |
| Russia | 80.496 | 68.136 | 76.620 | 76.524 | 77.832 | 72.984 | 69.408 | 73.248 |
| Romania | 31.956 | 28.512 | 28.668 | 33.396 | 32.088 | 22.896 | . | 24.204 |
| Serbia | 38.520 | 38.280 | 37.800 | 40.812 | 38.028 | 40.092 | 29.940 | 37.656 |
| United States | 68.659 | 65.751 | 70.970 | 73.574 | 71.602 | 70.061 | 72.110 | . |
| Thailand | 17.976 | 16.356 | . | 21.324 | 18.072 | 18.348 | 17.988 | . |
| Turkey | 86.076 | 82.164 | 74.760 | 79.020 | 74.652 | 63.048 | 66.936 | 51.444 |
| Hungary | 9.404 | 8.986 | 9.113 | 9.555 | 9.290 | 9.558 | . | . |

*a including sub-bituminous coal*

**Table 6.** Brown coal - million Mg (Source: own study based on data of Polish Geological Institute).

| Item | Number of deposits | Geological reserves | | | | Industrial reserves |
|---|---|---|---|---|---|---|
| | | Total | balance A+B+$C_1$ | $C_2$+D | off-balance | |
| TOTAL RESERVES | 91 | 23.516.19 | 6.067.91 | 17.448.28 | 3.522.44 | 1.122.670 |
| **including - developed deposits of resources** | | | | | | |
| Deposits of operating plants | 9 | 1.418.70 | 1.406.82 | 11.89 | 48.31 | 1.112.23 |
| **including - undeveloped deposits of resources** | | | | | | |
| Total | 74 | 22.081.18 | 4.645.43 | 17.435.75 | 3.447.62 | 16.83 |
| 1. Deposits explored in detail | 35 | 5.838.65 | 4645.43 | 1.193.23 | 872.64 | 16.83 |
| 2. Deposits explored initially * | 39 | 16.242.52 | 0.00 | 16.242.52 | 2.574.98 | - |
| **including - no longer mined deposits** | | | | | | |
| Production stopped | 8 | 16.30 | 15.66 | 0.64 | 26.51 | - |

* including resources of deposits in so-called Poznań fault of 3,690 million Mg

Developed balance reserves amount to 1.418 million Mg. This accounts for only 6% of all balance reserves. Coal from those reserves is mined by 5 mining plants, i.e.: Bełchatów, Turów, Adamów, Konin and Sieniawa [3].

Global reserves of brown coal are estimated according to World Energy Council (WEC) at c. 195 bn Mg. In Poland only developed deposits can be considered for mining, i.e. c. 1,418 million Mg of reserves, which at the current average coal production of about 60 million metric tons gives about 24 years. Therefore the Polish energy industry will be able to use brown coal until 2040 at the current production level.

After 2040 brown coal must be substituted by other fuels, e.g. nuclear energy. The same applies to hard coal after 2070.

*2.3. Natural gas*

Industrial reserves of natural gas in Poland are estimated at c. 54.913 million $m^3$. Gas deposits can be found in the following regions of Poland: Baltic Sea, Carpathian Mountains, Lowlands and Foothills Developed and undeveloped gas deposits amount to about 51 billion $m^3$, including c. 3.9 billion $m^3$ of gas in undeveloped deposits. The balance reserves of the developed deposits amount to c. 101 billion $m^3$ of gas [3]. Details of natural gas reserves in Poland are presented in table 7.

Natural gas consumption in Poland in 2016 was about 15 billion $m^3$. Therefore, if the balance reserves were used completely, they would last for seven years at the most. Natural gas production from domestic deposits is about 5.2 billion $m^3$ [3]. In such a situation gas reserves would last for about 20 years. However, it is impossible to extract completely gas from the deposit, so the period of its exploitation will be definitely shorter. Natural gas extraction from individual deposits in 2015 is presented in table 8. The data presented in Table 8 show that the Lowland and Foothills deposits were exploited most intensively.

Generally, it can be stated that natural gas deposits in Poland are insufficient for the needs of the Polish economy. A lot of hope was put on shale gas, widely present in Poland - figure 3. Reserves of this gas, initially considered as considerable, shrunk as they were identified in detail [6]. Current reserves of this gas are estimated at 346 to 762 billion $m^3$ (according to PIG).

Natural gas production in Poland compared to selected countries is presented in table 9. Global production in 2015 was 138,479 PJ. The largest share in this production had the USA (29,426 PJ) and Russia (24,386 PJ) [5]. To obtain approximate values expressed in billion $m^3$, multiplythe values in PJ by the conversion factor dependent on gas calorific value, i.e. from 36 to 42. Then production in the USA will be c. 1,059,336 billion $m^3$, and production in Russia will be: 877,896 million $m^3$ (Note! the lower value has been used).

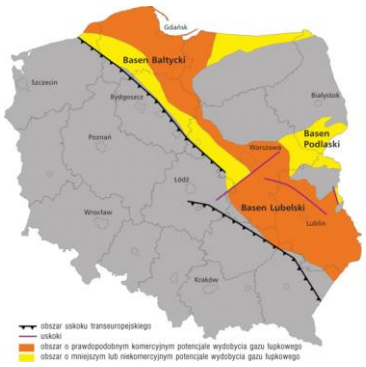


**Figure 3.** Map of shale gas occurrence in Poland
(Source: http://www.gazownictwopolskie.pl/gaz-z-%C5%82upk%C3%B3w/polskie-perspektywy)

**Table 7.** Natural gas - million $m^3$ (Source: own study based on data of Polish Geological Institute).

| Item | Number of deposits | Recoverable resources | | | | Industrial reserves |
|---|---|---|---|---|---|---|
| | | Total | balance A+B | C | off-balance | |
| TOTAL RESERVES - total | 292 | 122.820.02 | 75.746.96 | 47.073.06 | 2.220.70 | 54.913.68 |
| from oil andcondensate deposits | | 27.168.97 | 10.480.93 | 16.688.04 | 654.52 | 10.642.95 |
| from gas deposits | | 88.929.48 | 58.544.46 | 30.385.02 | 1.566.18 | 43.691.34 |
| from underground gas storage facilities | | 6.721.57 | 6.721.57 | - | - | 579.39 |
| including - developed deposits of resources | | | | | | |
| Total- | 207 | 101.679.10 | 69.965.50 | 31.713.60 | 663.04 | 51.006.78 |
| | | 14.695.13 | 6.259.36 | 8.435.77 | 651.04 | 6.821.06 |
| | | 80.262.40 | 56.984.57 | 23.277.83 | 12.00 | 43.606.33 |
| | | 6.721.57 | 6.721.57 | - | - | 579.39 |
| Baltic Sea (off shore) | 2 | 542.26 | 109.46 | 432.80 | - | 525.81 |
| | | 542.26 | 109.46 | 432.80 | - | 525.81 |
| | | - | - | - | - | - |
| | | - | - | - | - | - |
| Carpathian Mountains | 28 | 1.115.84 | 682.56 | 433.28 | 10.77 | 386.72 |
| | | 115.25 | 96.83 | 18.42 | 1.04 | 3.73 |
| | | 879.09 | 464.23 | 414.86 | 9.73 | 261.49 |
| | | 121.50 | 121.50 | - | - | 121.50 |
| Lowlands | 94 | 68.444.57 | 50.381.47 | 18.063.10 | 650.00 | 41.460.02 |
| | | 12.485.17 | 4.558.05 | 7.927.12 | 650.00 | 5.404.08 |
| | | 49.874.93 | 39.738.95 | 10.135.98 | - | 36.055.94 |
| | | 6.084.47 | 6.084.47 | - | - | - |
| Foothills | 83 | 31.576.43 | 18.792.01 | 12.784.42 | 2.27 | 8.634.23 |
| | | 1.552.45 | 1.495.02 | 57.43 | | 887.44 |
| | | 29.508.38 | 16.781.39 | 12.726.98 | 2.27 | 728.890.00 |
| | | 515.60 | 515.60 | | | 457.89 |
| including - undeveloped deposits of resources | | | | | | |
| Total- | 53 | 20.775.83 | 5.755.85 | 15.019.98 | 1.421.68 | 3.889.11 |
| | | 12.371.96 | 4.221.57 | 8.150.39 | 1.93 | 3.820.87 |
| | | 8.403.87 | 1.534.28 | 6.869.59 | 1.419.75 | 68.24 |

**Table 8.** Natural gas production - million $m^3$
(Source: own study based on data of Polish Geological Institute).

| Item | Total | From documented balance reserves | | | off-balance |
|---|---|---|---|---|---|
| | | Total | A+B | C | |
| Total | 5,213.52 | 5,212.04 | 4,226.02 | 986.02 | 1.48 |
| from gas deposits | 4,455.91 | 4,455.29 | 3,705.87 | 749.42 | 0.62 |
| from crude oil deposits | 367.14 | 366.28 | 129.70 | 236.58 | 0.86 |
| from condensate deposits | 390.47 | 390.47 | 390.45 | 0.02 | - |
| Baltic Sea (off shore) | 18.24 | 18.24 | 14.69 | 3.55 | - |
| from gas deposits | 0.00 | 0.00 | - | - | - |
| from crude oil deposits | 18.24 | 18.24 | 14.69 | 3.55 | - |
| from condensate deposits | 0.00 | 0.00 | - | - | - |
| Carpathian Mountains | 32.84 | 31.99 | 27.06 | 4.93 | 0.85 |
| from gas deposits | 29.61 | 29.10 | 25.17 | 3.93 | 0.51 |
| from crude oil deposits | 3.23 | 2.89 | 1.89 | 1.00 | 0.34 |
| from condensate deposits | 0.00 | 0.00 | - | - | - |
| Lowlands | 3,697.13 | 3,696.61 | 3,212.92 | 483.69 | 0.52 |
| from gas deposits | 3,019.09 | 3,019.09 | 2,766.94 | 252.15 | - |
| from crude oil deposits | 287.59 | 287.07 | 55.53 | 231.54 | 0.52 |
| from condensate deposits | 390.45 | 390.45 | 390.45 | - | - |
| Foothills | 1,465.31 | 1,465.20 | 971.35 | 493.85 | 0.11 |
| from gas deposits | 1,407.21 | 1,407.10 | 913.76 | 493.34 | 0.11 |
| from crude oil deposits | 58.08 | 58.08 | 57.59 | 0.49 | - |
| from condensate deposits | 0.02 | 0.02 | - | 0.02 | - |

**Table 9.** World's natural gas production between 2008 – 2015
Source: GUS (Central Statistical Office).

in PJ (to obtain approximate a value in billion $m^3$, multiplya given values by conversion factor from 36 to 42)

| COUNTRY | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 |
|---|---|---|---|---|---|---|---|---|
| World | 121.361 | 117.882 | 126.332 | 126.332 | 132.003 | 135.455 | 136.264 | 138.479 |
| Algeria | 3.433 | 3.299 | 3.348 | 3.348 | 3.374 | 3.206 | 3.266 | 3.257 |
| Saudi Arabia | 2.840 | 2.855 | 2.787 | 2.787 | 3.081 | 3.114 | 3.235 | 3.300 |
| Argentina | 1.821 | 1.729 | 1.645 | 1.645 | 1.589 | 1.507 | 1.513 | 1.554 |
| Australia | 1.698 | 1.722 | 2.069 | 2.069 | 2.123 | 2.426 | 2.462 | 2.594 |
| Azerbaijan | 634 | 635 | 651 | 651 | 691 | 715 | 753 | 762 |
| Bangladesh | 655 | 713 | 774 | 774 | 818 | 882 | 905 | 960 |
| China | 3.126 | 3.320 | 3.729 | 3.729 | 4.306 | 4.705 | 5.067 | 5.214 |
| Egypt | 2.366 | 2.359 | 2.159 | 2.159 | 2.056 | 2.099 | 2.146 | 1.955 |
| Netherlands | 2.786 | 2.624 | 2.951 | 2.951 | 2.672 | 2.873 | 2.333 | 1.776 |
| India | 1.223 | 1.792 | 1.999 | 1.999 | 1.551 | 1.351 | 1.279 | 1.235 |
| Indonesia | 2.991 | 3.120 | 3.480 | 3.480 | 3.132 | 3.105 | 3.056 | 2.952 |
| Iran | 5.025 | 5.408 | 5.662 | 5.662 | 6.154 | 6.169 | 6.873 | 7.237 |
| Canada | 6.746 | 6.298 | 6.160 | 6.160 | 6.033 | 6.064 | 6.400 | 6.378 |
| Qatar | 3.242 | 3.701 | 4.992 | 4.992 | 5.977 | 6.759 | 6.624 | 6.789 |
| Kazakhstan | 1.000 | 1.099 | 1.145 | 1.145 | 1.329 | 1.428 | 1.455 | 1.530 |
| Libya | 651 | 604 | 639 | 639 | 464 | 486 | 473 | 444 |
| Malaysia | 2.390 | 2.175 | 2.373 | 2.373 | 2.394 | 2.707 | 2.737 | 2.699 |
| Mexico | 1.775 | 1.787 | 1.981 | 1.981 | 1.897 | 1.883 | 1.734 | 1.627 |
| Nigeria | 1.206 | 882 | 1.237 | 1.237 | 1.566 | 1.412 | 1.612 | 1.660 |
| Norway | 4.053 | 4.219 | 4.429 | 4.429 | 4.688 | 4.447 | 4.419 | 4.773 |
| Oman | 1.057 | 1.095 | 1.106 | 1.106 | 1.219 | 1.317 | 1.260 | 1.298 |
| Pakistan | 1.231 | 1.270 | 1.255 | 1.255 | 1.262 | 1.234 | 1.224 | 1.291 |
| Poland | 172 | 171 | 172 | 172 | 182 | 178 | 173 | 171 |
| Russia | 24.879 | 22.071 | 25.128 | 25.128 | 25.158 | 26.204 | 24.083 | 24.386 |
| United States | 21.855 | 22.317 | 23.018 | 23.018 | 25.976 | 26.238 | 28.027 | 29.426 |
| Thailand | 1.071 | 998 | 1.150 | 1.150 | 1.219 | 1.321 | 1.348 | 1.276 |
| Trinidad and Tobago | 1.629 | 1.683 | 1.667 | 1.667 | 1.597 | 1.604 | 1.596 | 1.503 |
| Turkmenistan | 2.671 | 1.445 | 1.716 | 1.716 | 2.616 | 2.972 | 3.033 | 3.163 |
| Ukraine | 837 | 752 | 718 | 718 | 717 | 746 | 699 | 680 |
| Uzbekistan | 2.555 | 2.321 | 2.278 | 2.278 | 2.384 | 2.259 | 2.339 | 2.227 |
| Venezuela | 1.070 | 1.023 | 891 | 891 | 945 | 911 | 914 | 1.005 |
| Great Britain | 2.917 | 2.500 | 2.394 | 2.394 | 1.630 | 1.529 | 1.532 | 1.660 |
| United Arab Emirates | 1.959 | 1.904 | 1.933 | 1.933 | 2.046 | 2.057 | 2.042 | 2.214 |

*2.4. Crude oil*

Crude oil reserves in Poland are very small, therefore, this energy raw material is almost entirely imported, in particular, from Russia. Crude oil reserves in Poland are shown in table 10. As at 31 December 2015 balance reserves of crude oil totalled c. 23 million Mg, and industrial reserves were only c. 14 million Mg. This material is present together with natural gas in the following deposits: Baltic Sea (off shore), Carpathian Mountains, Lowlands and Foothills The reserves in table 10 are shown as balance, off-balance and industrial ones, and developed and undeveloped, and deposits exploitation of which has stopped.

Crude oil production in the world and Poland between 2010 - 2015 is presented in table 11. The data in table 11 show that, similarly to natural gas production, the biggest crude oil producers in 2015 were: The USA – 640,699 thousand Mg, Russia – 501,857 thousand Mg. Poland with production of 894 thousand Mg occupies the last position in table 11 [5]. Refining capacities of the petrochemical industry in Poland are c. 21 million Mg per annum. The main consumers of crude oil in Poland are PKN ORLEN and LOTOS Gdańsk Refinery. Crude oil is supplied to those companies mainly through the 'Przyjaźń' pipeline and the Northern Port in Gdańsk. In the light of the presented figures it can be stated that Poland does not have crude oil as a raw material, which could ensure its energy security.

**Table 10.** Crude oil - thousand Mg
(Source: own study based on data of Polish Geological Institute).

| Item | Number of deposits | Recoverable resources | | | off-balance | Industrial reserves |
|---|---|---|---|---|---|---|
| | | Total | balance A+B | C | | |
| TOTAL RESERVES - total | 86 | 22.824.28 | 9.496.80 | 13.327.48 | 395.40 | 14.191.12 |
| Crude oil | | 21.338.91 | 9.473.22 | 11.865.69 | 395.40 | 14.131.10 |
| Oil condensate | | 1.485.37 | 23.58 | 1.461.79 | - | 60.02 |
| including - developed deposits of resources | | | | | | |
| Total- | | 22.260.68 | 9.378.91 | 12.881.77 | 9.76 | 14.074.24 |
| | | 20.931.13 | 9.378.91 | 11.552.22 | 9.76 | 14.074.24 |
| | | 1.329.55 | | 1.329.55 | - | |
| Baltic Sea | | 4.654.27 | 1.059.10 | 3.595.17 | | 4.518.44 |
| | | 4.654.27 | 1.059.10 | 3.595.17 | - | 4.518.44 |
| Carpathian Mountains | | 547.18 | 441.18 | 106.00 | 6.55 | 47.35 |
| | | 547.18 | 441.18 | 106.00 | 6.55 | 47.35 |
| Lowlands | | 16.682.91 | 7.652.79 | 9.030.12 | 3.21 | 9.460.43 |
| | | 15.353.36 | 7.652.79 | 7.700.57 | 3.21 | 9.400.41 |
| | | 1.329.55 | - | 1.329.55 | - | 60.02 |
| Foothills | | 376.32 | 225.84 | 150.48 | | 48.02 |
| | | 376.32 | 225.84 | 150.48 | - | 48.02 |
| including - undeveloped deposits of resources | | | | | | |
| Total- | | 507.03 | 108.29 | 398.74 | 329.53 | 116.50 |
| | | 363.03 | 89.29 | 273.74 | 329.53 | 116.50 |
| | | 144.00 | 19.00 | 125.00 | - | - |
| Lowlands | | 391.10 | 108.29 | 282.81 | - | 116.50 |
| | | 247.10 | 89.29 | 157.81 | - | 116.50 |
| | | 144.00 | 19.00 | 125.00 | - | |
| Foothills | | 115.93 | | 115.93 | 329.53 | |
| | | 115.93 | - | 115.93 | 329.53 | |
| including deposits exploitation of which has stopped | | | | | | |
| Total- | | 56.57 | 9.60 | 46.97 | 56.11 | 0.38 |
| | | 44.75 | 5.02 | 39.73 | 56.11 | 0.38 |
| | | 11.82 | 4.58 | 7.24 | - | - |
| Carpathian Mountains | | 1.50 | | 1.50 | 3.75 | - |
| | | - | - | - | 3.75 | |
| | | 1.50 | - | 1.50 | - | |
| Lowlands | | 50.49 | 5.02 | 45.47 | 1.43 | 0.38 |
| | | 44.75 | 5.02 | 39.73 | 1.43 | 0.38 |
| | | 5.74 | - | 5.74 | - | - |
| Foothills | | 4.58 | 4.58 | | 50.93 | |
| | | - | - | - | 50.93 | - |
| | | 4.58 | 4.58 | - | - | |

**Table 11.** World's crude oil production between 2008 – 2015 in thousand Mg [4]
Source: GUS (Central Statistical Office).

| COUNTRY | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 |
|---|---|---|---|---|---|---|---|---|
| World | 3.728.306 | 3.634.622 | 3.689.826 | 3.718.712 | 3.799.594 | 3.783.850 | 3.857.747 | . |
| incl: | | | | | | | | |
| Algeria | 61.048 | 54.736 | 54.048 | 52.976 | 55.776 | 54.617 | 54.275 | . |
| Angola | 93.790 | 85.582 | 84.588 | 79.670 | 83.932 | 83.820 | 81.349 | 86.807 |
| Saudi Arabia | 460.145 | 407.938 | 406.997 | 464.098 | 487.968 | 480.355 | 484.116 | 508.026 |
| Argentina | 32.352 | 31.138 | 30.690 | 29.047 | 28.766 | 26.996 | 26.954 | 27.194 |
| Australia | 23.742 | 23.032 | 23.729 | 20.585 | 20.778 | 17.262 | 18.145 | 16.457 |
| Azerbaijan | 44.026 | 50.539 | 51.035 | 45.487 | 42.985 | 43.084 | 41.880 | 41.311 |
| Brazil | 92.376 | 99.500 | 104.801 | 107.436 | 105.398 | 103.147 | 114.910 | 124.178 |
| China | 190.024 | 189.606 | 203.832 | 203.646 | 206.998 | 208.202 | 209.450 | . |
| Egypt | 33.264 | 33.150 | 35.928 | 35.376 | 36.269 | 35.338 | . | . |
| Ecuador | 26.196 | 24.256 | 24.890 | 26.089 | 26.326 | 27.445 | 29.006 | 28.320 |
| Equatorial Guinea | 17.397 | 15.406 | 13.629 | 13.885 | 14.434 | . | . | . |
| India | 33.972 | 33.229 | 36.704 | 38.237 | 37.990 | 37.678 | 37.543 | 37.238 |
| Indonesia | 48.312 | 46.700 | 46.003 | 44.675 | 42.592 | 40.717 | 39.106 | 39.046 |
| Iraq | . | 114.761 | 116.971 | 130.330 | 145.357 | 146.275 | 152.795 | 172.141 |
| Iran | 202.368 | 176.638 | 175.976 | 180.684 | 189.846 | 177.575 | 154.794 | 156.510 |
| Canada | 126.588 | 125.634 | 133.879 | 141.761 | 153.042 | 163.595 | 175.207 | 178.612 |
| Qatar | 41.128 | 35.677 | 35.683 | 35.692 | 35.797 | 35.226 | 34.507 | 31.915 |
| Kazakhstan | 66.584 | 64.292 | . | . | . | . | 67.924 | 66.514 |
| Columbia | 30.136 | 34.556 | 40.468 | 47.140 | . | . | . | . |
| Kuwait | 134.926 | 113.860 | 116.401 | 133.931 | 150.269 | 147.108 | 144.445 | . |
| Libya | 83.368 | 70.968 | 71.584 | - | 70.015 | 47.728 | . | . |
| Malaysia | 33.048 | 31.427 | 30.254 | 27.346 | 27.864 | 27.214 | . | . |
| Mexico | 145.524 | 135.246 | 133.916 | 132.575 | 132.464 | 131.126 | 126.275 | 117.851 |
| Nigeria | 103.740 | 104.370 | 120.083 | 116.558 | 114.864 | 107.975 | 106.532 | 103.886 |
| Norway | 99.288 | 98.255 | 91.316 | 85.664 | 78.299 | 74.382 | 76.150 | 77.611 |
| Oman | . | 40.459 | 43.051 | 44.128 | 45.865 | 46.906 | 46.978 | 48.847 |
| Poland* | 755 | 687 | 686 | 618 | 678 | 961 | 949 | 894 |
| Russia | 471.426 | 489.450 | 505.327 | 509.441 | 495.199 | 498.563 | 500.476 | 501.857 |
| *1* | *2* | *3* | *4* | *5* | *6* | *7* | *8* | *9* |
| United States | 337.460 | 361.228 | 376.576 | 391.656 | 444.247 | 507.360 | 591.200 | 640.699 |
| Sudan | 23.098 | 23.738 | 23.104 | 22.632 | 5.079 | . | . | . |
| Syria | 18.647 | 18.325 | 19.785 | 18.033 | 8.253 | . | . | . |
| Venezuela | 163.288 | 149.347 | 144.752 | 147.446 | 146.644 | 145.348 | 139.924 | 138.888 |
| Great Britain | 65.497 | 62.820 | 58.046 | 48.571 | 42.053 | 38.456 | 37.475 | 42.826 |
| United Arab Emirates | 124.914 | 107.536 | 111.650 | 123.204 | 128.024 | 146.456 | 145.928 | . |

* Petroleum oils and oils obtained from bituminous minerals, crude

## 3. Renewable energy sources (RES)

Renewable energy sources include water, sun, water, biomass and biogas energy. These sources can be converted into electricity. Renewable energy includes also thermal sources, which are present in small quantities in Poland. They are of insignificant importance for energy security.

The EU energy policy, which should be followed by Poland, provides for systematic increase of the share of renewable energy in the energy mix of the Member States. Installed power in the Polish energy industry from renewable energy sources between 2005 and 2016 is shown in table 12. The data presented in table 12 show that to 2016 included 8.4 GW from RES were installed [7]. The most energy was obtained during that period from wind (58%), water (16%), biomass (22%), biogas (4%) and sun (0,03%).

**Table 12.** Power installed in the Polish energy industry obtained from renewable energy sources between 2005 – 2016 (Source: Own study based on the Energy Regulatory Office (URE) data)

| Year | RES installation type - Installed power [MW] | | | | | | |
|---|---|---|---|---|---|---|---|
| | biogas | biomass | solar power | wind power | water power | Total | increase y/y |
| 2005 | 31.972 | 189.790 | - | 83.280 | 852.495 | 1.157.537 | |
| 2006 | 36.760 | 238.790 | - | 152.560 | 934.031 | 1.362.141 | 204.604 |
| 2007 | 45.699 | 255.390 | - | 287.909 | 934.779 | 1.523.777 | 161.636 |
| 2008 | 54.615 | 231.990 | - | 451.090 | 940.576 | 1.678.271 | 154.494 |
| 2009 | 70.888 | 252.490 | 0.001 | 724.657 | 945.210 | 1.993.246 | 314.975 |
| 2010 | 82.884 | 356.190 | 0.033 | 1.180.272 | 937.044 | 2.556.423 | 563.177 |
| 2011 | 103.487 | 409.680 | 1.125 | 1.616.361 | 951.390 | 3.082.043 | 525.620 |
| 2012 | 131.247 | 820.700 | 1.290 | 2.496.748 | 966.103 | 4.416.088 | 1.334.045 |
| 2013 | 162.241 | 986.873 | 1.901 | 3.389.541 | 970.128 | 5.510.684 | 1.094.596 |
| 2014 | 188.549 | 1.008.245 | 21.004 | 3.833.832 | 977.007 | 6.028.637 | 517.953 |
| 2015 | 212.497 | 1.122.670 | 71.031 | 4.582.036 | 981.799 | 6.970.033 | 941.396 |
| 2016 | 233.967 | 1.281.065 | 99.098 | 5.807.416 | 993.995 | 8.415.541 | 1.445.508 |

## 4. Nuclear Energy

### *4.1. Nuclear power throughout the world*

The information material developed by the Nuclear Energy Department of the Ministry of Energy in March 2017 [8] describes 449 operating nuclear reactors in 30 countries. In 2016 7 new reactors were put into service. Next 60 blocks is under construction and over 160 are planned. As a result global energy production capacities in nuclear power plants increased by about 9 GWe and at the end of 2015 their total power reached 392.23 GWe. Electricity production in nuclear power plants also increased and in 2015 was 2,441 TWh. The share of nuclear energy in total electricity production has been at a similar level for four years, and in 2015 it increased by hefty 11.5%. Apart from reactors generating electricity, there are also 228 research reactors used for scientific and educational research.

Table 13 presents the number of reactors, installed power and electricity production in those reactors. After a short period of investment stagnation in the nuclear energy industry, the boom in the nuclear energy sector can be currently observed.

**Table 13.** Energy reactors and world's electricity production in EJ [8].

| | Number of reactors | Net installed power (GWe) | Energy production (TWh) | Share (%) |
|---|---|---|---|---|
| 2008 | 439 | 371.56 | 2597 | 15.0 |
| 2009 | 437 | 370.7 | 2558 | 14.0 |
| 2010 | 441 | 375.28 | 2630 | 13.8 |
| 2011 | 435 | 368.92 | 2518 | 13.5 |
| 2012 | 437 | 373.26 | 2346 | 11.0 |
| 2013 | 434 | 371.79 | 2359 | 11.0 |
| 2014 | 438 | 376.34 | 2410 | 11.0 |
| 2015 | 441 | 382.86 | 2441 | 11.5 |
| 2016 | 448 | 391.23 | | |
| 2017 | 449 | 392.23 | | |

The number and power of active reactors in the nuclear energy sector is presented in figure 6. Decisions on the construction of new power units or new nuclear power plants are currently taken in developing countries, in particular in South-East Asia (China, India, South Korea). Electricity production in nuclear power plants is shown in figure 4 [8]. Noticeable decrease of production is made up in 2014 and 2015.

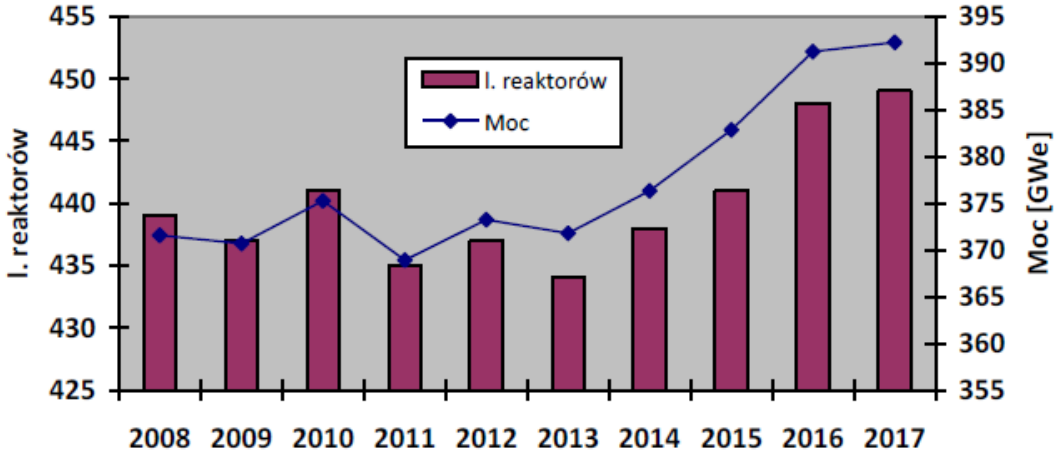


**Figure 4.** Number and power of world's active power reactors [8].

*4.2. Nuclear power in Poland*

After long discussions devoted to threats resulting from a potential breakdown of a nuclear power plant, social acceptance of construction of the first nuclear power plant has been obtained. Its opening is foreseen for 2026 and included in 'The assumptions of the Polish energy policy until 2030'. Nuclear power was to gradually substitute coal in the energy mix. Time necessary to construct a nuclear power plant is estimated at about 15 years. Therefore, it is impossible to construct such a power plant before 2030, all the more so since public feeling is also changing against nuclear power. Meanwhile, domestic hard and brown coal deposits are running out and not later than in the years 2050 - 2070 [3] they will have to be substituted with other primary energy source or imported. Public concern is unjustified, because around the Polish borders nuclear power plant already exist. Therefore, any breakdown of those power plants threatens also Poland. The public should be therefore convinced of such solutions.

## 5. Production and consumption of electricity in Poland

In 'The assumptions of the Polish energy policy' [2] it is assumed that the installed power in the National Power System in 2020 should be around 44 GW. It means increase of installed power by 7 GW. However, in the same document the same amount of power is assumed to be phased out by 2020 due to its wear and necessary modernisation. It is estimated that in the following years 15 GW of new production capacities should be created, which seems to be a difficult task. Current and until 2050

demand for electricity shows that extension of power infrastructure is a must not to experience 'Black point'. Along with the issue of reconstructing production capacities in the power industry, the issue of supplying of energy raw materials to power plants must be solved. Currently the power industry, as is well known, is based on hard and brown coal. These materials will be depleted from the domestic reserves between 2040 and 2070. How to ensure energy security in Poland, whether to rely on coal, even imported, or whether to focus on other, more ecological, energy sources.

Table 14 presents production and consumption of electricity in the years 2015 - 2016. The data in table 14 shows that domestic electricity consumption in 2016 was 161,438 ( in GWh) and was higher by 1.97% than in 2015. Total production was higher by 0.53%, and similarly, production in utility hydro power plants was higher by 6.1%. Considerable increase of electricity production was reported in gas-fired power plants (by 37.77%) and renewable energy sources (by 100.03%), including wind farms by 15.76%.

On the other hand, electricity production based on hard coal decreased by 0.65% and on brown coal by 4.41% [9]. Could these data show the withdrawal from coal-based power?

**Table 14.** Structure of electricity production in domestic power plants, volume of electricity exchange with foreign countries and domestic electricity consumption - monthly volumes and from the beginning of year - gross values (Source: Polskie Sieci Elektroenergetyczne – monthly reports).

| Item | December | | | Cumulatively from January to December | | |
|---|---|---|---|---|---|---|
| | 2015 (GWh) | 2016 (GWh) | Dynamics ((b-a)/a*100) (%) | 2015 (GWh) | 2016 (GWh) | Dynamics ((e-d)/d*100) (%) |
| Total production | 14.464 | 15.218 | 5.22 | 161.772 | 162.626 | 0.53 |
| Utility power plants | 11.859 | 12.559 | 5.9 | 141.901 | 140.727 | -0.83 |
| Water utility power plant | 229 | 272 | 18.64 | 2.261 | 2.399 | 6.1 |
| Thermal utility power plant | 11.630 | 12.287 | 5.65 | 139.640 | 138.328 | -0.94 |
| hard coal | 6.972 | 7.381 | 5.87 | 81.883 | 81.348 | -0.65 |
| brown coal | 4.166 | 4.375 | 5.02 | 53.564 | 51.204 | -4.41 |
| gas | 493 | 532 | 7.89 | 4.193 | 5.776 | 37.77 |
| Other renewable sources power plants | 6 | 12 | 100 | 73 | 146 | 100.03 |
| Wind farms | 1.612 | 1.599 | -0.78 | 10.041 | 11.623 | 15.76 |
| Industrial power plants | 986 | 1.047 | 6.2 | 9.757 | 10.130 | 3.82 |
| Foreign exchange balance | -334 | -243 | -27.26 | -334 | 1.999 | - |
| Domestic electricity consumption | 14.129 | 14.975 | 5.99 | 161.438 | 164.625 | 1.97 |

Table 15 present perspective demand for electricity included in 'The assumptions of the Polish energy policy until 2050' [2]. In the assumptions substantial volume of electricity production is based on nuclear power, whose presence in the Polish energy mix at that time is doubtful. If such energy is to be substituted by coal, coal will have to be imported.

**Table 15.** Electricity production estimate broken down by fuel (TWh) in Poland until 2050
Source: Schedule to 'The Polish energy policy until 2050' (draft).

| Energy source | 2010 | 2015 | 2020 | 2030 | 2035 | 2040 | 2045 | 2050 |
|---|---|---|---|---|---|---|---|---|
| Hard coal | 87.9 | 72.5 | 76.9 | 75.9 | 84.4 | 88.8 | 82.3 | 74.5 |
| Brown coal | 48.6 | 58.4 | 53.8 | 49.6 | 11.1 | 11.3 | 10.7 | 10.3 |
| Natural gas | 6.8 | 5.8 | 11.8 | 11.9 | 18.4 | 17.5 | 23.3 | 20.4 |
| RES | 11.6 | 20.6 | 34.0 | 36.9 | 61.1 | 65.1 | 67.5 | 73.2 |
| Nuclear energy | 0.0 | 0.0 | 0.0 | 11.8 | 45.1 | 45.4 | 44.2 | 43.2 |
| Other | 2.6 | 1.4 | 1.4 | 1.4 | 1.4 | 1.4 | 1.4 | 1.4 |
| Total | 157.5 | 158.7 | 177.9 | 187.5 | 221.5 | 229.5 | 229.4 | 223.0 |

## 6. Polish energy security indicators

An indicator determining national energy security is Stirling indicator (formula 1) [10],which determines a degree of diversification of energy supply:

$$d_N = -\sum_{j=1}^{m} u_j \ln u_j \quad (1)$$

where: $u_j$ – share of $j^{th}$ energy carrier in national energy supply structure, $m$ – number of energy carriers, $ln$ – natural logarithm.

Even structure of energy supplied to the domestic market is the most favourable. In Poland the Stirling indicator is about 1.0 and differ from the EU level (1.4), which is caused by a considerable share of domestic solid fuels (coal) in the Polish energy balance. The indicator can be improved by diversification of energy sources supplies. Not more than 30% can be imported from one direction (gas 85%, crude oil 95% from Russia).

The second parameter determining the condition of energy security is country's energy self-sufficiency [10]. It is defined as the ratio of volume of domestic fuel acquisition to primary energy consumption:

$$W_s = \frac{P \cdot 100\%}{Z_k} \quad (2)$$

where: $P$ – fuel production in a given year, $Z_k$ – domestic global consumption equal to the sum of individual fuels supplied to the domestic market less domestic reserves balance.

This indicator is currently about 85% and decreases as own resource diminishes.

**Table 16.** Global documented industrial reserves of conventional energy raw materials and their sufficiency

| Materials | Reserves (million toe) | Reserves structure (%) | Reserves consumption (million toe) | Use structure (%) | Reserves sufficiency (years) | |
|---|---|---|---|---|---|---|
| | | | | | world | Poland |
| Hard/brown coal | 469.298 | 59.6 | 2.957.0 | 31.7 | 158 | 48<br>24 |
| Crude oil | 159.644 | 20.3 | 3.861.3 | 41.4 | 41 | 1 |
| Natural gas | 158,815 | 20.1 | 2.512.2 | 26.9 | 63 | 7 |
| **Total** | **787.757** | **100.0** | **9.330.5** | **100.0** | **84** | **-** |

Note: 1 toe = 41.868 GJ

Calculated per $m^3$ global natural gas reserves as at 2009 amounted to 187.47 trillion $m^3$. In the following years, despite current production, global natural gas reserves increased due to new discoveries. The situation is similar as far as crude oil is concerned - global reserves of this material according to the situation as at 2013 amounted to 234 billion metric tons. The richest deposits are in Saudi Arabia (36.5 bn t), Iran (20.8 bn t), Iraq (19.3 bn t), Venezuela (46.3 bn t), Kuwait (14.0 bn t) and Canada (28.2 bn t).

## 7. Summary

The article describes all available energy sources, which can be used to generate electricity, considered to be the cleanest form of energy. Such energy sources include: hard coal, brown coal, natural gas, crude oil, nuclear power and renewable energy sources (RES). Renewable energy sources include, in particular: water, solar, wind, biomass and biogas power.

All the mentioned energy sources, also called primary energy sources, has been described in detail in the context of economic usefulness and analysed in the context of sufficiency for social needs defined as National Energy Security. Individual types of primary energy sources, belonging to fossil fuels, have been analysed in terms of their reserves and recoverability in Poland and the world.

The Polish power industry is currently based on hard and brown coal, which generate c. 81% of total electricity - hard coal accounts for c. 50% from and brown coal for c. 31%. The above are followed by: natural gas (c. 3%) and water power (c. 3%). Water power is recognised as Renewable

Energy Sources. Other renewable energy sources develop according to the guidelines of the European Union and in 2020 they will reach about 15% - it is an estimated share in our energy mix [1]. There are not many good conditions for development of RES in Poland. Apart from the mentioned water power, solar and wind power have the largest share in RES. As far as fossil fuels are concerned, hard coal, at the current level of development and production (c. 70 million Mg/year), will last for about 50 years, i.e. to 2070. Brown coal from currently developed deposits, with annual production of c. 60 million Mg will last for about 30 years, i.e. to 2050. Natural gas, with deposits of about 100-120 billion $m^3$ and current production of c. 5 billion $m^3$, will last for about 20 years. However, natural gas consumption in Poland amounts currently to 15 billion $m^3$ and is likely to increase - therefore Poland is will have to import. When importing it is necessary to diversify gas supplies. The LNG terminal in Świnoujście with annual capacity of 5 billion $m^3$ of liquefied gas constitutes an important, but not sufficient, support of the national energy security. It is a pity that the project of 2001, which provided for connection of the Norwegian shelf and Poland in Niechorze with a pipeline with annual capacity of 10 billion $m^3$ of gas, where about 5 billion $m^3$ were intended for Poland. Currently Poland still has to import gas from the east through the existing pipelines.

Finally, crude oil scarce in Poland - 20-25 million metric tons. At current annual production levels of c. 1 million Mg, it will last for 20-25 years. However, annual needs relating to oil refining in Polish refineries are at a level of c. 20 million Mg. Crude oil is delivered to Poland through the 'Przyjaźń' pipeline from Russia and by tankers to the Northern Port in Gdańsk from other directions. So far such transport system has worked correctly, however, there is a project providing for crude oil transport through a new pipeline, 'Golden Gate', from the Caspian Sea, via Ukraine to Poland.

Assuming that it will be possible to extract the hard and brown coal deposits completely - the country's energy security is ensured until about 2050. If, however, coal will be gradually withdrawn from the Polish energy mix, it is urgent now to seek for other solutions, including nuclear power.

## 8. Conclusions

- Hard and brown coal reserves are running out in the developed deposits.
- Despite large reserves of brown coal are present in Poland - it should be assumed that they will not be exploited due to opposition of the local population.
- Hard coal reserves, although still quite rich, may not be fully exploited due to increasing natural hazards, such as methane, crumps and rockmass temperature. Also in this case Silesian community opposes to building new coal mines (e.g. near Pszczyna).
- The EU guidelines on environmental protection do not promote development of coal-based power generation.
- In the search for new energy sources it is necessary to start to construct nuclear power plants to make up for the losses of coal-based power generation.
- An alternative to coal power plants can be also gas power plants, especially in the light of the reports of the Polish Geological Institute (PIG) on shale gas deposits (deposits of 346 to 768 billion $m^3$).
- Nuclear power as well gas power plants (if shale gas is not available) are based on imported primary energy sources.
- Decrease of hard and brown coal production to extend the period of its production and introduction of other energy sources (gas, nuclear power) should also be considered. A source of uranium supplies to Polish nuclear power plants is equally important. Considerable deposits of uranium can be found in Canada.

## References

[1] Energy Law Act of 10 April 1997 as amended (J.L. 153.1504)
[2] Draft of Polish energy policy until 2050 (in polish: Projekt Polityki energetycznej Polski do 2050 roku), http://bip.me.gov.pl/node/24670, access of 11 May 2017.
[3] Balance of fossil fuel reserves in Poland as at 31 December 2015, Polish Geological Institute,

Polish Reserach Institute Warszawa 2016.
[4] Sobczyk E J, Kicki J, Jarosz J, Kowalczyk I and Stachurski K 2016 Gospodarka zasobami złóż węgla kamiennego w Polsce w latach 1990–2015 *Zeszyty Naukowe Instytutu Gospodarki Surowcami Mineralnymi i Energią Polskiej Akademii Nauk* **92** pp 37–56.
[5] GUS reports, March 2017 (in polish: Raporty GUS marzec 2017), http://stat.gov.pl/statystyka-miedzynarodowa/porownania-miedzynarodowe/tablice-o-krajach-wedlug-tematow/przemysl-i-budownictwo/, access of 10 May 2017.
[6] Polish shale gas reserves https://www.polskielupki.pl/artykul-gaz-lupkowy-w-polsce/74129/ zasoby-gazu-lupkowego-w-polsce, access of 21 April 2017.
[7] Installed power, reports of URE https://www.ure.gov.pl/pl/rynki-energii/energia-elektryczna/ odnawialne-zrodla-ener/potencjal-krajowy-oze/5753,Moc-zainstalowana-MW.html, access of 10 May 2017.
[8] World's nuclear energy, Information material developed by the Nuclear Energy Department of the Ministry of Energy, March 2017.
[9] Polskie Sieci Elektroenergetyczne – monthly reports http://www.pse.pl/index.php?modul =8&y=2016&m=12&id_rap=212, access of 08 May 2017.
[10] Kaliski M and Staśko D 2003 Rola krajowej infrastruktury paliwowo – surowcowej w kształtowaniu bezpieczeństwa energetycznego Polski *Wiertnictwo, nafta, gaz* **20/1** pp 101-10.