Current Opinion in Environmental Science & Health. Volume 3, June 2018, Pages 47–51
DOI: 10.1016/j.coesh.2018.04.006

Assessing unconventional natural gas development: Understanding risks in the context of the EU

George Prpich*
Department of Chemical Engineering, University of Virginia, US

Frédéric Coulon
School of Water, Energy, and Environment, Cranfield University, UK

*corresponding author: prpich@virginia.edu

Abstract

Unconventional natural gas development (UNGD, e.g. shale gas) poses a threat to the environment and human health. While the Member States of the European Union (EU) decide whether to develop this resource, they require evidence to assess the associated risks. Much of the evidence regarding the risks (e.g. contamination, exposure, disturbance) comes from the US, and we argue this evidence cannot be used by the Member States to conduct risk assessments due to demographic differences, geological differences, and differences in regulation. The EU, as a whole, has recognized their need for evidence and has funded research partnerships to explore the environmental effects of UNGD. We argue that such research efforts need to be extended further in order to address the gaps in human health studies and to develop comprehensive environmental baseline studies.

Introduction to the Problem

The development of unconventional fossil fuels could transform the energy landscape in Europe. The European Commission's Joint Research Centre estimates the technically recoverable potential of unconventional natural gas (UNG) to be approximately 16 trillion cubic meters.[1] The exploitation of UNG has been made possible by two engineering advancements: horizontal drilling and high-volume hydraulic fracturing (HVHF). Of these techniques, HVHF has caused considerable public concern because of the risks it poses to the environment and human health, e.g. the release of fugitive methane emissions, contamination of surface and groundwater

Published by Elsevier. This is the Author Accepted Manuscript issued with: Creative Commons Attribution Non-Commercial No Derivatives License (CC:BY:NC:ND 4.0).
The final published version (version of record) is available online at DOI:10.1016/j.coesh.2018.04.006. Please refer to any applicable publisher terms of use.

sources, induced seismicity, and noise.[2,3] Because the risks to the European community are uncertain, MS decision makers have hesitated over the decision to exploit UNG reserves.[4,5] This has led to different approaches to exploiting these resources within the EU: countries such as France and Bulgaria have banned HVHF altogether, whereas others such as Poland and the United Kingdom have granted permission to drill and hydraulically fracture test sites. It is not likely that one unified approach to UNG development and regulation will be adopted. As member States move towards making final decisions about UNG development, they will need sound scientific evidence about the risks and benefits of development to inform their risk assessments and environmental policies.

Such evidence about risks and benefits tends to be gathered from sites located in the US, largely because this is where the shale gas revolution began in 2008.[6] In this paper, we argue that the evidence from the US is site-specific and should not form the basis for Member State policies and risk assessments.[7] In Section 1, we summarize the recent peer-reviewed evidence about environmental and human health risks associated with UNGD, which is mostly US-driven. Then, in Section 2, we critically review the relevance and limitations of this evidence with respect to supporting risk assessments in the EU. In Section 3, we review the current and ongoing UNG research activities in the EU.

SUMMARY OF CURRENT RESEARCH

In this paper, we focus on risks related to the environment and human health. In Table 1 we have identified some recent empirical research on these risks. This list is not comprehensive; it is meant to highlight recent relevant studies on UNG that have been conducted in the US and are relevant to human health risks and the environment.

Table 1. Summary of evidence to support environment and human health risk assessments

	Specific issues	**Relevant Evidence**
Human Health Effects	Noise from HVHF activities (e.g. drilling, compressors, heavy vehicle traffic)	8,9,10

	Health effects due to chemical exposure (e.g. air emissions, contaminated water)	11,12,13,14,15,16
Environmental Contamination and Disturbances	Wastewater treatment and disposal of HVHF flowback and produced water	17,18
	Water quality of surface water and shallow aquifers	18,19,20,21
	Spills and above ground accidents affecting surface waters and soils	22,23,24
	Emissions such as methane, and CO_2 and CO from heavy vehicles	25

LIMITATIONS OF CURRENT RESEARCH FOR EU POLICY

Below, we discuss three ways in which the current evidence about environmental and human health risks linked to UNGD does not generalize to specific Member State settings. For example, studies about the environment and human health largely emerge from the Marcellus shale (Appalachian Basin), one of the five largest shale plays in the US.[27] Moreover, these studies have often focused on Pennsylvania, a region with a rich history of conventional oil and gas development, coal mining, and heavy industry.[35] Subsequently, we contend that policymakers should be careful in their use of these studies to inform policy.

Link to human health exposure

To date, few studies investigate the impacts of HVHF on human health. These studies have identified an association between UNGD and negative human health effects, but have not been able to establish causality. Though these studies might assist Member State decision-makers in arguing that UNG poses health risks, they have not firmly established causality, nor can they narrow down the source of health effects to UNG exposure alone.

For instance, using household proximity to natural gas wells as a surrogate for exposure to UNGD hazards, researchers have found an association between proximity and prevalence of dermal and respiratory conditions,[15] and sinus, migraine headaches, and fatigue symptoms.[11] Similarly, others have found an association between residential proximity to natural gas wells and an increased risk in asthma exacerbations,[13] increased inpatient prevalence,[14] and prevalence of congenital heart defects in infants.[16] Findings from these studies fall short of establishing a causal link between the hazards of UNGD and health effects for a number of reasons. First, studies that use residential proximity as a surrogate for exposure cannot confirm that exposure has occurred, nor account for the level or duration of exposure. Second, methods that use self-reporting can be limited by awareness bias; being made aware of a possible association with health issues increases the likelihood of reporting adverse health conditions.[15] Third, as a surrogate for exposure, proximity aggregates all environmental exposures into a single measure, which makes it impossible to determine whether the hazard is responsible for eliciting the health effect.

Biomonitoring studies can overcome these issues. Caron-Beaudoin and colleagues (2018) evaluated the effects of exposure to VOC emissions from UNGD operations on pregnant women. The results showed that there were elevated levels of VOC metabolites in participants' urine, compared to the general Canadian population. The narrow scope of this study – a specific hazard - enables researchers to more closely understand the effects that an environmental hazard has on a receptor. Further biomonitoring studies conducted in the EU can enable Member State decision makes to assess and verify the risks of UNGD to human health.

Context Dependent Evidence – Pennsylvania ≠ Poland

That Pennsylvania is not Poland goes without saying. Each region has a unique geology, demography, and socio-economic character, and these differences mean that evidence generated to assess risks in the US cannot be generalized to Member State risk assessments.[29]

Take, for example, studies on water quality in shallow aquifers in the Marcellus shale. The potential for HVHF to stimulate unintended transmission of brine, methane, and chemical contaminants has been raised,[30] yet recent work has found that the water quality of shallow aquifers might not be affected by UNG activities.[31] Further, water quality remains similar to historic levels.[32] That being said, in one study nearly all analyzed samples in the Marcellus region failed on at least one water quality metric, and the cause of these failures were uncertain.[33] Aquifer water quality is site specific: a function of, for example, geology, aquifer depletion, agricultural activity.[34] In order to assess change (and quantify risks) due to UNGD, Member State policy makers require baseline studies of aquifers and surface waters, as well as a robust monitoring program.

The differences in population density also make it difficult to generalize results from the US to the EU. Projected regions for UNGD in the EU are more densely populated than corresponding US regions,[35] and this increase in population density will amplify the risk posed by hazards such as noise. Noise is a biological stressor known to cause annoyance, sleep disturbance, cardiovascular health problems,[10] and is therefore of increasing regulatory concern in the EU.[36] Noise is generated from UNG activities, due to drilling and heavy equipment, and is not limited to well-pads. Populations some distance beyond the well-pad setback also tend to be affected (due to roadways, pipelines, and compressors).[8,9]

US study sample demographics also make it difficult to generalize study results to the EU and Member States. For example, Finkel (2016) reported higher-than-expected rates of some cancers among populations living within the Marcellus region, but simultaneously acknowledged that the observed higher frequency of cancer occurred before the introduction of HVHF (i.e. 2008). The author suggested that confounding socio-economic factors in this region (e.g. wealth) might have played a role, as these factors are also associated with poorer health outcomes. Another study also concluded that there were no significant difference between observed and expected rates of cancer in children in a UNGD region.[37] Due to the variable findings of these and other studies regarding the health risks associated with UNGD, we suggest that generalizing the results of these studies to the EU, with its different demographics and historical environmental exposures,

should be done cautiously. Therefore, Member States will need to conduct their own site-specific studies to support health risk assessments.

Stringent Environmental Regulation

The European Commission's environmental regulations are more stringent than those in the US. Member States are responsible for administering the Commission's comprehensive environmental regulations (e.g. Directive 2010/75/EU (Industrial Emissions), Directive 2006/21/EC (Extractive Waste), and Directive 2000/60/EC (Water Framework)[38], however, Member States differ in their views on developing additional regulations to manage HVHF. Because this robust and strict regulatory structure already exists and is meant to manage environmental risks,[39] some environmental issues that have occurred in the US (e.g. chemical use, wastewater disposal) are less applicable in the EU.

Chemical use in the EU is highly regulated. Unlike in the US, chemicals used for HVHF must be disclosed and registered under the EU Chemical Substances Regulation (REACH). Most of the chemicals used in HVHF are registered in REACH[40] and are currently used in conventional oil and gas development.[41] A study of HVHF chemicals used in the US suggested that most lack reproductive or developmental toxicity data[42], yet perhaps a more challenging issue for EU risk assessors is the lack of data on how potential transformative products[43] and endocrine disrupters[44] impact environment and human health.

Wastewater disposal activities precipitate many HVHF contamination events in the US[45] but would not even be permitted in the EU due to environmental regulations. Consider the storage and treatment of HVHF wastewater: In the US, wastewater can be stored on site in open pits, and 95% of HVHF wastewater is injected into Class II deep wells.[46] In some instances, wastewater is disposed into receiving waters, which leave a chemical fingerprint in the sediments.[19] By contrast, in the EU, HVHF wastewater must be contained in a closed vessel on site and cannot be reinjected into the subsurface. However, although treatment is mandated in the EU, it does not assure removal of all contaminants, and studies find that there are contaminants in receiving waters downstream from treatment facilities.[17,18] Therefore, the EU still cannot claim that the

impact of UNG wastewater has been fully mitigated. Further research is needed to monitor wastewater effluent in the EU, and again, policies should not be informed by US studies alone.

Though EU environmental regulations address most environmental risks linked to HVHF,[39] future environmental contamination is most likely to be caused by unpredictable and unmanageable risks.[23,24] For example, as UNGD scales up, elevated production levels will generate greater volumes of wastewater, requiring increased numbers of transports and thus potentially increasing the frequency of accidents and spills.

CURRENT RESEARCH IN THE EU

The Precautionary Principle is enshrined in the law and informs much European environmental policy. The central tenant of the Precautionary Principle is to protect the public and the environment from harms that might arise from the making of a decision in the absence of adequate scientific information. In the US, environmental policy is risk-based, and decisions are made that maximize benefit and manage risks to provide an appropriate level of protection. The science behind the risks posed by HVHF is uncertain, and therefore these two ideologies can illuminate the availability of evidence about UNGD in the EU versus the US.

EU policy makers want to overcome precaution by reducing uncertainty, but the majority of scientific evidence about UNG risks comes from the US and it is uncertain how this evidence will generalize to the EU. The EU recognized this issue and have setup programs to collect and analyze information about the risks of UNGD in Europe. For example, the European Science and Technology Network on Unconventional Hydrocarbon Extraction was setup to collect, analyze, and review results from shale gas exploration projects in the EU (example output, Baranzelli et al 2015). A number of funded academic/industrial partnerships have also been established (Table 2). These partnerships conduct research about environmental risks with the intent of characterizing and mitigating the risks associated with UNGD.

Table 2. Summary of EU funded research programs looking at the impacts of UNGD. Programs represent a multi-party partnership between academia and industry.

Project Name	Project Aims
M4SHALEGAS	Measure, monitor, mitigate, and manage environmental impact of shale gas
SHEER	Develop best practices to assess and mitigate environmental footprint of shale
SHALEXENVIRONMENT	Assess the environmental footprint of shale gas exploitation
FRACRISK	Develop evidence to mitigate the environmental impacts of shale gas development

These partnerships have begun to generate research outputs that will support environmental risk assessments. Data is also being collected and analyzed from test sites in Poland.[48] Research is also being conducted to establish pre-drilling baseline environmental conditions.[49,50]. Despite this concerted collection of data, there remains a lack of effort committed to investigating the potential impacts of UNGD on human health in the EU.

CONCLUSIONS

In sum, EU Member State policy makers currently rely on evidence from the US to inform environmental and human health risk assessments. We believe that EU policy makers should use caution when considering this evidence for three reasons: 1) evidence has yet to establish firm causality between human health risks and UNGD activities; 2) evidence from the US is site-specific and does not generalize to an EU setting; 3) EU environmental regulation was not conceived with HVHF in mind (e.g. induced seismicity).

Regulation to manage the environmental and human health risks associated with conventional oil and gas development in the EU exists. It is conceivable that these regulations could address most hazards associated with UNGD, however, recent events in the UK (i.e. induced seismicity) suggest otherwise. As Member States address the gaps in policy, they will need activity specific evidence to support comprehensive risk assessments. We believe that these risk assessments would benefit from three recommendations: 1) establishment of a program to assess the impact of UNGD on human health, for example, biomonitoring of flare emissions; 2) conduct

comprehensive environmental baseline studies for water, air, and soil quality; 3) continue to collect, analyze, and review evidence from controlled HVHF test sites in the EU. We believe that our recommendations provide a useful way forward for gathering evidence specific to UNGD to inform risk assessments about UNGD in the EU.

References

1. Sorrell, S., Gracceva, F., Eriksson, A., Zeniewski, P., Speirs, J., McGlade, C., ... & Alecu, C. (2012). Unconventional gas: potential energy market impacts in the European Union.
2. European Commission. (2016). *Study on the assessment and management of environmental impacts and risks resulting from the exploration and production of hydrocarbons*. Luxembourg: Office for Official Publications of the European Communities.
3. Prpich, G., Coulon, F., & Anthony, E. J. (2016). Review of the scientific evidence to support environmental risk assessment of shale gas development in the UK. *Science of the Total Environment*, *563*, 731-740.
4. Small, M. J., Stern, P. C., Bomberg, E., Christopherson, S. M., Goldstein, B. D., Israel, A. L., ... & North, D. W. (2014). Risks and risk governance in unconventional shale gas development.
5. SCHEER (2017) Scientific Committee on Health, Environmental and Emerging risk, Requesting for an opinion on public health impacts and risks resulting from onshore hydrocarbon exploitation and production in the European Union; available at https://ec.europa.eu/health/sites/health/files/scientific_committees/scheer/docs/scheer_q_007.pdf - [accessed on 9 January 2018]
6. Hays, J., & Shonkoff, S. B. (2016). Toward an understanding of the environmental and public health impacts of unconventional natural gas development: a categorical assessment of the peer-reviewed scientific literature, 2009-2015. *PloS one*, *11*(4), e0154164.
7. Hays, J., Finkel, M. L., Depledge, M., Law, A., & Shonkoff, S. B. (2015). Considerations for the development of shale gas in the United Kingdom. *Science of The Total Environment*, *512*, 36-42.
8. Boyle, M. D., Soneja, S., Quirós-Alcalá, L., Dalemarre, L., Sapkota, A. R., Sangaramoorthy, T., ... & Sapkota, A. (2017). A pilot study to assess residential noise exposure near natural gas compressor stations. *PloS one*, *12*(4), e0174310.
9. McCawley, M. (2013) Air, noise, light monitoring results for assessing environmental impacts of horizontal gas well drilling operations (ETD-10 Project). Available: http://wwwri.org/wp-content/uploads/2013/10/A-N-L-Final-Report-FOR-WEB.pdf
10. Hays, J., McCawley, M., & Shonkoff, S. B. (2016). Public health implications of environmental noise associated with unconventional oil and gas development. *Science of The Total Environment*.

11. **Tustin, A. W., Hirsch, A. G., Rasmussen, S. G., Casey, J. A., Bandeen-Roche, K., & Schwartz, B. S. (2017). Associations between unconventional natural gas development and nasal and sinus, migraine headache, and fatigue symptoms in Pennsylvania. *Environmental health perspectives*, *125*(2), 189.
12. Finkel, M. L. (2016). Shale gas development and cancer incidence in southwest Pennsylvania. *Public health*, *141*, 198-206.
13. *Rasmussen, S. G., Ogburn, E. L., McCormack, M., Casey, J. A., Bandeen-Roche, K., Mercer, D. G., & Schwartz, B. S. (2016). Association between unconventional natural gas development in the Marcellus Shale and asthma exacerbations. *JAMA internal medicine*, *176*(9), 1334-1343.
14. **Jemielita, T., Gerton, G. L., Neidell, M., Chillrud, S., Yan, B., Stute, M., ... & Roy, J. (2015). Unconventional gas and oil drilling is associated with increased hospital utilization rates. *PloS one*, *10*(7), e0131093.
15. **Rabinowitz, P. M., Slizovskiy, I. B., Lamers, V., Trufan, S. J., Holford, T. R., Dziura, J. D., ... & Stowe, M. H. (2015). Proximity to natural gas wells and reported health status: results of a household survey in Washington County, Pennsylvania. *Environmental Health Perspectives*, *123*(1), 21.
16. *McKenzie, L. M., Guo, R., Witter, R. Z., Savitz, D. A., Newman, L. S., & Adgate, J. L. (2014). Birth outcomes and maternal residential proximity to natural gas development in rural Colorado. *Environmental health perspectives*, *122*(4), 412.
17. Landis, M. S., Kamal, A. S., Kovalcik, K. D., Croghan, C., Norris, G. A., & Bergdale, A. (2016). The impact of commercially treated oil and gas produced water discharges on bromide concentrations and modeled brominated trihalomethane disinfection byproducts at two downstream municipal drinking water plants in the upper Allegheny River, Pennsylvania, USA. *Science of the Total Environment*, *542*, 505-520.
18. Ferrar, K. J., Michanowicz, D. R., Christen, C. L., Mulcahy, N., Malone, S. L., & Sharma, R. K. (2013). Assessment of effluent contaminants from three facilities discharging Marcellus Shale wastewater to surface waters in Pennsylvania. *Environmental science & technology*, *47*(7), 3472-3481.
19. **Burgos, W. D., Castillo-Meza, L., Tasker, T. L., Geeza, T. J., Drohan, P. J., Liu, X., ... & Warner, N. R. (2017). Watershed-scale impacts from surface water disposal of oil and gas wastewater in western Pennsylvania. *Environmental Science & Technology*, *51*(15), 8851-8860.
20. Burton T.G., Rifai H.S., Hildenbrand Z.L., Carlton D.D., Fontenot B.E., K.A. Schug H.S. (2016). Elucidating hydraulic fracturing impacts on groundwater quality using a regional geospatial statistical modeling approach. *Sci. Total Environ., 545–546*, 114-126.
21. Vidic R.D., Brantley S.L., Vandenbossche J.M., Yoxtheimer D., Abad J.D. (2013) Impact of shale gas development on regional water quality *Science, 340*, 1235009(1-9)
22. Kuwayama Y., Roeshot S., Krupnic A., Richardson N., Mares J. (2017) Risks and mitigation options for on-site storage of wastewater from shale gas and tight oil development. *Energy Policy, 101*, 582-593.
23. Maloney, K. O., Baruch-Mordo, S., Patterson, L. A., Nicot, J. P., Entrekin, S. A., Fargione, J. E., ... & Saiers, J. E. (2017). Unconventional oil and gas spills: Materials, volumes, and risks to surface waters in four states of the US. *Science of the Total Environment*, *581*, 369-377.

24. **Cozzarelli, I. M., Skalak, K. J., Kent, D. B., Engle, M. A., Benthem, A., Mumford, A. C., ... & Iwanowicz, L. R. (2017). Environmental signatures and effects of an oil and gas wastewater spill in the Williston Basin, North Dakota. *Science of the Total Environment*, *579*, 1781-1793.
25. Roy A, Adams P, Robinson A. (2014) Air pollutant emissions from the development, production and processing of Marcellus Shale natural gas. *J Air Waste Manage Assoc., 64*, 19–37
26. Striolo A., Cole D.R. (2017) Understanding Shale Gas: Recent Progress and Remaining Challenges. *Energy Fuels, 31,* 10300-10310.
27. US EIA. Independent Statistics and Analysis. December 2016. Accessed December 2017. https://www.eia.gov/dnav/ng/ng_prod_shalegas_s1_a.htm
28. **Caron-Beaudoin, É., Valter, N., Chevrier, J., Ayotte, P., Frohlich, K., & Verner, M. A. (2018). Gestational exposure to volatile organic compounds (VOCs) in Northeastern British Columbia, Canada: A pilot study. *Environment International*, *110*, 131-138.
29. Reap, E. 2015. The risk of hydraulic fracturing on public health in the UK and the UK's fracking legislation. *Environ Sci. 27*:27, DOI 10.1186/s12302-015-0059-0
30. Warner, N. R., Jackson, R. B., Darrah, T. H., Osborn, S. G., Down, A., Zhao, K., ... & Vengosh, A. (2012). Geochemical evidence for possible natural migration of Marcellus Formation brine to shallow aquifers in Pennsylvania. *Proceedings of the National Academy of Sciences*, *109*(30), 11961-11966.
31. St Thomas, M. L., Szynkiewicz, A., Faiia, A. M., Mayes, M. A., McKinney, M. L., & Dean, W. G. (2016). Chemical and isotope compositions of shallow groundwater in areas impacted by hydraulic fracturing and surface mining in the Central Appalachian Basin, Eastern United States. *Applied Geochemistry*, *71*, 73-85.
32. *Siegel, D. I., Smith, B., Perry, E., Bothun, R., & Hollingsworth, M. (2015). Pre-drilling water-quality data of groundwater prior to shale gas drilling in the Appalachian Basin: Analysis of the Chesapeake Energy Corporation dataset. *Applied Geochemistry*, *63*, 37-57.
33. Reilly, D., Singer, D., Jefferson, A., & Eckstein, Y. (2015). Identification of local groundwater pollution in northeastern Pennsylvania: Marcellus flowback or not? *Environmental Earth Sciences*, *73*(12), 8097-8109.
34. Fontenot, B. E., Hunt, L. R., Hildenbrand, Z. L., Carlton Jr, D. D., Oka, H., Walton, J. L., ... & Schug, K. A. (2013). An evaluation of water quality in private drinking water wells near natural gas extraction sites in the Barnett Shale Formation. *Environmental Science & Technology*, *47*(17), 10032-10040.
35. US EIA (Energy Information Administration) (2017). Pennsylvania State Energy profile. https://www.eia.gov/state/print.php?sid=PA Accessed on 9 January 2018
36. King, E. A., & Murphy, E. (2016). Environmental noise–'Forgotten'or 'Ignored'pollutant ? *Applied Acoustics*, *112*, 211-215.
37. Fryzek, J., Pastula, S., Jiang, X., & Garabrant, D. H. (2013). Childhood cancer incidence in Pennsylvania counties in relation to living in counties with hydraulic fracturing sites. *Journal of occupational and environmental medicine*, *55*(7), 796-801.
38. European Commission. (2015). *Study of the application in relevant member states of the Commission recommendation on minimum principals for the exploration and production of hydrocarbons (such as shale gas) using high-volume hydraulic fracturing*. Luxembourg: Office for Official Publications of the European Communities.

39. Mair, R., Bickle, M., Goodman, D., Koppelman, B., Roberts, J., Selley, R., ... & Younger, P. (2012). Shale gas extraction in the UK: a review of hydraulic fracturing.
40. Gottardo, S., Amenta, V., Mech, A., & Sokull-Klüttgen, B. (2013). Assessment of the use of substances in hydraulic fracturing of shale gas reservoirs under REACH. *European Commission JCR Scientific and Policy Reports. Report EUR*, *26069*.
41. Stringfellow, W. T., Camarillo, M. K., Domen, J. K., & Shonkoff, S. B. (2017). Comparison of chemical-use between hydraulic fracturing, acidizing, and routine oil and gas development. *PloS one*, *12*(4), e0175344.
42. Elliott, E. G., Ettinger, A. S., Leaderer, B. P., Bracken, M. B., & Deziel, N. C. (2017). A systematic evaluation of chemicals in hydraulic-fracturing fluids and wastewater for reproductive and developmental toxicity. *Journal of Exposure Science and Environmental Epidemiology*, *27*(1), 90-99.
43. Elsner, M., & Hoelzer, K. (2016). Quantitative survey and structural classification of hydraulic fracturing chemicals reported in unconventional gas production. *Environmental science & technology*, *50*(7), 3290-3314.
44. Kassotis, C. D., Iwanowicz, L. R., Akob, D. M., Cozzarelli, I. M., Mumford, A. C., Orem, W. H., & Nagel, S. C. (2016a). Endocrine disrupting activities of surface water associated with a West Virginia oil and gas industry wastewater disposal site. *Science of The Total Environment*, *557*, 901-910
45. Orem, W., Varonka, M., Crosby, L., Haase, K., Loftin, K., Hladik, M., ... & Bates, A. (2017). Organic geochemistry and toxicology of a stream impacted by unconventional oil and gas wastewater disposal operations. *Applied Geochemistry*, *80*, 155-167
46. Kassotis, C. D., Tillitt, D. E., Lin, C. H., McElroy, J. A., & Nagel, S. C. (2016b). Endocrine-disrupting chemicals and oil and natural gas operations: potential environmental contamination and recommendations to assess complex environmental mixtures. *Environmental health perspectives*, *124*(3), 256
47. Baranzelli, C., Vandecasteele, I., Barranco, R. R., i Rivero, I. M., Pelletier, N., Batelaan, O., & Lavalle, C. (2015). Scenarios for shale gas development and their related land use impacts in the Baltic Basin, Northern Poland. *Energy Policy*, *84*, 80-95.
48. Montcoudiol, N., Isherwood, C., Gunning, A., Kelly, T., & Younger, P. L. (2017). Shale gas impacts on groundwater resources: Understanding the behavior of a shallow aquifer around a fracking site in Poland. *Energy Procedia*, *125*, 106-115.
49. Schloemer, S., Elbracht, J., Blumenberg, M., & Illing, C. J. (2016). Distribution and origin of dissolved methane, ethane and propane in shallow groundwater of Lower Saxony, Germany. *Applied Geochemistry*, *67*, 118-132
50. Bell, R. A., Darling, W. G., Ward, R. S., Basava-Reddi, L., Halwa, L., Manamsa, K., & Dochartaigh, B. Ó. (2017). A baseline survey of dissolved methane in aquifers of Great Britain. *Science of the Total Environment*, *601*, 1803-1813.

https://dspace.org/

Assessing unconventional natural gas development: understanding risks in the context of the EU

Prpich, George; Coulon, Frederic

2018-05-04
Elsevier
https://doi.org/10.1016/j.coesh.2018.04.006
Prpich G, Coulon F. (2018) Assessing unconventional natural gas development: understanding risks in the context of the EU. Current Opinion in Environmental Science & Health, Volume 3, June 2018, pp. 47-51

Downloaded from a DSpace repository. https://dspace.org/