Project Acronym and Title:

M4ShaleGas - Measuring, monitoring, mitigating and managing the environmental impact of shale gas

ENVIRONMENTAL MONITORING FOR SHALE GAS

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Public introduction

M4ShaleGas stands for *Measuring, monitoring, mitigating and managing the environmental impact of shale gas* and is funded by the *European Union's Horizon 2020 Research and Innovation Programme.* The main goal of the M4ShaleGas project is to study and evaluate potential risks and impacts of shale gas exploration and exploitation. The focus lies on four main areas of potential impact: the subsurface, the surface, the atmosphere, and social impacts.

The European Commission's Energy Roadmap 2050 identifies gas as a critical fuel for the transformation of the energy system in the direction of lower CO_2 emissions and more renewable energy. Shale gas may contribute to this transformation.

Shale gas is – by definition – a natural gas found trapped in shale, a fine grained sedimentary rock composed of mud. There are several concerns related to shale gas exploration and production, many of them being associated with hydraulic fracturing operations that are performed to stimulate gas flow in the shales. Potential risks and concerns include for example the fate of chemical compounds in the used hydraulic fracturing and drilling fluids and their potential impact on shallow ground water. The fracturing process may also induce small magnitude earthquakes. There is also an ongoing debate on greenhouse gas emissions of shale gas (CO_2 and methane) and its energy efficiency compared to other energy sources

There is a strong need fora better European knowledge base on shale gas operations and their environmental impacts particularly, if shale gas shall play a role in Europe's energy mix in the coming decennia. M4ShaleGas' main goal is to build such a knowledge base, including an inventory of best practices that minimise risks and impacts of shale gas exploration and production in Europe, as well as best practices for public engagement.

The M4ShaleGas project is carried out by 18 European research institutions and is coordinated by TNO-Netherlands Organization for Applied Scientific Research.

Executive Report Summary

Shale gas development is believed to have significant influence on the natural environment, including soil quality and the surface water and groundwater qualitative and quantitative status. To identify and document scale and severity of any impact as well as to control proper work conducting by operators, monitoring system covering whole shale gas development process is considered.

In general, environmental monitoring systems operating very well in all European countries and results are available for public and decision makers. This might be useful but not sufficient for shale gas monitoring.

In order to be able to protect both surface and groundwater in terms of their availability and quality as well as secure soil layer against any loss in productivity and chemical properties, it is very important to define all possible hazards but also existing legal and technical means which allow to protect soil and water resources against any irreversible deterioration.

In Poland, in 2010-2016 intensive exploratory works have been done, whereas in UK legal framework was enforced and exploratory works are expected. Safety assurance and measures applicable for water and soil were described.

A crucial issue while considering safety of natural environment is a proper management of drilling waste generated during shale gas operations. Flowback and produced water generated during shale gas activities is distinct from typical conventional produced water derived from conventional oil and gas production, its proper classification might cause a problem and there may be a hazardous waste category applicable. Depending on proper classification, some waste management options are available, with re-use as a preferable one.

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1 INTRODUCTION

1.1 Context of M4ShaleGas

Shale gas source rocks are widely distributed around the world and many countries have now started to investigate their shale gas potential. Some argue that shale gas has already proved to be a game changer in the U.S. energy market (EIA 2015[1]). The European Commission's Energy Roadmap 2050 identifies gas as a critical energy source for the transformation of the energy system to a system with lower CO_2 emissions that combines gas with increasing contributions of renewable energy and increasing energy efficiency. It may be argued that in Europe, natural gas replacing coal and oil will contribute to emissions reduction on the short and medium terms.

There are, however, several concerns related to shale gas exploration and production, many of them being associated with the process of hydraulic fracturing. There is also a debate on the greenhouse gas emissions of shale gas (CO_2 and methane) and its energy return on investment compared to other energy sources. Questions are raised about the specific environmental footprint of shale gas in Europe as a whole as well as in individual Member States. Shale gas basins are unevenly distributed among the European Member States and are not restricted within national borders, which makes close cooperation between the involved Member States essential. There is relatively little knowledge on the footprint in regions with a variety of geological and geopolitical settings as are present in Europe. Concerns and risks are clustered in the following four areas: subsurface, surface, atmosphere and society. As the European continent is densely populated, it is most certainly of vital importance to understand public perceptions of shale gas and for European publics to be fully engaged in the debate about its potential development.

Accordingly, Europe has a strong need for a comprehensive knowledge base on potential environmental, societal and economic consequences of shale gas exploration and exploitation. Knowledge needs to be science-based, needs to be developed by research institutes with a strong track record in shale gas studies, and needs to cover the different attitudes and approaches to shale gas exploration and exploitation in Europe. The M4ShaleGas project is seeking to provide such a scientific knowledge base, integrating the scientific outcome of 18 research institutes across Europe. It addresses the issues raised in the Horizon 2020 call LCE 16 – 2014 on *Understanding, preventing and mitigating the potential environmental risks and impacts of shale gas exploration and exploitation.*

[1] EIA (2015). Annual Energy Outlook 2015 with projections to 2040. U.S. Energy Information Administration (*www.eia.gov*).

1.2 Study objectives for this report

Shale gas development in Europe (if happens) is believed to have significant influence on the natural environment, including the surface and groundwater status both in terms of quality and quantity as well as soil quality with regard to its productivity and chemical elements content. The significance of this influence will depend predominantly on exploratory and production activities and their compliance with Health, Safety, and Environment (HSE) standards but also on local conditions in gas perspective areas and vulnerability of the local environment.

To be able to assess and control any adverse change in environmental status, one needs to have tools to measure particular features and original benchmarks to compare ongoing measurements to.

Monitoring of changes in local environment relative to a baseline is an essential tool to determine the impact of shale gas operations on the environment.

1.3 Aims of this report

This report is aiming at summarizing information about environmental monitoring for water and soil and assessment of its importance for shale gas development in particular as well as presenting data gathered in terms of legal and technical tools used for water and soil protection. An identification of protective measures follows up a short summary of the knowledge on possible soil and water hazards imposed by shale gas activities. The report presents collected facts and arguments for shale gas monitoring recommendations.

2 ENVIRONMENTAL MONITORING SYSTEMS FOR SURFACE WATER, GROUNDWATER AND SOIL

The environment in Europe is widely monitored. Environmental data and knowledge about the state of the environment are both commonly used for managing and taking informed decisions by many stakeholders, according to an idea of sustainable development. At European level, basic principles for environmental monitoring are established by some European Directives e.g., the Water Framework Directive. Moreover, there is a strong aspiration for standardization and unification of results, which is – in case of water monitoring - provided by a codified reporting system. However, goals, measures and results are diverse among countries. The system of environmental management and monitoring differs across Member States and the scope of responsibility is divided between institutions of various character (administration, geological and other surveys, academic organizations, etc.) and responsibilities. A major information source about state of the environment in Europe is The European Environment Agency (EEA), an agency of the European Union, which coordinates the European environment information and observation network – Eionet[2]. However environmental monitoring in field is conducted by many different institutions at regional and local level.

Despite much work that has been done, there is still no issue of any soil directive, which might specify objectives and principles of unified approach to soil status monitoring in terms of its natural properties and anthropogenic changes including both contamination and deterioration of natural properties due to different human activities on land surface.

Environmental monitoring system comprises testing, sampling, analysis and assessment of the state of the environment in order to register changes going on. A reasonable assumption is that monitoring of changes in local environments in relation to a defined baseline is an essential tool to determine the environmental impact of shale gas. The main questions are: (1) whether the currently operating environment monitoring systems are also applicable in shale gas development?(2) whether the existing survey results and database collections are sufficient in order to establish actual baseline conditions for water resources quality and soil quality and productivity in areas potentially facing shale gas exploration and future production?

To address these questions a review of the current state-of-the-art in European soil and water monitoring systems was prepared and stakeholders' opinions were collected about currently operating monitoring networks with special regard to their views on whether it is possible to use them effectively for monitoring of shale gas development impact (Fajfer et al, 2016).

The data on water and soil status observations gathered at member states and regional levels is reported, collected and stored by the European Environment Agency, though information on results is also available through different dissemination systems in particular countries or regional institutions (use of local languages may a serious obstacle while one looks for information). There is huge number of institutions in EU

[2]EEA(http://www.eea.europa.eu/) sub-page 'Who we are'(http://www.eea.europa.eu/about-us/who),visited in May 2016

member states responsible and engaged in both environmental status assessment and environmental monitoring with regard to surface water, groundwater and soils in Europe.

The environmental monitoring systems operating in European countries and regions are well defined, stable and comprehensive. Systems do not respond immediately to any changes in policy or industry, like shale gas development. This is actually their strong advantage. Main goal, which is to monitor environmental status, is achieved constantly with firm and consistent approach, so it is not expected to change or adjust instantly. Institutions are generally aware of shale gas issue and its potential hazards. However, it seems that there is no prepared scenario or opinion on requirements or approaches to surface and groundwater and soil status monitoring with regard to potential hazards posed by unconventional oil and gas exploration and production activities.

3 MONITORING DATA ASSESSMENT

Shale gas development in Europe (if happens) is believed to have significant influence on the natural environment. Surface and groundwater as well as surface soils and subsoils can be affected as in case of any other industrial activities. In order to be able to protect both surface and groundwater in terms of their availability and quality as well as secure soil layer against any loss in productivity and chemical properties, it is very important to define:

- all possible hazards that shale gas activities can pose on the media
- all existing legal and technical means which allow to protect soil and water resources against any irreversible deterioration
- existing gaps in soil and water protection system with regard to shale gas activities
- additional measures that should be implemented in order to fill the gaps and ensure soil and water long term protection.

This report is aiming at summarizing the knowledge on possible soil and water hazards imposed by shale gas activities and at identifying existing legal and technical tools which can be used in order to protect soil properties and both surface and groundwater resources in terms of their abundance and quality. Some additional measures and actions also will be proposed which can help to protect surface environment against adverse changes due to shale gas development challenges.

3.1 Fresh water

Water is clearly the most important asset that the earth grants for humans life and economy, so the special care for fresh water resources and its quality is something that we owe both the earth and future generations. According to European legislation, fresh water has to be used at first as drinking water supply and as such its resources in terms of quality and quantity have to be preserved. Only fulfilling this condition, humans can think of other activities relying on water consumption.
Shale gas development as it can proceed at present inevitably needs significant amount of water and deals with substances which can be dangerous to water quality if misused or incidentally released. Waste it produces, mainly liquid, namely flowback and produced water, must be managed in proper, safe way otherwise it also might put a threat to fresh water quality. It is very important to learn and be aware of all the hazards which can endanger water aquifers and surface water bodies while planning and performing exploration and production of hydrocarbons from shales.

3.1.1 Surface water and groundwater hazards related to shale gas development

Shale gas development has a potential to impact water resources both quantity and quality. Risk assessment in terms of water resources, taking into consideration probability and severity of possible impact, is presented widely in literature, particularly summarized and evaluated in some M4ShaleGas project's reports (Jacobsen et al, 2015, Clancy et al, 2016). Mentioned studies and research are prevalently based on American experiences, as in US and Canada unconventional hydrocarbons extraction has been carried out for about fifteen years now, delivering data and case studies. While Werner et al (2014) reviewed numerous studies reporting of environmental hazards from unconventional natural gas development activities associated with adverse human health outcomes, water issues are one of the mostly covered. The main water-related concerns reported in the literature are: hydraulic fracturing (in terms of surface and groundwater contamination), methane gas migration from the shale formations to shallower aquifers, potential surface discharges of contaminated produced water (Werner et al, 2014).

The importance of water safety was considered by Polish Geological and Hydrogeological Surveys at a very early stage of prospecting for and exploration of unconventional gas resources in Europe (Woźnicka, Konieczyńska, 2011, PGI-NRI, 2013). The analysis of possible migration pathways related to wellbore was conducted before assessing environmental impact of first full-scale fracturing treatment performed in Poland. The main potential possibilities were identified as follow (Konieczyńska et al, 2011): migration of liquid and gaseous pollutants to water-bearing horizons from the horizontal well section (along privileged circulation routes), or from the well bore area, or from the land surface. Also water management as well as waste and wastewater management has been recognized as a crucial issue in terms on natural environment safety (Woźnicka, Konieczyńska, 2011, PGI-NRI, 2013). Firstly, water is a key medium in technological process, actually at every stage of the work, particularly to fracturing treatment. Secondly, there is a risk of water (surface water and groundwater) contamination in the area where the work is carried out. Moreover, as a result of significant amount of water used, large amount of waste materials (namely flowback fluid) is generated.

An inventory of water consumption for shale gas operations in United States ranges between 13 700 and 23 800 m^3 per well (Kondash, Vengosh, 2015). Preliminary Polish experiences show similar range from 1 284 to 37 849 m^3 per well (Konieczyńska et al, 2015). Lower amounts of water (<10 000 m^3 per well) are typical for vertical wells, which are drilled commonly for prospection and exploration. Due to technological process, there is a need for collecting large amount of water in a mining plant before the fracturing treatment has started. As a result the need for significant water withdrawal within relatively short period of time occurs, which might cause so called cumulative water abstraction. There is a risk of excessive water depletion which may have serious ecological effects and lead to conflicts among water consumers (PGI-NRI, 2013). Going further the availability of water resources, a question arises: should groundwater be allowed to use for the purpose of shale gas production, even if there is considerable reserve of the water? As a matter of fact, in Poland groundwater resources are the basic potable water supply for the population due to best quality, and in large areas of the country it is the only source of water supply. This is why the possibility of groundwater

use for other purposes causes an anxiety and variety of water resources should be considered for hydraulic fracturing.
In terms of quality deterioration, possible hypothetical threats arise from surface sources (emissions of pollutants via spills, uncontrolled released, accidents) and from subsurface (uncontrolled, fugitive emissions along privileged zones or due to well damages). It is worth noting, that threats from surface, if arise, will firstly affect soils, surface waters and perched and top aquifers. In case of subsurface threats, deep groundwater horizons will be affected firstly. Whereas usually monitored are commercial aquifers or main groundwater reservoirs. This issue should be considered while environmental monitoring related to shale gas operations is planned.

3.1.2 Safety of fresh water resources and quality

The Water Framework Directive (2000/60/EC), which came into force in 2000, provides a framework for integrated water management in river basin districts across the European Union. Member States are obliged to protect and restore all bodies of groundwater and surface water to achieve ‘good status’, which is defined in terms of both quantity and chemical status. A basic management tool in integrated water resources management is river basin management plans. These plans contain an assessment of water quality within each River Basin District and introduce a list of actions, called ‘programme of measures’, to protect water bodies of good ecological and chemical status from deterioration, and to restore water bodies that are currently not of good ecological or chemical status. Each Member state shall establish a programme of measures for each river basin district. In terms of water quality, general rules are given and basics for monitoring are established (for more details see: D7.3 M4Shale Gas report). In terms of quantity, one of the most important basic measures, which must be complied with for programme of measures, are controls over the abstraction of fresh surface water and groundwater, including register of water abstraction and a requirement of prior authorisation for abstraction (2000/60/EC, article 11).
An indicator of the pressure or stress on freshwater resources is the water exploitation index (WEI), which is the total water abstraction per year as a percentage of total renewable freshwater resources (Collins et al., 2009). A WEI above 20 % implies that a water resource is under stress and values above 40 % indicate severe water stress and clearly unsustainable use of the water resource (Raskin et al., 1997). Europe is not widely regarded as an arid continent, however nearly half the EU’s population lives in ‘water-stressed’ countries, where the abstraction of water from existing freshwater sources is too high (EU, 2010). Moreover, as the WEI is calculated based on annual data and cannot, therefore, account for seasonal variations in water availability and abstraction, it does not reflect fully the level of stress upon local water resources (Collins et al., 2009). For that reason local perspective need to be taken when assessing safety of fresh water resources.
Under European Water Framework Directive, water bodies that are used for the abstraction of drinking water have to be delineated and designated drinking water Protection areas. Article 7.3 requires the protection of these water bodies ‘with the aim of avoiding deterioration in their quality in order to reduce the level of purification treatment required in the production of drinking water’.Source Protection Zones (SPZ)

are a key regulatory tool for protecting abstraction sources used for drinking water or food production. The SPZs are defined by the time it would take for pollutants to travel through the aquifer from the edge of a zone to a source of drinking water.
In relation to review of environmental monitoring (for more details see: D7.2 & D7.3 M4Shale Gas report), a situation in selected European countries in terms of protection of fresh water resources was recognized.

Poland

During shale gas exploration in Poland 72 exploratory boreholes were drilled between 2009 and 2017, including 18 horizontal (directional) and 54 vertical. Hydraulic fracturing treatment was performed in 28 wells (14 horizontal, 14 vertical) and micro treatment was performed in 9 wells (PGI-NRI, 2017). The latest borehole was drilled in December 2015, in Pomerania region and it was hydrofracked in June/July 2016.
Since 2016, due to new legal act in force, concession for exploration and prospecting of hydrocarbons and production of hydrocarbons from deposits is provided in the tender. The procedure encompasses a decision on the environmental conditions (when appropriate according to legal provisions), which is obtained by the concession authority, as a part of preparation of tender documentation. Previously it was investor who shall obtain this decision. Other environmental permits comprise water and waste management.
In terms of water quantity assurance, water permit is a basic legal instrument and must be obtained by investor for water intake exceeding 5m^3/day and for sewage discharge. The water permit is a control measure which defines provisions and quantities of water intake for particular users, based on available resources. An average and maximum intake is defined among others. It is local authority who issues the water permit. Each water intake should be measured and a water fee is charged based on that measure. Fee rates are set out in regulations. Water administration authorities and inspectors are authorized to control the quantity and method of water extraction.
Groundwater prospection and intake construction is subjected to the requirements of the Geological and Mining Law, as a geological works, and require a geological project (before) and hydrogeological documentation (after work completion) to be approved. This documentation is required to issue a water permit.
A water register (pol.: kataster wodny) is a water management information system used to collect and update data about, among others: groundwater resources, quantity of water intake, water users and water permits, as well as local and regional sources of pollution.
The groundwater protection system in Poland provides several forms of protection interfering with land use as well as the rules of conducting business in accordance with the Water Law provisions. This includes protection zones for groundwater and surface water intakes, including areas for water supply and protection areas for groundwater bodies. The restrictions may be imposed in the protection zones on land management and use of water.
At present, some of the groundwater intakes serving primarily the population are designated as protection zones. This applies in particular to water intakes from poorly insulated aquifers. The required legislative acts formally establishing the protection zones for selected groundwater bodies are in the preparation phase. While implemented,

prohibitions and restrictions may apply to activities related to the hydrocarbons development and to the use of groundwater and surface waters.

United Kingdom

Shale gas exploration in the UK is still in initial phase. Currently (August 2017) drilling is expected to commence (Preston New Road) (Cuadrilla, 2017) after few years suspension, due to seismic events experienced in 2011 resulted in a temporary suspension of fracking for shale gas.

A number of regulatory steps must be completed by a company wishing to explore for or extract gas, including (GOV.UK, Guidance on fracking, 2017): Petroleum Exploration and Development Licences (PEDLs), planning permission, environmental permits, inspection of the well design, consent to drill, submission and review of Hydraulic Fracture Plan. Matters concerned with protection of water resources are regulated by the Environment Agency (currently all planned shale gas developments are located in England; elsewhere in the UK the Scottish Environmental Protection Agency (SEPA), Natural Resources Wales (NRW) and the Northern Ireland Environment Agency (NIEA) fulfil the role of the environmental regulator).

An abstraction licence from The Environment Agency is mandatory to abstract more than 20 cubic metres of water a day from a watercourse or underground water reserve. Separate groundwater investigation consent may be needed to construct the borehole or well and complete test pumping. A licence will only be granted where a sustainable water supply is available. The water may be also obtained from the local water supply company. In that case companies assess the amount of water available before providing it to operators. They are also obliged to follow a long-term plan with contingency reserves in case of a drought, which they must produce, and then update every 5 years.

The Environment Agency is responsible for managing water resources and controls how much water is taken with a permitting system, assuring there is enough water for public water supply, industry, agriculture, and a healthy environment. To regulate existing licences and grant new ones the catchment abstraction management strategy (CAMS) is used in each particular catchment area. During this process evidence and information are gathered to manage abstraction sustainably. The CAMS document provides information on how existing abstraction is regulated and if water is available for further abstraction.

Most licences require accurate measures and reports on the quantity of abstracted water to keep within the limits allowed in the licence. A water meter with certificated accuracy has to be installed. Records of all flow checks, including the date, the method and the result, have to be collected. The abstraction licence sets how often to record water abstraction and when submit to the Environment Agency. Any records, the manufacturer's certificate and any laboratory certificates must be kept and shown to an Environment Agency inspector for request (GOV.UK, Managing your water abstraction, 2017).

The Royal Society and The Royal Academy of Engineering reviewed the risks associated with fracking in their report (RS/RAE, 2012), concluded that water use can be managed sustainably in the UK due to standing abstraction control system. According to the UK Government (Delebarre et al, 2017), before permission for shale gas development is granted, a thorough assessment will be made considering the existing water users' needs and the environmental impact. Moreover, the Secretary of State will only be able to issue hydraulic fracturing consent if satisfied that planning authorities have consulted the relevant water company, according to The Infrastructure Act 2015.

The Infrastructure Act 2015 placed additional safeguards in England and Wales which prohibits hydraulic fracturing onshore at a depth of less than 1000 meters and within protected groundwater source areas. These provisions are enacted in the Onshore Hydraulic Fracturing Protected Areas Regulations 2015 which further restrict hydraulic fracturing to below 1200 meters in Source Protection Zones and in National Parks, the Broads, Areas of Outstanding Natural Beauty or a World Heritage site.

To minimise the risks of groundwater contamination, gas or oil operators must submit (to appropriate environmental regulator: EA, NRW or SEPA) detailed plans containing a hydro-geological assessment, including details of the presence of groundwater or surface water, details of borehole construction, monitoring plan, fracturing fluids, naturally occurring radioactive minerals, water abstraction and management of abstracted water. The environmental regulator assesses the proposal's risks and decides whether to issue the relevant permits.

Chemicals used in drilling and frack fluids are assessed for hazards on a case-by-case basis for each well by the appropriate environmental regulator. Operators must declare the full details of the chemicals to the regulator and will publish a brief description of the chemical's purpose and any hazards it may pose to the environment (Department of Energy & Climate Change, 2014, CIWEM, 2016).

The operator is required to make appropriate plans for storing fluid safely and not in open pits and design the site so spills are avoided (and are contained if they do happen). The operator must dispose of the flowback fluid safely. It is categorised as mining waste, so the operator must obtain an environmental permit for its disposal from the relevant environmental regulator and have an agreed waste management plan in place. Operators must carry out trials including laboratory tests, to identify the best way to dispose of the flowback fluids. All the treatment and disposal facilities that operators use must also hold the appropriate permits from the environmental regulator, who will be notified in advance of any movement of the waste.

Groundwater monitoring (requisite surveillance) will be required at any site that has a groundwater activity included in the permit. However, the Environment Agency consider it to be best practice for all oil and gas sites to undertake groundwater monitoring, even if this is not required as part of a groundwater permit.

Germany

In Germany, the first and to date only hydraulic fracturing activity to test the shale gas resources was undertaken by Exxon Mobil on a site "Damme Z3" Lower- Saxony in 2008. Commercial fracking of shale gas is not permitted. Four exploratory boreholes for scientific purposes are to be permitted in compliance with strict regulations, to make it possible to assess the consequences for the natural environment. Experts from public authorities and research institutions will monitor the test sites and will provide yearly reports to the German Bundestag, which will, in 2021, reassess whether the ban of unconventional hydraulic fracturing should continue. The reports of the expert commission will be open-access published (Bundesregierung, 2017).

New legislation came into force on 6 August 2016 and it imposed mandatory environmental impact assessments for all fracking operations to identify and extract natural oil and gas. This also applies to drilling operations designed to explore and tap geothermal energy as well as conventional hydraulic fracturing in sandstone for the production of tight gas, as performed for decades in German natural gas fields. Safety and environmental standards for the traditional extraction of natural gas, oil and geothermal power have also been tightened. Only fracturing fluids that are non-hazardous or low hazardous to water may be used. Hydraulic fracturing is prohibited in water protection areas, in catchment areas of lakes which are used for public water supply and catchment areas of mineral springs and wells that supply water for the production of food, including beverages (SHIP, 2017).
In terms of water abstraction, the water management aspects are in general regulated in the Federal Water Act, however it is the “Bundesländer”, the individual parts of Germany, which execute, with a different level of organization in particular states. The supreme authority is the ministry (of environment), upon the district government that is responsible for a management of regional water resources. Next, the lower water authorities (“untere Wasserbehörde”) issues permit for any water usage and they are also responsible for controlling if the individual person/company acted according to the given permit.
In terms of soil protection, there is a federal law about soil protection (Bundes-Bodenschutzgesetz) but this is not applicable to areas of gas and oil production, because these special areas are regulated by mining laws. With the allowance for gas and oil production, the company has to declare that the drill site/area of activity will be “reconstructed” after end of gas and oil production. This would mean that the “pre-drill” state of the soil has to be re-established. Details are part of the general permit for gas and oil production as well as of the operational plan (“Betriebsplan”), the announcement of the company with all details about planned activities at the site.

Other countries notes

In Denmark the overall water planning is submitted to the Danish Environmental Protection Agency, while the municipal authorities administer it in cooperation with the water companies and issue water permits.
In Ukraine the water management is regulated by the Water Law Act, which sets out the principles of water use, protection and resources. Water management instruments include water management plans, permits, official fees for the use of water and water structures, water inventory (water cadaster). The coordinating body responsible for the proper water management is Water Resources Agency of Ukraine and supervisory body is Ministry of Ecology and Natural Resources of Ukraine. At regional level works are carried out by nine Basin Organizations of Water Resources Management (of Dnipro, Dniester and Prut, Western Bug, Siverski Dinec, Danub, Desna, Southern Bug, Tysa, Ros), which administrate public water (rivers with a multi-year flow more than 2,0 m3 /s in outfall, lakes, border waters, hydrotechnical structures). Permits required by Water Law Act are granted by the provincial offices. The Environmental Inspection of Ukraine is responsible for controlling, environmental monitoring and the quality of surface water. The surface water inventory and the monitoring of quality of surface water is the responsibility of Ukrainian Hydrometeorological Center. In terms of groundwater, the

Geology and Mineral Resources of Ukraine, supervises by Ministry of Ecology and Natural Resources of Ukraine. Geology and Mineral Resources of Ukraine, is responsible for the specific use of groundwater permits, the water inventory and groundwater monitoring.

In Latvia it is the Ministry of Environment and Regional Development (VARAM - Vides aizsardzības un reģionālās attīstības ministrija) who enforce the Law on Water Management. The role encompasses establishing surface water and groundwater protection and management system that promotes sustainable and rational use of water resources, improves protection of water environment, ensures water protection and facilitates achievement of goals set in international agreements. The institution responsible for the monitoring programmes, elaborating the river basin management plans and preparing the reports as required by the Water Framework Directive is the State limited Liability Company "Latvian Environment, Geology and Meteorology Centre" (LVĢMC - Latvijas Vides, Ģeoloģijas un Meteoroloģijas Centrs). The State Environmental Service (Valsts vides dienests) in co-operation with their eight subordinates Regional Environmental Boards, is responsible for organizing inland water and groundwater monitoring funded by the EU. Moreover, this authority issues the licences for any geological exploration including the hydrogeological exploration. All data regarding the water resources are collected in the LVĢMC and this authority deals both with surface water and groundwater (Gawena, 2000).

In Sweden, the Groundwater Bodies and Water Sources Database (DGV), operated by the Geological Survey of Sweden (SGU), contains information on public water supply sources and on other sources supplying more than 10 m^3 of water a day or serving more than 50 people for at least one week every year. The data are provided by the country's local authorities and are used to monitor progress towards the environmental quality objective and by local authorities in their water supply planning. At the regional level, county boards are the enforcement authorities for issues associated with water and most environmentally hazardous activities. Municipalities themselves are also responsible for planning, building, and operating water and wastewater facilities.

In Estonia the water management structure is under jurisdiction of the Ministry of Environment (Keskkonnaministeerium), which deals with water protection and use, pollution, water of special and public use and water services. This authority coordinates and develops instruments for water management, which includes surface and drinking water, groundwater, dangerous substances, agricultural water, waste-water and sludge (Banhard, 2001). The Estonian State Agency (EEIC - Kesskkonaagentuur) is a state agency administered by the Ministry of Environment which, among others, collecting, processing, analysing water data, publishing domestic and international reports on groundwater, surface water and water use, and, finally, administrating water related databases, including water intakes.

Summary

Water legislation provides guidance on how much water can be safely abstracted from the environment and from which sources. Water abstraction permit is the key legal and administrative instrument, which define the conditions/limits on abstraction to be met individually for a water user.

3.2 Soil

Soil and surface regolith are directly impacted by shale gas operations as all the infrastructure of any well pad must be placed on it. But despite the soil layer is covered by the equipment or removed and stored in heaps there are several types of possible adverse influence on both its physical properties and chemical composition. As exploration drillings and production sites are most often located in rural areas on grazing or arable land, which is only for some time turned into industrial estate, it is very important to make sure that loses in soil quality and productivity will be limited to the minimum and they will not affect future agricultural use of the land.

3.2.1 Soil hazards related to shale gas development

Due to the fact that in Europe agricultural lands represent significant share of land use (21.5 % of land area (Worldstat, 2007)), the location of well pad on such valuable terrain seems inevitable. For example, all 7 exploratory wells tested in Poland within environmental studies (Konieczyńska et al, 2015) were located on arable lands. Therefore agricultural properties of soils should be considered as essential feature of a state of local environment.

Soil might be deteriorated due to compaction and erosion, which are actual and adverse processes that may be triggered by shale gas activities. During well pad construction topsoil is usually removed and stockpiled. This is a prevailing technique for both, levelling the ground and protecting soil. However, it may contribute to excessive water and wind erosion which results in fertility loss. In addition, due to overburden from piles and well pad infrastructure, subsoil undergoes substantial compaction, which also may significantly reduce future crops production for several vegetation seasons.

Another type of potential impact is soil contamination. Sources of contaminants include the natural gas itself, technological fluids and materials used during operations or while stored, transported, and disposed, namely chemical ingredients, lubricants, fuels, drilling mud and cuttings, fracturing fluid, flowback and produced water.

The possibility of unwanted releases of substances during shale gas operations comprises transport of materials, including chemicals, to and from well sites, well pad preparation, well drilling, well completion (including fracturing and flowback recovery), gas production (and other deposit fluids separation and collection), and well decommission. Soil can become contaminated from land surface by incidents, like spills, leaks, well installation failures as well as emissions from equipment used in well production and maintenance. Another possibility is a fugitive emission of gases or liquids from drilled through geological strata via natural pathways (e.g. fault zones) or through borehole failures.

With reference to soil safety it is important to consider a whole well lifecycle, as spin-off issues, namely improper chemical and waste management, may be significant adverse factors. Results of eco-toxicological tests conducted within environmental studies in Poland (Konieczyńska et al., 2015) show that, in general, all of the tested drilling wastes (spent drilling mud, cuttings, fracturing chemicals, flowback fluid and flowback proppant) produced in significant amounts of thousands of tons were toxic to test organisms. In case of improper management and unwanted release to the environment they might pose a straight threat to soil quality and soil biota and put

indirect adverse impact on higher organisms fed on crops grown in an affected area (Kantor et al., 2015).
Moreover, once contaminated, the ground might subsequently pollute surface water, subsoil and groundwater, conveying re-released chemical substances by surface run-off and rain water infiltration
Except for danger caused by human activity on the surface, an uncontrolled escape of gas (methane in particular) to the near-surface zone and to the atmosphere caused by e.g. leaking wells must be considered. Surface geochemical survey conducted in Poland in vicinity of exploratory wells indicated the presence of anomalous concentrations of methane and carbon dioxide together with the increased contents of higher gaseous alkanes and alkenes in soil gas (Sechman et al, 2015). In this case, the results of stable isotope analyses revealed that methane and carbon dioxide were generated mostly during the recent microbial fermentation with possible small share coming from coal seams drilled through before reaching shale reservoir. They precluded hydrocarbons thermogenic origin related to shale gas formation under exploration. However, regardless the gas origin, an impermeable lining applied for surface protection under well pad area restrained the migrating gases and caused increase in their concentrations, even up to 35.4vol.% in case of methane (Sechman et al., 2015), which normally may even pose a risk of explosion in some unfavourable circumstances. Moreover, presence of methane from coal seams indicates actual possibility of natural gas migration from geological reservoirs along well column due to failures in its sealing, which is getting more likely as the well casing and cementing deteriorates with time. This may mean that even decommissioned wells still need to be considered potential soil contamination source.

3.2.2 Soil safety assurance and measures

There is an order of soil protection resulting from legal provisions, which are present both at EU level and in the national legislation. However, there is no direct law for soil environment and the soil issues appear in some different pieces of legislation.
First of all, land, as a natural resource, next to protected species and natural habitats and water, is subject to environmental damage in case of contamination that creates a significant risk of human health being adversely affected as a result of the introduction of substances, preparations, organisms or micro-organisms (DIRECTIVE 2004/35/CE, art. 2). Remediation of land damage ensure, as a minimum, that the contaminants are removed, controlled, contained or diminished so that the contaminated land no longer poses any significant risk of adversely affecting human health (DIRECTIVE 2004/35/CE, Annex II).
A claim for environmental damage may be filed by any person and the environmental authority is required to accept such a report. If the application is considered justified, following examination, the appropriate decision shall initiate proceedings for an obligation to take remedy actions. The basic condition to comply with the law is that the environmental authority receives information about the occurrence of environmental damage or the risk of harm to the environment. The factors needed to fully implement the provisions include: the sense of responsibility for the state of environment, awareness of the inevitability of the obligation to take corrective and preventive action,

the high quality of administrative decisions, proper and efficient monitoring, and wise use of reports prepared and submitted to the relevant authorities (Sołtysiak et al., 2015).
One of the most important elements of environmental policy implemented in EU Member States is EIA procedure, which is designed to determine whether an environmental impact of a project or investment will be significant. To implement a project a decision on the environmental conditions is needed (the so-called "environmental decision"). Soil is mentioned among others factors subjected to EIA. Direct and indirect effects of a project on soil should be identified and assessed (DIRECTIVE 2011/92/EU, art. 3) and an estimate of expected emissions of soil pollution resulting from the operation of the proposed project should be given (DIRECTIVE 2011/92/EU, Annex IV).
Integrated approach to pollution prevention and control is an important EU instrument regulating pollutant emissions from industrial installations aiming to achieve a high level of protection of human health and the environment taken as a whole. Different approaches to controlling emissions into air, water or soil separately may encourage the shifting of pollution from one environmental medium to another rather than protecting the environment as a whole (DIRECTIVE 2010/75/EU, art. 3). The Industrial Emissions Directive or IED is based on an integrated approach, use of best available techniques, and public participation.
Soils are derived from various geological units. As there is wide geological diversity, it is very hard to establish worldwide standards and rather area-specific, local standard are being developed, including specific conditions for soil's purpose and use. No one standard will suffice everywhere even may not be so in different parts of an individual country.

3.3 Common legal measures

Pursuant to the Environmental Impact Assessment Directive, extraction of petroleum and natural gas for commercial purposes where the amount extracted exceeds 500 Mg per day in the case of petroleum and 500000 cubic meters per day in the case of gas is subjected to compulsory EIA. Also, deep drilling is subjected to a screening process on the basis of a case-by-case examination or thresholds or criteria set by the Member States, or both procedures to decide if an EIA is necessary. The status of EIA requirement for exploration and/or extraction differs amongst the individual Member States, as it depends on how the EIA Directive requirements are transposed and applied. With regard to assessments of risk and impacts pursuant to the EIA legislation, there is no common understanding amongst the selected Member States as to the scope of the EIA and when it is required, in particular, whether or not it covers the whole unconventional gas development area, the well pad or wells individually (Milieu Ltd, 2013).
The Environmental Liability Directive 2004/35/EC is a relevant judicial tool, which can be used in surface water, groundwater and soil protection. It establishes a framework based on the polluter pays principle to prevent and remedy environmental damage. The Directive defines "environmental damage" as damage to protected species and natural habitats, damage to water and damage to soil. Operators carrying out dangerous activities (listed in Annex III of the Directive) fall under strict liability (no need to proof

fault). Operators carrying out other occupational activities than those listed in Annex III are liable for fault-based damage to protected species or natural habitats. The establishment of a causal link between the activity and the damage is always required. Affected natural or legal persons and environmental NGOs have the right to request the competent authority to take remedial action if they deem it necessary.
An environmental standard is a policy guideline that regulates the effect of human activity upon the environment. Standards may specify a desired state (e.g. lake water pH should be between 6.5 and 7.5) or limit alterations (e.g. no more than 50% of natural forest may be damaged). Environmental standards are a set of quality conditions that are adhered or maintained for a particular environmental component and function. There are three important types of environmental standards, which are ambient standards, emission standards, and technology standards. Ambient standard refers to the constraint level of pollutants that is allowed to have in the ambient environment. Emission standard specifies the maximum amount of pollutants that is legally allowed. Technology standards specify the requirement of technologies that polluters must adopt.

3.4 Methane

Methane is a pretty common component of soil gas as it can be produced by soil bacteria in process of organic matter decay. Concentration of such methane depends on organic matter quality and quantity, atmospheric conditions, soil ventilation possibility, agricultural practices and many other factors and can change substantially due to these factors changes. Only long term observations of methane concentration changes in soil gas can give a reliable pattern of biogenic methane presence in particular place.
But methane in soil gas can also originate from thermogenic hydrocarbons sources when the migration pathways of such are open by natural tectonic processes or because of human activities such as borehole drilling and completion. Stray natural gas migrating towards land surface can also significantly raise a concentration of methane in soil.
These two sources of methane can be distinguished by analyzing isotopic signatures of carbon in methane particles. However such analyses are not easy and expensive, and when the methane is a mixture from two sources, it is very difficult to establish how significant stray gases share is.
As methane background concentrations had not been observed normally in environmental monitoring but a need for assessment of stray methane migration from thermogenic sources due to shale gas operations was very high in Poland during shale gas development in 2011-2015, PGI-NRI together with AGH University of Science and Technology proposed a methodology (Sechman et al. 2015) to indicate if any migration around borehole column appeared. First step was to establish background values for methane concentration around planned borehole. Several sampling and measuring series over at least a year would give a pattern of biogenic methane behavior in investigated soil. Unfortunately, in real life study, there was no time for such survey as operations were already at some stages. In most of the cases background concentrations were measured only once, but survey was repeated several times on different technological stages and long term monitoring after boreholes decommission and land restoration planned.

The main measurements the method proposes were methane, ethane and propane concentration analyses and additional isotopic research in case of significant raise in methane values and/or increase in higher hydrocarbons concentrations, which might indicate stray gases inflow from subsurface. Samples of soil gas needed to be taken next to well pad edges while site still in operation and there was no possibility to pierce impermeable isolation liner and around former well head (and any other identified migration pathway) after well pad decommission.

The conducted research showed that stray gases from subsurface were able to migrate along borehole column which could significantly increase hydrocarbons concentration under well pad impermeable liner (Konieczyńska et al, 2015). Such migration can appear for many years after borehole decommission, moreover it may increase in volume due to cement seal deterioration around abandoned in subsurface casing. Long term monitoring of hydrocarbons concentration in such cases will be the only indication and warning tool.

Methane is a common trace component of groundwater so the presence of methane in an aquifer is not a proof of contamination. Methane in groundwater is formed by one of two processes: biogenic and thermogenic. Biogenic methane is bacterially produced and is associated with shallow anaerobic environments (e.g. peat bogs, wetlands) and is generally the most common form of methane detected in shallow groundwater. Thermogenic methane is formed from thermal decomposition of organic matter at depth and under high pressures and is often associated with coal, oil and gas fields. Natural gas is thermogenic. Generally, most methane in groundwater is likely to be biogenic in origin, although thermogenic contributions may be locally important where gases have migrated from depth or there is slow release from previously deeply buried, low permeability, organic-rich rocks. The biogenic and thermogenic methane have different characteristics so dissolved gas and stable isotope analysis of groundwater samples can be used to identify the different sources and potential origin of methane.

The British Geological Survey (BGS) has undertaken a national baseline survey of the distribution of methane concentrations in UK groundwater, focusing on areas where aquifers are underlain by shale units that may be exploited for shale gas. The National Methane Baseline dataset will be a reference point against which any future changes in groundwater methane concentrations can be measured. These surveys will enable environmental regulators to understand background methane levels prior to assessing permit applications.

Methane baseline samples have been collected from potable water supplies — either drinking water or groundwater quality monitoring boreholes. To get an accurate concentration measurement, groundwater has to be sampled before it comes into contact with air so that no gas can escape. This means collecting a sample directly from a pumped borehole, by attaching a hose with an airtight connection at the top of the borehole before the pumped water enters a storage tank or is treated in any way. Special containers are used to preserve the sample until it reaches the laboratory. In addition to sampling for dissolved methane, a number of chemical parameters are measured in the field (e.g. groundwater temperature, dissolved oxygen and redox potential) and samples are collected for laboratory analysis of a broader range of chemical parameters. Summary results are presented online (BGS, 2017).

The BGS is also undertaking comprehensive baseline monitoring at two proposed sites in Lancashire and one in Yorkshire where planning applications have been submitted for hydraulic fracturing (CIWEM, 2016)

3.5 Mining Waste Management

As it has been already mentioned, a proper management of drilling waste generated during shale gas operations is a crucial issue while considering safety of natural environment. Significant amounts of waste produced, its complicated and varied chemical composition, eco-toxicity and mostly liquid or semi-liquid state are the reasons that in case of accidental release as well as improperly planned and conducted treatment and/or disposal the soil, surface and groundwater quality may be endangered not only around a well pad where the waste is generated but also wherever it is transported, stored, treated or disposed.

In case of types of waste which are similar to conventional hydrocarbons production waste, namely drill cutting and spent drilling mud, management procedures are quite well recognized and introduced, especially in those countries which produce from conventional hydrocarbons deposits. The new challenge starts when flowback and produced water from being tested or producing well are considered, as this type of waste has not been known in Europe in quantities it may appear in case of successful shale gas exploration. And it is worth mentioning here that there is no sharp distinction between flowback and produced water in production from unconventional hydrocarbons sources. All fluid recovered after hydraulic fracturing before placing a production head on a wellbore is called a flowback fluid and non-hydrocarbon liquids collected after production head is installed are known as produced water. Usually most of the flowback and produced water is recovered in the first months, sometimes years, of production (Kondash et al., 2017, King, 2012) and it goes up to thousands of cubic meters of fluid from one wellbore.

It needs to be emphasized that produced water from shale gas activities is distinct from typical conventional produced water derived from conventional oil and gas production, which usually can be considered as formation brine, with for example no limitation for its re-injection into original geological formation. Therefore special attention should be paid for proper classifying of the first to prevent inappropriate and undesired decisions on the management.

3.5.1 Flowback and produced water classification

Shale gas technology results in considerable amounts of mining waste, including spent drilling mud and flowback or produced water in particular (Konieczyńska et al, 2015). Waste is classified according to the List of Waste established by European Commission's Decision (2014/955/EU), which was implemented by all Member States.

The different types of waste in the list are fully defined by the six-digit code for the waste and the respective two-digit and four-digit chapter headings (2014/955/EU).

Extractive waste is included in 01 chapter - '*waste resulting from exploration, mining, quarrying, and physical and chemical treatment of minerals'*. Spent drilling muds fall into different types in 01 05 chapter - '*drilling muds and other drilling waste'*, depending on their properties.

Due to the fact that flowback and produced water are not directly mentioned and there is no dedicated code for them, their distinct classification might cause a problem, as it is based thoroughly on waste producer judgment. Different approaches have been applied so far. In Poland, where some experiences were acquired from dozens exploratory wells drilled, abovementioned waste was classified most often as the 01 05 99 type, namely '*wastes not otherwise specified'*, in the chapter 01 05: '*drilling muds and other drilling wastes* (Konieczyńska et al, 2015; Fajfer et al, 2016). In the UK otherwise, the 01 01 02 type is suggested, namely 'waste from mineral non-metalliferous excavation' (Environment Agency, 2016). Moreover, there may be a hazardous waste category applicable, as flowback commonly contains wide range of chemical substances, some of them might be hazardous, depending on concentration in a particular fluid composition. The issue has been already mentioned in literature (Frimell, Gordalla, 2013;Gordalla at al, 2013; Konieczyńska et al, 2015, Gomez et al, 2016).Requirements for the classification of waste as hazardous regarding the hazardous properties are established (2008/98/EC) and have been notified specifically as relevant for unconventional hydrocarbons extraction in a new, draft version of BREF for the Management of Waste from Extractives Industries (MWEI BREF Draft, 2016). Waste should be regarded as hazardous while having one or more of the following properties: flammable, irritant, harmful, toxic, carcinogenic, corrosive, and eco-toxic. The currently in force BREF document, published in 2009, does not mention any particular type of waste, especially relatively novel type as flowback or produced water (MTWR BREF, 2009). Updated version with the latest technology review discerns these new types of waste and attempts to fill the gap. However, there are still insufficient recommendations on proper flowback management, which seems to be extremely difficult medium to test, to treat as well as to dispose, mainly due to rich matrix composition (in many cases unpredictable especially in exploration phase) and high salinity.

Appropriate classification is necessary for proper waste management. Based on presented data and experience with shale gas related waste management in Poland (Konieczyńska et al., 2015) there is a strong need for amendment of the List of Waste with new positions (new waste codes) dedicated directly for flowback (and produced water) with hazardous and non-hazardous characteristics.

In Poland, according to guidelines of the Ministry of Environment (Ministry of Environment, Poland, 2014), flowback is not considered as being a waste as long as: (1) flowback treatment for reuse stays in fracturing process loop, (2) flowback is stored in tanks within a well pad where has been produced, (3) flowback is prepared for reuse in other fracturing job, even on different borehole. In any other case, flowback needs to be considered as liquid excavation waste.

It is important not to classify the recovered flowback as a wastewater, as according to WFD wastewater cannot be introduced into groundwater under no circumstances, so flowback could not be reused for fracking if classified as wastewater unless one would be able to proof there was absolutely no water in target formation (which practically is not feasible).

3.5.2 Waste management alternatives and hazards

Deep well injection is a flowback disposal most popular technique in the USA, except from Pennsylvania State. In Europe however, this technique is not in use for flowback, although allowed under certain restrictions according to European law (Gomez et al, 2016, CIWEM, 2016). The underground injection is not recommended as BAT (Best Available Technique) due to the risk of environmental pollution (especially groundwater) (Gomez et al, 2016, CIWEM, 2016). Other possibilities of flowback treatment are (Gomez et al, 2016, CIWEM, 2016, Konieczyńska et al, 2015):

- re-used as fresh injection fluid for other hydraulic fracturing process (on-site - treatment processes reduce the risks associated with transporting waste),
- transferring to wastewater treatment facilities or other facilities (which have permission to treatment the appropriate mining waste code for flowback),
- disposal within extractive waste facilities.

Quantitative and qualitative records about flowback together with the whereabouts treatment information are of paramount importance for environmental safety reason. In Poland, for example, this is not obligatory for waste holders and shale gas operators to record and reveal full information about thorough fate of waste.

It is mandatory, under the Polish Waste Act, to record qualitative and quantitative data on every single type of produced waste. This is waste holders and waste producers responsibility. The exact template for recording this is given by law.

The problem is, that data flows only one way, from producer (e.g. shale gas operator), via consecutive waste holders to final treatment facility. Waste producer is not responsible to track waste fate. Due to chain of waste holders, waste fate might be unable to trace, which pose possible environmental hazards, as competent authority cannot supervise properly and assure compliance with waste handling procedures.

Also data gathering process about flowback composition and properties should continue and further amendments are expected based on newly obtained data.

4 ENVIRONMENTAL MONITORING AS A SAFETY CONTROL MEASURE

Environmental monitoring could be a safety control measure in shale gas development and may help to find tools to minimize surface impact of shale gas activities. However, surveillance monitoring with locally adjusted solution is the most suitable option. The main foundations for effective and successful monitoring are:

- a properly defined purpose
- an identification of the scope and frequency of testing, including economic reasonableness
- an adequate testing methodology (e.g. selected sampling points justification, choosing adequate limits of determination and detection, sensitivity, uncertainty and precision of used methods) (Konieczyńska et al, 2015).

A four-step approach is recommended to ensure environmental safety control for the whole life-cycle process: (1) baseline status assessment, (2) tests during site operations, (3) assessment on wells completion for production or decommission prolonged with (4) long-term observations of site and operations specific parameters in properly chosen site specific monitoring points and adjusted to local conditions measurements and sampling schedule.

Environmental baseline status assessment (1) must be conducted with regard to local geological and natural conditions and preceded by historical study which ought to identify any possible historical contamination in shale gas development region. Measurements should cover at least soil fertility and soil gas composition with regard to methane concentration and, if necessary, carbon isotopic signature to recognize methane sources, in justified cases (e.g. on industrial areas) hydrocarbons presence in soil and vegetation condition (especially in rural areas and wild-life regions). Groundwater composition should be determined in all usable aquifers, starting from the most shallow one (even if not in use) as an early warning indicator of spills and leachates migrating from land surface. The broader scope of analyses can be conducted at this stage, the better, as it is necessary to assess natural factors which influence water composition as well as possible contamination from various sources not linked with shale gas development (contemporary or historical). Providing, that future drilling and fracturing will be performed with technological fluids based on brine solutions, the least array of analyses must contain pH, electrical conductivity, redox conditions, concentration of chlorides, potassium, sodium, cadmium, strontium, lithium, barium and boron, TOC (in non-industrial areas) and/or particular species of petroleum hydrocarbons (in industrial or historically industrial regions) and methane. Former results from any type of groundwater monitoring in the area need to be assess for applicability as a benchmark for future observations. In areas where groundwater will be used for operations water tables' levels and their yearly fluctuations must be determined (if possible for several years, according to natural changes in local water recharge/drainage conditions).

During borehole drilling, hydraulic fracturing and well tests (2) it is extremely important to collect information on technology and chemical compounds used for operations. Monitoring of processes should be and actually is nowadays an operational standard so all possible spills, drilling mud escapes, blow-outs or other drilling failures are to be registered, cause a holdup of operations and require immediate remedy actions. As far as this standard is kept, there is a very little possibility that the drilling and completion operations would cause not recorded and counteracted environmental damage. The other thing is with events that may happen after well completion or even after well decommission and site restoration. Deep underground interference may cause opening migration pathways (e.g. along renewed deep formation faults) for formation and pumped down technological fluids. Even more likely such fluids may find their migration way along borehole casing, especially when, with time, the cement seal and casing itself will deteriorate due to natural factors as high and changing pressure, corrosive liquids, etc. The more information about possible migrating fluids characteristics, including natural and technological additives and formation gases, is collected, the better future monitoring of any possible fugitive migration may be planned. Therefore drilling mud composition for each drilling interval as well as overall characteristics of fracking fluid need to be recorded and kept in dedicated database. Flowback composition needs to be analysed during well tests and results also stored in the database. I case of any detected contamination of groundwater or changes in soil gas in future control measurements, such information repository will enable to recognize if former shale gas operations could have been responsible for the changes or the source needs to be searched for somewhere else. Quick and accurate identification of pollution sources and mechanisms is key issue in undertaking proper corrective actions.

Despite following all above mentioned safety procedures, it is highly recommended to check the environmental status **after drilling and completion operations (3)** both when site is prepared for production from drilled wells and after wells have been decommissioned and site restored. Measurements ought to be conducted in monitoring points established with regard to local conditions, in a well site area and temporary delivery roads and parking space for soil and soil gases and in groundwater wells downstream from the well site in a distance justified by groundwater flow velocity. Reference measurement in groundwater bodies should be also conducted upstream to make sure that well site operations are responsible for any detected changes and they are not caused by other factors upstream.

At this stage it is very important especially in rural areas to ensure that soil fertility has been restored during site reclamation and that there is no contamination that might endanger a quality of future crops. At least petroleum hydrocarbons and chlorides concentrations are recommended for laboratory testing as pollution indicators. In justified cases when particular chemical compounds have been in use during operations, testing for their concentrations in soil may be needed. Soil gas methane and ethane concentration measurements at least in vicinity of production and/or decommissioned wells will show if there is any migration of formation gases (and possibly fluids).

Shallow groundwater tables which are vulnerable for contamination from land surface should be check for any changes in parameters measured at the initial stage (pH, electrical conductivity, redox conditions, concentration of chlorides, potassium, sodium, cadmium, strontium, lithium, barium, boron, TOC) and when specific chemical compounds have been in use during operations – for concentration of these. In deeper aquifers concentrations of chlorides and methane will play a role of indicators of any migration from deep formations, providing that both drilling mud and fracturing fluid were prepared on brine basis. In case of use of other drilling and/or fracturing technology, there may be a need for choosing additional parameters as migration indicators. Measurement points in deep groundwater levels have to be established with decent knowledge of local geological conditions with regard to groundwater overall system. One has to foresee possible migration pathways and place monitoring points in most likely places to detect such migration. Such task is very difficult and in many cases there may be very little data for proper monitoring wells placing. Sometimes the only prerequisite for placing a monitoring well might be – as close to the exploration/production borehole as possible as the borehole column is always a potential migration pathway.

Long term monitoring (4) ought to be established in each exploration/production area, during years of oil/gas production (it is believed that such production from one well can last up to 30-40 years with technology known today) and after wells' decommission. Measurements of methane and ethane concentrations in soil gas near all working and liquidated well heads are recommended for detection of any deep formation gas migration along wellbore column to ground surface. In case of significant raise in concentration of any or both – isotopic analysis will indicate the actual source of gas. If possible, measurements need to be taken in low temperature season, when microbial activity is the least.

As long as hydrocarbons production is continued, observations need to be conducted in shallow and deep groundwater tables in points selected based on local groundwater pressures, flow directions and velocities (in most cases the same points as in the previous stage). In deeper aquifers concentrations of chlorides and methane need to be measured as indicators of any migration from deep formations, providing that both drilling mud and fracturing fluid were prepared on brine basis. In case of use of other drilling and/or fracturing technology, there may be a need for choosing additional parameters as migration indicators. Shallow groundwater tables must be observed downstream from a well site for basic physio-chemical parameters such as pH, electrical conductivity, redox conditions, concentration of chlorides and TOC as well as specific additional indicators chosen based on the types of chemicals used on production site to enable detection of any spills or leachates due to site operations. The frequency of monitoring series depends on local flow condition, but in general it is recommended to take measurements in deep aquifers at least once a year and in shallow ones the same or more often in case of any operations on production site (e.g. drilling additional wells, re-fracturing, etc.).

When the production is entirely finished in an area, it is very unlikely that any undetected migration may occur after years of observations. But soil gas composition ought to be occasionally checked around legacy wells as deterioration of cement seal may open migration for gases and fluids after many years. Also deep water horizons monitoring ought to be sustained for time needed according to local geological conditions. The frequency of measurements may decrease with time if no adverse changes are observed.

All monitoring data, starting from baseline should be recorded and stored together and results of every new monitoring round need to analysed by experts to make sure that no indication of any unwanted effects would be missed or unnoticed and if needed, necessary remedy action will be undertaken properly on time.

5 CONCLUSIONS

Unconventional hydrocarbons exploration and future production (E&P) including deep directional drilling and high volume hydraulic fracturing with the technology used nowadays require substantial quantities of water of certain quality. Uncontrolled withdrawal of that much water in short time in some areas in Europe could cause significant drop down in available fresh water resources. Fortunately, most European countries are already well prepared for controlling of water use in terms of safety of renewable water resources. Shale gas activities have to follow already existing legal procedures so it is very unlikely that they might overuse accessible and permissible amount of water.

Unconventional hydrocarbons E&P can also theoretically endanger quality of soils and water resources in the area of activities on land surface. Only obeying strict health safety and environmental standards and procedures (HSE) on each well site which minimize spills and leakages danger and introduce quick remedy actions in case of any accident may significantly diminish probability of unnoticed events which might cause adverse effect in environmental quality. But even with highest technology standards, there is a need for additional control tool which could track and detect any unwanted changes in soils and natural water and groundwater bodies. Such a tool is even more necessary to detect any signs of adverse impact of possible shale gas development legacy – stray gases and fluids migration towards fresh water zone and land surface along wellbore casing or other potential natural or induced migration pathways. Properly designed dedicated environmental monitoring is believed to be able to play a role of such early warning control tool.

There are many different institutions in EU countries responsible and engaged in environmental monitoring, representing administration, academia, geological and other surveys or contracted companies depending on different stage of the process (planning, field works, lab analysis, data gathering and analyzing, reporting etc.). At the moment not many of them are prepared for new challenges that possible shale gas development would require facing in terms of environmental changes observations in their countries. Only few countries in Europe actually have done anything to face challenges of unconventional hydrocarbons environmental impact (Poland with survey done on several exploration drilling sites and on-going post-activities monitoring, UK with baseline measurements in shale gas prone areas and some dedicated legal regulations, Germany with tighten environmental requirements for hydraulic fracturing, pilot exploration projects and ban for commercial shale fracturing to be re-considered based on pilot projects results).

In Europe there is a common basis for environmental monitoring, national systems are affiliated within European Environmental Agency and The European Environment Information and Observation Network (Eionet) operates. Goals, measures and results are diverse among countries. In many countries environmental monitoring is actually operated at regional level. At state level aggregated results are provided.

National environmental monitoring systems may be very useful in planning dedicated monitoring and establishing baseline status, however due to their resolution (both network and scope of tested parameters), are not sufficient for dedicated shale gas monitoring.

Shale gas development has brought new technology and new applications. With this innovative industry, new challenges appeared. A number of papers, articles, opinions, prognoses and models have been issued on the topic. However there is still lack of European real life data on actual impact of necessary shale gas operations on the natural environment. Therefore, locally designed and properly aimed, dedicated monitoring programmes should be a very useful tool, not only for assuring environmental safety as a control measure but also for delivering data on regional, national and European level, improving general knowledge and understanding of natural and industrially induced phenomena and of actual scale and severity of adverse changes on the environment caused by unconventional hydrocarbons development.

Such monitoring programmes have to be designed according to local conditions and technology to be employed for exploration and production of hydrocarbons from unconventional sources. They must recognize the baseline conditions before launch of any shale gas operations, collect all needed data during drilling and completion operations, measure actual impact of surface activity and anticipate possible long term processes like fluid and gas unwanted migration towards groundwater resources and land surface. The monitoring network and observation frequencies must be adjusted to local environmental conditions and development stage, reaching far to the future, when all surface activities are ceased but induced processes may still operate.

Soil gas composition and deep groundwater aquifers are recommended for observations as early warning system for stray gas and fluid migration towards potable water sources and ground surface. Shallow usable water tables monitoring is to be designed accordingly to local groundwater flow dynamics and is responsible for detection of any unwanted changes in groundwater quality due to surface spills and leachates. Results of properly designed monitoring campaigns analysed by specially trained team of specialists will enable detection of any unwanted impact and let the remedy action on soil or groundwater resources to be undertaken as soon as possible.

Generation of substantial amounts of liquid or semi-liquid mining waste is one more challenge that shale gas development creates. Improper way of such waste handling may cause environmental contamination around hydrocarbons well sites but also in any place that it is transported for treatment or disposal, sometimes far from exploration and production areas. It is not possible to set up dedicated environmental monitoring along all potential waste transportation routes and temporary storage, treatment and disposal sites. There must be a systematic management scheme, starting from waste distinct classification (especially flowback fluid and shale gas production water as a new waste type), methods and conditions of re-use and treatment and ways of final disposal. It has to take into account possibility of hazardous substances present in this waste stream and the fact that actual waste characteristics, especially in exploration phase, may not be predictable in advance and also may vary with time of waste generation. It is highly recommended that such scheme would have control tools and supervising authority which would ensure that the waste is properly managed along all process and its fate is trackable till final disposal.

6 REFERENCES

1. Banhard P., 2001, Water pricing and policy in Estonia. Presentation for the First Conference of the NIS Water Senior Officials, Kiev, September 9-11, 2001
2. BGS, 2017, National methane baseline survey of UK groundwaters, http://www.bgs.ac.uk/research/groundwater/shaleGas/methaneBaseline/home.html
3. Bundesregierung, 2017, No fracking in Germany, https://www.bundesregierung.de/Content/EN/StatischeSeiten/Schwerpunkte/Nachhaltigkeit/2016-07-08-fracking-gesetz_en.html
4. CIWEM, 2016, Shale Gas and Water 2016. An independent review of shale gas extraction in the UK and the implications for the water environment, http://www.ciwem.org/wp-content/uploads/2016/02/Shale-Gas-and-Water-2016.pdf
5. Clancy S.A., Worrall F., 2016, Review of spills and leaks from normal shale gas operations, M4ShaleGas - Measuring, monitoring, mitigating and managing the environmental impact of shale gas
6. Collins R., Kristensen P., Thyssen N., 2009, Water resources across Europe — confronting water scarcity and drought. EEA Report, No 2/2009
7. Commission Decision 2014/955/EU of 18 December 2014 amending Decision 2000/532/EC on the list of waste pursuant to Directive 2008/98/EC of the European Parliament and of the Council. Official Journal of the European Union L 370/44
8. Cuadrilla (https://cuadrillaresources.com/) sub-page 'Preston New Road' (https://cuadrillaresources.com/site/preston-new-road/),visited in April 2017
9. Delebarre J., Ares E., Smith L., 2017, Shale gas and fracking. House of Commons Library, Briefing paper no 6073, January 2017, https://www.google.pl/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=0ahUKEwiO4v2d84zTAhUJBiwKHQr7A-oQFggcMAA&url=http%3A%2F%2Fresearchbriefings.files.parliament.uk%2Fdocuments%2FSN06073%2FSN06073.pdf&usg=AFQjCNEOsdlwp7M78S6Sf49doyKJ8zC_LQ&sig2=eUEEeUoTxdzE55tDgwgbCA&cad=rjt
10. Department of Energy & Climate Change, 2014, Fracking UK Shale: water
11. Directive 2000/60/EC of the European Parliament and the Council of 23 October 2000 establishing a framework for Community action in the field of water policy (WFD). Official Journal of the European Communities, L 327/1.
12. Directive 2004/35/EC of the European Parliament and the Council of 21 April 2004 on environmental liability with regard to the prevention and remedying of environmental damage. Official Journal L 143 , 30/04/2004 P. 0056 - 0075
13. Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives. Official Journal of the European Union L 312/3.
14. Directive 2010/75/EU of the European Parliament and of the Council of 24 November 2010 on industrial emissions (integrated pollution prevention and control). Official Journal of the European Union L 334/53.
15. Directive 2011/92/EU of the European Parliament and of the Council of 13 December 2011 on the assessment of the effects of certain public and private projects on the environment. Official Journal of the European Union L 335/1
16. Environment Agency, 2016, Onshore Oil and Gas Sector Guidance, Version 1.

17. EU, 2010, Water is for life: How the Water Framework Directive helps safeguard Europe's resources, http://www.eurosfaire.prd.fr/7pc/doc/1301470143_kh3109164enc_002.pdf
18. European Commission (2003) Common Implementation Strategy for the Water Framework Directive (2000/60/EC). Guidance document n.o 7. Monitoring under the Water Framework Directive. 160 p. (CIRCABC, 2016 [3])
19. Fajfer J., Lipińska O, Konieczyńska M., 2016, Flowback fluids treatment technology with water recycling and valuable metals recovery. 18th International Conference on Solid Waste, France
20. Frimell F., Gordalla B., 2013, Unconventional gas exploitation in Germany - some water related consideration, Gas for Energy, Issues 1/2013, page 26-33
21. Gavena I., 2000. Groundwater management in Latvia, http://agris.fao.org/agris-search/search.do?recordID=LV2000000406
22. Gomez V.R, Fernandez L.V., Naranjo F.J.F., 2016, Sustainable alternatives for water management related to shale gas activities in the European context, M4ShaleGas D11.1, http://www.m4shalegas.eu/downloads/M4ShaleGas%20-%20D9.2%20-%20Sustainable%20alternatives%20for%20water%20management%20-%20February%202017.pdf
23. Gordalla B., 2013, Hydraulic fracturing: a toxicological threat for groundwater and drinking-water?http://link.springer.com/article/10.1007%2Fs12665-013-2672-9
24. Guidance on fracking: developing shale gas in the UK(https://www.gov.uk/government/publications/about-shale-gas-and-hydraulic-fracturing-fracking/developing-shale-oil-and-gas-in-the-uk),visited in April 2017
25. Infrastructure Act 2015, chapter 7, Parliament of the United Kingdom, http://www.legislation.gov.uk/ukpga/2015/7/contents/enacted
26. Jacobsen O.S., Johnsen A.R., Gravesen P., 2015, Risk assessment of impacts on groundwater quantity and quality, M4ShaleGas - Measuring, monitoring, mitigating and managing the environmental impact of shale gas
27. Kantor M., Konieczyńska M., Lipińska O., 2015, Shale gas exploration – the results of environmental field studies. Przegląd Geol., 63: 404–409
28. King G. E., 2012, Hydraulic Fracturing 101: What Every Representative, Environmentalist, Regulator, Reporter, Investor, University Researcher, Neighbor and Engineer Should Know About Estimating Frac Risk and Improving Frac Performance in Unconventional Gas and Oil Wells, https://fracfocus.org/sites/default/files/publications/hydraulic_fracturing_101.pdf
29. Kondash A. J., Albright E., Vengosh A., 2017, Quantity of flowback and produced waters from unconventional oil and gas exploration, Science of the Total Environment 574 (2017) 314–321, http://sites.nicholas.duke.edu/avnervengosh/files/2011/08/Quantity-and-source-of-unconventional-wastewater.pdf

[3] CIRCAB (https://circabc.europa.eu/), document downloaded from: https://circabc.europa.eu/sd/a/63f7715f-0f45-4955-b7cb-58ca305e42a8/Guidance%20No%207%20-%20Monitoring%20%28WG%202.7%29.pdf, visited on January 2016

30. Kondash A., Vengosh A., 2015, Water Footprint of Hydraulic Fracturing. Environmental Science Technology. Lett. 2: 276–280 http://sites.nicholas.duke.edu/avnervengosh/files/2011/08/Water-Footprint-of-Hydraulic-Fracturing_EST_Letters.pdf
31. Konieczyńska et al, 2011, Environmental Aspects of Hydraulic Fracturing Treatment Performed on the Łebień LE-2H Well, https://www.pgi.gov.pl/docman-dokumenty-pig-pib/docman/kopalnia-wiedzy/gaz-lupkowy/786-the-lebien-report/file.html
32. Konieczyńska et al, 2015, The Environment and shale gas exploration – results of studies on the soil-water environment, ambient air, acoustic climate, process fluids and wastes, Directorate General for Environmental Protection, http://www.gdos.gov.pl/files/artykuly/38173/The_environment_and_shale_gas_exploration_RESULTS_OF_STUDIES_ON_THE_SOIL_WATER_ENVIRONMENT_AMBIENT_AIR_ACOUSTIC_CLIMATE_PROCESS_FLUIDS_AND_WASTES.pdf
33. Kostecki J., Fruzińska R., 2012, Ochrona Gleb w świetle prawa krajowego i Europejskiego, Uniwersytet Zielonogórski, Zeszyty Naukowe Nr 146, Inżynieria Środowiska Nr 26
34. Managing your water abstraction or impoundment licence (https://www.gov.uk/guidance/water-management-managing-your-water-abstraction-or-impoundment-licence), visited in April 2017
35. Milieu Ltd, 2013, Regulatory provisions governing key aspects of unconventional gas extraction in selected EU Member States
36. MWEI BREF Draft, 2016, Best Available Techniques Reference Document for the Management of Waste from the Extractive Industries, Joint Research Centre http://susproc.jrc.ec.europa.eu/activities/waste/documents/MWEI_BREF_Draft.pdf
37. MTWR BREF, 2009, Reference Document on Best Available Techniques for Management of Tailings and Waste-Rock in Mining Activities, European Commission, http://eippcb.jrc.ec.europa.eu/reference/BREF/mmr_adopted_0109.pdf
38. Ministry of Environment, Poland, 2014, Możliwości postępowania z płynem zwrotnym powstałym podczas procesu szczelinowania w kontekście przepisów z zakresu gospodarki odpadami, https://www.mos.gov.pl/fileadmin/user_upload/odpady/Mozliwosci_postepowania_z_plynem_zwrotnym_powstalym_podczas_procesu_szczelinowania.pdf
39. PGI-NRI, 2013, Shale Gas as seen by Polish Geological Survey, http://infolupki.pgi.gov.pl/sites/default/files/czytelnia_pliki/Dodaj%20Czytelnia/gaz_lupkowy_ang_wersja_koncowa.pdf
40. PGI-NRI, 2017, Stan prac poszukiwawczych za gazem z łupków w Polsce – kwiecień 2017, Serwis Informacyjny Państwowej Służby Geologicznej, http://infolupki.pgi.gov.pl/pl/stan-prac-poszukiwawczych/aktualnosci/stan-prac-poszukiwawczych-za-gazem-z-lupkow-w-polsce-0
41. Polish Waste Act, 2012, The Act of December 2012,14 on Waste – Journal of Law 2012, item 21 as amended
42. Raskin, P.; Gleick, P. H.; Kirshen, P.; Pontius, R. G. Jr; and Strzepek, K., 1997. Comprehensive assessment of the freshwater resources of the world. Stockholm

Environmental Institute, Sweden. Document prepared for the fifth session of the United Nations Commission on Sustainable Development, 1997.
43. Regulation (EC) No 1907/2006 of the European Parliament and of the Council of 18 December 2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH), establishing a European Chemicals Agency, amending Directive 1999/45/EC and repealing Council Regulation (EEC) No 793/93 and Commission Regulation (EC) No 1488/94 as well as Council Directive 76/769/EEC and Commission Directives 91/155/EEC, 93/67/EEC, 93/105/EC and 2000/21/EC. Official Journal of the European Communities, L396.
44. RS/RAE, 2012, Shale gas extraction in the UK: a review of hydraulic fracturing, The Royal Society, The Royal Academy of Engineering
45. Sechman H., et al, 2015, The results of geochemical survey in the vicinity of wells exploring and developing the unconventional gas deposits, Przegląd Górniczy, 10/2015
46. SHIP Shale Gas Information Platform, 2017, German parliament passed bill on hydraulic fracturing, http://www.shale-gas-information-platform.org/areas/news/detail/?tx_ttnews%5Btt_news%5D=648&cHash=8c60e014c9dc7a83962212c056e2becb
47. Sołtysiak M., Dąbrowska D., Kupiec M., 2015, Application of The Prevention and Remedying of Environmental Damage Act in Groundwater Protection. Prz. Geol., 63: 1068–1073.
48. Veith-Hillerbrand A., Schmid F., 2015, Review of the composition of operational fluids and flowback water in hydraulic fracturing, M4 Shale Gas, http://www.m4shalegas.eu/downloads/M4ShaleGas%20-%20D11.1%20-%20Composition%20of%20operational%20fluids%20in%20hydraulic%20fracturing%20-%20Nov.%202015.pdf
49. Water Resources Act 1991, chapter 57, Parliament of the United Kingdom, http://www.legislation.gov.uk/ukpga/1991/57/contents
50. Werner A.K., Vink S., Watt K., Jagals P., 2014, Environmental health impacts of unconventional natural gas; http://www.sciencedirect.com/science/article/pii/S0048969714015290
51. Witter R.Z., McKenzie L.M., Towle M., Stinson K., Scott K., Newman L., et al., 2011, Health impact assessment for Battlement Mesa, Garfield County Colorado, Colorado School of Public Health (2011) http://www.garfield-county.com/environmental-health/battlement-mesa-health-impact-assessment-draft2.aspx
52. Worldstat (http://en.worldstat.info), sub-page "Land use in Europe, Arable land - percentage of total area as of 2007 (http://en.worldstat.info/Europe/Land), visited in March 2017
53. Woźnicka M., Konieczyńska M., 2011, Hydrogeologiczne uwarunkowania procesu poszukiwania, rozpoznawania i eksploatacji gazu łupkowego i gazu zamkniętego w Polsce., Biul. Państw. Inst. Geol., 445: 717-724, http://biuletynpig.publisherspanel.com/resources/html/article/details?id=45932

