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INNOVATIVE METHODS OF NATURAL GAS EXPLOITATION AS A FACTOR OF SUSTAINABLE DEVELOPMENT OF WORLD ECONOMY

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ABSTRACT: The paper identifies unconventional techniques and technologies of exploitation of natural gas contained in shale rocks, i.e. drilling directional wells and hydraulic fracturing, against the background of the importance of natural gas for the world economy. The crucial importance of the innovative methods of extracting shale gas has been shown through the example of the impact of exploitation of unconventional gas deposits on halting the process of pushing the energy intensive industries out of the United States. The paper also highlights the importance of the dynamic increase in financial expenditure incurred by many countries on all continents on recognising and analysing gas deposits contained in rocks, hydrates or aquifers. As a result of geological exploration, the volume of global proven geological resources of unconventional gas is by 66% greater than the global resources of conventional natural gas deposits recognised over a period of many decades. The paper characterises the consequences of utilising the innovative methods of natural gas exploitation for raising the level of the sustainability and balance of the world economy development and also for the radical reduction of the cost of gas transport in the global scale.

KEY WORDS: unconventional gas, directional drillings, hydraulic fracturing, sustainable development

Introduction

Natural gas is a mixture of gaseous hydrocarbons, mainly ethane, methane and propane and also liquid hydrocarbons, carbon dioxide, nitrogen, hydrogen, hydrogen sulphide and noble gases, in particular argon and helium. The content of each constituent varies and depends on the extraction site but the predominant constituent is always methane – its content in natural gas is 90-98%.

The importance of natural gas for the world economy stems from the fact that applications of natural gas cover a constantly growing number of processes and facilities that are essential for sustaining the development of industry and the municipal and household sector with regard to energy and raw material supplies. The most important ones include:

- public power plants and combined heat and power plants;
- industrial heating furnaces;
- industrial production processes, particularly in factories manufacturing ceramics and building materials;
- iron and steel industry for the production of excellent quality steel as well as non-ferrous metallurgy;
- glass-making industry for the production of window and domestic glass as well as various types of technical glass;
- production of nitrogen fertilisers, chloromethanes, acetylene as well as many other organic compounds;
- obtaining hydrogen, used inter alia in refineries, in the processes of purifying and refining crude oil;
- as fuel in cars and other vehicles, especially in public transport;
- individual heating of residential and farm buildings;
- heating water and preparing meals;
- plant and animal breeding; drying cereals and seeds.

The fastest developing field of application of natural gas is currently cogeneration, i.e. generation of electricity and heat in the combined system, which allows for a considerably higher degree of utilising the primary energy of gas than in the traditional power plants and combined heat and power plants (CHPs). A very effective fuel in the cogeneration and microgeneration systems is liquefied petroleum gas (LPG), which is a mixture of propane and butane. It is used as gas but stored in cylinders under pressure it is a liquid. LPG is obtained from natural gas deposits and also as a by-product during the refining of petroleum.

Beside LPG, also liquefied natural gas (LNG) is more and more commonly used. It is gas in liquid state, stored at temperatures below -162°C. Over 30%

of natural gas in international trade is transported in the liquid state. Liquefied gas is an extremely pure fuel with an octane number of 130.

Natural gas does not contain large amounts of sulphur or heavy metals and therefore no dusts or other solid wastes are generated in the process of its combustion. The volume of emissions of sulphur compounds and nitrogen is also insignificant.

Utilisation of natural gas in technological processes involves a lot of benefits:

- smooth adjustment of production processes;
- high level of occupational safety;
- reduction or elimination of losses in the start-up phase of the production process;
- possibility of quickly stopping the manufacturing process;
- clean and simple maintenance of gas devices.

Innovative techniques and technologies of natural gas exploitation

Natural gas was formed over millions of years as a result of anaerobic decomposition of organic substances. Deposits of natural gas occur on their own or in association with petroleum and hard coal deposits.

Natural gas can be broken into:

- gas from conventional deposits;
- gas from unconventional deposits.

The term *unconventional* does not only refer to the sort of gas but also to the natural gas extraction techniques and technologies in which two processes are used: directional drillings and hydraulic fracturing. Both directional drilling and hydraulic fracturing have all the characteristics of innovative methods (Unconventional, 2016; Fundamentals, 2017).

A breakthrough in the process of extracting gas with the use of hydraulic fracturing was the mastering of the technique and technology of directional drilling, i.e. drilling wells that inclined in space as a result of deliberate human intervention. Directional wells are drilled both on land and under the seabed and ocean bottom. Directional wells are a very cost-effective and environmentally safe technique of completion drilling for deposits of natural gas or other hydrocarbons located under an urbanised area or under the seabed at a small distance from the coastline. Investment expenditure necessary for the purchase and installation of an offshore drilling rig as well as its running costs are much higher than capital expenditure and running costs related to

drilling a directional well or even of group thereof from a device located on the land (Artymiuk, Bednarz, 2011; Journal, 2016).

Hydraulic fracturing (also: fracking, hydrofracturing or hydrofracking) is a technological process designed to improve drilling efficiency by injecting a fracking liquid, i.e. a mixture of water with chemical additives and sand under high pressure in order to create, maintain or expand cracks in rocks. The fracturing process is used on a large scale for extracting natural gas from shales in the United States.

Issues concerning exploration of unconventional gas deposits and also exploitation of such deposits as well as transport and storage of the extracted gas are the subject of scientific research, both basic and applied, innovations and implementations of new techniques and technologies. The planning, programming and designing of these ventures is the subject of numerous conferences, symposia and seminars, often of a global character.

There is a dynamic growth in the number of literature items concerning the environmental, legal, technological, economic, financial and social determinants and factors associated with management of unconventional deposits of natural gas on all continents (Fundamentals, 2017; Natural, 2008-2017; Oil&Gas, 2010-2017).

Many studies stress the fact that investments in exploration and extraction of shale gas may significantly contribute to increasing the GNP growth rate, creating new effective jobs as well as increasing tax revenues, both at the level of states budgets and the local budgets (Annual, 2016).

There are also extensive international statistics concerning geological and industrial resources of natural gas and its deposits, as well as the production, consumption, export, import and prices of gas (Reserves, 2016; British, 2017; World, 2016).

Global resources of non-renewable primary energy

The structure of non-renewable primary energy resources in the world in 2015 has been presented in table 1 and in figure 1. The top position in the global ranking of resources of primary energy carriers, with regard to the category of proved reserves: geological knowledge in the United Nations Framework Classification (UNFC) is occupied by hard coal, with a share of 79.4% of total global resources of non-renewable primary energy (Energy, 2016; Pindór, 2016a; Pindór, Preisner, 2013).

In total, geological resources of natural gas deposits including both conventional and unconventional gas deposits, accounted in 2015 for 5.9% of the total global resources of primary energy carriers recoverable from the deposits in the geosphere (World, 2010-2017).

The total geological resources of natural gas, in energy units, were by over 65% greater than the total global resources of petroleum, both from conventional and unconventional deposits. It is also important to observe that the total geological resources of natural gas – with regard to energy – were by over 228% greater than the global geological resources of uranium and thorium together.

Table 1. The structure of non-renewable geological resources of primary energy in the world in 2015

Primary energy carrier	Primary energy resources	Share in global resources
	[EJ]	[%]
Hard coal	438,705	79.4
Lignite	52,019	9.4
Natural gas	32,695	5.9
Petroleum	19,059	3.5
Uranium and thorium together	10,047	1.8
Total world	552,524	100.0

Source: Reserves, 2016.

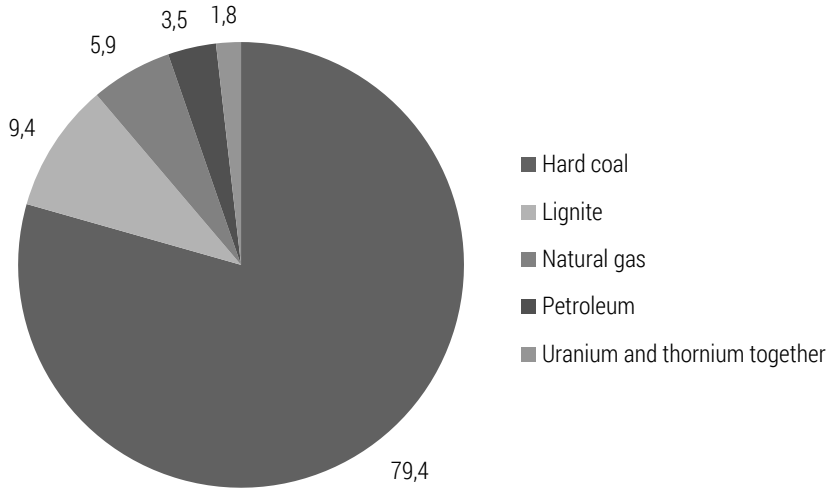

Figure 1. The structure of non-renewable geological resources of primary energy in the world in 2015

Source: Reserves, 2016.

The resources of unconventional gas are distributed exceptionally uniformly in the global scale. Large reserves of this gas have been discovered and proven in Latin America and in Africa where reserves of conventional natural gas, as well as of other primary energy carriers, are many times smaller (Pindór, 2016b; World, 2017).

Structure of global geological resources of unconventional gas

The structure of geological resources of unconventional natural gas in the world in 2015, in volume units and in energy units, has been presented in table 2 and in figure 3 while figure 2 shows the structure of total natural gas resources in the world in 2015 broken down into resources of conventional and unconventional deposits. Analysis of the data contained in table 2 provides a lot of essential conclusions concerning the utilisation of natural gas in the context of the criteria of balanced and sustainable development. The most important of them can be formulated as follows:

- geological resources of unconventional natural gas are by 66.2% greater than the conventional resources;
- the greatest shares in the global geological resources of unconventional natural are accounted for by resources of shale gas – 40.0%, and gas hydrates – 34.3%; a significantly smaller shares are accounted for by resources of tight gas – 11.7%, coalbed methane – 9.5%, and aquifer gas – 4.3%.

Table 2. The structure of unconventional natural gas resources in the world in 2015

Kind of gas	Resources of natural gas	
	[trillion m^3]	[EJ]
Conventional gas	323	12,293
Total unconventional gas	537	20,402
Shale gas	215	8,162
Gas hydrates	184	6,992
Tight gas	63	2,385
Coalbed methane	51	1,950
Aquifer gas	24	912
Total natural gas	860	32,695
Total non-renewable primary energy carriers	-	552,523

Source: Reserves, 2016.

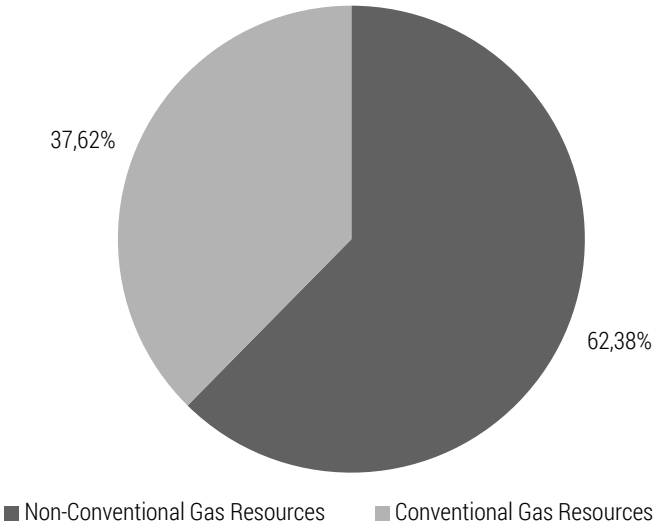

Figure 2. The structure of total natural gas resources in the world in 2015

Source: Reserves, 2016.

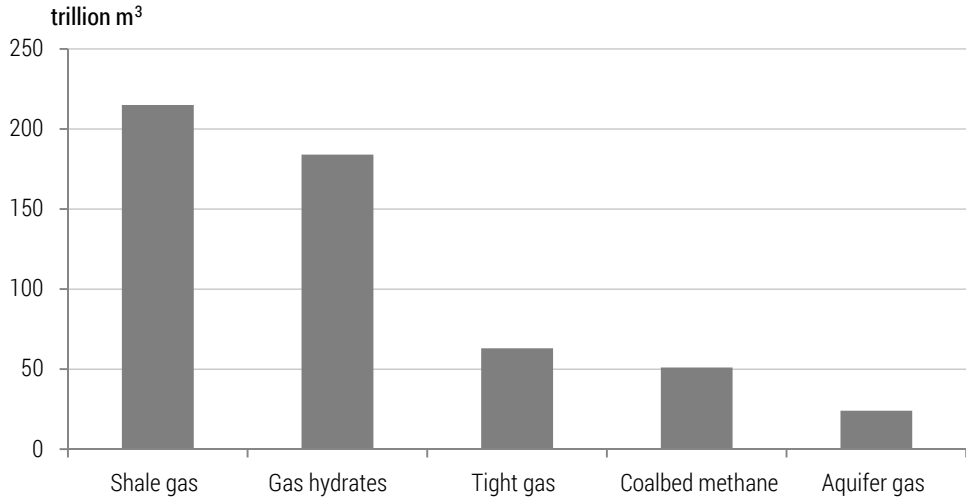

Figure 3. The structure of geological resources of unconventional natural gas in the world in 2015

Source: Reserves, 2016.

Production of natural gas in the world

Extraction of natural gas in selected countries in 2015 has been shown in table 3 and in figure 4. The world ranking of natural gas producers clearly reveals the impact of the development of extraction of unconventional natural gas in the United States as this country become the world leader in 2009 after the hegemony of producers from Russia, and formerly the Soviet Union, which had lasted since 1983.

According to the United States Energy Information Administration (US EIA), production of natural gas in the United States will rise up to approximately 1 trillion m^3 in 2040, which means an increase by over 30% compared with the 2015 level (Annual, 2016). The increase of production will be almost entirely the result of the increase in unconventional gas extraction, in particular from shale deposits, and also from tight gas deposits. Extraction of gas from deposits of gas hydrates will also increase significantly as well as of coalbed methane, undertaken in the United States on an industrial scale already in the 1990s. It is also expected that the coming years will see commencement of unconventional exploitation of aquifer gas. According to a US EIA forecast, extraction of natural gas from resources of all the unconventional deposits will reach the level of 472 billion m^3 in 2040 (World, 2017; Energy, 2016; Journal, 2016).

Among other major producers of conventional natural gas, it is Russia, Iran, Qatar, Saudi Arabia, Iraq, Turkmenistan and Algeria that have significant growth potential. In these circumstances, it is of decisive importance that there are plans to embark on extraction of unconventional natural gas in regions that have so far been bound to import gas, in particular China, Argentina, Brazil, Australia, Indonesia, India, Ukraine as well as countries of Central and South Africa. Significant geological resources of unconventional natural gas have already been discovered and proven in all of these areas.

Extraction of natural gas from shale rocks by means of hydraulic fracturing requires constant monitoring of the impact of this process on the components and functions of the environment. Hydraulic fracturing in Poland is being monitored by a lot of institutions, in particular such as: the Chief Inspectorate for Environmental Protection, the Chief Inspector of Environmental Protection, the National Water Management Authority and the State Mining Authority. A comprehensive project, commissioned by the Ministry of Environment, is being carried out with respect to in-depth monitoring of various environmental aspects of shale gas exploration. These efforts are considered to be the so far most extensive research in Europe on the impact of the process of hydraulic fracturing on the environment (Energy, 2015-2017; Strategia, 2017).

Table 3. Production of natural gas in selected countries in 2015

No.	Country	Production	Share in global production
		[billion m³]	[%]
1	United States	768.1	21.5
2	Russia	636	17.8
3	Iran	183.9	5.1
4	Qatar	171.3	4.8
5	Canada	154.8	4.3
6	China	138.2	3.9
7	Norway	121.3	3.4
8	Saudi Arabia	106.4	3
9	Algeria	82.3	2.3
10	Turkmenistan	80.2	2.2
	other countries	1131.2	31.7
	The world	3573.7	100

Source: Reserves, 2016.

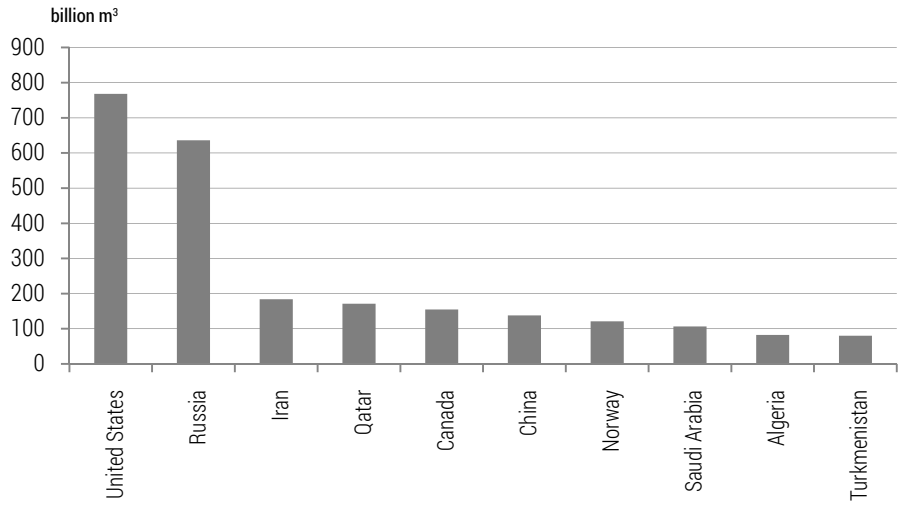

Figure 4. Production of natural gas in selected countries in 2015

Source: Reserves, 2016.

Consumption of natural gas in the world

Consumption of natural gas in selected countries in 2015 in volume units and the shares of the consumption by these countries in the global consumption have been presented in table 4 and in figure 5. This listing reveals the consequences of the introduction of gas from unconventional deposits to supply the economy of the United States. The dynamically growing utilisation of this gas, considerably cheaper than that imported and reckoned one of the best sources of supply, has substantially transformed the sector of extraction and exploitation of fuels and energy in the United States and has been the main factor in halting the process of *pushing* the most energy intensive industries *out* of the United States (Global, 2017).

Table 4. Consumption of natural gas in selected countries in 2015

No.	Country	Consumption	Share in global consumption
		[billion m^3]	[%]
1	United States	777.6	21.8
2	Russia	461.5	13
3	China	191	5.4
4	Iran	182.7	5.1
5	Japan	114.1	3.2
6	Saudi Arabia	106.4	3
7	Canada	102.5	2.9
8	Germany	96.5	2.7
9	Mexico	83.2	2.3
10	UAE	69.1	1.9
	other countries	1377.1	38.7
	The world	3561.7	100

Source: Reserves, 2016.

The increase of shale gas production brought about the situation in which the United States became independent of foreign suppliers and consequently was the decisive factor in making the American economy independent of the effects of natural gas price fluctuations in the international markets and also of the frequent supply disruptions related to the functioning of the thousands-of-nautical-miles-long transport and logistic chains connecting the Middle East exporters with import harbours in the United States (International, 2017).

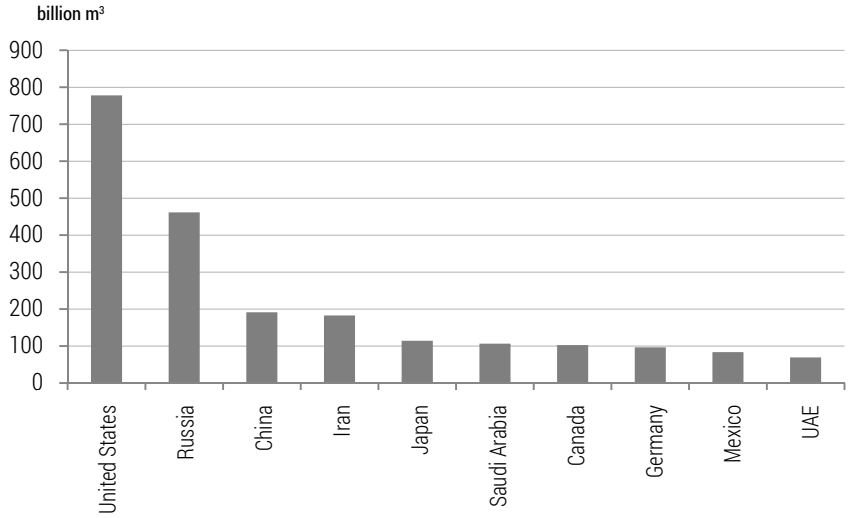

Figure 5. Consumption of natural gas in selected countries in 2015

Source: Reserves, 2016.

An analysis of the distribution of geological resources of unconventional gas in the world indicates that they are located very close to the main centres of consumption of primary energy. Significant shortening of transport routes in the global scale due to exploitation of unconventional gas implies a corresponding reduction of energy needed to provide gas to the consumers, which significantly improves the sustainability of the utilisation of the total gas resources for global development.

Summary

In the summary of the paper, the most important conclusions have been formulated as well as final statements.

The importance of natural gas in the world economy stems from the numerous uses of natural gas as a primary energy carrier and also the key raw product or semi-finished product in many sectors of material manufacturing.

Utilisation of natural gas does not cause significant pollution of any component of the environment nor does it restrict the environment in fulfilling its natural and economic functions.

The application of unconventional methods, i.e. drilling of directional wells and hydraulic fracturing, have opened up previously unknown possibilities in the exploration of natural gas deposits in shale rocks and proving the

volume and structure of the natural deposits of shale gas, and consequently – also exploitation of these gas deposits.

The possibility of exploiting natural gas by unconventional methods caused – on all continents – a dynamic growth in financing recognition and analysis of gas reserves contained in rocks, hydrates or aquifers. The volume of global proven geological resources of unconventional gas after over a dozen, and in the majority of countries just a few, years of exploration efforts is by 66% greater than the global resources of conventional natural gas deposits recognised over a period of many decades. As a result of discovering and proving deposits of unconventional gas, a new item appeared in the balance of resources in many countries, both in volume and energy units, and that was natural gas.

Utilisation of unconventional methods of exploitation of natural gas deposits in the industrial scale means most especially:

- extension of the service life of the global resources of natural gas, i.e. an increase in the sustainability of development through the use of natural gas resources;
- balancing the global economy development due to diversification of resources of a significant source of energy and methods of transport of this primary energy carrier to secondary energy consumption centres;
- the possibility of taking advantage of natural gas to develop those areas of the world where the use of gas was only possible through imports;
- radical shortening of gas transport routes in the global scale resulting from launching exploitation of unconventional natural gas deposits located in the proximity of the major global centres of primary energy consumption, which implies a significant reduction of energy use in the processes of gas transport, and consequently a significant reduction of the costs associated with transporting gas to its users.

A significant increase in the production of unconventional gas implies a rise in the level of global energy security as well as a diversification with regard to the types and the geographical structure of the primary energy balance on the demand side, which provides a solid fundament for sustainable economic and social development in the global scale.

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