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European Science and Technology Network on Unconventional Hydrocarbon Extraction

Annual Report 2015

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Abstract
The present report firstly summarizes the background for creating the "European Science and Technology Network on Unconventional Hydrocarbon Extraction", based on a Communication from the European Commission to the Council and the Parliament. It further describes the organisation and functioning of the Network as well as the status of the foreseen deliverables of the Working Groups realized in 2015.

Title
European Science and Technology Network on Unconventional Hydrocarbon Extraction – Annual Report 2015

- *Annual reporting of the Network.*
- *Database on exploration, demonstration and production projects in the EU*
- *Emerging technologies for well stimulation*

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Executive summary

The Communication (COM(2014) 23 final) from the Commission to the Council and the European Parliament from 22.1.2014 on the exploration and production of hydrocarbons (such as shale gas or shale oil) using high volume hydraulic fracturing concluded that "it is necessary to continue increasing our knowledge on unconventional hydrocarbon extraction technologies and practices also in order to further reduce potential health and environmental impacts and risks. In this context, it is essential that information is open and transparent to the public".

In that context a "European Science and Technology Network on Unconventional Hydrocarbon Extraction" was established, which is bringing together practitioners from industry, research and academia as well as from civil society. The Network is collecting, analysing and reviewing results from exploration and exploitation projects as well as assessing the development of technologies used in unconventional gas and oil projects".

For the Network Launch in July 2014, two working groups were created, namely on "Exploration, Demonstration and Production Projects in the EU" (WG1) and on "Emerging Technologies for Well Stimulation"(WG2).

More than 150 persons registered in WG1 and WG2 activities, representing four stakeholder's groups: (1) industries, (2) research organisations and public bodies with a research/technical role, (3) academia and (4) non-governmental organisations and the civil society.

In line with the above Communication, WG1 was created in order to produce a database on exploration, demonstration and production projects in the EU. A comprehensive list of projects in the EU should be set up. Then a comparative analysis should be prepared based on the data collected. For preparing the output, the WG1 was split into the following Tasks: (A) Collation of existing and where relevant, planned unconventional hydrocarbon exploration/production projects in the EU, (B) Comparative assessment of environmental data gathered in the database, including comparison at international level (beyond EU), (C) Identification of gaps and R&D needs, building on assessment of project specific data carried out, (D) preparation of an annual conference and report. Currently, a preliminary database on exploration, demonstration and production projects in the EU is gradually populated with incoming new data, obtained from their owners. When a tool is upgraded based on that data, it will be linked to the UH Network website https://ec.europa.eu/jrc/en/uh-network .

With regard to the exploration and exploitation of unconventional hydrocarbons, the EU is still in early exploration phase. The shale gas drilling activity in the EU remains very low. It accounts for less than 3% of the shale wells drilled outside North America. Exploration activities are generally low and currently take place mostly in Poland, although activities are expected to develop also in the UK in the near future. There are also a number of site scale research activities now underway or beginning. These can also provide useful information particularly for baseline environmental conditions. There is already limited commercial production of tight gas and coal bed methane in the EU.

Hydraulic fracturing of horizontal wells has been limited, in part due to difficult geology resulting in low test outputs and low gas and oil prices as well as public acceptance issues.

Based on information collected, it appears that at least 132 shale gas wells have been drilled or are planned to be drilled so far in the EU (out of which at least 13 horizontal wells and one vertical well were fractured), 327 tight gas wells and 106 CBM wells. This list may not be fully comprehensive, notably with regard to tight gas and CBM wells as data collection efforts focussed primarily on shale gas wells.

In terms of availability of technical and environmental data for identified wells, some confidentiality issues on the operator's side prevented them providing access to geological data, due to the protection of commercial interests. If released, the data is usually in "raw" digital format. As far as environmental data is concerned, it was only partially collected in certain sites (mainly the Polish) and integrated in the database. However, it should be noted that such data was not available systematically for all other sites, and not necessarily for similar project phases. During the Working Group meetings it was noted that there is still an issue of common language, particularly in the debate between NGOs, science and industry, because some words used can be very misleading in a different context. There is even sometimes confusion between traditional conventional oil and gas and unconventional resources such as tight gas.

Three WG1 meetings were organized back-to-back with WG2 during the year 2015 as plenary meetings (February 22; June 10 and November 5).

In line with the 2014 Communication, the aim of the second working group (WG2) dedicated to "Emerging Technologies for Well Stimulation" was to provide a techno-economic-environmental performance evaluation of the technologies alternative to the current hydraulic fracturing method. To get to this point, the work was subdivided in 3 tasks : (1) status of the current technologies (baseline); (2) list of emerging technologies; (3) qualification of these emerging technologies with regards to cost, maturity level, pros & cons.

It was decided for gathering the information and providing an easy way for benchmarking the said technologies to define first Key Performance Indicators (KPI) and then use a matrix to represent the technologies performances as a function of these KPI's. KPI's were defined as such : (1) operational experience; (2) technical performance; (3) environmental impact with consideration to : (a) water usage; (b) waste stream; (c) impact on groundwater; (d) impact on surface water; (e) emissions to air; (f) land impact; (g) induced seismicity

During year 2015, the first two tasks were performed. Namely the performance of the current water-based hydraulic fracturing techniques was informed and alternative technologies were classified as such : (a) foam-based hydraulic fracturing; (b) hydrocarbon-based hydraulic fracturing; (c) gas-phase hydraulic fracturing; (d) cryogenic hydraulic fracturing.

To deliver these results four meetings were organized during the year 2015. Three were organised as plenary meetings:

- Feb. 22, 2015 : launching WG2 activities, agreeing on the method of work, defining the work programme, its organisation in tasks, its time schedule.
- June. 10, 2015 : presentation of the results achieved at date and discussion of ways to complete the on-going task (definition of the baseline).
- Nov. 5, 2015 : agreement on the baseline, the working method, the way forward.

and one more dedicated was organised on April 30, 2015 with the aim to agreeing upon the different technologies to consider, the techno-environmental performances of the current water-based hydraulic fracturing techniques (baseline) and identifying ways of obtaining data to benchmark the performances of alternative technologies.

WG2 concluded that water-based hydraulic fracturing is expected to remain the most commonly used technique in the sector in the coming years. Most of emerging technologies except hydrocarbon-based hydraulic fracturing techniques (in their gelled version) that have been deployed in Canada and USA exhibit small TRL[1] values (less than 5). As such it is hardly possible to find any field example or even pilot tests of the application of such alternative technologies.

Therefore it was decided to list research organisations located in Europe (with the support of the EERA Shale Gas alliance) or alternatively in USA that are involved in the development of such technologies. Once these R&D teams have been identified then it

[1] TRL : Technology Readiness Level

will be possible to share publicly available information on the techno-environmental performances of the alternative technologies and the hurdles which remain to remove.

1. Introduction

The Communication (COM(2014) 23 final) from the Commission to the Council and the European Parliament from 22.1.2014 on the exploration and production of hydrocarbons (such as shale gas) using high volume hydraulic fracturing concluded that "it is necessary to continue increasing our knowledge on unconventional hydrocarbon extraction technologies and practices also in order to further reduce potential health and environmental impacts and risks. In this context, it is essential that information is open and transparent to the public".

It announced that "the Commission will establish a *European Science and Technology Network on Unconventional Hydrocarbon Extraction,* bringing together practitioners from industry, research, academia as well as civil society. The Network will collect, analyse and review results from exploration projects as well as assess the development of technologies used in unconventional gas and oil projects".

This Network was launched on 14 July 2014 and has started meeting in 2015.

The content of this Annual Report is providing the background of creating the Network, its functioning and organization, as well as the status of the deliverables achieved in 2015.

2. Organization and Objectives of the Network

The network was established and managed by the JRC, on the basis of the guidance provided by the Steering group composed of DG ENV, ENER, RTD, CLIMA, GROWTH and JRC.

DG ENV and ENER co-chaired the Steering group.

The objectives of the Network were:

- Structuring the dialogue among the stakeholders, fostering open information and knowledge sharing;
- Presenting and discussing research activities and their results, as well as identifying gaps and R&D needs;
- Examining knowledge gained from exploration and demonstration projects;
- Identifying and assessing emerging technologies including their economic, environment and climate impacts.

This was carried out by:

- Bringing together relevant stakeholders to foster a common understanding on relevant topics;
- Sharing information on science & technology developments and reviewing R&D results and needs.

Participants in the network were relevant practitioners from industry, research, academia, and civil society, the objective being to ensure a fair and balanced exchange of ideas.

The necessary resources to manage the network were provided by the JRC. In addition, Horizon 2020 funding was provided to ensure a balanced participation.

The work of the network was coordinated by JRC in agreement with the Steering group. It was complementary to related Commission initiatives, in particular to the revision of the BREF on the management of extractive waste, the development of a new BREF on hydrocarbon exploration and production, the exchange with Member States in the Technical Working Group on environmental aspects of unconventional fossil fuels and EU funded research activities.

JRC took charge of interacting with the members of the Network, and of organizing all relevant meetings and activities, including communication activities. In particular JRC supported the production and publishing of the Network's report, working documents and the database.

The Network operated in full transparency. Reports, technical documents, minutes of meetings are made available on the internet.

It was not within the mandate of the Network to give advice to the Commission on shale gas policy. Participants to the Network cannot be considered as shale gas advisers to the Commission. Views expressed by participants of the Network do not necessarily represent the views of the Commission.

The Network was initially set up for a period of 3 years (2014-2017). Following the annual Conference on 23 February 2016, it was agreed to pause its activities.

All related information, including the rules of procedures for the management of the network can be found on the network's webpage https://ec.europa.eu/jrc/en/uh-network.

2.1 Working Groups

The Network has established 2 initial Working Groups of which the participants can be found in **annex 1-2**, namely:

- WG1 - Exploration, Demonstration and Production Projects in the EU
- WG2 - Emerging Technologies for Well Stimulation.

The call for interest to participate to the Network and Working Groups was continuously open on the website. At the time of drafting this report there were more than 200 interested individuals for receiving updates on the UH Network and more than 150 registered participants to the Working groups coming from different areas, i.e. industry, academia, research, civil society and the EC.

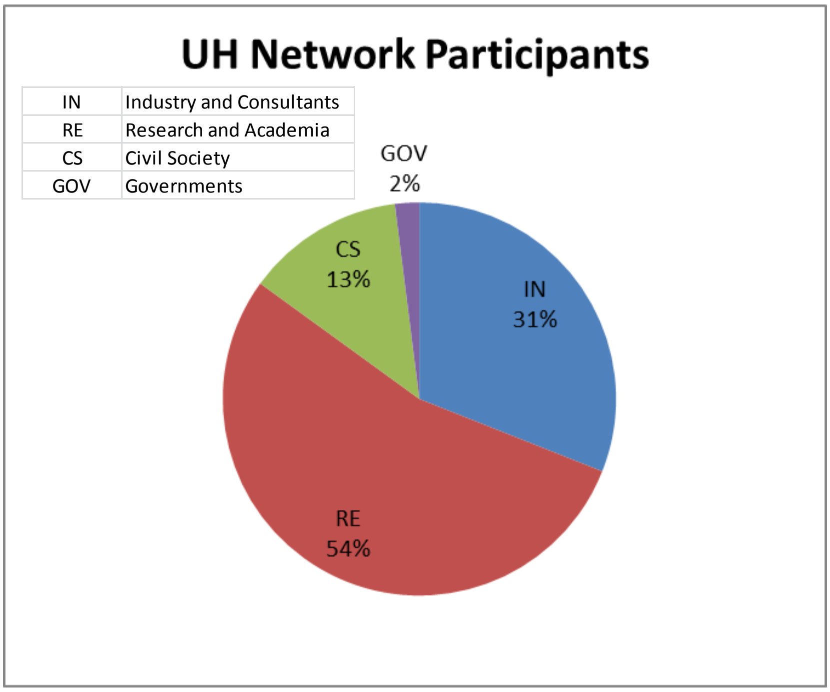


Fig. 2.1: Distribution of participants according to the stakeholder sector

Figure 2.1 shows the subdivision of to which sector the participants belong. Most participants are subscribed to both Working Groups.

2.1.1 Exploration, Demonstration and Production Projects in the EU

The objective of this Working Group was to collect data obtained from exploration, possible demonstration and production projects as well as related research projects carried out in the EU. A comparative assessment was also foreseen, which could be put in perspective with similar projects carried out abroad. This effort was expected to take into account data inter alia gathered from the reporting of Member States on exploration and production of hydrocarbons using high volume hydraulic fracturing (as per Recommendation 2014/70/EU) but should not be restricted to this technology.

The Steering Group defined the following deliverables for this Working Group:

- Comprehensive list of existing as well as, where relevant, planned projects in the EU;
- Database, which is continuously updated, specifying for each project:

- Location and operator;
    - technical and environmental data available;
    - data related to the potential of the reservoir;
    - assessment of data gathered with regard to technically and economically recoverable potential and environmental impacts and risks;
    - occurrences of incidents, their causes, consequences and remediation actions taken (per project);
- Comparative analysis of all projects assessed, including, if appropriate, comparison at international level;
- Presentation of results at the annual conference;
- Summary of the results in yearly reports.

The Steering Group nominated the following Chair-persons for WG1:

- Chair: Prof. Grzegorz Pieńkowski
  Polish Geological Institute
- Vice-Chair: Dr. Alwyn Hart
  Theme Expert, Air, Land and Water Research
  Evidence Directorate, England Environment Agency

2.1.2 Emerging Technologies for Well Stimulation

The objective of this Working Group was to complement, further deepen and update the JRC document of 2013 providing "an overview of hydraulic fracturing and other formation stimulation technologies for shale gas production" based on practical experience with these technologies in exploration, possible demonstration and production projects in and outside the EU.

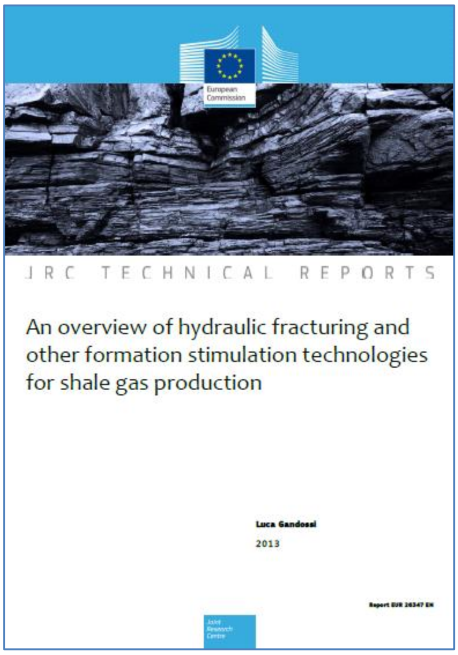


Fig. 2.2: JRC Technical Report EUR 26347 EN

The Steering Group defined the following deliverables:

- Comprehensive list of emerging technologies used in exploration and possible demonstration and pilot production projects at global scale;
- Based on this list, a yearly report on
    - Emerging technologies that may be suitable for use in the EU and their possible timeframe for use;
    - Assessment of economic, environmental and climate change related pros and cons in comparison to currently used fracturing techniques;
- Presentation of results at the annual conference.

The Steering Group nominated the following Chair-persons for WG2:

- Chair: Dr. François Kalaydjian
Resource Technical Business Unit
Deputy Director IFP Energies nouvelles
- Vice-Chair: Eric Vaughan
Well Services Director, Cuadrilla Resources Ltd.

2.2 Website, Meetings and Minutes

The dissemination portal for the Network is the JRC Science Hub. The direct link can be found here https://ec.europa.eu/jrc/en/uh-network. Meetings were announced and agendas, minutes and final documents were published on this webpage.

Fig. 2.3: Screenshot of the UH Network website

A brief history of meetings can be found hereunder:

- UH Network Launch 08 July 2014
- 1st series of WG Meetings 23/24 February 2015
- 2nd series of WG Meetings 10 June 2015
- 3rd series of WG Meetings 05 November 2015

At the first two series of WG meetings around 75 participants were present, at the third one around 45. The minutes of the 3 WG meetings in 2015 can be found on the Network's website.

The Annual Conference of the Network took place on 23 February 2016, where the status of the work carried out in 2015 was presented and questions were received. The conference had about 90 participants. The Annual Conference was open to anybody and served as a dissemination event for the work carried out in the Network Working Groups.

In the first session of the Conference it was announced, that no further Working Group Meetings will be convened. Nevertheless, the Commission will continue to work on the scientific and technical aspects of unconventional hydrocarbons.

3. Status of the Deliverables

This section describes in detail the progress made within each Working Group in reaching its specific objectives. Some information was publicly available, but had to be searched for in various national and international reports/websites. The Working Group participants gave also very valuable links. The information received was collected and structured through an iterative process between the Chairs, the JRC and the Working Group participants.

The present status is reported in the following sections.

3.1 WG 1: Exploration, Demonstration and Production Projects in the EU

A set of environmental worksheets (templates for data input) were created as well as a special section for occurrences of incidents, their causes, consequences and remediation actions taken (per project). This will feed into the Unconventional Hydrocarbons Database which was developed with a GIS online interface and tools.

Another target was to use the gathered information about the current exploration and possible demonstration projects as well as related research projects and contribute to the subsequent WG1 tasks such as assessing data gathered with regard to technically and economically recoverable potential and environmental impacts and risks. Further data on the technically and economically recoverable potential will be available to the Commission only after first half of 2016. The findings of other ongoing projects such as EUOGA may be helpful in this regards.

3.1.1 Comprehensive list of existing and planned projects in the EU

The first deliverable of Workgroup 1 is a comprehensive list of existing and planned projects in the EU. In its initial stages the list concentrated on project scale review and reporting but it was established that a higher resolution is desired. Hence, the list was updated and presently the information is recorded on well by well case instead of project. The overall distribution per country of shale gas wells is presented in Figure 3.5.

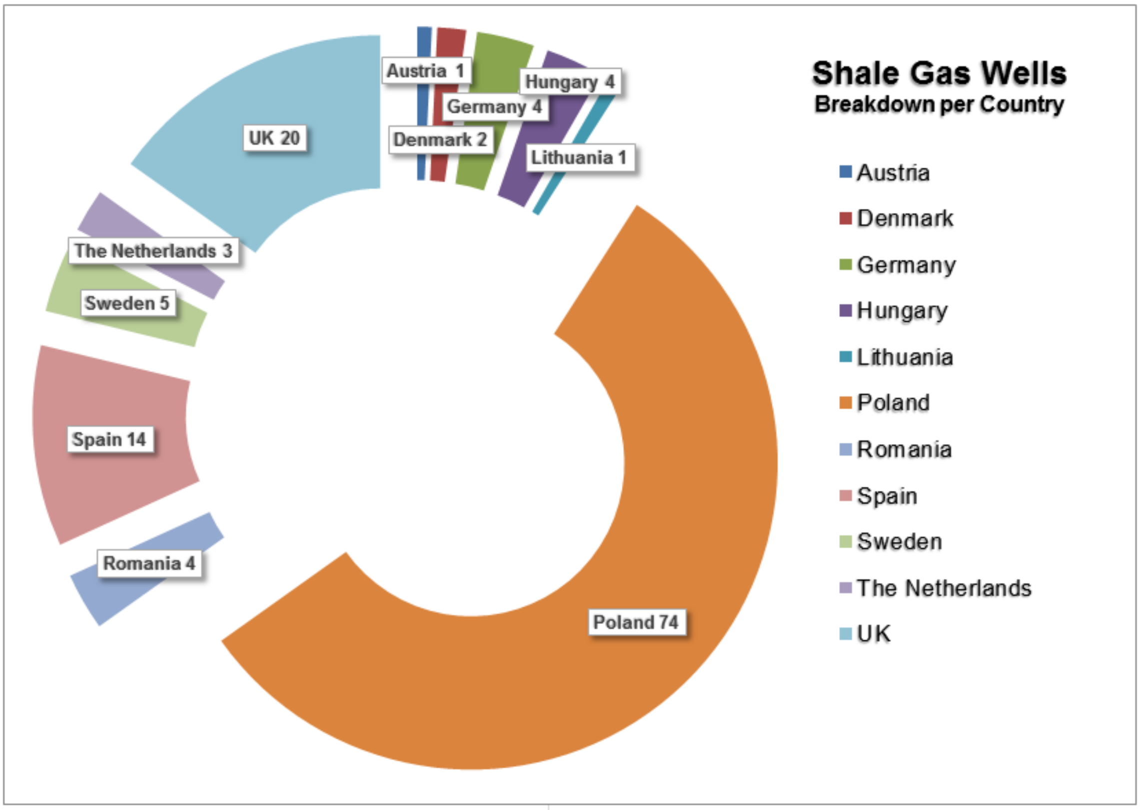
The last updated Shale Gas list contains a total number of **132** Shale Gas/Oil sites (of which at least **13** were hydraulically fractured in horizontal wells and 1 in a vertical well), distributed among the following countries in Fig. 3.1.

It is to be noted that the total number of shale gas "wells" may include wells that have been drilled but not necessarily fractured, wells that are no longer active, licences that may target shale gas resources but with no wells yet drilled. No assessment was made of the quality of information received. This list will be further reviewed by the JRC in the months to come.

The initial well list which focused only on shale gas wells was increased to cover also other types of unconventional hydrocarbons such as Tight Gas or CBM. As such, the following worksheets have been added to the file: Tight Gas wells containing **327** entries from Germany; and, CBM wells containing **106** entries from UK (of which 3 are production wells) and **2** entries from Poland (exploratory wells with test production, currently closed). Additionally, there were several CBM exploratory wells drilled in France, but which are not yet listed in the database.

Information on tight gas and CBM wells drilled and possibly fractured in the EU is still to be completed and fine-tuned, so as to distinguish between active, closed and planned wells.

At this stage, based on data collected so far, it was partly possible to distinguish in the database which wells used high-volume hydraulic fracturing (as defined in EC Recommendation 2014/70/EU). Of 12 horizontal, hydraulically fractured wells in Poland, 3 were the high-volume ones (10.000 m^3 or more of water during the entire fracturing process). In the Annual Report, when there is a reference to "hydraulic fracturing", it is defined as encompassing any hydraulic fracturing activity, regardless of volumes used.



Country	Number of Shale Gas Wells
Austria	1
Denmark	2
Germany	4
Hungary	4
Lithuania	1
Poland	74
Romania	4
Spain	14
Sweden	5
The Netherlands	3
UK	20
Grand Total	**132**

Fig. 3.1: Shale Gas wells[2] distribution in Europe by country. Note that only 13 horizontal wells (12 in Poland, 1 in UK) and 1 vertical well (in Germany) were hydraulically fractured

[2] The total number of shale gas "wells" may include wells that have been drilled but not necessarily fractured, wells that are no longer active, licenses that may target shale gas resources but with no wells yet drilled

Assessment parameters for unconventional hydrocarbons wells (including environmental)

Below is the list of parameters/attributes used to characterise the unconventional hydrocarbons wells:

1. OPERATOR
2. LICENSE OR CONCESSION
3. PERMITS GRANTED (per well)
4. PERMITTING AUTHORITIES
5. ADDITIONAL INFORMATION ABOUT LICENCE AND PERMIT
6. BOREHOLE
7. TYPE OF BOREHOLE
8. WELL DEPTH (m)
9. GEOLOGICAL FORMATION
10. LONGITUDE WGS84
11. LATITUDE WGS84
12. ADMINISTRATIVE COUNTRY
13. ADMINISTRATIVE REGION
14. ADMINISTRATIVE COUNTY
15. ADMINISTRATIVE LOCAL (COMMUNE)
16. DRILLING STATUS
17. OPERATING STATUS (Exploration / Production)
18. START OF DRILLING (YYYY)
19. START OF DRILLING (MMM-YY))
20. YEAR OF COMPLETION (YYYY)
21. END OF DRILLING (MMM-YY)
22. LIQUIDATION
23. WELL STIMULATION
24. HYDRAULIC FRACTURING DEPTH (M)
25. DATE OR WELL STIMULATION (YYYY)
26. DATE OF FIRST WELL STIMULATION (MMM-YY)
27. DATE OF SECOND WELL STIMULATION (MMM-YY)
28. DATE OF THIRD WELL STIMULATION (MMM-YY)
29. TEST OR PRODUCTION RESULTS (best results given in m3/24h)
30. DATE FOR WELL DECOMISSIONING (MMM-YY)
31. EIA/SCREENING
32. EIA/SCREENING YEAR
33. EIA ADDITIONAL INFORMATION
34. ENVIRONMENTAL DATA (data resolution
35. ENVIRONMENTAL MONITORING DATA, see parameters under EC Recommendation 2014/70/EU (point 11and 6.2 on baseline and environmental monitoring)
36. INCIDENTS (causes, consequences and remediation; per well)
37. OTHER COMMENTS

In order to assess the environmental impact for each well, the data input templates/worksheets used the parameters listed in the Recommendation 2014/70/EU point 6.2 and point 11.3 referring to conducting baseline studies and respectively monitoring. As such, we created a separate worksheet for baseline study containing the following parameters/attributes for input and assessment:

Baseline Studies

- BOREHOLE
- NAME OF CONCESSION
- Timeline
  - T0 - baseline status parameters; T1 - parameters prior to drilling; T2 - parameters prior to fracturing; T3 - parameters during fracturing; T4 - parameters after fracturing; T5 - parameters after closure of the well
- BASELINE FOR (in accordance with the **EC Recommendation 6.2. a-j**[3]):

a. Quality and flow characteristics of surface and ground water

- Number of aquifers/water-bearing levels and their interrelations
- Depth to the top of any aquifer present
- Type of groundwater table (confined/unconfined)
- Permeability of natural sealing
- Vertical separation distance between fractured zone & groundwater
- Distance between the exploration fracturing site and nearest surface water
- Quantitative status of groundwater
- River basin specific pollutants
  - ↪ Benzene; BTEX; aliphatic hydrocarbons; PAHs; corrosion inhibitors (triazoles, etc.); LAS; nonyphenol, its ethoxylates; biocides; methanol; heavy metals; NORMs; and, salinity
- Quantitative status of surface water
  - ↪ Benzene; BTEX; aliphatic hydrocarbons; PAHs; corossion inhibitors (triazoles, etc.); LAS; nonyphenol, its ethoxylates; biocides; methanol; heavy metals; NORMs; and, salinity

b. Water quality at drinking water abstraction points parameters

- pH
- Spectro-photometric
- Conductivity
- Benzene
- BTEX
- Aliphatic hydrocarbons
- PAHs
- Corrosion inhibitors (triazoles, etc.)
- LAS
- Nonyphenol, its ethoxylates
- Biocides
- Methanol
- Heavy metals
- NORMs
- Salinity

c. Air quality parameters

- Sulphur dioxide
- Nitrogen oxides converted to NO2
- Particulate matter (PM10/PM2.5)
- Lead
- Benzene
- Carbon monoxide
- Methane
- Ozone

[3] *2014/70/EU: Commission Recommendation of 22 January 2014 on minimum principles for the exploration and production of hydrocarbons (such as shale gas) using high-volume hydraulic fracturing.*

- Polycyclic aromatic hydrocarbon
- Hydrogen sulfide
- Dioxins/furans
- Volatile organic compounds (VOC)
- NMVOC
- Grit/dust

d. Soil condition parameters
- Topsoil preservation
- Sealing
- Soil gases
- Other parameters relevant for agricultural production
- Hydrocarbons content (incl. chlorinated)
- Mineral oil
- Polycyclic aromatic hydrocarbons (PAH)
- Heavy metals
- Phenols
- Aromatic hydrocarbons
- Cyanides
- Other (e.g. explosives, pesticides)

e. Presence of methane and other volatile organic compounds in water

f. Seismicity
- Number of events/earthquakes
- Below permissible vibration levels (country specific)
- Above permissible vibration levels (country specific)
- Below magnitude 3 (< 3M Richter Scale)
- Above magnitude 3 (< 3M Richter Scale)

g. Land use
- Proximity to residential areas; population, people/ km2
- Size of land take, ha
- Changes in land morphology
- Imprint on the landscape
- Topography changes
- Agricultural/ ecological value of the site

h. Biodiversity
- Consequences to biota
- Toxicity tests
- Quantitative ecotoxicological tests
- Impact on species subject to individual protection
- Proximity to protected/ sensitive areas

i. Status of infrastructure and buildings
- Noise monitoring
- Distance to residential area/ other buildings
- Drill site access roads
- State of infrastructure before/ after drilling and/or fracturing

j. Existing wells and abandoned structures
- Existing gas/oil wells
- Existing water wells
- Other existing man-made underground structures

Similarly, we created a separate worksheet for the operational monitoring that contains the following parameters/attributes for input and assessment:

Operational Monitoring

BOREHOLE

NAME OF CONCESSION

MONITORING FOR (in accordance with the **EC Recommendation point 11.3. a-e**):

a. Composition of the fracturing fluid, Ingredients, %

- Volume of proppant used, t
- Proppant max mass % of total hydraulic fracturing fluid
- Water
- chemical substances/compounds of the fracturing fluid or Priority Substances[4] in the fracturing fluid

b. Volume of water used for the fracturing

c. Pressure applied during high-volume fracturing

d. Fluids, emerging at the surface following high-volume hydraulic fracturing

- Volume of flowback fluid, m3
- Volume of water, re-used in other fracturing operations
- Volume of treated water
    - ↪ underground injection via disposal wells; treatment for discharge into surface water; treatment prior to recovery; treatment for discharge into the sewer system
- Chemical characteristics of the flowback water:
    - pH
    - Alkalinity
    - Nitrate
    - Phosphate
    - Sulphate
    - Radium 226
    - Hydrogen carbonate
    - Aluminium
    - Antimony
    - Boron
    - Barium
    - Bromine
    - Cadmium
    - Calcium
    - Chloride
    - Copper
    - Fluoride
    - Iron
    - Potassium
    - Lithium
    - Magnesium
    - Manganese
    - Mercury
    - Selenium
    - Sodium
    - Strontium
    - Zinc

[4] Directive on environmental quality standards (2008/105/EC)

- Return rate, % of flowback fluid to the total injected fracturing fluids

e. Air emissions of methane, other volatile organic compounds & other gases that are likely to have harmful effects

- methane, volume
- other volatile organic compounds (NMVOC), volume
- other gases, volume
- water (dehydrators present)

f. Occupational exposure

- direct impact on human health (toxicity & hazard classification, persistence and bioaccumulation)

3.1.2 Unconventional Hydrocarbons Database

The second deliverable of Workgroup 1 is a database that contains a minimum set of information such as:

- Location and operator;
- Technical and environmental data available;
- Occurrences of incidents, their causes, consequences and remediation actions taken (per project).

This information is organised and collected on well by well and it will be continuously updated with records. Presently, there is information on technically recoverable resources available about the major European basin unconventional hydrocarbons potential but they have varied, sometimes with a high degree of uncertainty and exhibits large assessment heterogeneity; additionally, they are not at the scale of the current database. However, new pan-European research such as the EUOGA project coordinated by EuroGeoSurveys, is planned in order to provide quantitative, comparable estimates of unconventional hydrocarbons resources (OOIP and OGIP). Within this project, based on information which is available in the public domain and has the proper resolution, technical and economical recoverable resources will be calculated. Though the EUOGA project is outside the Network's mandate, where possible, the results from EUOGA will be transposed to the database together with the accompanying background maps. Much of existing information can be found in attached references and CIRCABC database.

The main scopes of the database is to aggregate information spread among various files and collate them in a single data repository using the well by well scale. As such, the wells list and the environmental worksheets were the main input files for the newly created database (including basic composition of fracturing fluids: http://www.ngsfacts.org/findawell and basic data about wells, i.e. http://infolupki.pgi.gov.pl/taxonomy/term/244). In this way the information about environmental impact, incidents, risks and monitoring is organised and presented using a single unit of assessment, the well.

Further, the database was broken-down in a number of tables that sit in one to many relationship between each other (see Fig.3. for more details). As mentioned above, the main entry point or unit of assessment is represented by the well (borehole). The information about each well is organised using the following categories (tables):

- Main entry point Shale Gas well (similarly Tight Gas, CBM)
- Physical
- Administrative
- Drilling
- Hydraulic Fracturing
- Environmental
  - Baseline data
  - Operational monitoring data
- Incidents

Each table contains a header where a set of identified parameters are listed specific to each category (e.g. physical, environmental). These parameters were considered of interest. Some of the information collected in Poland through government-funded research at seven shale gas exploration sites was integrated in the database. Such information was made available in the following two reports: "The environment and shale gas exploration – Results of studies on the soil-water environment, ambient air acoustic climate, process fluids and wastes" (along with an earlier report from Łebień well, 2011) and "Environment and exploration of shale gas – The results of seismic monitoring".

3.1.3 Online Interactive Interface for the Database

An online interactive interface for the database was created in order to enable the UH Network participants to access the database in an easy and straightforward manner. This would allow to the online database users to perform various operations such as basic filtering, creation of infographics and charts, or display datasets statistics. However, the present online database interface is only a temporary solution. At a later stage (Q2 2016) the database and its interface together with all its functionalities will be transposed to the Unconventional Hydrocarbons Information System (U-HIS) website where it will become a fully-fledged online interactive database with full GIS support. Hence, some additional tools will be added like the possibility to select subsets, conduct more in-depth analysis or exporting data and images. The database will also be fully integrated with the UH Atlas once this will be created. The database will follow the INSPIRE Energy Resources and Geology technical guidelines for sharing spatial information. The Shale Gas,Tight Gas and CBM wells worksheets can be accessed at https://goo.gl/lgw3nd, https://goo.gl/m6Msyi, and respectively https://goo.gl/DhXtI4 (Fig. 3.3-3.5).

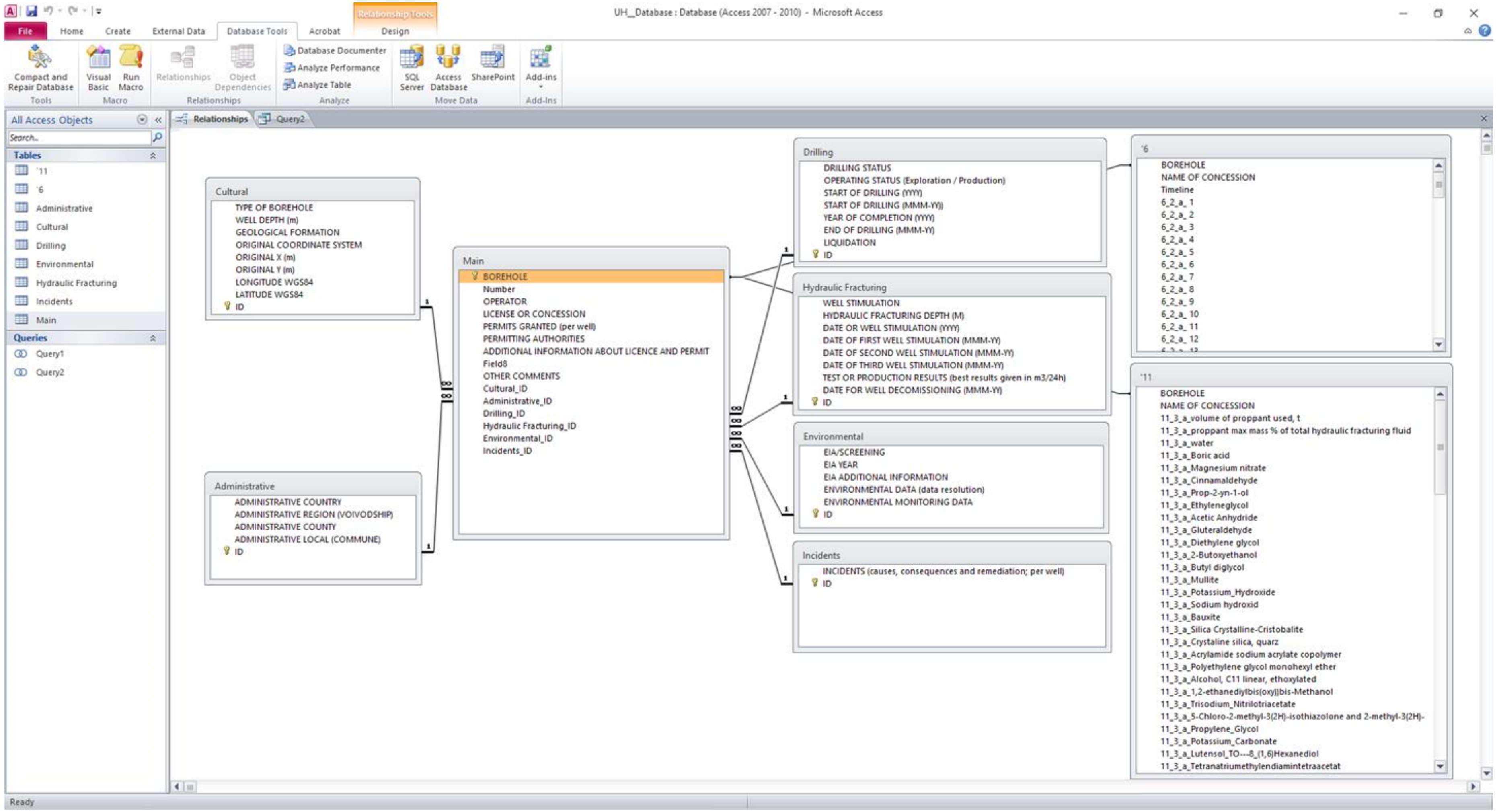


Fig. 3.2: Unconventional Hydrocarbons Database structure. Snapshot showing the break-down of database information in categories (tables) of interest and the list of parameters available for each category in part. The figure shows also the main and secondary relationships between each table of the database. Database format: Microsoft Office Access 2010.

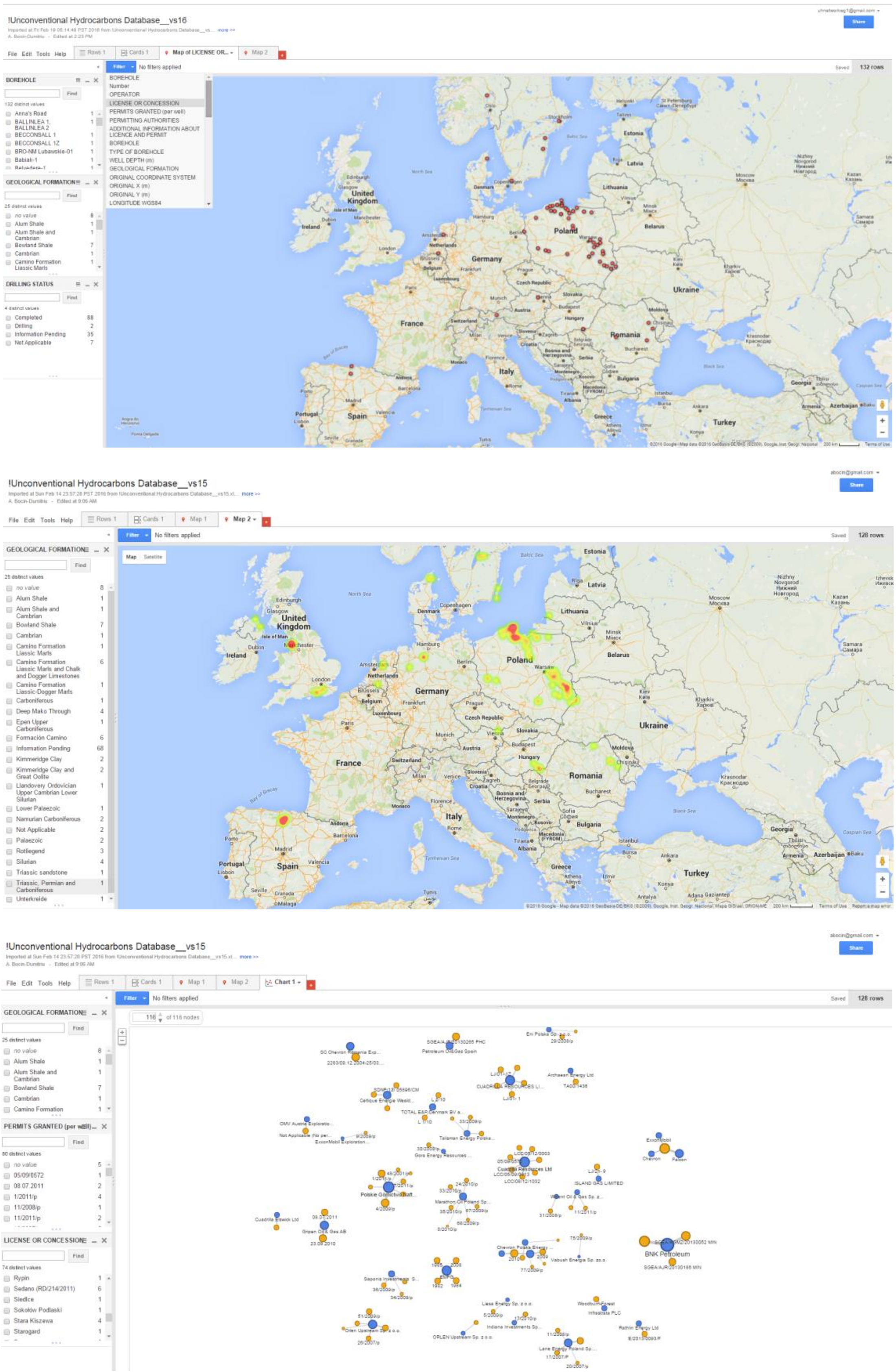
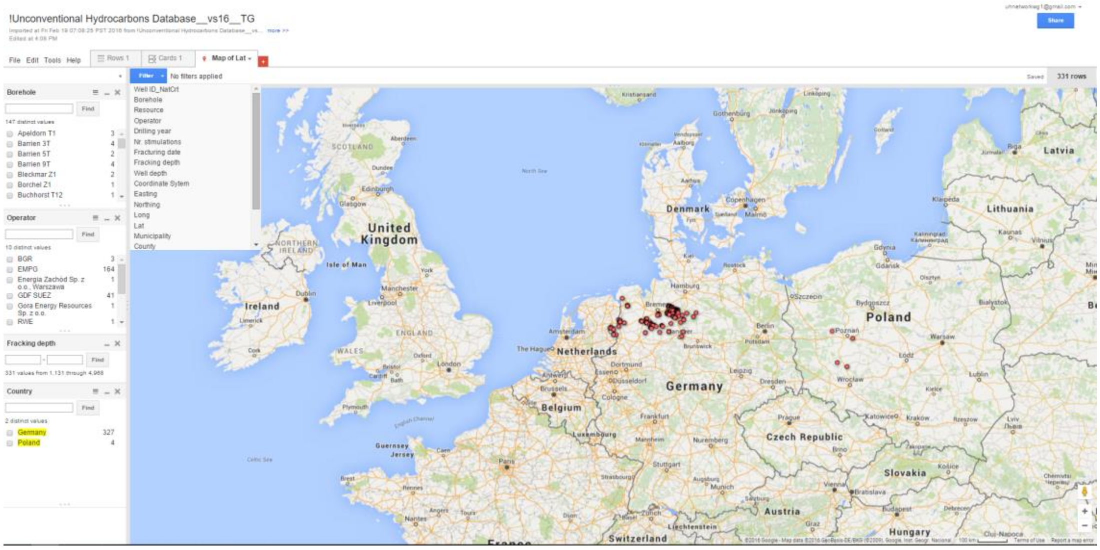
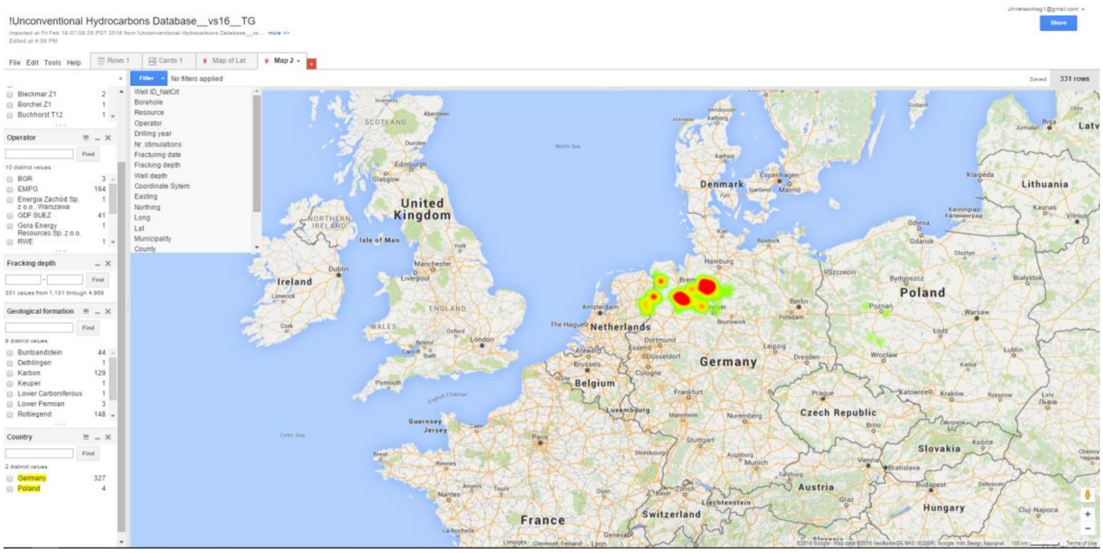


Fig. 3.3: Snapshots of the online interactive interface of the database. Top. Shale Gas wells displayed as points on the map; some wells in Poland have been displayed using dummy coordinates (the rectangular aggregation of points); Middle. Heat map showing Shale Gas wells distribution. Bottom. Nodes showing the wells distribution per operators.





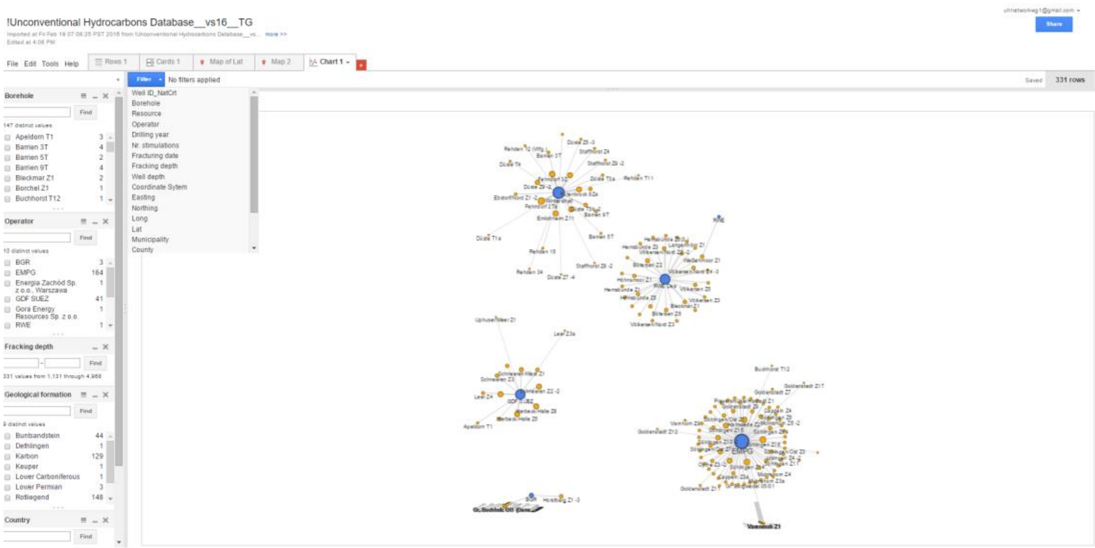


Fig. 3.4: Snapshots of the online interactive interface of the database. Top. Tight Gas wells displayed as points on the map; the database entries for Tight Gas wells is limited for the moment only to Germany; Middle. Heat map showing Tight Gas wells distribution. Bottom. Nodes showing the wells distribution per operators.

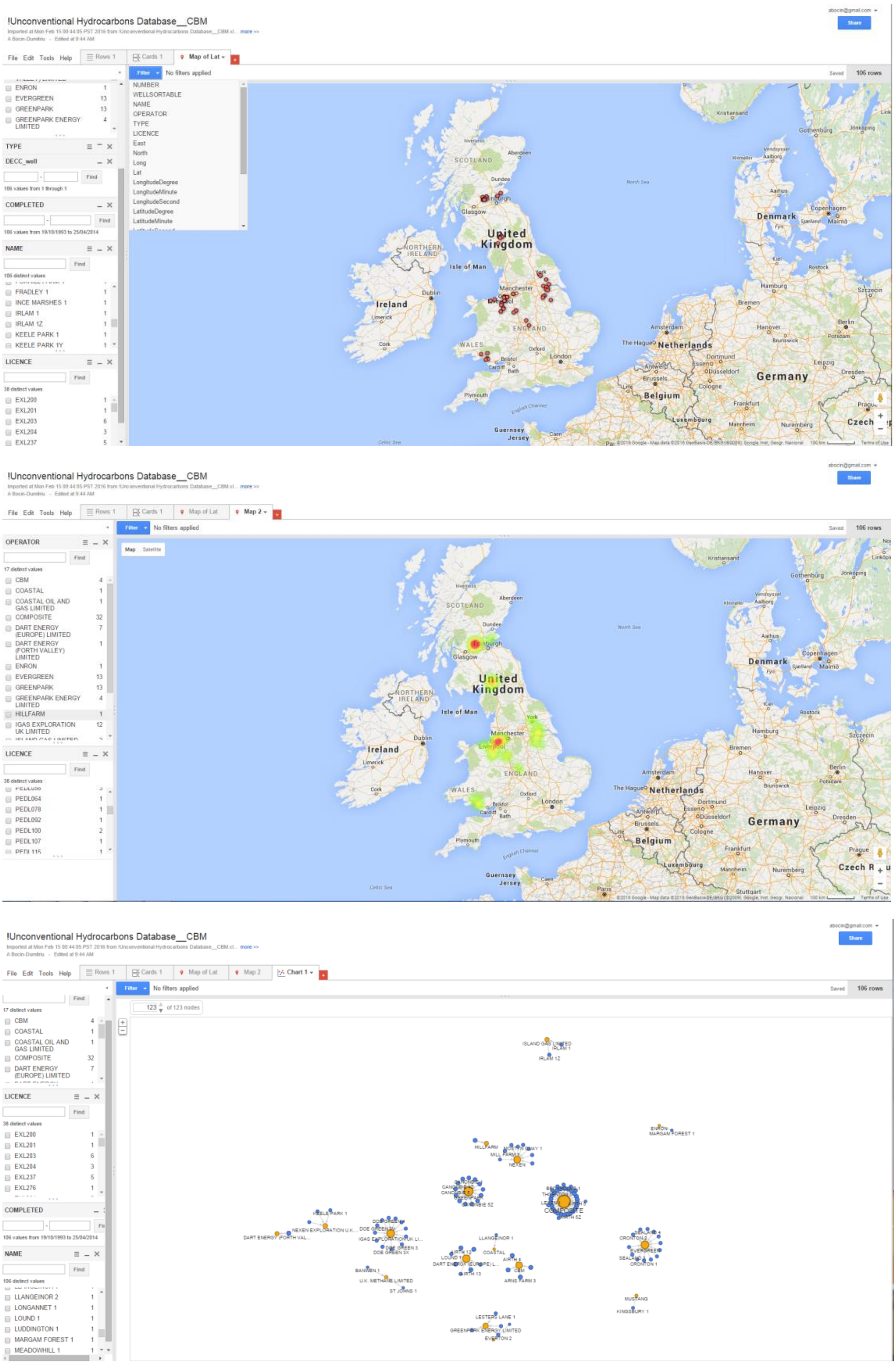


Fig. 3.5: Snapshots of the online interactive interface of the database. Top. CBM wells displayed as points on the map; presently the database entries are limited only to UK (source DECC) whereas additional wells have been drilled in other EU countries (e.g. France) but no location could be obtained; Middle. Heat map showing CBM wells distribution. Bottom. Nodes showing the wells distribution per operators.

3.1.4 GIS and WebGIS

In order to organise the information aggregated within the Unconventional Hydrocarbons database in a geographically referenced environment the data were transposed to an ArcGIS vers.10.1 project. For this purpose the wells list file was imported in a geodatabase and a map containing the locations of the wells was created (see Fig. 3.5.).

Future target is to port all the information online by moving the platform to an interactive environment using WebGIS. Hence, the Unconventional Hydrocarbons database and maps could be accessed online while various tools will facilitate filtering, collating or displaying the information in a consistent manner. This would allow the user to perform custom analysis that will enrich the content and scope of the database.

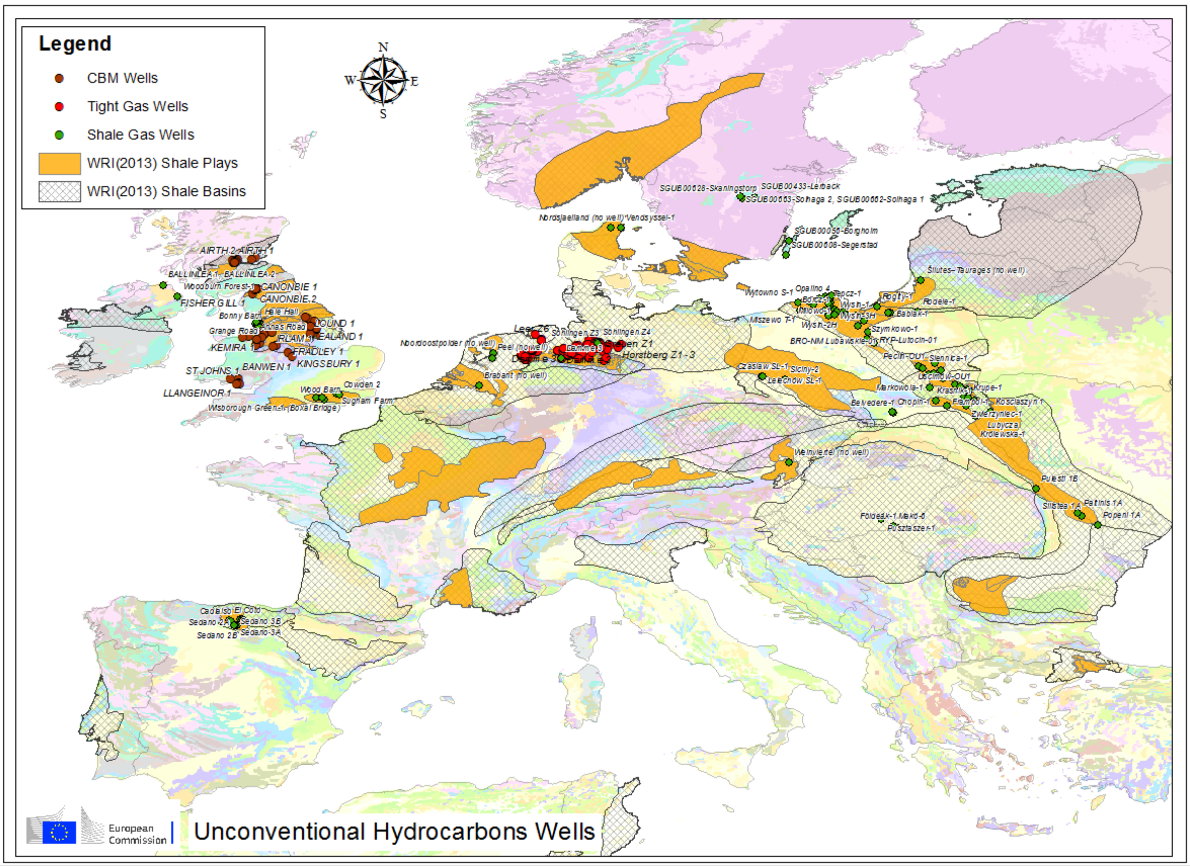


Fig. 3.5: Database and GIS project containing all (planned, ongoing, closed or cancelled) unconventional hydrocarbons "wells" in the EU (Shale Gas, Tight Gas, and CBM) collected so far by the Network.

3.1.5 Status of the WG1 Deliverables

The following was created by WG1: the main repository for the list of European unconventional hydrocarbons wells which was partially populated with the latest available information (activity performed by JRC in-house); the list was complemented with two working worksheets (for user input) focusing on the environmental baselines and monitoring as established in the Commission Recommendation (2014/70/EU); the Unconventional Hydrocarbons database that aggregates the information collected in the wells list and environmental worksheets and organise them in a consistent manner having as central unit of assessment, the well; a GIS project assembling the information from all input files (wells list, environmental worksheets, database) into a geodatabase and presenting the content on geo-referenced maps; an online interactive database interface allowing basic operations like filtering, creating various infographics or conduct statistical analysis to be performed.

Beyond the need to keep filling the database with further technical and environmental data, there is also one pending task regarding the database deliverable which is to provide the assessment of data gathered with regard to technically and economically recoverable potential as well as of the environmental data. These tasks will be completed by the Commission services.

3.1.6 Challenges identified and topics for further discussions

The JRC database on environmental aspects of UH exploration and production has an objective of establishing the measurable parameters, assessing environmental impacts and risks of unconventional hydrocarbons wells drilled in the EU.

The main challenge is to evaluate if the right parameters are chosen for the assessment and monitoring of each environmental impact. Existing Commission Directives and the Recommendation 2014/70/EU were the main references for the establishment of these parameters.

One aim was to consider requirements stemming from the relevant EU legislation on water with special emphasis on:

- Priority substances
- Compounds of Emerging Concern (CEC)
- River-basin specific pollutants

But is it reasonable to include the list of 33 priority substances in the field of water policy under the Environmental Quality Standards Directive (2008/105/EC) in the database, considering that only 5 of them have been identified among all chemical components of hydraulic fracturing products used between 2005 and 2009 in the USA (House of Representatives Report, 2011). On the other hand, it should be noted that this period of time was an incipient stage of hydraulic fracturing technology and composition of fracturing fluids has been significantly changed since then. CEC (10 substances, including pharmaceutics, hormones, pesticides) seem to not have direct connection to the UH exploration. The assessment of river-basin specific pollutants is not included in the current version of the database; hence, there is the pending question of including this assessment to the database or not which leads to a more general question regarding where the environmental assessment should stop looking into greater detail. Already the sampling might be too high to allow a regional scale comparative assessment. It is foreseen that due database granularity (well by well) this database could be a good start for conducting further local environmental assessment.

Another issue to discuss is the practicality of including into the database all the ingredients composing the fracturing fluid used per each well. In the effort to perform this exercise for 7 Polish wells one will end up with the list of 50 ingredients. Besides, only few of them appeared in more than one fracking fluid. In case of the wells from different countries and regions the comparability will be even more difficult. There is no doubt that the inventory of all chemicals used for hydraulic fracturing in the EU during last 5 years is an absolute priority (the data disclosed on http://www.ngsfacts.org/findawell is a step forward), but its presentation within the database requires further discussion.

The issue of comparability of the measurements from different organisations, sites, countries remains. It is necessary to standardize methodologies to quantify impacts, footprint and risks of European unconventional hydrocarbons exploration activities. Recommendations on methodology can be included in the "User manual" of the database. At the national levels, such manual (technical guidance) are already prepared, i.e. Onshore Oil & Gas Sector Guidance by UK Environment Agency, 2015: https://consult.environment-agency.gov.uk/portal/ho/ep/oog/ , there are also specific recommendations included in the Polish report on 7 wells.

The issue of occupational exposure is not addressed in our set of parameters. Direct impact on human health is not addressed adequately – and how it can be addressed remains a question, particularly in terms of background data.

The risk of using chemicals in fracking is not only determined by the toxicity of the chemicals used. It is determined by the risk that chemicals have a harmful effect on the earth's surface or in the subsurface and the effect of the harmful action on the environment. For the effect in the subsoil it is furthermore important how the chemicals behave at higher temperature and pressure. Some chemicals decompose quickly in the subsurface and are as a result less or not harmful in the subsoil, at the same time, there is quite a lot of uncertainty on how chemicals injected breakdown/degrade/transform in the underground. The remaining question is – to which extent the industry players will cover all these aspects in their assessment and is this feasible? The screening had to be limited to key factors and parameters at certain stage, acceptable for the Network members.

The database parameters are set to assess the individual sites only. The issue of combined emissions and impacts of multiple sites is not covered.

Many of the issues above are now the subject of research efforts by EC and individual MS. In 2014 4 projects on environmental impacts of shale gas were funded under the Horizon2020 research programme. In England, at least two research sites with deep boreholes are being planned. Similar initiatives may be expected in other MS.

3.2 WG 2: Emerging Technologies for Well Stimulation

As described above, the aim of Working Group 2 (WG2) is to establish a list of emerging technologies that could be used in the EU as alternatives to the current hydraulic fracturing technologies. This could influence positively some issues, such as reduce or even eliminate the water consumption and resolve conflicts in water usage, minimize surface pollution, reduce surface footprint, avoid triggered seismic events and maximise the production while minimizing the number of wells drilled. The planned work was meant to assess economic, environmental and climate change related pros and cons in comparison to currently used fracturing techniques (high-volume slick-water hydraulic fracturing).

The first meeting took place on the 24th of February 2015. During this meeting the activities were kicked off. A discussion took place on the WG2 common objectives, timeline and internal organization into specific Task sub-groups. Fig. 3.6 depicts how work was structured during this first meeting, and the various sub-groups are described more in detail in the following.

A relevant point that was highlighted was the importance of an effective exchange of information between members of Tasks teams and chairs. The chairs of the working groups clearly stated their intention to steer and moderate the discussions (both at the meetings and during e-mail exchanges) in a spirit of open dialogue and collaboration.

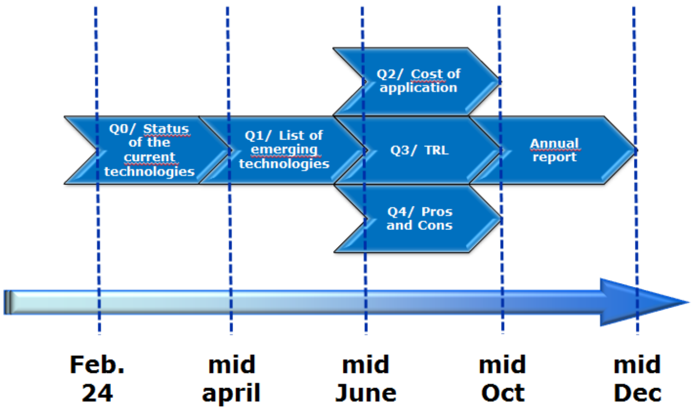


Fig. 3.6: Work organisation within WG2 as discussed during first meeting

The following Tasks were identified.

Task A: Establishing a technical and environmental baseline of the existing hydraulic fracturing technologies.

The work was intended to consist of collecting data to qualify the technical and environmental performances of the current technologies both locally (such as water consumption, impacts on water quality, air, noise, soil , risk assessment at the surface and in the underground) and globally (emissions with global warming impact) as a function of the reservoir properties and nature of hydrocarbons. What will be accounted for is the identification of production sweet spots, the design and cost of the stimulation equipment required, the well design and its completion, the composition of the hydraulic fracturing fluid, the fracturing job efficiency, the flowback production and treatment and the well productivity (decline and cumulative).

Task B: Producing cost estimates of the commercially available technologies.

This Task intended to assess the value chain and to produce a cost range for its different segments. Combined with the techno-environmental analysis performed by Task A, this was intend to allow the identification of the main hurdles to overcome and selection of parameters needing improvement.

Task C: Assessing the economic, environmental and climate change related pros and cons of alternative technologies in comparison with currently used technologies.

This Task was intended to use the results obtained in Task B to allow the identification of the most interesting alternatives to consider based on the technologies identified in the JRC (2013) report, possibly complemented by the WG 2 participants. The idea was to organize these under two categories: (1) those which are considered as improvement of the current commercially available technologies, (2) others that are based on brand new concepts for stimulating the source rock. For each of these categories a technology readiness level should be produced. In particular, the potential gains in terms of technical and environmental performances and economic viability should be identified along with the necessary R&D steps required.

Task D: Preparation of the annual conference and edition of yearly report.

A second meeting took place in June 2015. During this meeting, the original idea was to carry out a preliminary analysis of the performances and limitations of the current hydraulic fracturing technologies with regards to technical feasibility, environmental and climate change footprint and economic viability. Unfortunately the work of Task A was much delayed, and the meeting was mainly dedicated to the discussion of the technology matrix to compare commercially-available technologies.

Task A was led by Luca Gandossi of JRC. The work was structured in sub-tasks, in the following way.

Sub-Task 1: Complete an exhaustive list of commercially available technologies (i.e. adding and deleting rows to the table)

Sub-Task 2: Complete an exhaustive list of relevant parameters and attributes to compare the technologies (i.e. adding columns to the table)

Sub-Task 3: Populate the table, for all technologies identified in sub-task 1, by:

3.1 agreeing on a sub-set of the parameters identifies in sub-task 2.

3.2 deciding what type of content each cell will receive (quantitative information, whenever possible, otherwise qualitative information).

3.3 collecting the required information and fill the table.

The matrix as was eventually finalised is depicted in Fig. 3.7. Table 3.1 reports the list of identified technologies (the column of the matrix), whereas Table 3.2 reports the parameters that were identified to carry out a meaningful comparison (the rows of the matrix).

A third meeting took place in November where JRC reported a serious lack of progress. A major problem was identified in the method of work, which is based on the idea of contribution in kind. Network members were invited to send all relevant information needed to fill in the matrix, but only very limited feedback was received. This prompted a discussion on how to improve the situation. The original timeline was considerably extended, and it was suggested to officially contact the United States' Department of Energy to ask for collaboration and data sharing.

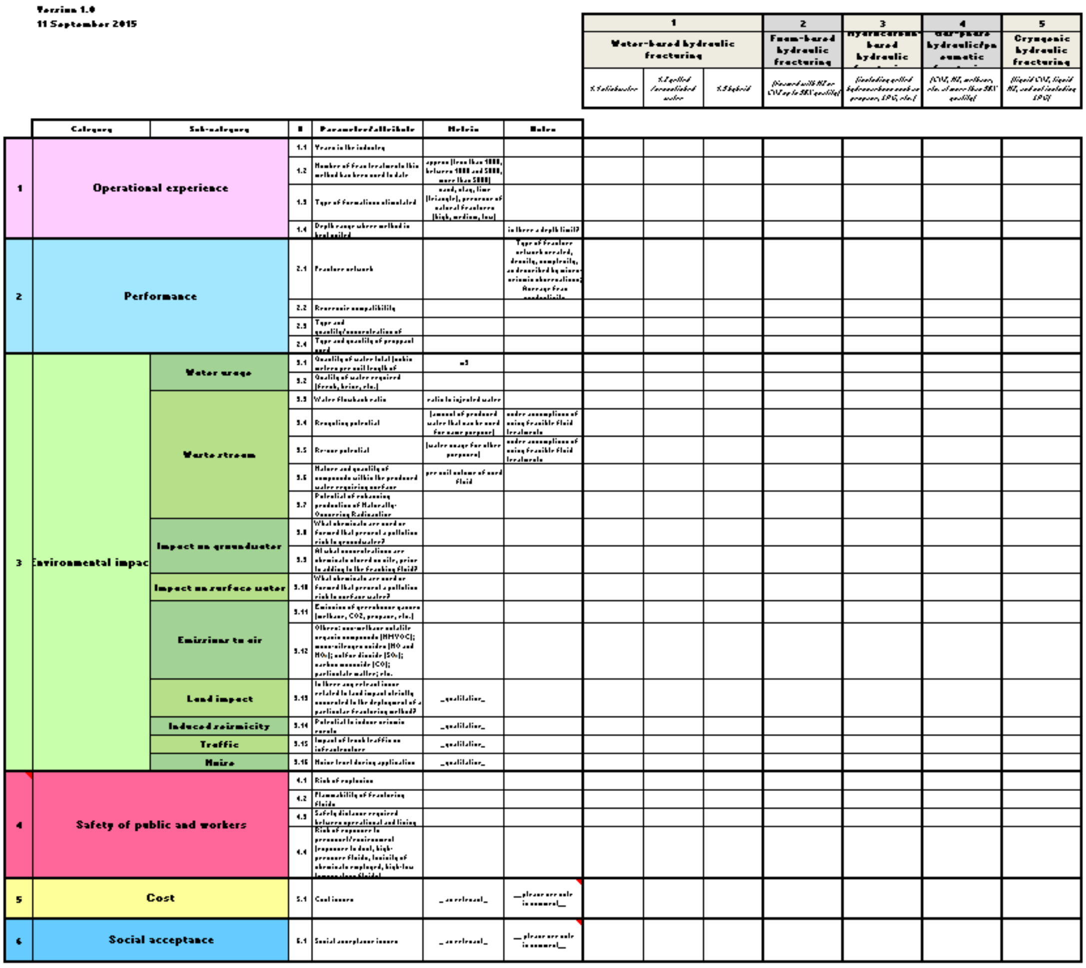


Fig. 3.7: Technology matrix

Table 3.1 Commercially available fracturing technologies as identified by WG2.

	Technology	Sub-technology	Notes
1	**Water-based hydraulic fracturing**	*1.1 slickwater*	
		1.2 gelled/crosslinked water	
		1.3 hybrid	
2	**Foam-based hydraulic fracturing**		*Foamed with N_2 or CO_2 up to 90% quality.*
3	**Hydrocarbon-based hydraulic fracturing**		*Including gelled hydrocarbons such as propane, LPG, etc.*
4	**Gas-phase hydraulic fracturing**		*CO_2, N_2, methane, etc. at more than 90% quality.*
5	**Cryogenic hydraulic fracturing**		*Liquid CO2, liquid N2, and not including LPG.*

Table 3.2 List of identified attributes for comparison.

	Category	Sub-category	#	Parameter/attribute
1	**Operational experience**		1.1	Years in the industry
			1.2	Number of treatments this method has been used to date
			1.3	Type of formations stimulated
			1.4	Depth range where method is best suited
2	**Performance**		2.1	Fracture network
			2.2	Reservoir compatibility
			2.3	Type and quantity/concentration of chemicals injected
			2.4	Type and quantity of proppant used
3	**Environmental impact**	**Water usage**	3.1	Quantity of water total (cubic meters per unit length of treated rock)
			3.2	Quality of water required (fresh, brine, etc.)
		Waste stream	3.3	Water flowback ratio
			3.4	Recycling potential
			3.5	Re-use potential
			3.6	Nature and quantity of compounds within the produced water requiring surface treatment
			3.7	Potential of enhancing production of Naturally-Occurring Radioactive Materials (NORMs)
		Impact on groundwater	3.8	What chemicals are used or formed that present a pollution risk to groundwater?
			3.9	At what concentrations are chemicals stored on site, prior to adding to the fracking fluid?
		Impact on surface water	3.10	What chemicals are used or formed that present a pollution risk to surface water?
		Emissions to air	3.11	Emission of greenhouse gasses (methane, CO2, propane, etc.)
			3.12	Others: non-methane volatile organic compounds (NMVOC); mono-nitrogen oxides

				(NO and NO_2); sulphur dioxide (SO_2); carbon monoxide (CO); particulate matter; etc.
		Land impact	3.13	Is there any relevant issue related to land impact strictly connected to the deployment of a particular fracturing method?
		Induced seismicity	3.14	Potential to induce seismic events
		Traffic	3.15	Impact of truck traffic on infrastructure
		Noise	3.16	Noise level during application
4	**Safety of public and workers**		4.1	Risk of explosion
			4.2	Flammability of fracturing fluids
			4.3	Safety distance required between operational and living areas
			4.4	Risk of exposure to personnel/environment (exposure to dust, high-pressure fluids, toxicity of chemicals employed, high-low temperature fluids)
5	**Cost**		5.1	Cost issues
6	**Social acceptance**		6.1	Social acceptance issues

3.2.1 Comprehensive list of emerging technologies

This deliverable had been initially discussed, but no follow-up was given in 2015.

3.2.2 Emerging technologies suitable for the EU: pros and cons

The following tables report the information that was collected from three Network members, respectively from the service company Halliburton, the Polish oil and gas company PGNiG and Mr. Trepess from the oilfield consultancy FracPT FZE. The individual contributors are specified in each cells. No information was collected for gas-phase hydraulic fracturing (technique #4 in Table 3.1) and for cryogenic hydraulic fracturing (technique #5 in Table 3.1). No assessment was made of the quality of information provided. The information collected does not represent the views of the Commission.

Table 3.3 Information collected for water-based hydraulic fracturing

				1		
				Water-based hydraulic fracturing		
				1.1 slickwater	***1.2 gelled water***	***1.3 hybrid***
1	**Operational experience**	1.1	Years in the industry	Halliburton: Wells have been hydraulically fractured for over 60 years. Halliburton pioneered HF technology in the mid-1940s. PGNiG SA has dozen year experience in exploration and exploitation of hydrocarbons. With regard to shale gas exploration is the last 5-6 years.		

				1		
				Water-based hydraulic fracturing		
				1.1 slickwater	***1.2 gelled water***	***1.3 hybrid***
		1.2	Number of frac treatments	Halliburton has hydraulically fractured tens of thousands of wells in the US and internationally. Research from 2012 shows over 2 million wells had been hydraulically fractured. (Hydraulic fracturing 101, King, George E (2012), Society of Petroleum Engineers (quoted in the UK's Department of Energy & Climate Change, Developing Onshore Shale Gas and Oil- Facts about 'Fracking', December 2013)) [Note: Minimal industry activity in the EU to date.] PGNiG SA: The number of HF quoted by Halliburton is really huge, especially when compared with our very limited one which concerns onl a few wells		
		1.3	Type of formations stimulated	Halliburton: Generally appropriate when there are brittle shales. However, other factors are also relevant (e.g. the stress contrast, where the rock shows a very high stress contrast a thicker more complex hydraulic fracturing (HF) fluid may be appropriate as a single wide fracture is expected). Please see the HF Fluid Products - Types and Composition Paper for more information.	Halliburton: Generally appropriate when the rock is ductile (e.g. certain forms of sandstone). However, other factors are also relevant e.g. the stress contrast. Please see the HF Fluid Products - Types and Composition Paper for more information.	Halliburton: Generally appropriate when the rock is quite brittle (e.g. certain types of clay). However, other factors are also relevant e.g. the stress contrast. Please see the HF Fluid Products - Types and Composition Paper for more information.
		1.4	Depth range	Halliburton: Depth is not the key factor that determines which type of HF fluid will be the most appropriate. The choice of HF fluid is determined by a range of factors, principally by reference to geological information. The geology of shale and tight sandstone reservoirs varies significantly across the world, even within the same reservoir. Each reservoir can also show different geology at different depths, requiring a different approach to HF fluid formulation for upper and lower zones. A one-size-fits-all approach to HF fluid is not appropriate as it does not address the distinctive qualities of each site. Even where wells are close geographically different HF fluid products and different HF fluid types may be selected to address the different issues expected at each particular site. Please see the HF Fluid Products - Types and Composition Paper for more information. Pickard Trepess: Depths are not limited by the fluid, but by the equipment limitations. Generally pumping pressure increases with depth, as does frition pressure. We are generally limited to 15,000 psi treatment pressure due both to the well equipment and the pumps and lines.		

				1		
				Water-based hydraulic fracturing		
				1.1 slickwater	***1.2 gelled water***	***1.3 hybrid***
2	**Performance**	2.1	Fracture network	Halliburton: Slick water fracturing fluid is generally appropriate when there is brittle rock which is expected to form complex narrow hairline fractures. Please see the HF Fluid Products - Types and Composition Paper for more information.	Halliburton:Cross linked gel fracturing fluids are generally appropriate when the rock is ductile and expected to form single wider fractures. Please see the HF Fluid Products - Types and Composition Paper for more information.	Halliburton: Hybrid fracturing fluid is generally appropriate where the rock is quite brittle and expected to form quite complex narrow hairline fractures (but wider and less complex than those formed through a slickwater fracturing fluid). Please see the HF Fluid Products - Types and Composition Paper for more information.
		2.2	Reservoir compatibility	Pickard Trepess: Any water based fluid may cause swelling and de-stabilization of clays. Some rocks are de-consolidated by water based fluids, though this is more common with acid based treatments.	Pickard Trepess: Similar to slickwater	Pickard Trepess: Similar to slickwater
		2.3	Type chemicals injected	Halliburton:Slickwater fracturing fluids are generally relatively simple, high-volume fluids which are pumped at high speeds. Often a friction reducer is added to reduce friction in the well making the water more slippery meaning it can be pumped faster. HF fluid typically comprises 90% water, 9.5% proppant and 0.5% HF fluid products. These are average values for the US and may be higher in other regions. (e.g. from data provided on the NGSFacts website for Polish exploration wells	Halliburton:Cross linked gel fracturing fluids are generally more complex that slickwater fracturing fluids involving different substances including a "crosslinker" to increase the viscosity of the fluid. This thick fluid is used to transport larger particles and concentrations of prop pant creating wider fractures. HF fluid typically comprises 90% water, 9.5% proppant and 0.5% HF fluid products. These are average values for the US	Halliburton:Hybrid fracturing fluid is similar to cross linked gels however, they are not as thick and generally contain fewer chemicals. HF fluid typically comprises 90% water, 9.5% proppant and 0.5% HF fluid products. These are average values for the US and may be higher in other regions. (e.g. from data provided on the NGSFacts website for Polish exploration wells the HF fluid contained 2.5% HF fluid products).

					1		
					Water-based hydraulic fracturing		
					1.1 slickwater	*1.2 gelled water*	*1.3 hybrid*
					the HF fluid contained 2.5% HF fluid products).	and may be higher in other regions. (e.g. from data provided on the NGSFacts website for Polish exploration wells the HF fluid contained 2.5% HF fluid products).	
			2.4	Type and quantity of proppant used	Halliburton:Very small particles of proppant. The quantity and proppant used is determined by site specific factors. Based on average values for US operations typically HF fluid is 9.5% proppant.	Halliburton:Large particles of proppant. The quantity and proppant used is determined by site specific factors. Based on average values for US operations typically HF fluid is 9.5% proppant.	Halliburton:Medium sized particles of proppant. The quantity and proppant used is determined by site specific factors. Based on average values for US operations typically HF fluid is 9.5% proppant.
					Pickard Trepess: Conventional proppant selection based on crush strength may be irrelevant in ultra-tight rock, where even crushed sand may give sufficient conductivity contrast. Thus where normally ISPs and HSPs would be selected, silica sand may be sufficient in tight shales		
3	**Environmental impact**	**Water usage**	3.1	Quantity of water total (cubic meters per unit length of treated rock)	Halliburton:A significant (and increasing) proportion of the water (30-60%) used in HF is recovered and can be potentially reinjected, probably after some treatment, reducing the amount of freshwater required. The volume of water needed is site specific and depends on a range of geological and local issues. The UK's Energy and Climate Change Committee reported that The Tyndall Centre estimated between 9-29 million litres of water were required per well. In comparison, according to API the water usage in shale gas plays ranges in the US from 7.5–15 million litres of water. PGNiG SA: 7963.91 M3		

				1		
				Water-based hydraulic fracturing		
				1.1 slickwater	***1.2 gelled water***	***1.3 hybrid***
		3.2	Quality of water required	Halliburton has developed HF fluid systems and other technologies to facilitate the use of produced water rather than relying solely on fresh water as the base fluid for HF. For example Halliburton's CleanWave® service treatment enables operators to reuse water in HF fluids or reuse in other drilling and production processes. This minimizes fresh water consumption. Halliburton has also developed systems which reduce the volume of water required to perform HF. By way of example the Halliburton CleanStim® fracturing service uses a new HF fluid formulation made entirely from ingredients sourced from the food industry. Using ingredients from the food industry provides an extra margin of safety to people, animals and the environment in the unlikely occurrence of an incident at the wellsite. This innovative fluid also requires a lower volume and so less water. Halliburton is participating in an initiative led by UKOOG (the United Kingdom Onshore Operators Group) on integrated water management. The initiative covers four key areas - water supply, on-site water management, operational re-use and waste water management). PGNiG SA: fresh water		
	Waste stream	3.3	Water flowback ratio	Halliburton: After a HF treatment is complete a portion of the HF fluid may return to the surface via the wellbore to either be recycled for use in a subsequent HF operation or disposed of. Estimates vary on the percentage of HF fluid which returns to the surface, ranging from 25-75%. This wide range is explained by differences in the properties of the shale and its response to HF. PGNiG SA: 30-40 %		

		1		
		Water-based hydraulic fracturing		
		1.1 slickwater	1.2 gelled water	1.3 hybrid
3.4	Recycling potential	Halliburton: Industry recycling efforts include advanced water treatment technologies that treat and reuse the water generated during the HF process at the well site, enabling operators to reuse water in HF fluids or reuse in other drilling and production processes. These waters may be filtered for solids, treated or diluted and reused for operations at the same well pad or transported to a nearby well pad. As a result of these technologies, PADEP (the US state of Pennsylvania's Oil & Gas Reporting website) recently reported that operators in the Marcellus Shale region of the state are recycling up to 90% of their flowback and 65% of their produced water. A recent paper by Jackson (Jackson RB and others, 2014, The Environmental Costs and Benefits of Fracking, Annu. Rev. Environ. Resour.) also comments on the positive trend of increased wastewater recycling from HF, which reduces freshwater requirements. For example, prior to 2011 only 13% of wastewater in the Marcellus Shale was recycled, but by 2011 this increased to 56%. Halliburton has developed HF fluid systems and other technologies to facilitate the use of produced water rather than relying solely on fresh water as the base fluid for HF. For example Halliburton's CleanWave® service treatment enables operators to reuse water in fracturing fluids or reuse in other drilling and production processes. This minimizes fresh water consumption. Halliburton has also developed systems which reduce the volume of water required to perform HF. By way of example the Halliburton CleanStim® fracturing service uses a new HF fluid formulation made entirely from ingredients sourced from the food industry. Using ingredients from the food industry provides an extra margin of safety to people, animals and the environment in the unlikely occurrence of an incident at the wellsite. This innovative fluid also requires a lower volume and so less water. PGNiG SA: Returned fracfluids are treated as waste and handed to authorized companies for recovery/ disposal.		
3.5	Re-use potential	PGNiG SA: From the point of view of the economic recovery fluid reusal was not justified in the exploration wells carried out so far by PGNIG, due to emerging small amount of fracfluid return and a very small amount of fracturing operations stretched over time.		

			1		
			Water-based hydraulic fracturing		
			1.1 slickwater	***1.2 gelled water***	***1.3 hybrid***
	3.6	Nature and quantity of compounds within the produced water requiring surface treatment	Halliburton: Recovered fluid quality (and quantity) is expected to vary significantly over time and with the type of formation concerned. Generally recovered fluid will mirror the natural formation water with the addition of small amounts of the returned HF fluid, some solubilized silt and clay particles or colloids and some dissolved hydrocarbons. Formation water naturally present and in contact with the rock in the target formation may contain: high levels of total dissolved solids which are brines (or salt solutions) such as calcium chloride, sulfate etc. Minerals that have leached out of the formation rock such as barium, calcium, iron, strontium and magnesium and particulates such as silt and clay, bacteria and trace amounts of NORM from the formation rock such as radium, uranium and lead. Halliburton has developed HF fluid systems and other technologies to facilitate the use of produced water rather than relying solely on fresh water as the base fluid for HF. For example Halliburton's CleanWave® service treatment enables operators to reuse water in HF fluids or reuse in other drilling and production processes. This minimizes fresh water consumption.		
	3.7	Potential of enhancing production of Naturally-Occurring Radioactive Materials (NORMs)	Halliburton: The potential for NORM is formation specific. It is not dependent on the type of HF fluid used. HF does not produce NORM. NORM is already present in the formation itself. PGNiG SA: An assessment of the radioactivity of fracfluids, both before treatment and after return (radioactivity in the flowback) was conducted in the exploration wells carried out so far by PGNIG. Up to now, studies have shown no increase of radioactivity in the flowback; i.e. .		
Impact on groundwater	3.8	What chemicals are used or formed that present a pollution risk to groundwater?	Halliburton: Industry and regulators acknowledge wellbore integrity is fundamental to the protection of groundwater. Wells are designed, constructed and integrity tests undertaken to ensure well integrity is maintained. There have not been any cases of groundwater pollution that are proven to have been associated with the propagation of stimulated high-volume hydraulic fractures. Therefore provided industry best practice relating to well integrity is applied the risk to groundwater as a result of HF is minimal. The HF Fluid Products - Types and Composition Paper sets out an example of the main constituent substances and function within a HF fluid. HF fluid formulation is site specific and the actual main constituent substances and HFfluid composition may vary. It should also be remembered that these constituents form only a small proportion of the HF fluid and are therefore diluted. Recovered fluid quality (and quantity) is expected to vary significantly over time and with the type of formation concerned. Generally recovered fluid will mirror the natural formation water with the addition of small amounts of the returned HF fluid, some solubilized silt and clay particles or colloids and some dissolved hydrocarbons. Formation water naturally present and in contact with the rock in the target formation may contain: high levels of total dissolved solids which are brines (or salt solutions) such as calcium chloride, sulfate etc. Minerals that have leached out of the formation rock such as barium, calcium, iron, strontium and magnesium and particulates such as silt and clay, bacteria and trace amounts of NORM from the formation rock such as radium, uranium and		

					1		
					Water-based hydraulic fracturing		
					1.1 slickwater	***1.2 gelled water***	***1.3 hybrid***
					lead. Groundwater in the EU is highly regulated through the Groundwater Daughter Directive and under the Water Framework Directive. as well as other regulation. Halliburton works collaboratively with EU regulators to ensure that it s products and services comply with all applicable regulation and best practice. Halliburton is participating proactively in the UK Environment Agency's initiative to pre-assess chemicals proposed for use in HF operations. Halliburton is a member of the Exposure Scenario Task Force (ESTF) (led by IOGP (the International Association of Oil and Gas Producers), CEFIC (the European Chemical Industry Council) and EOSCA (the European Oilfield Speciality Chemicals Association)) which has ben proactively working on a generic exposure scenario and background document to demonstrate environmental risk from HF activities is minimal and manageable. These documents are expected to be finalised shortly and shared with the Commission. PGNiG SA: 2-Bromo-2-nitro-1,3- propanediol –biocide, isopropanol– surfactant, 2,2-dibromo-3-nitrylopropionamid – biocide, Ammonium persulfate – breaker, Pottasium hydroxide – pH control		
			3.9	At what concentrations are chemicals stored on site, prior to adding to the fracking fluid?	Halliburton: HF fluid compositions vary according to the specific needs of each area and rock type. The composition of each HF fluid is designed to specifically address the individual characteristics of each site. The chemicals (and their concentrations) stored on site will therefore depend on the design of the HF fluid. Industry has developed many different types of HF fluid products that can be used, however, any single HF operation would only use a few of the available fluid products. It is not uncommon for some HF fluid designs to omit some categories of fracturing fluid products, if the function served by a category of products is not required for the specific well design. The HF Fluid Products - Types and Composition Paper provides an example of the main constituent substances and functions within HF fluid.		

				1		
				Water-based hydraulic fracturing		
				1.1 slickwater	*1.2 gelled water*	*1.3 hybrid*
	Impact on surface water	3.10	What chemicals are used or formed that present a pollution risk to surface water?	Halliburton: A high-volume HF installation must be designed and constructed in such a way as to prevent the downward migration of chemicals used in HF fluid that may be released through leaks or spills. For example, this can involve the removal of an upper layer of soil from the site and the excavation of a ditch around the perimeter. A non-permeable membrane, which lines the entire area, including the intercepting ditches may then be installed. This is covered in surfacing material such as aggregate. In the unlikely event that surface water at the installation is contaminated with HF fluid products it will be held in the ditches and removed for disposal according to EU and local regulations and conditions. The membrane under the installation (or other similar means of secondary containment) prevents flow downwards to soil and groundwater. As such the chemicals used in HF fluid and those within recovered fluid do not represent a pollution risk to surface water. The HF Fluid Products - Types and Composition Paper sets out an example of the main constituent substances and function within a HF fluid. HF fluid formulation is site specific and the actual main constituent substances and HF fluid composition may vary. It should also be remembered that these constituents form only a small proportion of the HF fluid and are therefore diluted. Recovered fluid quality (and quantity) is expected to vary significantly over time and with the type of formation concerned. Generally recovered fluid will mirror the natural formation water with the addition of small amounts of the returned HF fluid, some solubilized silt and clay particles or colloids and some dissolved hydrocarbons. Formation water naturally present and in contact with the rock in the target formation may contain: high levels of total dissolved solids which are brines (or salt solutions) such as calcium chloride, sulfate etc. Minerals that have leached out of the formation rock such as barium, calcium, iron, strontium and magnesium and particulates such as silt and clay, bacteria and trace amounts of NORM from the formation rock such as radium, uranium and lead. See also above reference to the ESTF. PGNiG SA: 2-Bromo-2-nitro-1,3- propanediol –biocide, isopropanol–surfactant, 2,2-dibromo-3-nitrylopropionamid – biocide, Ammonium persulfate – breaker, Pottasium hydroxide – pH control		
	Emissions to air	3.11	Emission of greenhouse gasses (methane, CO2, propane, etc.)	Halliburton: Industry has developed technologies that can help prevent or reduce greenhouse gas emissions from shale gas operations. These have been shown to be very effective in the United States. For example operators can reduce emission through the use of "green completions". It is in industry's best interest to minimise release of methane, propane etc. in order to realise as much commercial value as possible from the hydrocarbons produced.		

					1		
					Water-based hydraulic fracturing		
					1.1 slickwater	***1.2 gelled water***	***1.3 hybrid***
			3.12	Others: non-methane volatile organic compounds (NMVOC); mono-nitrogen oxides (NO and NO_2); sulfur dioxide (SO_2); carbon monoxide (CO); particulate matter; etc.			
		Land impact	3.13	Is there any relevant issue related to land impact strictly connected to the deployment of a particular fracturing method?	Halliburton: EU and national legislation sets out how habitats and diversity are protected. Any environmental impact of proposed activities is assessed when determining whether to issue onshore licences and allow development. By way of example in the UK, which issues licenses to exploit hydrocarbons through competitive licensing rounds, a Strategic Environmental Assessment is undertaken prior to each round. This allows for environmental implications of the proposed plan to be considered. Issues relating to land take and diversity are also considered as part of the planning regime. Halliburton has developed further initiatives to minimise land impacts including Halliburton's FracFactory® which allows for well stimulation from up to several hundred metres away reducing the impact on local roads. The SandCastle® unit is a more efficient way of storing proppant which addresses problems with space constraints at well site locations as well as using solar power for its power needs. This unit is not currently available in the EU but may be in the future.		
		Induced seismicity	3.14	Potential to induce seismic events	Halliburton: HF activities do not cause significant seismic disturbances that pose a threat to humans or the environment. Appropriate controls are available to mitigate the risks of undesirable seismic activity associated with HF. The UK government confirmed, in December 2012, that seismic risks associated with HF could be managed. This followed analysis of detailed studies and advice from leading experts. New controls to manage risks of seismic activity were imposed. There is also technology to monitor seismic activity/fracture growth in real time. The UK's Department of Energy and Climate Change has confirmed that there are no documented cases of HF operations causing subsidence or tremors large enough to cause damage at the surface. It has also explained that after a decade of extensive HF activity in the US there is no evidence to suggest that ongoing HF increases the likelihood of earthquakes. In addition to the controls imposed induced seismicity also has to be considered as part of the planning process.		

					1		
					Water-based hydraulic fracturing		
					1.1 slickwater	1.2 gelled water	1.3 hybrid
		Traffic	3.15	Impact of truck traffic on infrastructure	Halliburton: The impact of traffic is considered as part of the granting of permits and licenses to drill and perform HF. By way of example in the UK traffic impacts are considered as part of an application for planning permission. Halliburton has developed, and continues to develop initiatives to reduce the impact on local roads and ensure remote locations can remain undisturbed. These initiatives include Halliburton FracFactory® which allows for well stimulation from up to several hundred metres away reducing the impact on local roads. Journey Management also reduces kilometres travelled thereby reducing traffic, fuel usage and the associated emissions.		
		Noise	3.16	Noise level during application	Halliburton: Potential noise impacts only arise during initial operations to construct, drill and complete a well which generally takes between 1 and 3 months. Very little of this noise is associated with HF, which takes only a few days at most. Typically any noise generated dissipates within 300 metres. Industry's efforts to reduce water consumption and minimise traffic also reduces the noise from trucks. PGNiG SA: acceptable levels of environmental noise		
4	Safety of public and workers		4.1	Risk of explosion	General Comments from Halliburton: The safety of the public and workers can be protected and any risks effectively managed. The oil and gas industry has been managing and reporting on these risks for decades. Many of these issues are not dependent on the type of HF fluid used and apply to all oil and gas exploration and production activities. In addition to EU laws relating to worker safety and the safe use of chemicals (e.g. through the use of Safety Data Sheets) Industry continues to develop standards to improve the management of these risks. These include guidelines produced by IOGP (the International Association of Oil and Gas Producers), by UKOOG (the United Kingdom Onshore Operator Group) , by the International Energy Agency and ISO standards. Halliburton believes safety is everyone's business. That's why every person at every worldwide location makes safety awareness their number one priority. Every member of every Halliburton team is tasked with taking personal ownership of his or her own safety and the safety of others. Halliburton's goal is to keep its people and the environments in which they work, safe and healthy. To that end, Halliburton puts policies and procedures in place to make sure that adherence to proper safety practices is a fulltime commitment on everyone's part.		
			4.2	Flammability of fracturing fluids			
			4.3	Safety distance required			
			4.4	Risk of exposure to personnel/environment			

				1		
				Water-based hydraulic fracturing		
				1.1 slickwater	*1.2 gelled water*	*1.3 hybrid*
5	**Cost**	5.1	Cost issues	Halliburton: Costs involved are based on site specific factors and are dependent on a number of issues (e.g. local factors, depth of targeted formation, rock type etc.). Halliburton uses its Cypher service with the goal to reduce the operators' costs. Using Cypher allows Halliburton to select the optimal drilling and stimulation needed for the relevant gas play. Further information on Cypher can be provided separately.		
6	**Social acceptance**	6.1	Social acceptance issues	Halliburton: Social acceptance issues do not relate to the specific type of HF fluid used but relate more generally to HF and the continued development of fossil fuels for energy use. Public concerns are unfounded given the robust regulatory regime in place in the EU and the significant body of scientific evidence available which demonstrates HF can be undertaken in a way that ensures human health and the environment are protected. Public concern will only be fully alleviated once this industry has developed in the EU and been effectively demonstrated. Industry has recognised the need for transparency with respect to HF fluids and industry has developed templates to disclose information to the public (on a well by well basis). In the EU this is through NGSFacts and specifically in the UK through the UKOOG template for public disclosure. In the US Halliburton supports FracFocus. This ensures adequate information on the constituents of HF fluid is made available to address the concerns of the public.		

Table 3.4 Information collected for foam-based hydraulic fracturing, gas-energized hydraulic fracturing and hydrocarbon-based hydraulic fracturing

				2		3
				2.1 Foam-based hydraulic fracturing	**2.2 Gas-energized hydraulic fracturing**	**Hydrocarbon-based hydraulic fracturing**
1	Operational experience	1.1	Years in the industry	Pickard Trepess: From mid 1970's	Pickard Trepess: From mid 1970's	Pickard Trepess: The first frac in 1947 used gelled gasoline using napalm
		1.2	Number of frac treatments	Pickard Trepess: More than 5000	Pickard Trepess: More than 5000	Pickard Trepess: More than 5000
		1.3	Type of formations stimulated	Pickard Trepess: Conventional tight sandstones as well as hard limestones and unconventional shale wells	Pickard Trepess: Conventional tight sandstones as well as hard limestones and unconventional shale wells	Pickard Trepess: Tight sandstones as well as hard limestones and shale wells, especially those containing water sensitive clays, or prone to deconsolidation by water based fluids
		1.4	Depth range	Pickard Trepess: Deeper wells cost more because of the higher pressures. Nitrogen fracs also cost more than CO2 fracs, also due to pressure differences	Pickard Trepess: No depth limitations for energised frac fluids. The deeper the well, the more advantage of using energised fluids for improved flowback	Pickard Trepess: Deeper wells cost more because of the higher pressures, and the reduced hydrostatic of the oil compared to water. Gelled oils tend to have higher friction pressures too.
2	Performance	2.1	Fracture network	Pickard Trepess: CO2 and N2 fracs will give a shorter but taller fracture than slickwater fracs	Pickard Trepess: Frac dimensions will generally be similar to non energized treatments	Pickard Trepess: The rheology of the gelled fluid will determine the fracture geometry

					2		3
					2.1 Foam-based hydraulic fracturing	2.2 Gas-energized hydraulic fracturing	Hydrocarbon-based hydraulic fracturing
			2.2	Reservoir compatibility	Pickard Trepess: Reduced water content will reduce effect on clays. The greater the FQ, the less water is present	Pickard Trepess: Only slightly less than water based fluids	
			2.3	Type chemicals injected	Pickard Trepess: Foamed fluids require at least a surfactant based foaming agent, and higher temperatures require a stabilizer similar to gelled fluids. Gelling agents are often used to perform that role	Pickard Trepess: A flowback surfactant may be added. The N2 or CO2 can be added to any fracturing fluid to provide additional energy for flowback	Pickard Trepess: Gasoline is no longer used as a base fluid, but any oil such as kerosene, diesel, or crude oil can be used. The gelling agents are specific to oil based fluids and are not guar gums, but more generally sodium salts of saponic acids.
			2.4	Type and quantity of proppant used	Pickard Trepess: Final proppant concentrations are generally lower than in water based fracs, due to the dilution effect of adding the gas. In the past proppant concentrators have been used, but these are rare today, having been scrapped during the last recession !	Pickard Trepess: Similar to foam fracturing. The higher the FQ, then the lower the final proppant concentration in the energized fluid	Pickard Trepess: Gelled oils have similar proppant carrying capabilities to gelled water
3	Environmental impact	Water usage	3.1	Quantity of water total (cubic meters per unit length of treated rock)	Pickard Trepess: Water consumption is significantly reduced (by the addition of the gas phase)	Pickard Trepess: Reduced water consumption	Pickard Trepess: Zero water comsumption. In fact the presence of water will usually destroy the properties of a gelled oil fluid.
			3.2	Quality of water required	Pickard Trepess: Generally fresh (drinking quality) is required for foam frac fluids, but the volumes will be significantly reduced	Pickard Trepess: Any frac fluid can be energized with N2. CO2, because of its acidity may require specific gelling agents, that in themselves mey be reliant on water quality	Pickard Trepess: N/A

					2		3
					2.1 Foam-based hydraulic fracturing	2.2 Gas-energized hydraulic fracturing	Hydrocarbon-based hydraulic fracturing
		Waste stream	3.3	Water flowback ratio	Pickard Trepess: As there is considerably less water used, there will be less flowback, but the efficiency may be higher than for pure water based systems	Pickard Trepess: Improved recovery is often seen due to the energy contained in the compressed gas	
			3.4	Recycling potential	Pickard Trepess: There will be less water to recycle, though the quality shouldn't be affected	Pickard Trepess: Similar to foam fracturing.	Pickard Trepess: Returned frac fluids may be added directly to the oil production stream
			3.5	Re-use potential	Pickard Trepess: Little potential for re-use of the liquid phase, practially zero possibility to recycle the gas phase	Pickard Trepess: Similar to foam fracturing.	Pickard Trepess: As the returned fluids will generally be live crides, these are not generally reused, but can generally be added to the oil flow stream
			3.6	Compounds within the produced water requiring surface treatment			Pickard Trepess: As the returned fluid will not be disposed of to the environment, then this is not relevant
			3.7	NORMs	Pickard Trepess: Similar to water based fluids, but reduced due to low water returns	Pickard Trepess: Similar to water based fluids, but reduced due to low water returns	Pickard Trepess: This would depend on the solubility of the NORM material in oil

					2		3
					2.1 Foam-based hydraulic fracturing	2.2 Gas-energized hydraulic fracturing	Hydrocarbon-based hydraulic fracturing
		Impact on groundwater	3.8	What chemicals are used or formed that present a pollution risk to groundwater?	Pickard Trepess: Foams do not pose additional risks to the groundwater	Pickard Trepess: Energized fluids do not pose additional risks, compared to water based fluids	Pickard Trepess: As the base fluid is oil, additional care must be taken to prevent spillage and other contamination with groundwater. The chemicals used to gel oils are not more of a hazard than water based additives
			3.9	At what concentrations are chemicals stored on site, prior to adding to the fracking fluid?			
		Impact on surface water	3.10	What chemicals are used or formed that present a pollution risk to surface water?	Pickard Trepess: Foams do not pose additional risks to the surface water	Pickard Trepess: Energized fluids do not pose additional risks, compared to water based fluids	Pickard Trepess: As the base fluid is oil, additional care must be taken to prevent spillage and other contamination with surface water. The chemicals used to gel oils are not more of a hazard than water based additives
		Emissions to air	3.11	Emission of greenhouse gasses (methane, CO2, propane, etc.)	Pickard Trepess: Nitrogen is not a 'Greenhouse gas' therefore poses no risk. Emissions during transport & pumping liquid CO2 will be higher.	Pickard Trepess: Nitrogen is not a 'Greenhouse gas' therefore poses no risk. Emissions during transport & pumping liquid CO2 will be higher.	
			3.12	Others			Pickard Trepess: The base fluid is an oil

					2		3
					2.1 Foam-based hydraulic fracturing	**2.2 Gas-energized hydraulic fracturing**	**Hydrocarbon-based hydraulic fracturing**
		Land impact	3.13	Is there any releant issue related to land impact striclty connected to the deployment of a particular fracturing method?			
		Induced seismicity	3.14	Potential to induce seismic events			
		Traffic	3.15	Impact of truck traffic on infrastructure	Pickard Trepess: The water transport will be much less, and as the 'gas' is delivered in liquid form, that transport will be smaller than the equivalent volume (to the vapourized gas) of water	Pickard Trepess: No significant difference to pure water based cases	Pickard Trepess: No significant difference to pure water based cases
		Noise	3.16	Noise level during application	Pickard Trepess: No significant difference to pure water based cases	Pickard Trepess: No significant difference to pure water based cases	Pickard Trepess: No significant difference to pure water based cases
4	**Safety of public and workers**		4.1	Risk of explosion	Pickard Trepess: Energized & foamed fluids pose an additional risk, but not explosion related		Pickard Trepess: The oil base fluid is often flammable, but not explosively so
			4.2	Flammability of fracturing fluids	Pickard Trepess: No different from pure water based fluids		Pickard Trepess: The oil base fluid is often flammable
			4.3	Safety distance required	Pickard Trepess: No different from pure water based fluids		Pickard Trepess: The oil base fluid is often flammable
			4.4	Risk of exposure to personnel/environment	Pickard Trepess: LN2 presents a cryogenic risk, and both N2 and CO2 pose risks to oxygen levels, so additional care should be taken		

				2		3
				2.1 Foam-based hydraulic fracturing	2.2 Gas-energized hydraulic fracturing	Hydrocarbon-based hydraulic fracturing
5	Cost	5.1	Cost issues	Pickard Trepess: Foam and energised fluids are more expensive than pure water based fluids due to both the cost of the gas phase and the equipment required to pump them. CO2 is somewhat cheaper, as it can be pumped with standard pumps, while LN2 requires specialist pumping and vapourization equipment		Pickard Trepess: The oil base fluids costs more than water.
6	Social acceptance	6.1	Social acceptance issues	Pickard Trepess: There are no specific public acceptance problems with energized or foam based fluids. We can readily point out the advantage of using less water		Pickard Trepess: In some countries such as Germany, there is an irrational fear of the use of oil based fluids, without any specific reason given

4. Conclusions

What regards the exploration and exploitation of Unconventional Hydrocarbons, the EU is still in the early exploration phase. The Shale Gas drilling activity in the EU remains very low. It accounts for less than 3% of the shale wells drilled outside North America. At the same time, there is already commercial production of tight gas and coal bed methane resources.

Hydraulic fracturing of horizontal wells has been limited, mostly due to difficult geology(resulting in poor test outputs) and low gas and oil prices and public acceptance issues.

Based on information collected, it appears that at least 132 shale gas wells have been drilled or are planned to be drilled so far in the EU (out of which at least 14 horizontal wells were fractured), 327 tight gas wells and 106 CBM wells. This list may not be fully comprehensive, notably with regard to tight gas and CBM wells as data collection efforts focussed primarily on shale gas wells. The list of wells still needs to be checked by the JRC for consistency and will be completed in the months to come.

In terms of availability of technical and environmental data for identified wells some confidentiality issues on the operator's side prevented them from providing access to geological data, mainly due to the protection of commercial interests. If released, the data is usually in "raw" digital format. As far as environmental data is concerned, it was only collected for certain sites and was partially integrated in the database. However, it should be noted that such data was not available systematically for all other sites, and not necessarily for similar project phases.

Judging which data is important and which is not so relevant is of big significance. More active knowledge sharing between operators and research centres would be advisable in that context.

During the Working Group meetings it was noted that there is still an issue of common language, particularly in the debate between NGOs, science and industry, because some words used can be very misleading in a different context. Therefore, true meanings of definitions are crucial for any communication and are particularly important in order to speak the same language.

What regards emerging technologies for well stimulation the performance of the current water-based hydraulic fracturing method was informed and alternative technologies were classified as such: (a) foam-based hydraulic fracturing; (b) hydrocarbon-based hydraulic fracturing; (c) gas-phase hydraulic fracturing; (d) cryogenic hydraulic fracturing.

WG2 concluded that water-based hydraulic fracturing is expected to remain the most commonly used technique in the sector in the coming years. Most of emerging technologies but hydrocarbon-based hydraulic fracturing techniques (in their gelled version) that have been deployed in Canada and USA exhibit small TRL[5] values (less than 5). As such it is hardly possible to find any field example of the application of such alternative technologies.

Therefore it was decided to list research organisations located in Europe (with support of EERA Shale Gas alliance) or alternatively in USA that are involved in the development of such technologies. Once these R&D teams have been identified then it will be possible to share publicly available information on the techno-environmental performances of the alternative technologies and the hurdles which remain to be removed.

[5] TRL : Technology Readiness Level

The Annual Conference of the Network took place on 23 February 2016, where the status of the work carried out in 2015 was presented and questions were received. In the first session of the Conference it was announced that no further Working Group meetings will be convened. The Commission will continue to work on the scientific and technical aspects of unconventional hydrocarbons.

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List of abbreviations and definitions

BREF	Best available techniques Reference document
CLIMA	General Directorate for Climate Action
EC	European Commission
ENER	Directorate General for Energy
ENV	Directorate General for Environment
EU	European Union
GROWTH	Directorate General for Internal Market, Industry, Entrepreneurship and SMEs
JRC	Joint Research Centre
R&D	Research and Development
RTD	Directorate General for Research and Innovation
UH	Unconventional Hydrocarbons
WG	Working Group

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Annex 1: Participants of WG1

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Baron	Cesar	UHN	
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Boll	Linda	Shell	Netherlands
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Britze	Peter	GEUS	Denmark
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Annex 3: Questions from the Commission and answers from the Polish authors on the report on environmental impacts of seven shale gas exploration wells in Poland

SOIL:

- Were the soil quality and the potential impact on the food chain of spill out liquids considered? A lot is reported about agricultural productivity, that is apparently marginally affected, but nothing is said about potential impact of fracking on food quality and contaminants that may enter the food chain.

- Was a full assessment of the chemicals used in the fracking process made, which could enter eventually the soil and therefore the food chain?

Any "spill out of liquids" is a serious accident, which regards any serious industrial accident– in case of an accident special remedy actions take place (immediate stoppage of the operation) to prevent the liquids to spill over outside the drilling pad. Then, other routine actions are undertaken, such as removal of soil, neutralizing of toxic compounds, reclamation). In Poland, there was no such an accident related to the UH exploration. However, in such exceptional catastrophic industrial accidents, you will have to refer to special emergency regulations and procedures, controlled by authorized and competent authorities (in Poland fire brigade special sections and other specialized services, including military ones). Such accidences in drilling operations are much less likely that elsewhere (i.e. in case of fires or leaks at filling stations), besides, all the drilling operations are continuously double controlled by independent bodies: the Central Mining Institute and Regional Inspectorates of Environmental Protection. Therefore, "food chain" is not an issue in case of hydraulic fracturing, as normal fracturing operation is separated from the "food chain". Nevertheless, a long-term monitoring is applied and any contamination would be reported (which, however, has not as yet been reported). All the parameters (hydrocarbons, mineral oils, PAHs, aliphatic compounds) measured in post-operation (reclamation) sites and were within the norms.

- Where the potentially harmful elements assessed, which could be released by the rock formations and reach the surface and be spilled on the soils (like done usually in risk assessment for mining and deep excavation)?

Concerning the spill accidents – see above. All the key elements released from the host rock were analysed (see the Report, p. 116-122). Flowback chemical composition is site-specific and depends both on frack fluid composition and local geochemistry of stimulated formation. Elevated content of Selenium and Antimony occur in most test sites, Mercury level was slightly above the threshold in two sites, Cadmium in one. Chlorides , fluorides, dissolved solids and organic matter were above the threshold for storage eligibility. Radioactive elements (Uranium, Thorium) were within safe limits. Thus, the flowback fluids and solids cannot be stored on the ordinary way and must be processed in specially designated treatment centers.

- Which parameters, relevant to agricultural production, were included in the environmental status determination on drill site abandonment and reclamation on the one site mentioned, regarding soils quality in terms of hydrocarbon content?

Hydrocarbons, PAHs, mineral oils, gasoline, aliphatic compounds

WATER:

- To which extent did you consider requirements stemming from relevant EU legislation on water with special emphasis on
  - Priority Substances
  - River-basin specific pollutants
  - Substances being regulated by the Groundwater Directive and Urban Waste Water Directive.
- What triggered the selection of the substances being considered in the baseline assessment for water quality?
- Why did you not apply a more innovative approach to monitor compounds of emerging concern (CEC) in water e.g. non-target screening or effect-directed analyses?

Priority substances (45 compounds) were designated only for the surface waters. These norms have been introduced recently, in 2015 for the first 33 substances, for the rest the norms will be introduced in 2018. Additionally, the "New emerging compounds" or "compounds of emerging concern" (CEC) should be monitored ("watch list" – 10 substances, including pharmaceutics, hormones and pesticides). However, what would be connection between these compounds and UH exploration? We checked the list of priority substances and watch list substances in order to compare them with possible polluting compounds related to the UH exploration, but we found that there was no match between these two groups. We followed all existing Polish and EU regulations and norms concerning underground water quality (i.e. underground water directive). We recommend long-term monitoring of underground water quality Yes, there is debate around introduction of priority substances screening in underground waters, but as yet there is no any reasonable template for such screening.

River basin specific pollutants should be characterized based on industrial activity in the whole catchment area, we are performing these studies, the results will be included in the water management plans concerning the river catchment areas in near future.

- How did you choose the ecotoxicological tests and endpoints for the aquatic testing?

Concerning the ecotoxicological tests , we based our tests on maximum allowed concentration of certain compounds in flora, fauna and sediments. These test are rather difficult in terms of comparability and methodology. If we could detect these substances in water, then the ecotoxicological tests were not necessary.

There are several main factors, which can be regarded as the most important at the stage of selection of biotest organisms. Firstly, one should select these organisms which react to the stress sharply and chronically, because such stress factors may occur on different stages of

technological processes of neutralization/utilization of the liquid and solid wastes. All the delivered samples of sediments and technological liquids were analysed. Analysed and reported endpoints are based on the analyses performed according to the ISO standards and specifications given by the producer, in order to reflect accurately the conditions occurring in the test/measurement points. Involvement of another endpoints would be unnecessary, because it would mean evaluation of (in terms of validity) new research methods, which would entail heavy cost and workforce, while the task was already completed by researchers – at the stage of evaluating the internationally accepted norms, including inter-laboratory research. The indicated groups of organisms were chosen on order to estimate the level of toxicity regarding a wide spectrum of organisms representing different trophic levels (producers, consumers, decomposers) – at a rational cost. Additionally, choosing bacteria for the biotests, one had to remember about presence of solid samples (technological liquids contain drilling particles).

The Ostracodtoxkit FTM test is the best known and first order biotest of direct contact of crustaceans with fresh-water or brackish sediments or soils – and such sediments were expected to occur, assuming geological characteristics of the drilled/fractured host rocks. Comparing to other biotests using crustaceans, one can notice that ostracods are relatively resistant to pollutions, which allows obtaining reliable data.

On the other hand, the Microtox® test is one of the first and best systematized and normalized biotests, using bioluminescent bacteria to evaluate hazards, connected with presence of wide spectrum of pollutants in environment. The test using higher plants (besides given above arguments) was chosen in order to learn about possible spill of liquid and solid wastes onto the fields surrounding the pads, which would result in polluting of the agricultural plants.

- What triggered the number of test sites as well as length of observation?

Concerning the number of test sites – we went for the representative sites covering different parts of the Polish shale basin (Pomerania, Podlasie, Lublin), choosing more than a half of all hydraulically fractured wells. Length of observation has to embrace baseline study, study performed during drilling process and post-drilling period, extending to land reclamation time and return of agricultural activity. The length of observation is dictated by technological conditions of drilling and reclamation period. In some cases (Łebień) we went for prolonged period of observation, as this well was first to be monitored.

Air

- Why is the air pollution study reduced to a few punctual measurements in the test sites, which seems not to have into account temporal and spatial variability?

Temporal and spatial variability can be assessed for a lasting process, not for punctual events, such as startup of engines, when the emissions are even visible - but last just for a few seconds. We tried to measure concentrations of pollutants in most severe moments, when the biggest possible concentrations were expected. In Łebień, in 2011, we tried to use passive samplers to

calculate loads over certain periods of time, but it did not work - loads did not vary from background values and even so, there would be impossible to distinguish between sources placed on well pad and others, like households, agricultural activities (especially with regard to dust), transport, etc.

- Why is there no information on the reproducibility of measurements, uncertainty, frequency and representativeness of the samples?

The reports, although based on extensive research, are not intended to become typical peer-reviewed scientific papers, but rather a compendium of knowledge, prepared for the government and the public - they only contain conclusions visualised by the results. It would be hard to imagine any report on unconventionals prepared for the EC that would contain all these methodological issues discussed in detail. However, all the procedures in sampling and analysis fulfilled the requirements essential for proper scientific assessment of the material studied. In particular, one of our aims was to establish the most effective and most reliable methods of environmetal measurements related to the shale gas operations.

- Why is there not more of the meteorological conditions and atmospheric stability during sampling provided?

There are many remarks on conditions during sampling, though, as already said, assessed events and processes did not last for a long time, the longest fracturing operation lasted less than 4 hours – usually, weather conditions in our part of Europe do not change rapidly enough to influence significantly the background conditions. Of course, any more significant weather change would be noted, and if more extreme – measurements in such conditions would be avoided.

- How meteorological conditions are taking into account when comparing measurements carried out at different times, sites and atmospheric conditions?

As said before, we tried to measure the worst possible case, so samples were collected downwind from the sources. Days with high wind speed were excluded, suspended particulate matter was not measured during rain or even high humidity.

- How baseline pollution was defined in the area and in which way this is comparable with other measurements carried out under different conditions?

We did not define the "baseline pollution", we measured concentrations of gases and dust in the atmospheric air before all particular activities, to compare them with those measured during the activities (site preparation, drilling, HF, gas testing, well pad demobilisation and site restoration) and after the operations. We did not notice any continuing increase in concentration of any substances after the activities had stopped.

- Why impact is considered with respect to reference concentrations and not with respect to relative values in the surrounding, i.e. upwind?

As it is hard to speak about stable levels of concentrations of measured substances in open air (especially at so low concentrations). It was a governmental request to compare all measurements to existing standards (if there was any). There are numbers of industrial standards of air quality,

but we chose those related to dwelling and agricultural areas - well pads were mainly situated in such areas.

- Why ozone was not measured downwind direction as secondary pollutant from ozone precursors emissions?

This was not found relevant in this case.

- The recommendation that a continuous air monitoring is not required during the operations seems to be addressed as a worker protection issue, leaving the decision on whether to install to the discretion of the drill site operator. No indications are however addressed for the general ambient air quality, in which plumes of pollutants could be an issue. Why this aspect is not considered?

There is no continuous (permanent) plume sources on the well pad. Any leaching from the installation must be monitored in different way, sampling or measurements in ambient air would not be a proper measure for these.

- Is any emission inventory currently being developed?

If this question refers to types of possible gases released - these are known. We seek for methane and other VHC most.

- Was an emission estimation for all of the pollutants made? How can this information in terms of emissions and level of pollution be extrapolated to a future developed scenery?

There is no estimation on the emissions and we showed this in the report. It's extremely difficult to measure emissions from such installation and nobody has done it so far. Emissions so far have been only counted, but the mistake of such calculations may be bigger than the numbers calculated.

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