Research Journal of Agricultural Science, 50 (4), 2018

ASSESSMENT OF THE ENVIRONMENTAL RISK ASSOCIATED WITH THE EXPLOITATION OF SHALE HYDROCARBONS

S. BOTAŞ[1], F. FAUR[1], Diana MARCHIŞ[1]

[1]University of Petrosani, Faculty of Mining
E-mail: botas.sebastian@yahoo.com

Abstract: *The idea of exploiting shale hydrocarbons has generated vivid and intense controversy in the European space, both at central and civil society levels. These controversies are due, on one hand, to the issue of the injection of hazardous chemicals during the exploitation process and, on the other hand, to the imbalance between the economic benefits of exploiting these hydrocarbons (the specific production of hydrocarbons being very low) and the environmental risks and challenges which under these conditions are not compensated. Given the fact that in the extraction process important land plots are diverted from other uses (e.g. agriculture) and the high possibility (close to certainty) of contamination of geological substrates (including groundwater), while the shale hydrocarbon deposits in Europe are too small to have a significant impact on the gas supply, we have considered that a simplified methodology for assessing the environmental risks associated with their exploitation is necessary. Among the possible risks, we mention: the discharge of fracturing fluid; the leakage of wastewater from ponds and pipes transporting fracturing fluid; the emissions of potentially explosive, greenhouse effect amplifying, carcinogenic and radioactive enhancing gases; changes in zonal seismicity etc. Considering the relationship according to which the environmental risk caused by an undesired event is equal to the probability of producing that event multiplied by the vulnerability of the natural and anthropic environment, at the time of that event, the proposed methodology is based on quantitative and qualitative data characterizing the American experience. We have started from this data because in Europe (in regions such as: Poland, France, Germany and Scandinavian peninsula) the extraction of shale hydrocarbons is at the beginning, while the United States has an experience in the field of over 45 years, with more than 50 thousands operating wells.*

Key words: *environmental impact, shale hydrocarbons, risk assessment, land contamination*

INTRODUCTION

Hydrocarbons, beyond conventional and those stored in compact formations, can also be stored in large amounts in rocks that are basically not typical reservoirs, but shale and other very fine-grained rocks where the required storage volume is provided by thin cracks and very small porous spaces. These rocks have extremely low permeability. The hydrocarbons present here are called shale gas or shale oils. The last one do not contain mature hydrocarbons, but only a precursor called kerogen, which can be converted to synthetic oil in chemical plants (FAUR ET AL., 2015).

Compared to conventional deposits, all unconventional deposits share a low content of oil and gas in relation to the rock volume. They are also dissipated on a considerable area of tens of thousands of square kilometers and have a very low permeability (GÉNY, 2010). Therefore, special methods are required to extract this type of oil or gas. In addition, since the host rocks have low hydrocarbon content, the extraction volume from bore hole/well is clearly inferior to that of the conventional deposits, making them less profitable (ALBOUDWAREJ ET AL., 2006). The hydrocarbons themselves are not unconventional, but the extraction methods. These methods require sophisticated technologies, large amounts of water and injection of additives that can be harmful to the environment

MATERIAL AND METHODES

At European level the specific risks of hydraulic fracturing are not sufficiently covered by legislation. Nine major gaps have been identified: 1. Lack of a framework directive on mining activities; 2. An insufficient threshold in the Environmental Impact Assessment (EIA) Directive for the extraction of natural gas; 3. The optional character of the Hazardous Materials Declaration; 4. Lack of approval methodologies on chemicals stored/left on the ground; 5. The absence of reference documents regarding the Best Available Techniques (BAT) in the field of hydraulic fracturing; 6. Wastewater treatment requirements are not properly defined and the capacities of water treatment plants are likely to be insufficient if injecting and disposal in underground layers is to be prohibited; 7. Insufficient participation of the public in decision-making at national level; 8. The ineffectiveness of the Water Framework Directive; 9. No obligations to perform a life cycle analysis (LECHTENBÖHMER ET AL., 2011).

Basically, in Europe, in the field of shale hydrocarbon exploitation, there are applied, directly or indirectly, a number of directives on: mining, exploitation and protection of water, environmental protection, health and safety at work, radiation protection, the regime of waste and chemical substances and accidents associated with these products.

The lack of legal regulation is also felt at national level: "Poland is traditionally a gas producing country, but the geological and mining law does not mention hydraulic fracturing or horizontal drilling. Neither the law currently under discussion will address these practices" (CHMAL, 2011).

Data regarding exploitation of shale hydrocarbons

The potential for unconventional gas availability should be seen in the context of conventional gas production (LECHTENBÖHMER ET AL., 2011):

- European gas production has experienced a pronounced decline for many years and it is expected to drop by another 30% by 2035;
- It is expected that the European demand to be steadily rising till 2035;
- If these assumptions are confirmed, gas imports will continue to increase inevitably;
- It is impossible to guarantee additional necessary imports of hundreds of billions m^3/year.

Hydrocarbon deposits are classified into resources and reserves. Although not a mandatory fact, resources are generally measured in terms of gas-in-place (GIP), while reserves already include assumptions about their recovery under ordinary economic and technical conditions. Table 1 shows some key parameters of large American gas shale deposits. These parameters refer to the covered surface, the depth and thickness of the shale, and the total organic carbon content (TOC).

Table 1

Analysis of large-scale shale gas operations in the United States (ARTHUR ET AL., 2008)

Bazin de șist gazeifer	**MU**	**Antrim**	**Barnet**	**Fayetteville**	**Haynesville**
Estimated area	km^2	30,000	13,000	23,000	23,000
Depth	km	0.2-0.7	2.1-2.8	0.3-2.3	3.5-4.5
Net thickness	m	4-25	30-200	7-70	70-100
TOC	%	1-20	4.5	4-9.8	0.5-4
Total porosity	%	9	4-5	2-8	8-9
Gas in situ	mil. m^3/km^2	70	720	65	880
Gas in situ	Tm^3	2.2	9.3	1.5	20.3
Recoverable resources	Tm^3	0.57	1.2	1.2	7.1
Efficiency	%	26	13	80	35
Cumulative production (Jan. 2011)	Tm^3	0.08	0.244	0.05	0.05
Estimated production rate	1000 m^3/day/well	3.5-5.7	9.6	15	18-51
Actual gas production rate (in 2010)	1000 m^3/day/well	~1	9.5	21.8	~90

Tm^3 – cubic tetrameter (the original data were converted: 1000 ft^3 = 28.3 m^3 and 1 m = 3 ft)

Table 2 shows conventional gas production in Europe at the level of 2009 (which has been declining in the last 10 years) and conventional gas reserves as well as hypothetical figures on shale gas resources. Technically recoverable shale gas resources are those quantities which, according to estimates, can be produced with existing technologies if the site is exploited intensively (CHARPENTIER AND COOK, 2010). By dividing the technically recoverable shale gas resources to the total in-situ gas resources, the recovery factor or efficiency is obtained. These data are in the last column (Hypothetical Recovery Factor).

Table 2

Estimation of production (in 2009) and reserves of conventional gas in relation to shale gas resources in Europe (US EIA, 2011; BP, 2010)

Country	Production (bcm)	Confirmed reserves of conventional gas (bcm)	GIP shale gas (bcm)	Technically recoverable shale gas resources (bcm)	Hypothetical Recovery Factor (%)
France	0.85	5.7	20,376	5,094	**25.0**
Germany	15.6	92.4	934	226	**24.2**
Netherlands	73.3	1,390	1,868	481	**25.7**
Norway	103.5	2,215	9,424	2,349	**24.9**
United Kingdom	59.6	256	2,745	566	**20.6**
Denmark	8.4	79	2,604	651	**25.0**
Sweden	0	0	4,641	1,160	**25.0**
Poland	4.1	164	22,414	5,292	**23.6**
Lithuania	0.85	NA	481	113	**23.5**
Total	**266.0**	**4,202**	**65,487**	**16,470**	**~25**

bcm – billion cubic meters

On average, the US EIA estimated a recovery factor of 25% efficiency between in situ gases and technically recoverable resources. The original US units have been converted into SI units (US EIA, 2011).

Generally, bituminous oil shale resources are enormous. Worldwide, they are likely to exceed conventional oil reserves (ALBOUDWAREJ ET AL., 2006; FAUR ET AL., 2015). Table 3 presents an estimate of these resources for Europe. Bituminous shale has been exploited for decades and in some places for centuries. However, given their low efficiency, these deposits have never played a major role, and their development has been interrupted when better alternatives have become available.

Table 3

Estimates of shale oil resources in Europe (WEC, 2010)

Country	In situ resource (Gb)	In situ resource (Mt)
Austria	0.008	1
Bulgaria	0.125	18
Estonia	16.286	1,494
France	7	1,002
Germany	2	286
Hungary	0.056	8
Italy	73	10,446
Luxembourg	0.675	97
Poland	0.048	7
Spain	0.28	40
Sweden	6.114	875
United Kingdom	3.5	501
Total	**109.1**	**15,775**

Gb – Giga barrels; Mt – million tons

The extraction of this oil falls into the category of producing petroleum from compact formations, even if it occurs between bituminous shale. For example, the Parisian basin contains an enormous formation of bituminous shale. At present, Europe focuses on extracting oil from compact formations captured in this shale (LETEURTROIS ET AL., 2011).

The environmental impact

Greenhouse gas emissions (GHG)

Fugitive emissions of methane from hydraulic fracturing processes can have a huge impact on GHG balance. According to existing assessments, for the development and production of unconventional natural gas, between 18 and 23 g of equivalent CO_2 per MJ are emitted. Emissions from methane infiltration in aquifers have not yet been evaluated. However, project-specific emissions may vary with a factor by up to ten, depending on methane production of the well.

Depending on a number of factors, shale gas GHG emissions relative to its energy content may be either relatively low, comparable to those of conventional natural gas transported over long distances or extremely high, comparable to anthracite over whole its life cycle (from extraction to combustion).

Other atmospheric emissions

Emissions may come from the following sources: from trucks and drilling equipment (noise, particles, SO_2, NO_x, non-metallic volatile organic compounds - NMVOCs and CO); resulting from the processing and transport of natural gas (noise, particulates, SO_2, NO_x, NMVOCs and CO); evaporation chemicals from wastewater basins; due to spills and explosions of the wells (dispersion of drilling or fracturing fluids mixed with deposited particles) (Figures 1 and 3).

Figure 1. Air pollution sources (LECHTENBÖHMER ET AL, 2011)

The impact on the landscape

An unavoidable impact of shale hydrocarbon extraction is the high occupancy of land needed for drilling facilities and extensions, the consumption of space in the landscape, as drilling facilities require extensive land for technical equipment, fluid storage, and access paths for delivery.

The impact on land (soil, groundwater and surface water)

Water and soil may be contaminated with chemicals from the fracturing process, but also with the wastewater from the deposit containing heavy metals (e.g. arsenic or mercury) or radioactive particles.

Pollutants could migrate to surface waters, groundwater and soil from various causes such as trucking, leakage in the collecting system, wastewater basins, compressors, etc., accidental leakage (e.g. explosions with fracturing liquid or waste water), damages to the cement wall and casing column, or simply uncontrolled underground flows along natural or artificial cracks present in formations (Figure 2). To this the release of radioactive particles from the underground (normally occurring radioactive substances NORM) is added (Figure 3).

Figure 2. Contamination of water and soil (LECHTENBÖHMER ET AL, 2011)

Also in the proximity of gas wells, methane contamination of groundwater is reported (OSBORN ET AL., 2011), which in extreme conditions causes the explosion of residential buildings, as well as contamination with potassium chloride, which causes a salinization of drinking water. These consequences accumulate with the density of shafts that exploit shale formations (up to six drilling platforms per km²).

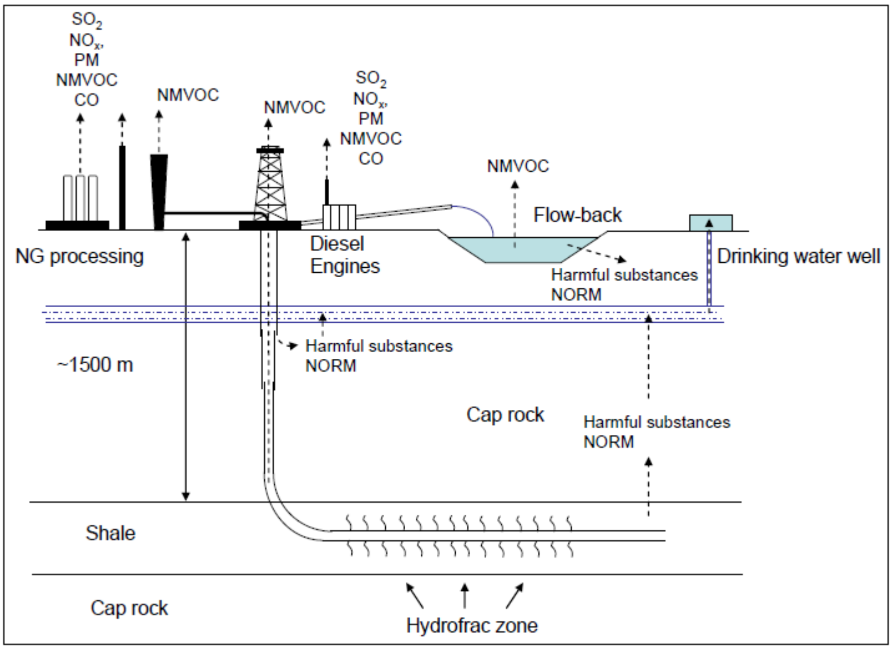

Figure 3. Fluxes of environmental pollutants and contaminants (SUMI, 2008)

Figure 4 and table 4 show the composition of the fluid used at the “Goldenstedt Z23” compact gas well in Lower Saxony, Germany. The fracturing fluid contains 0.25% of toxic substances, 1.02% of harmful or toxic substances for human health (0.77% are classified as harmful "Xn" and 0.25% as acute toxicity, T); and 0.19% of substances harmful to the environment (LECHTENBÖHMER ET AL, 2011).

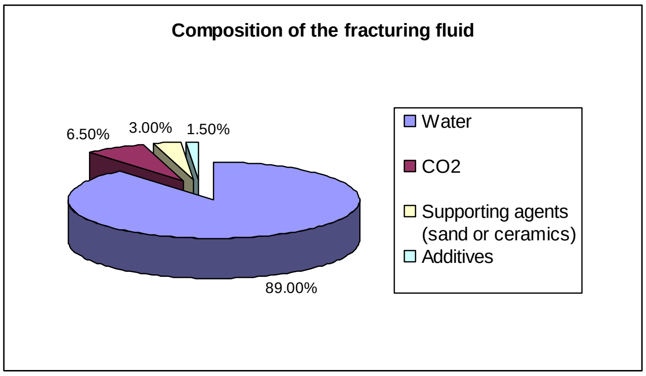

Figure 4. Typical composition of the fracturing fluid

Table 4

The chemicals contained in the additives (LECHTENBÖHMER ET AL, 2011)

CAS No.	Substance	Formula	Effects on human health	GHS classification
111-76-2	2-butoxiethanol	$C_6H_{14}O_2$	toxic	GHS07
26172-55-4	5-cloro-2-metil-4-izotiazol-3-ona	C_4H_4ClNOS	toxic	GHS05 GHS08 GHS09
2682-20-4	2-metilizotiazol-3(2H)-ona	C_4H_5NOS	toxic	GHS05 GHS08 GHS09
9016-45-9	Nonilfenol etoxilate	C_mH2_{m+1} - $C_6H_4OH(CH_3CH_2O)_n$	toxic	GHS05 GHS07 GHS09
75-57-0	Tetrametilamonium chloride	$C_4H_{12}ClN$	toxic	GHS06 GHS07

In the active shale gas extraction area, about 0.1-0.5 liters of chemicals are injected per square meter.

Fracturing or waste water injection usually leads to the occurrence of earthquakes.

The impact on resources and biodiversity

The process of extracting shale hydrocarbons through fracturing involves an enormous consumption of natural and technical resources compared to conventional gas or oil and should be analyzed through a cost-benefit analysis of these operations.

Regarding the risk and impact on biodiversity, although these certainly exist, so far there are no rigorous systematic studies not only for identifying but also for quantifying them, which represents another major global problem.

RESULTS AND DISCUTIONS

In order to assess the environmental risk associated with the exploitation of shale hydrocarbons, a simple procedure has been developed, starting from the specialized materials published by various authors (DUMITRAN AND ONUTU, 2010; SMITH, 1996) and from the ones described in the present paper.

The vulnerability level is determined in most cases by the physical exposure of the components of the natural and anthropic environment, given their location in areas where there is a likelihood of destructive phenomena to occur.

In the specialty literature, there is a matrix to determine the vulnerability of environmental components to natural hazards (landslides) that has been adapted in this paper (LAZĂR ET AL., 2015). Thus, a new vulnerability assessment matrix was built. This matrix determines the level of vulnerability of the components of the natural and anthropic environment, in correlation with the type of environmental impact generated by the exploitation of shale hydrocarbons (Table 5).

Table 5

Environmental vulnerability assessment matrix (adapted after LAZĂR ET AL., 2015)

Possible environmental risks **Natural and anthropogenic components of the environment in the area of influence**	**Massive CH_4 emissions** **Massive GHG emissions** **Massive VOC emissions** **Massive radioactive emissions** **Contamination of surface and ground waters** **Earthquakes larger than 3 degrees**	**Moderate CH_4 emissions** **Moderate GHG emissions** **Moderate VOC emissions** **Moderate radioactive emissions** **Contamination of surface water** **Earthquakes between 2 and 3 degrees**	**Normal CH_4 emissions** **Normal GHG emissions** **Low VOC emissions** **Low (normal) radioactive emissions** **Accidental contamination of surface water** **Earthquakes between 1 and 2 degrees**	**Fugitive CH_4 emissions** **Fugitive GHG emissions** **Fugitive VOC emissions** **Fugitive radioactive emissions** **Water pollution within accepted limits** **Earthquakes under 1 degree**
Anthropic components **Residential areas, households and social constructions** ***Natural components*** **Woodlands, watercourses and/or wetlands, high value land**	**V = 5**	**V = 4**	**V = 4**	**V = 3**
Anthropic components **Industrial constructions and installations, intensive communication routes** ***Natural components*** **Arable lands, wooded areas, productive land, watercourses**	**V = 4**	**V = 4**	**V = 3**	**V = 3**
Anthropic components **Communication routes with limited traffic and restricted movement of people** ***Natural components*** **Wooded pastures, limited resources of water, low value land**	**V = 4**	**V = 3**	**V = 3**	**V = 2**
Anthropic components **Areas without construction or communications routes, sporadic access of people** ***Natural components*** **Unproductive land, degraded pastures with shrubs**	**V = 3**	**V = 3**	**V = 2**	**V = 1**

The matrix in Table 5 proposes 5 categories of environmental vulnerability:

- V = 1 – very low vulnerability (emissions are rare and small in size, surface or underground water is not contaminated, no earthquakes are induced);
- V = 2 – low vulnerability (gaseous emissions are within the normal range associated with shale hydrocarbon platforms, surface or underground water is not contaminated, rare and low intensity induced earthquakes);
- V = 3 – average vulnerability (gaseous emissions are within normal limits associated with conventional hydrocarbon platforms, surface water is contaminated, induced earthquakes are frequent and of medium intensity);
- V = 4 – high vulnerability (gaseous emissions are within normal limits associated with conventional hydrocarbon platforms, surface or subterranean waters are contaminated, frequent induced earthquakes of medium intensity);
- V = 5 – very high vulnerability (explosive gas emissions are at hazardous concentrations, greenhouse gas emissions above normal levels associated with conventional hydrocarbon exploitation platforms, massive VOC emissions and radiation, surface and groundwater is contaminated, induced earthquakes have high frequency of production and intensity over 3 degrees).

Based on the recommendations presented in various studies (LAZĂR ET AL., 2015; SMITH, 1996; US ACE, 1997) on the delimitation of the intervals for the probability of producing an unwanted event associated with conventional and unconventional hydrocarbon extraction platforms, we set the following scale:

- P = 1 (P_r = 0÷20%) → very low probability of producing unwanted events;
- P = 2 (P_r = 21÷40%) → low probability of producing unwanted events;
- P = 3 (P_r = 41÷60%) → moderate probability of producing unwanted events;
- P = 4 (P_r = 61÷80%) → high probability of producing unwanted events;
- P = 5 (P_r = 81÷90%) → very high probability of producing unwanted events (can only be associated with operating platforms based on concrete measurements and equipment status evaluations). It is recommended to stop the activity and to apply remediation measures.
- P = 6 (P_r = 91÷100%) → almost certain probability of producing unwanted events – imminent danger (can only be associated with operating platforms based on concrete measurements and equipment status evaluations). Involves immediate stoppage of the activity and emergency remediation actions.

Risk can be defined as the product of the probability of occurrence of a potential hazard and the vulnerability of the natural and anthropic environment that may be affected. According to the simplified risk equation, in the case of the exploitation of shale hydrocarbons, the following relation can be applied to determine it: $R = P \cdot V$ (R - the environmental risk caused by an undesirable event, P - the probability of occurrence of the event, V – the vulnerability of the natural and anthropic environment in the conditions of an unwanted event occurring).

Knowing the vulnerability of the environment and the probability of producing an undesirable event (explosion, fire, air contamination, soil, surface water and groundwater, earthquakes), a new risk assessment matrix is presented in Table 6.

Table 6

Environmental risk assessment matrix

Probability Vulnerability class	P = 6	P = 5	P = 4	P = 3	P = 2	P = 1
V = 5	**R = 30**	**R = 25**	**R = 20**	**R = 15**	**R = 10**	**R = 5**
V = 4	**R = 24**	**R = 20**	**R = 16**	**R = 12**	**R = 8**	**R = 4**
V = 3	**R = 18**	**R = 15**	**R = 12**	**R = 9**	**R = 6**	**R = 3**
V = 2	**R = 12**	**R = 10**	**R = 8**	**R = 6**	**R = 4**	**R = 2**
V = 1	**R = 6**	**R = 5**	**R = 4**	**R = 3**	**R = 2**	**R = 1**

Based on the studies in the relevant literature (DUMITRAN AND ONUTU, 2010; LAZĂR ET AL., 2015), the following risk scale associated with the exploitation of shale hydrocarbons was established:

- R = 1 ÷ 2 → minimal risk - insignificant damage to the natural and anthropic environment, with reversible effects in very short term;
- R = 3 ÷ 7 → reduced risk - minor damage to the natural and anthropic environment, with reversible effects in a relatively short time;
- R = 8 ÷ 13 → medium risk - partial destruction of habitats and associated biocenosis, endangering the anthropic environment, medium-term consequences;
- R = 14 ÷ 19 → high risk - the destruction of associated habitats and biocenosis on significant surfaces, long-term reversible consequences;
- R = 19 ÷ 25 → high risk - total destruction of the natural and anthropic environment, irreversible consequences;
- R = 26 ÷ 30 → extreme risk - loss of life, total destruction of the natural and anthropic environment, irreversible consequences.

The proposed methodology can be used to determine the environmental risk associated with the implementation or operation of any shale hydrocarbons exploration project. For this purpose a careful analysis of the environmental components present in the area of influence of the project and a proper assessment of the proposed or applied exploitation procedures (at the level of the technical details of the installations, the verification of the intervention procedures in emergency situations and the preparation intervention staff) is necessary.

CONCLUSIONS

At present, the social, economic and technological environment is constantly changing, and climate change (which can no longer be denied) forces us to move towards a sustainable energy system. This is a first-rate priority and it is necessary to engage the public at regional and local level and to homogenize national interests so that a common policy on the exploitation of shale hydrocarbons in Europe can be generated.

In reassessing national, regional and community policies an essential condition must be the life cycle analysis for new projects, including an environmental impact and risk assessment. Only a full cost and benefit analysis enables a fair assessment of the relevance of the various projects and their justification.

As is well known, hydraulic fracturing technology has a notable impact on the environment in the United States, the only country currently with several decades of experience and long-term statistical archives. All American experience shows that this damage to the environment is offset by the economic benefits to a small extent.

Given its characteristics, the technology used to develop shale gas exploitation has an inevitable environmental impact. It presents a high risk of misuse and, even when properly applied, can pose a high risk of environmental damage and human health hazards.

The American experience also shows that, in practice, accidents are possible. Too often, the companies in question are being fined by the competent authorities for such deviations.

For these reasons, Europe needs to adopt a common legislative framework for the exploitation of shale hydrocarbons. This legislative framework should start from what is known so far in terms of environmental impact and set clear rules, strict but achievable environmental targets, harsh sanctions but also the obligation of ecological reconstruction of the affected environment and the adoption of a compensation mechanism for damage during the exploitation period.

For this purpose, the present paper may represent a first conceptual model for achieving a common environmental risk assessment methodology associated with the exploitation of shale hydrocarbons through the hydraulic fracturing process.

BIBLIOGRAPHY

1. ALBOUDWAREJ H., FELIX J., TAYLOR S., BADRY R., BREMNER C., BROUGH B., SKEATES C., BAKER A., PALMER D., PATTISON K, BESHRY M., KRAWCHUK P., BROWN G., CAVALO R., TRIANA J.A.C., HARTCOCK R., KOERNER K., HUGHES T., KUNDU D., LOPEZ DE CARDENAS J., WEST C., 2006, Highlighting Heavy Oil, Oilfield Review, Schlumberger, pp 34-53.
2. ARTHUR J.D., BRUCE P.E., LANGHUS P.G., 2008, An overview of modern shale gas development in the United States, ALL Consulting. 2008. URL: http://www.allllc.com/publicdownloads/ALLShaleOverviewFINAL.pdf
3. BRITISH PETROLEUM (BP), 2010, British Petroleum Statistical Review of World Energy, URL: http://www.bp.com
4. CHARPENTIER R.R., COOK T., 2010, Applying probabilistic well-performance parameters to assessments of shale-gas resources, U.S. Geological Survey Open-File Report No. 2010-1151, 18 p.
5. CHMAL T., 2011, Oppening speech, International conference „Shale Gas Eastern Europe 2011”, Varșovia, Polonia.
6. DUMITRAN C., ONUTU I., 2010, Environmental risk analysis for crude oil soil pollution. Carpathian Journal of Earth and Environmental Sciences, Vol. 5, No. 1, pp. 83 - 92.
7. FAUR F., LAZĂR M., DUNCA E., CIOLEA D.I., 2015, Critical Analysis of the Trends in Use of Classical Energetic Resources, 15th International Multidisciplinary Scientific GeoConference SGEM 2015, www.sgem.org, SGEM2015 Conference Proceedings, DOI: 10.5593/SGEM2015/B13/S3.022, pp. 163-170, Albena Bulgaria.
8. GÉNY F., 2010, Can unconventional gas be a game changer in European gas markets? The Oxford Institute for Energy Studies, NG 46.
9. LAZĂR M., NYARI I.M., FAUR F., 2015, Methodology for assessing the environmental risk due to mining waste dumps sliding - case study of Jiu Valley, Carpathian Journal of Earth and Environmental Sciences, Vol. 10, pp. 223-234.
10. LECHTENBÖHMER S., ALTMANN M., CAPITO S., MATRA ZS., WEINDRORF W., ZITTEL W., 2011, Impacts of shale gas and shale oil extraction on the environment and on human health, Directorate General for Internal Policies, Policy Department A: Economic and Scientific Policy, European Parliament, Bruxeles.
11. LETEURTROIS J-P., DURVILLE J-L., PILLET D., GAZEAU J-C., 2011, Les hydrocarbures de roche-mère en France, Rapport provisoire, Conseil général de l’énergie et des technologies,

CGEIT No. 2011-04-G, Conseil général de l'énvironment et du développement durable, CGEDD NO. 007318-01.

12. OSBORN ST.G., VENGOSH A., WARNER N.R., JACKSON R.B., 2011, Methane contamination of drinking water accompanying gas-well drilling and hydraulic fracturing, April 2011.
13. SMITH K., 1996, Environmental hazards, Routeledge, London, p 389.
14. SUMI L., 2008, Shale gas: focus on Marcellus shale. Report for the Oil & Gas Accountability Project/ Earthworks. May 2008.
15. UNITED STATES ARMY CORPS OF ENGINEERS (US ACE), 1997, Introduction to probability and reliability methods for use in geotechnical engineering. No. 1110-2-547.
16. UNITED STATES ENERGY INFORMATION ADMINISTRATION (US EIA), (2011). World Shale Gas Resources: An Initial Assessment of 14 Regions outside the US, April 2011. URL: http://www.eia.gov/analysis/studies/worldshalegas/?src=email
17. WORLD ENERGY COUNCIL (WEC), 2010, 2010 Survey of Energy Resources, London, URL: www.worldenergy.org