UNCERTAINTY IN THE SHALE GAS DEBATE: VIEWS FROM THE SCIENCE–POLICYMAKING INTERFACE

Constantin Marius PROFIROIU
Paolo GASPARINI
Valentina IVAN

Constantin Marius PROFIROIU
Professor, Faculty of Public Administration and Management, Academy of Economic Sciences, Bucharest, Romania
E-mail: profiroiu@gmail.com

Paolo GASPARINI
Professor Emeritus, University of Napoli Federico II, Napoli, Italy, and AMRA Scarl, Napoli, Italy
E-mail: gasparin@na.infn.it

Valentina IVAN
Assistant professor, Faculty of Public Administration and Management, Academy of Economic Sciences, Bucharest, Romania
E-mail: valentina.ivanjb@gmail.com

Abstract

Shale gas involves a technology which is a controversial method of energy production mainly because there are uncertainties about the possible environmental and human health impacts. The article aims to identify the level of knowledge in relation to the impact of environmental risks attached to shale gas exploitation in the academic and scientific community. It does so by employing the expert elicitation approach which has the benefit of quantifying the judgment of individual experts. We have revealed a consistency among researchers in assessing the level of uncertainty of the main environmental risks and a preferred policy option in dealing with uncertainty, a vow for improved transparency, openness and ease of access to information. Shale gas policy-making in Europe needs a science-based approach as science informs policy by delivering objective and reliable knowledge. The article concludes that developing a comprehensive approach based on scientific data and an appropriate regulatory framework will provide a path forward for the future development of contested policies like shale gas.

Keywords: shale gas, uncertainty, access to information, expert elicitation.

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1. Introductory remarks

Shale gas, an unconventional hydrocarbon resource which became accessible through a contested technology occurs within a complex, multilevel context, involving multiple stakeholders and different levels of governance. Europe has so far experienced a hesitant progress, mainly on environmental grounds. Policy formulation in Europe poses a great challenge because it represents a problem of decision-making under uncertainty considering that impact assessments are still being carried at European level. The European Commission has released so far only a non-binding Recommendation aimed to guide Member States and has sponsored several reports aimed to assess the environmental, economic and social impact of shale gas(European Commission's website, undated). Ivan (2013, p. 82) highlights that the European Commission has to make sure that operations comply with all applicable EU legislation and safeguard the safety of the environment and humans, in particular to paint a clear picture on potential risks and impacts. In an attempt to address concerns with sound scientific evidence, the European Commission has decided beginning with 2015, as part of its Horizon 2020 research and innovation program to grant about € 12 million to two studies aimed to assess and mitigate the environmental footprint of shale gas exploration and exploitation (Kelly, 2015).

The article is split in three main sections. First, the introductory part will briefly point to the literature on the environmental impact with the aim to identify the main risks,as well as knowledge about their impacts on environment. Considering that production from shale rock formations has not yet started in Europe, uncertainties should be clarified and properly assessed before being incorporated in the decision making process. The literature review shows that uncertainty significantly limits the degree to which science can provide a solid fundament for policy making. The second part sets out the research design based on an expert elicitation questionnaire which was employed to gain knowledge into the views of representatives of academia and scientific environment which have expertise in the shale gas research field. Lastly, the discussions section will reveal experts' view on the uncertainties in the process, barriers encountered when assessing relevant information, type of information which should be considered confidential and policy options to ease the science – policy relation. To conclude with, the article argues that, although environmental risks of shale gas development have been reviewed,the context is still surrounded by uncertainty which has to be properly assessed when taking governmental decisions or drafting regulatory framework to accompany the development of shale gas in Europe.

2. Shale gas: a tale of two sides

There have been many discussions about the costs and benefits of developing shale gas among scientists, industry, representatives of environmental organizations, policy makers, and the general public. The debate was polarized around the potential gains in scoring emission targets (Howarth, Santoro and Ingraffea, 2011, p. 679; Wang, Ryanand Anthony, 2011, pp. 8196-8199), economic benefits (Husain *et al.*, 2011;

Medlock, 2012, pp. 33-37), energy independence (Gény, 2010, p.10; Melikoglu, 2014, p. 460) and national security (Kuhn and Umbach, 2011), as well as likely threats to the environment and public health. Boersma and Johnson (2012, p. 570) split the environmental impacts associated with shale gas in three main categories: (i) groundwater contamination and release of waste water, (ii) greenhouse gas and fugitive methane emissions, and (iii) increased seismic activity. First, hydraulic fracturing has been criticized for excessive water use (Kargbo, Wilhelm and Campbell, 2010, p. 5681; Zobak, Kitasei andCopithorne, 2010, p. 7) and polluting water due to potential toxicity of fracturing fluids (Chen *et al.*, 2014, pp. 2546-2555; Colborn*et al.*, 2011, pp. 1039-1056) and methane contaminating drinking water (Osborn *et al*., 2011, pp. 8172-8176; Wood, 2012, p. 4). Ground water issues have become an increasingly important area of research (Younger, 2014, p.7), particularly 'as a number of knowledge and information gaps relating to hydrogeological data exist, especially in the European context'. Second, shale gas emits greenhouse gas caused by fugitive methane, thus leading to harmful health impacts (Howarth, Santoro and Ingraffea, 2011, pp. 679-690; Wigley, 2011, pp. 601-608; White *et al*., 2015; Jones, Hillier and Comfort., 2013, p. 387). Finkel and Hays (2013, p. 889) have emphasized that 'scientific evidence on the impact of shale gas development on climate change is also highly contested considering that, despite the fact that natural gas burns cleaner than coal, methane is leaked and vented into the atmosphere throughout the lifecycle of shale gas development'. Researchers (Wigley, 2011, pp. 601-608; Cathles*et al.*, 2012, pp. 525-535; Howarth, Santoro and Ingraffea, 2012, pp. 1-13; Wang *et al.*, 2014, p. 16) sharing different views on the impact have emphasized that there are uncertainties related to methane leaks. Third, researchers have assessed the seismic risks (Ellsworth, 2013; Green, Styles and Baptie, 2012) portraying the likely impacts. To conclude with, Styles (2015, p. 314) reviews in detail the main environmental impacts of shale gas extraction concluding that there do not seem to be insurmountable obstacles to the extraction of shale gas 'in a properly regulated regime'.Wang *et al.* (2014, p. 1) have summarized the key reports, papers and analyses that show the evolution of shale gas, reviewed evidence of revolution in US, and discussed environmental challenges attached to shale gas exploration and exploitation and portrayed a wide range of views on the environmental impacts. Furthermore, Barcelo and Bennett (2015), scientists and co-Editors-in-Chief of Science of the Total Environment journal have painted a clear picture of environmental and human health risks of fracking by reviewing papers from 2012 up to first half of 2015 covering climate change, environmental health impacts, and risks to the aquatic environment issues. The scientists have concluded that fracking operations are not free of risk to the environment and human health; however, scientists have a different view when assessing impact.

Cairney*et al.* (2015, p.1) argue that 'there are two types of information relevant for the shale gas debate, that is the technical information, used to address scientific uncertainty, and political information, used to bolster agenda setting strategies'. This article will focus on the technical information used to address the scientific uncertainties, defined by the researchers (Cairney, Fischer and Ingold, 2015, p. 1) as 'the information on the technical aspects of unconventional gas development, as well as scientific information on potential implications for the environment'. For the purpose of this article, we argue that technical information relevant (but not exclusive) to the shale debate is data related to greenhouse gas emissions, leaked methane gas, groundwater pollution, chemicals used in the fracking technology, data on the water supply, risk of earthquakes-seismicity data, air and noise pollution to local areas, and infrastructure issues. The UK Environment Agency (2013, p.5) has summarized in a diagram the main risks (see Figure 1) which were taken into consideration for this research.

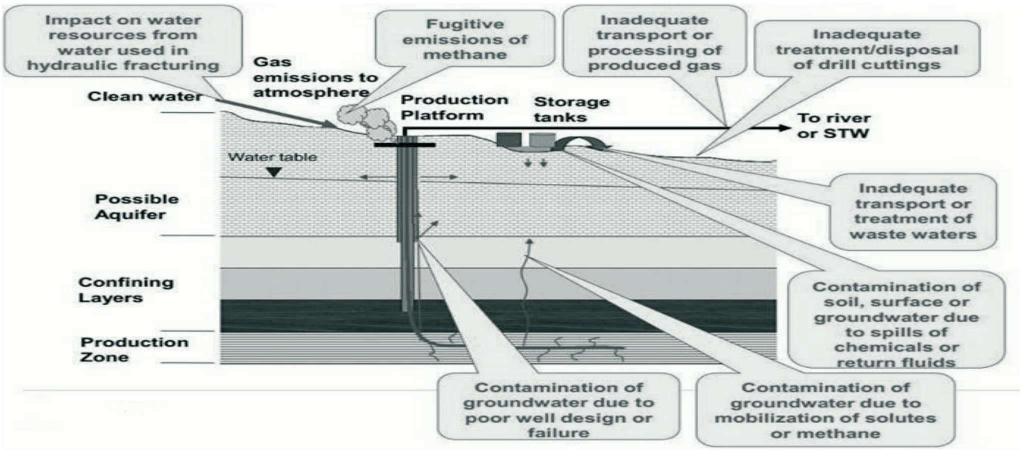

Figure 1: Environmental impact from Shale Gas Hydraulic Fracturing Operations

Source: Environment Agency, UK, 2013, p. 5.

We argue that science plays a key role in providing societal responses to these problems, but more importantly, it informs policy by producing objective, valid and reliable knowledge. Environmental issues are complex and fall within the realm of a number of scientific and socio-economic disciplines; are subject to integrated approaches and public participation.To better respond to the shale gas debate, a wide area of resources are employed, among which science and evidence based decision making (AEA, 2012; Boersmaand Johnson, 2012, pp. 570-576; Pearson *et al.*, 2012; Eaton, 2013, pp. 158-169; Gamper-Rabindran, 2014, pp. 977-987), social dialogue and stakeholder consultation (North *et al.*, 2014, pp. 8388-8396; Jacquet, 2014, pp. 8321-8333; Wheeler *et al.*, 2015, 299-308) are of paramount importance. Environmental regulation, and in particular tailor made shale gas policy begs for a more rational, rigorous and systematic approach to policy-making. Fischer (2001, p. 34) argues that 'the demand for scientific expertise is especially strong among policy-makers in the environmental and natural resources policy, mainly because of the long term impact and uncertainty', view shared by Profiroiu (2006, p. 45) who draws attention to the fact that, in relation to environmental issues,'expertise becomes a key factor in organizing political activity'. This is particularly the case of shale gas which involves a new technology whose long-term impact is still under consideration and raises fierce debates.

The link between scientific information and policy is not linear or unproblematic (Cairney, 2014). Involving science in the decision making process bears some criticism considering that scientific consensus does not necessarily guarantee the level of certainty demanded by policy makers. First, Levin and Cooper (2012, p.18) underlined that 'knowledge emerging from research (...) is subject to revision as time goes on'. This is especially a limiting factor in the shale gas process due to the insufficient track record. Second, Carney *et al.* (2015, p.3) emphasize that 'policymakers decide who and what information to trust, to help them develop a sense of risk associated with any decision'. Based on the risk level, policy makers decide on the acceptable risks counterbalanced by the likely benefits and take a decision. Policy makers are urged to take decisions despite the scarce availability of data and the knowledge gaps, despite their limited abilities to comprehend scientific reports. Third, while 'expert power' may to an extent be necessary, Haas (2004, p. 115-136) suggests that 'more stringent "science policy" involving careful and transparent coordination by government of the use of expertise is key to legitimacy'. Despite the limitations in considering uncertainty, disregarding it can negatively impact the policy making process as poor informed decisions in this case are likely to lead to negative long term environmental and human health consequences.van der Sluijs (1997) highlights that 'the failure to acknowledge and treat uncertainty can lead to poor decisions', while Walker *et al.*, (2003, p. 5) stress that especially for environmental science a 'better understanding of uncertainty and of how the level of uncertainty influences action is a prerequisite'.

van Asseltand Rotmans (1996, p. 121) highlights that there are three main reasons for the degree of uncertainty attached to scientific problems: (1) they are universal in scale and long-term in their impact; (2) available data is lamentably inadequate; and (3) the phenomena, being novel, complex and variable, are themselves not well understood. The shale gas debate scores all these three. First, considering that unconventional gas resources such as shale gas can be found in the US, Europe, China or Australia, solving the shale gas related uncertainties is likely to lead to responses to a universal scale issue. Second, data on environmental impact attached to shale gas exploitations is still being piled up, with a thorough long term impact lacking. In Europe, the situation is even more in the dark considering that production from shale gas formations has yet to happen. Third, evidence of its environmental impact is still under consideration, with risks still under review, which makes drawing scientific conclusions with a high level of certainty very difficult. Uncertainty may arise because of incomplete information – whatwill be the environmental impact in the year 2030 of shale gas on groundwater in the U.S., or what will be the impact of the fracturing process in 30 years on environmental parameters (water chemistry and flow, air quality, micro-seismicity and seismicity, ground deformation). Refsgaard *et al.* (2006, p. 1547) concludes that main reasons for uncertainty might include a judgment of the information as incomplete, blurred, inaccurate, unreliable, inconclusive, or potentially false.

To better exemplify how science can support the decision making process on the shale gas debate and reduce uncertainty, we will portray a short case study on assessment of seismic risk in UK. In April 2011 there were small tremors (which measured magnitude 2.3 and 1.5 on the Richter scale) at Preese Hall near Blackpool, where hydraulic fracturing operations were taking place. Styles (2015, p. 332) highlights that 'the felt seismicity (...) attracted significant public interest worldwide, resulting in a government enquiry and an 18-month suspension of operations'. The UK Department of Energy and Climate Change (DECC) suspended all hydraulic fracturing (June 2011) operations to investigate the issue and commissioned three independent experts[1] to assess thecauses based on available geological and geophysical data. The scientists were selected because of their knowledge of geology, seismicity, and fracking (DECC, 2014). Detailed technical investigations were undertaken, which concluded that the tremors were probably caused by fracking fluids flowing into a geological fault (Green, Styles and Baptie, 2012). Based on scientists' recommendation a traffic light system was put in place which was aimed to determine whether the injection of water is safe; a threshold was set, with operations to be ceased if a tremor of magnitude 0.5 or greater is detected. This has also created a window of opportunity for the UK government which introduced new controls and checks for operators using hydraulic fracturing and imposed a stricter monitoring. Based on available data, science has informed decision makers in this respect. Studies carried have also shown that the probability of further earthquake activity is low which has given confidence to the authorities to allow fracturing operations in UK and lift the moratorium in December 2012. DECC (2014, p. 1) highlights in its final report assessing the seismic risk that 'as more data becomes available, the effectiveness of the new rules, including the threshold imposed will be reviewed', fact which streamlines the importance of new evidence brought by science in taking decisions and drafting policy.

The article argues that in contested policy issues, such as the shale gas, science is set to be an influential player in the public arena, a stakeholder which should contribute to a more democratic public debate by informing, communicating results and sharing knowledge. We emphasize that informed shale gas (policy) decisions require constant review of the uncertainties taking into consideration a range of possible scenarios. Decision making over shale gas in Europe will be most effective if scientific uncertainty is incorporated into a rigorous theoretic framework, and not ignored. Moreover, the effective access to information and expertise represents a prerequisite for the use of science to inform policy-making and regulation. Scientific community struggle to bring light to the debate should be complemented by policy makers' efforts to design better methods to incorporate science into the policy-making process

1 Brian Baptie from the British Geological Survey, Peter Styles from Keele University and Chris Green from G-frac.

and address the growing public concerns and diminish inaccuracies. This is likely to require improvements in the regulatory framework on public participation process, as well as on issues of transparency, accountability, and access to information.

3. Research design

The article's main objective is to identify environmental risks attached to shale gas exploitation and the level of knowledge in relation to the impact of these identified hazards in the academic and scientific community. First, a literature review was performed to point to the main environmental risks attached to shale gas exploitation based on information extracted from specialized publications, peer-reviewed, impact studies and reports of international bodies and academic research institutions. Second, we emphasize that involving science in the decision making process leads to a more rigorous and systematic approach to policy-making. Finally, we aim to question experts' judgment on the level of data reliability with regard to environmental impacts. The article will empirically examine two hypotheses. First, our assumption is that there is a limited degree of certainty in relation to environmental risks attached to shale gas exploitations. Second, we intend to find out which are the most suited policy options to deal with uncertainty issues at the European level.

The list of researchers targeted for this study was put together using the snowball sampling instrument. Based on the studies commissioned by the EC between 2012 and 2014 to external consultants (who provided a comprehensive and trustworthy list of references), we have drafted a list of potential respondents for our research. On top of this, we have used the following criteria: (a) membership to a specific science institutional field (university) or to a research institute, or think-tank; (b) within the scientific field, membership to a specific discipline (such as geology, mining, hydrology); (c) has carried research on shale gas, preferably commissioned by a state/national governmental body, European bodies/agencies. In total, the list numbered about 150 representatives to whom a questionnaire was sent. This method was preferred because EC has stressed that these studies have been used when drafting key recommendations for Member States pondering upon investigating potential for shale gas. This stands for an indication of data (information, knowledge) a decision maker would use in making decisions and shaping policy.

The research was conducted using a quantitative methodology, employing a questionnaire base research, encompassing scale, open end and multiple answers type of questions. A questionnaire-based expert elicitation was performed which is usually used when a research needs to achieve knowledge from individuals that have a particular expertise on a subject where there is insufficient knowledge (Refsgaard*et al.*, 2006, p. 1590; Knol*et al.*, 2010, p.1) or when issues are contentious and complex (O'Hagan, 1998, p. 21). The questionnaire was sent via email to the 150 representatives of the academic and scientific community who were engaged (or still are) in shale gas research. Sills and Song (2002, p. 24) indicate that 'a non-response rate of 80% for web-based questionnaires is not uncommon'. Our response rate was low, a total of 17 experts out of 150 responded (11%), most likely due to holiday period (we had a significant number of 'out of office' replies). Responses were submitted during May-July 2015. Results should thus be treated with care as our sample is a limited subset of the total expert-population, thus the results are not necessarily representative, but rather valuable for the line of arguments and the insights into this highly contested issue. However, the ensemble of information we have from our literature review and the consistency of answers is significant enough for our purposes. Researchers have participated in the study on the understanding that their contributions would remain anonymous. The questionnaire was structured in three main parts: 1) environmental impact and reliability of present data on shale gas exploration, 2) access to data when doing research in this field (including barriers), and 3) potential solutions to improve the situation.

4. Discussion

From the 17 replies that we have got from the academic and scientific community, all of the respondents have carried research on shale gas, eight being commissioned to carry research on shale gas for a national/local governmental office or European Commission. This has confirmed the snowball sampling methodology employed has led to a correct identification of respondents for this research. For a detailed list of respondents' affiliation see Figure 2 below. There were eleven representatives of universities, two from geological research institutes, and other four research institutes with competences in environment and energy related issues; with ten answers from U.S. and Canada, while the rest came from European countries (United Kingdom, Germany, Poland, Romania and Italy). Out of the ten researchers from U.S. and Can-

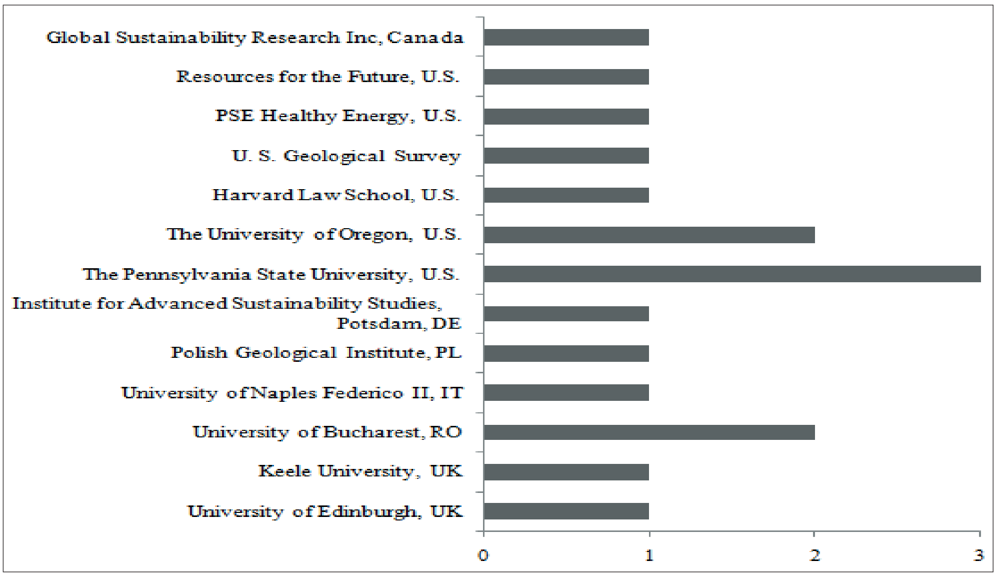

Figure 2: Respondents' affiliation

ada, four have been involved in information sharing with governmental offices of European Member States or bodies of the European Commission with respect to shale gas knowledge.

We have asked researchers to indicate their main area of expertise with the aim to identify researchers that could evaluate risks associated with the environmental impact of shale gas development (see Figure 3 below). We argue that researchers from the geology, hydrology, and natural sciences have expertise in assessing environmental impacts identified through the literature review, such as impact on water resources and pollution of water, seismic risk or impact of greenhouse gas on the environment. We have not disregarded answers from the environmental economics and law which are assessing the environmental impact from an economic perspective (for example, costs attached to hazards) and from the regulatory point of view aimed to accompany the shale gas development. The proportion of experts from each specialization is uneven, which has an impact on the findings; on the other hand the heterogeneity is a preferential feature of the sample of experts and this is why we aimed for experts from different fields.

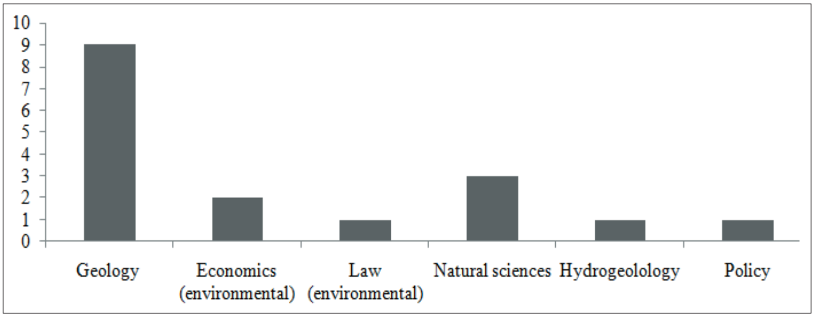

Figure 3: Respondents' area of expertise

Second, we have asked researchers to rank using a 3 point Likert scale (limited, medium and robust) the level of precision with which environmental hazards related to shale gas exploration and exploitation can be estimated, given the present state of knowledge. Based on the literature review on environmental risks attached to shale gas hydraulic fracturing operations, we have drafted a list of main risks. We claim that the views of the interviewees are neither exhaustive, nor representative of scientific and academia community, but it rather holds subjective beliefs, experts' judgment for a small sample.

The impact on water resources from water for the hydraulic fracturing process was identified as being the risk for which there is a robust level of knowledge, closely followed by the risk related to contamination of soil, surface or groundwater due to spills of chemicals or return fluids (see Figure 4 below). Most of the scientists argued that there is a medium level of knowledge in relation to the risks related to earth tremors and earthquakes and treatment or disposal of waste waters. Respondents' view shows there is predominantly a medium level of information on the risks at-

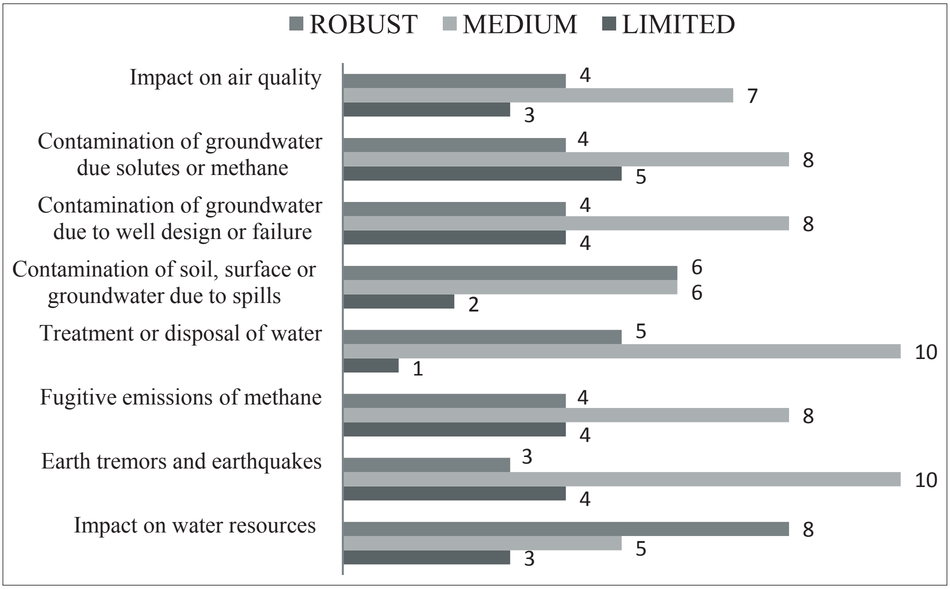

Figure 4: Reliability of assessment of environmental impacts from shale gas hydraulic fracturing operations

tached to shale gas development, with contamination of groundwater due to mobilization of solutes or methane perceived as baring a limited level of knowledge, closely followed by the risks attached to fugitive emissions of methane and contamination of groundwater due to poor well design or failure. This comes to infirm our hypothesis that there is a limited degree of certainty in relation to environmental risks attached to shale gas exploitations. There are three possible explanations for this. First, considering that shale gas exploitations are in an early stage of development, evidence to assess the impact is being collected at an impressive speed. The literature review section has mentioned peer-reviewed articles, most of them dating from years 2011 and 2012. This is likely to show that an increasing volume of impartial, evidence-based information now exists as science helps build the evidence for this very recent and contested topic. Second, we have a limited number of answers which make our findings bias to experts' judgment. Third, specialization of the respondent is relevantwhen weighing the environmental risks. For example, for the risks related to contamination of groundwater dueto solutes or methane, or due to poor well design or failure, half of the respondents argued that there is a medium level of certainty. However, the only hydrologist who has participated to this research has indicated that there is limited knowledge with regard to the two mentioned risks.

Third, in order to identify the reasons for uncertainty in the field, we have asked whether the lack of access to relevant data needed to carry the research was one of the barriers. This was a simple 'yes or no' type of question. Fifteen out of seventeen respondents stressed that relevant data was missing, showing that some of the uncertainty in the field is likely to stem from the scarcity of data. Using a 'yes or no' type of question, we than asked whether researchers have encountered barriers in accessing relevant information when carrying research on shale gas and 14 respondents mentioned 'yes', which shows that data needed to carry research is not publicly available. With an open type of question we wanted to identify how respondents have overcome constraints in assessing data. Barriers seem to derive from three main factors. First, *'much of the relevant data are proprietary'* and when made available by the corporate sector, the data *'is viewed with suspicion by some parties in the public debate'*. Second, *'there is a general lack of data on impacts of operations on broader landscape'*, fact that stresses that the long term impact were not properly assessed up to this moment. Lastly, sometimes the regulation forbids operators to make data public.

Forth, we have asked respondents to mention whether any type of data should not be disclosed. The literature review on main environmental risks has helped us categorize relevant data for the debate; furthermore, we have identified data supplied by operators (revenue and cash flow data – capital and operating expenditures), as well as operational data (well productivity, construction and development plans) as being relevant for the debate. Our assumption was that some sensitive data (such as company related data) should be protected and kept confidential, and thus the access to this type of data would be restricted. Furthermore, we have assumed that relevant data is also in the possession of governments, thus making licensing data procedures leading to the grant of an exploration and exploitation authorization) and geo scientific data (seismic and geological profiles, quality and quantity of resources) of key importance. We have asked respondents to mention which type of information should be considered confidential and/or protected in oil and gas exploration and exploitation of unconventional resources. The company data, in particular the revenue and cash flow data of operators (including capital and operating expenditures) was identified by eleven respondents as being the most sensitive. This was followed by operational data (such as well productivity, construction and development plans), with ten replies, out of which three scientists argued that it should only be partially confidential. Geo scientific data ranked third with eight replies, of which two scientists argue that it should only be partially confidential.

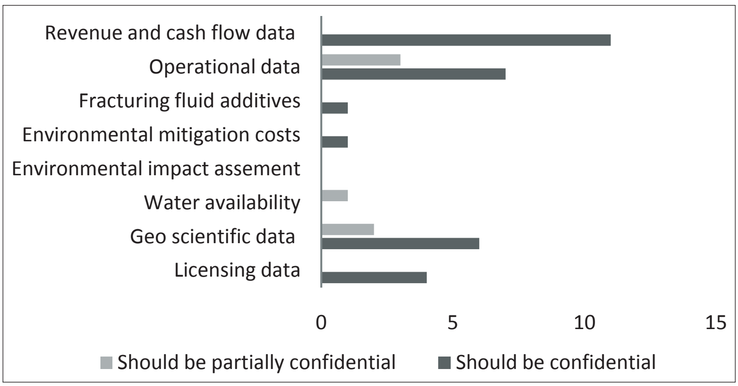

Figure 5: Type of data which should be kept confidential

Respondents have shown that with the exception of company specific data, most of the data relevant for the debate should be made public. There are mixed views regarding access to data which is usually in government's possession, such as geo scientific data and licensing data procedures. Our example on the science-policy making link has proved how relevant data regarding seismic and geological profiles was to identify the problem and take a decision in this respect. In this particular case, policy makers have used scientific conclusions grounded on reliable and accurate data, information which was used to create important scientificresearchresultsandleadtoimproved quality of information on the topic.

Fifth, we then wanted to identify the way forward in dealing with hindered access to data,so we have advanced a list of policy options which could accompany the process and lead to improved quality of governance and science-based policy making. We have identified the policy options based on the stakeholder consultation carried by the European Commission (2013, pp. 67-83) with the aim to better understand stakeholders' views and concerns. In total, 22,875 respondents participated in the consultation. This consultation was the basis for the Recommendation on minimum principles for the exploration and production of hydrocarbons (such as shale gas) using high volume hydraulic fracturing issued on January22, 2014. The main policy options tested by EC have revealed that 51% of individual respondents believe that a comprehensive and specific EU piece of legislation for shale gas should be developed while 47% recommend clarifying existing EU legislation through guidelines, with 45% of individual respondents disagreeing with the statement that the current framework is appropriate to address the identified challenges and environmental risks.

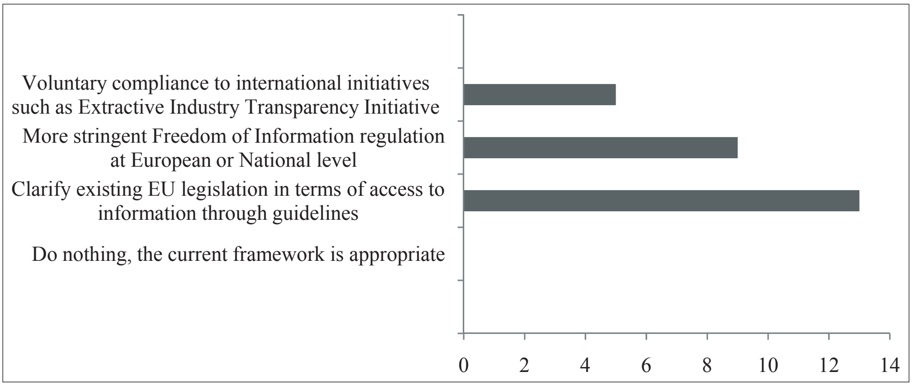

Figure 6: Preferred policy option

Respondents have indicated 'clarifying existing EU legislation in terms of access to information through guidelines' (13 out of 17) as most preferred policy option (see Figure 6 above), followed by 'imposing more stringent Freedom of Information regulation at European or national level' (9 out of 17). Third preferred option was voluntary compliance with international initiatives such as Extractive Industry Transparency Initiative. This has shown that researchers feel there are inconsistencies in terms of regulation and even legislative gaps, and that more accountability and increased transparency is needed. We have assumed that clarifying legislation in terms of access to information is the most preferred policy option by the researchers as sometimes the regulatory framework hinders access to data. Public disclosure of data related to shale gas development is likely to gain public trust and therefore improve public governance in the opinion of most of the scientists interviewed.

Finally, we have asked our respondents, through an open question, their view on disclosure on data and whether it can contribute to an improved act of governance.*'More information should be compiled and shared in a way to facilitate research'* which can be used to inform the public at large considering that the debate is an emotion fuelled one, an ideological battle. One respondent emphasized that*'both the public and the press are, in general, poorly informed about the main environmental issues; all would be better served by more transparency and public disclosure about operations, potential impacts and mitigation plans'*.A way forward would be for the *'regulators to see researchers as helpful partners in the safe oversight of industrial activities'* as *'limited data access always breeds suspicion'* concludes one researcher. On the other hand, some expressed wariness because disclosure will not achieve what it is expected*'due to the already large mistrust of the public in oil and gas companies'*and the fact that it has to be supplemented by other aspects (*'there is a lot more to gaining public trust than information disclosure')* while other, building on U.S. experience has argued that *'you could have a 100% risk free well drilling and natural gas production process and 10-15% of a very vocal part of the population would still be strongly against it'*. Reluctance of governments and companies does not encourage research, and mechanisms aimed to ease access to data or compile and share information to facilitate research are sometimes missing. To conclude with, one researcher streamlines the debate by putting forward the argument that *'government data should be public by definition; however, the situation with corporate data is trickier for competitive reasons'*and this could be solved by limiting the scope of what is considered trade secret. Improved access to information and data should facilitate research which in turn could help close the knowledge gaps by providing unbiased, reliable information to be incorporated in the decision making process. Without relevant information, hazards directly attributable to fracking operations cannot be quantified.

5. Concluding remarks

Literature review on the environmental challenges attached to shale gas exploration and exploitation portrayed a wide range of views on the magnitude of impacts. It is acknowledged that fracking operations are not free of risk to the environment; however, scientists have a different view when assessing the impact. Scholars have emphasized that there is predominantly a medium level of information on the risks attached to shale gas development, highlighting that evidence to assess the impact is being collected in a fast-paced manner, with an improved accuracy of data provided by science.The findings contribute to the current state of art reviewing the main environmental impacts by identifying the risk perceived to hold limited knowledge.

Clarity in science should be supplemented by clarity in regulation which safeguards access to information and transparency. Our research has showed that the most preferred option in dealing with uncertainty is clarifying existing EU legislation in terms of access to information through guidelines. Respondents have shown that more accountability and openness towards the general public and increased transparency is needed. Considering that the shale gas debate is mainly an emotional fuelled one, an ideological battle, the lack of science, evidence and scarce data breeds suspicion. Making reliable and accurate data available for research purposes will lead to scientific evidence grounded on quality data which can be easily reviewed, thus eliminating inconsistencies and biases. There are significant challenges attached to effectively incorporating science, out of which limited disclosure of data relevant for the shale gas debate makes it difficult for representatives of academia and scientific community to carry research. We think that further research should be done to assess which data should be considered confidential in this debate. Our case study on incorporating science and evidence when making decisions has revealed that scientific data on the issue should be open access. Furthermore, instead of shaping a transparent framework for the debate, the regulatory framework hinders access to information. Future research should be carried in assessing the regulatory framework at European level in terms of access to information. However, a significant part of uncertainty related to shale gas development may be unavoidable and scientific truths should be subject to review and revision. Thus, when dealing with controversial issues, policymakers will always face significant uncertainty when drafting policies, which requires a robust behavior in dealing with uncertainty and risk, encompassing communication of uncertainties, good scientific practice, accountability and openness towards the general public.

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