Impacts of shale gas and shale oil extraction on the environment and on human health
– Executive Presentation –

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1. INTRODUCTION
Types of Unconventional Gas

**Shale Gas**
- has remained in the source rock without migrating upwards to a seal forming a conventional gas deposit. The permeability is even lower than in tight gas formations.

**Tight Gas**
- has migrated into reservoir rocks of very low porosity and permeability. Typically, the permeability is 10-100 times lower than in conventional fields.

**Coalbed Methane**
- is confined in the pores of coal deposits.
2. ENVIRONMENT, HUMAN HEALTH
Key Findings: Environment, Human Health

- **Landscape:** Unavoidable impacts are *area consumption* due to drilling pads, waste water ponds, parking and maneuvering areas for trucks, equipment, gas processing and transporting facilities as well as access roads: 0.4 – 6 wells per km² in USA.
- Major possible impacts are *air emissions of pollutants, groundwater contamination* due to uncontrolled gas or fluid flows due to blowouts or spills, leaking fracturing fluid, and uncontrolled waste water discharge.
- **High water consumption:** 15,000 m³ per well (Barnett Shale, USA), increasing regional water consumption by one third.
- Fracturing fluids contain *hazardous substances*, and flow-back in addition contains *heavy metals* and *radioactive materials* from the deposit.
- Experience from the USA shows that many accidents happen, which can be harmful to the environment and to human health. The *recorded violations of legal requirements amount to about 1-2 percent of all drilling permits*. Many of these accidents are due to improper handling or leaking equipment.
- Also in Europe, accidents have already happened in hydraulic fracturing operations. For instance, waste water pipes from the tight gas field “Söhlingen” in Germany leaked in 2007. This caused *groundwater contamination with benzene and mercury, killed fish and contaminated the soil*. Though the corresponding Mining Agency of Lower Saxony (“Landesbergbehörde”) was correctly informed, the public noticed the accident only in 2011 when the company started to replace the agricultural soil where the fluids had leaked into the ground.
- *Groundwater contamination by methane*, in extreme cases leading to explosion of residential buildings, and potassium chloride leading to *salinization of drinking water* is reported in the vicinity of gas wells.
- *Hydraulic fracturing can induce small earthquakes* in the order of 1 – 3 at the Richter scale.
- The *impacts add up* as shale formations are developed with a high well density (up to six wells per km²).
<table>
<thead>
<tr>
<th>Site/Region</th>
<th>Total (per well)</th>
<th>Only Fracturing</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barnett Shale</td>
<td>17000</td>
<td></td>
<td>Chesapeake Energy 2011</td>
</tr>
<tr>
<td>Barnett Shale</td>
<td>14000</td>
<td></td>
<td>Chesapeake Energy 2011</td>
</tr>
<tr>
<td>Barnett Shale</td>
<td>no data</td>
<td>4500 - 13250</td>
<td>Duncan 2010</td>
</tr>
<tr>
<td>Barnett Shale</td>
<td>22500</td>
<td></td>
<td>Burnett 2009</td>
</tr>
<tr>
<td>Horn River Basin (Canada)</td>
<td>40000</td>
<td></td>
<td>PTAC 2011</td>
</tr>
<tr>
<td>Marcellus Shale</td>
<td>15000</td>
<td></td>
<td>Arthur et al. 2010</td>
</tr>
<tr>
<td>Marcellus Shale</td>
<td>1500 – 45000</td>
<td>1135 – 34000</td>
<td>NYCDEP 2009</td>
</tr>
<tr>
<td>Utica shale, Québec</td>
<td>13000</td>
<td>12000</td>
<td>Questerre Energy 2010</td>
</tr>
</tbody>
</table>
## Selected substances used in Germany

<table>
<thead>
<tr>
<th>CAS number</th>
<th>Substance</th>
<th>Formula</th>
<th>Health effect</th>
<th>Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>111-76-2</td>
<td>2-butoxy ethanol</td>
<td>C(<em>6)H(</em>{14})O(_2)</td>
<td>toxic</td>
<td>GHS07</td>
</tr>
<tr>
<td>26172-55-4</td>
<td>5-Chloro-2-methyl-4-isothiazolin-3-one</td>
<td>C(_4)H(_4)CINOS</td>
<td>toxic</td>
<td>GHS05, GHS08, GHS09</td>
</tr>
<tr>
<td>2682-20-4</td>
<td>2-Methylisothiazol-3(2H)-one</td>
<td>C(_4)H(_5)NOS</td>
<td>toxic</td>
<td>GHS05, GHS08, GHS09</td>
</tr>
<tr>
<td>9016-45-9</td>
<td>Nonylphenol-ethoxylate</td>
<td>C(<em>m)H(</em>{2m+1})(^-)(\text{C}_6\text{H}_4\text{OH(CH}_3\text{CH}_2\text{O})_n)</td>
<td>toxic</td>
<td>GHS05, GHS07, GHS09</td>
</tr>
<tr>
<td>75-57-0</td>
<td>Tetramethylammoniumchloride</td>
<td>C(<em>4)H(</em>{12})ClN</td>
<td>toxic</td>
<td>GHS06, GHS07</td>
</tr>
</tbody>
</table>
Water Contamination Pathways

Possible water contaminations might be induced by

- **Spills** of drilling mud, flowback and brine, from tailings or storage tanks causing water contamination and salinization.

1. Leaks or accidents **from surface activities**, e.g. leaking fluid or waste water pipes or ponds, unprofessional handling or old equipment.

2. Leaks from **inadequate cementing of the wells**.

3. Leaks through **geological structures**, either through natural or through artificial cracks or pathways.
Potential flows of critical substances

- **SO₂, NOₓ, PM, NMVOC, CO**
- **NMVOC**
- **SO₂, NOₓ, PM, NMVOC, CO**
- **NMVOC**
- **Flow-back**
- **Drinking water well**
- **Harmful substances NORM**
- **Cap rock**
- **Harmful substances NORM**
- **Cap rock**
- **Shale**
- **Hydrofrac zone**

Flow paths:
1. **NG processing**
2. **Diesel Engines**
3. **Drinking water well**

~1500 m
3. GREENHOUSE GAS BALANCE
Key Findings: Greenhouse Gas Balance

- **Fugitive methane emissions** have a huge impact on the greenhouse gas balance.

- **Existing assessments** give a range of 18-23 g CO\(_2\)-equivalent per MJ as indirect GHG emissions from the production and processing of unconventional natural gas.

- The potential emissions due to **methane intrusion of aquifers** are not yet assessed.

- However, **project specific emissions** might vary up to a factor of ten, depending on the total methane production of the well.

- Depending on several factors, greenhouse gas emissions of shale gas relative to its energy content are **as low as those of conventional gas transported over long distances** or as high as those of hard coal over the entire life cycle from extraction to combustion.
Greenhouse Gas Emissions of Shale Gas

<table>
<thead>
<tr>
<th></th>
<th>Coal</th>
<th>max</th>
<th>min</th>
<th>NG/coal production</th>
<th>NG compression to 20 MPa</th>
<th>NG transport via trailer, 100 km</th>
<th>NG/coal transport</th>
<th>NG distribution (pipeline, 500 km)</th>
<th>Coal transport (train, 250 km)</th>
<th>Combustion</th>
</tr>
</thead>
<tbody>
<tr>
<td>NG, 7000 shale &amp; tight gas, km</td>
<td>80</td>
<td>60</td>
<td>40</td>
<td>70</td>
<td>50</td>
<td>30</td>
<td>50</td>
<td>30</td>
<td>50</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>80</td>
<td>60</td>
<td>40</td>
<td>70</td>
<td>50</td>
<td>30</td>
<td>50</td>
<td>30</td>
<td>50</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>80</td>
<td>60</td>
<td>40</td>
<td>70</td>
<td>50</td>
<td>30</td>
<td>50</td>
<td>30</td>
<td>50</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>80</td>
<td>60</td>
<td>40</td>
<td>70</td>
<td>50</td>
<td>30</td>
<td>50</td>
<td>30</td>
<td>50</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>80</td>
<td>60</td>
<td>40</td>
<td>70</td>
<td>50</td>
<td>30</td>
<td>50</td>
<td>30</td>
<td>50</td>
<td>10</td>
</tr>
</tbody>
</table>

GHG [g CO2 equivalent/MJ]
4. EU REGULATORY FRAMEWORK
Key Findings: EU Regulatory Framework

- There is no EU (framework) directive governing mining activities.

- A publicly available, comprehensive and detailed analysis of the European regulatory framework concerning shale gas and tight oil extraction has not yet been developed.

- The current EU regulatory framework concerning hydraulic fracturing contains a number of gaps. Most importantly, the threshold for Environmental Impact Assessments to be carried out on hydraulic fracturing activities in natural gas or tight oil extraction is set far above any potential industrial activities of this kind, and thus should be lowered substantially. Along with this, the scope of the water framework Directive should be reassessed.

- A detailed and comprehensive analysis of declaration requirements for hazardous materials used in hydraulic fracturing needs to be carried out.

- In the framework of a Life Cycle Analysis (LCA), a thorough cost/benefit analysis could be a tool to assess the overall benefits for each individual Member State and its citizens.
Today: Plentitude of Partially Relevant Directives

- There is no EU directive governing mining activities.
- The purpose of a mining law is to provide a legal framework to facilitate:
  - a prosperous industry sector,
  - a secure energy supply and to secure
  - sufficient protection for health, safety and the environment.

- Out of 39 relevant directives, only 4 were made specifically for Mining

- Directives on Environment, Safety at Work, Chemicals, and Water have second strongest impact

- EIA (Environmental Impact Assessment) is not compulsory
Identified Gaps (1.-2.)

1. Investment Security

- Extractive industries face problems due to insufficient legislation
- Tomas Chmal, Partner at White & Case, at the conference Shale Gas Eastern Europe 2011 in Warsaw, Poland: “Poland is traditionally a gas country, but the Geologic and Mining Law does not say anything about hydraulic fracking or horizontal drilling. The new law being discussed doesn’t cover these either.” [NGE 2011]
- National laws are often based on historical needs.
- ➔ Further investigation should evaluate the need and possible scope of a Mining Framework Directive

2. Protection of Environment and Human Health

- Directive 97/11/EC defines a threshold of 500,000 m³ daily extraction rate for natural gas wells above which an EIA is compulsory [EIA cod]. Exploitation of shale gas does not reach this threshold by far, and therefore EIAs are not carried out [Teßmer 2011].
- ➔ Projects including hydraulic fracturing should be added independently of a production threshold or the threshold value should be lowered to close this gap.
Identified Gaps (3.-4.)

3. Declaration of Hazardous Materials

- A first US study provides a nearly comprehensive list of hydraulic fracturing chemicals. [Waxman 2011] Experiences from the USA show that the extraction companies themselves do not necessarily know which chemicals they are actually using (“trade secrets”).
- ➔ The current legislation (REACH, Water, Seveso II) on the duty of declaration and the associated permitted limit values for the fracturing chemicals should be assessed in this respect.

4. Approval of Chemicals remaining in the ground

- When hydraulic fracturing is completed, a mixture of hazardous materials remains in the ground. These chemicals are distributed over time and space in a neither controllable nor predictable fashion.
- ➔ [Teßmer 2011] suggests that an introduction of chemicals that will partially remain in the ground should require an approval under consideration of possible long-term effects.
Identified Gaps (5.-6.)

5. No BREF on Fracking yet

- "Each document generally gives information on a specific industrial/agricultural sector in the EU, techniques and processes used in this sector, current emission and consumption levels, techniques to consider in the determination of BAT, the best available techniques (BAT) and emerging techniques." [EC BREF]
- Legislative authorities at national and international level can refer to these and incorporate them in laws and provisions.
- Consideration should be given to define harmonised requirements in a BREF on hydraulic fracturing.

6. Capacity of water processing facilities

- In the US, problems were reported with the water processing capabilities of sewage treatment plants that discharged water to rivers. In October 2008, the level of total dissolved solids ("TDS") in the Monongahela River exceeded water quality standards and therefore the volume of gas drilling wastewater they were allowed to accept, was reduced from 20% to 1% of their daily flow. [NYC Riverkeeper]
- As a precaution, the prior examination of the capacity of wastewater facilities should be required.
Identified Gaps (7.-8.)

7. Public participation in decision-making at regional level

- As part of the review of the Seveso II Directive, one of the main changes proposed is: “To strengthen the provisions relating to public access to safety information, participation in decision-making and access to justice, and improve the way information is collected, managed, made available and shared” [EC 2011 S]
- Industrial projects such as exploitation of shale gas or tight oil, should require public consultation as part of the authorization procedure.

8. Legal effectiveness of water framework directive and associated legislation

- The Water Framework Directive entered into force in the year 2000. As hydraulic fracturing was not a prominent topic at that time, hydraulic fracturing and the related risks were not considered. The list of priority substances is reviewed every four years; the next review is due in 2011.
- The Directive should be reassessed in view of its capacity to effectively protect water from accidents and regular operations accompanying hydraulic fracturing.
Identified Gaps (9.)

9. Life Cycle Analysis (LCA) mandatory

• Life Cycle Analyses are actively promoted by the European Commission stating on its Life Cycle website: “The key aim of Life Cycle Thinking is to avoid burden shifting. This means minimising impacts at one stage of the life cycle, or in a geographic region, or in a particular impact category, while helping to avoid increases elsewhere.” [EC LCA]

• This holds especially for hydraulic fracturing, where strong impacts in specific geographic regions will occur, not the least due to the number of wells per km² and the required infrastructure.

• ➔ Consideration should be given to including a cost/benefit analysis as compulsory, based on an extensive LCA for each project.
5. ROLE IN LOW-CARBON ECONOMY
Key Findings: Role in Low-Carbon Economy

- Many European countries have shale gas resources, but only a small amount of the gas in place might be converted into reserves and ultimately be produced.

- Gas shales are extended over large areas with low specific gas content. Therefore, the extraction rate per well is much lower than in conventional natural gas extraction. The development of shale gas requires many wells with corresponding impacts on landscape, water consumption and the environment in general.

- The decline rate of shale gas wells is up to 85% in the first year. A typical regional production profile rises fast but soon slows down. After several years all new wells are used to compensate for the decline of elder wells. As soon as the development of new wells stops, the overall production immediately declines.

- Even an aggressive development of gas shales in Europe could only contribute to the European gas supplies at one-digit percentage share at best. It will not reverse the continuing trend of declining domestic production and rising import dependency. Its influence on the European greenhouse gas emissions will remain small if not negligible, or could even be negative if other more promising projects are skipped due to wrong incentives and signals.

- At regional level shale gas might play a more significant role, e.g. in Poland which has large shale resources and a very small gas demand (~14 bcm/yr) of which 30% are already produced domestically.
**Shale Gas in Europe**

<table>
<thead>
<tr>
<th>Country</th>
<th>Production 2009 [bcm] (^{(1)})</th>
<th>Proven conventional Gas reserves [bcm] (^{(1)})</th>
<th>Shale-Gas Gas in Place [bcm] (^{(2)})</th>
<th>Technically Recoverable Shale-Gas Resources [bcm] (^{(2)})</th>
<th>Assumed Recovery Factor (^{(2)})</th>
</tr>
</thead>
<tbody>
<tr>
<td>France</td>
<td>0.85</td>
<td>5.7</td>
<td>20,376</td>
<td>5,094</td>
<td>25 %</td>
</tr>
<tr>
<td>Germany</td>
<td>15.6 (13.6)</td>
<td>92.4 (81.5)</td>
<td>934</td>
<td>226</td>
<td>24.2 %</td>
</tr>
<tr>
<td>(data for 2010)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Netherlands</td>
<td>73.3</td>
<td>1,390</td>
<td>1,868</td>
<td>481</td>
<td>25.7 %</td>
</tr>
<tr>
<td>Norway</td>
<td>103.5</td>
<td>2,215</td>
<td>9,424</td>
<td>2,349</td>
<td>24.9 %</td>
</tr>
<tr>
<td>UK</td>
<td>59.6</td>
<td>256</td>
<td>2,745</td>
<td>566</td>
<td>20.6 %</td>
</tr>
<tr>
<td>Denmark</td>
<td>8.4</td>
<td>79</td>
<td>2,604</td>
<td>651</td>
<td>25 %</td>
</tr>
<tr>
<td>Sweden</td>
<td>0</td>
<td>0</td>
<td>4,641</td>
<td>1,160</td>
<td>25 %</td>
</tr>
<tr>
<td>Poland</td>
<td>4.1</td>
<td>164</td>
<td>22,414</td>
<td>5,292</td>
<td>23.6 %</td>
</tr>
<tr>
<td>Lithuania</td>
<td>0.85</td>
<td>0</td>
<td>481</td>
<td>113</td>
<td>23.5 %</td>
</tr>
<tr>
<td><strong>Total EU 27 +Norway</strong></td>
<td><strong>266</strong></td>
<td><strong>4202</strong></td>
<td><strong>65,487</strong></td>
<td><strong>16,470</strong></td>
<td><strong>~25 %</strong></td>
</tr>
</tbody>
</table>
Major European Gas Shales

Based on general geological considerations, Eastern European shales in **Poland** seem to be the most promising European shales exhibiting the largest gas in place volumes. Other shales are much less producible, though their extension is much larger. This implies that the specific effort to produce that gas increases considerably with corresponding impacts on land use, water demand, etc.

<table>
<thead>
<tr>
<th>Region</th>
<th>Basin/Shale</th>
<th>Prospective Area (km²)</th>
<th>Net-Thickness (m)</th>
<th>TOC (%)</th>
<th>GIP (Mio m³/km²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poland</td>
<td>Baltic</td>
<td>8846</td>
<td>95</td>
<td>4</td>
<td>1600</td>
</tr>
<tr>
<td>Poland</td>
<td>Lublin</td>
<td>11660</td>
<td>70</td>
<td>1.5</td>
<td>900</td>
</tr>
<tr>
<td>Poland</td>
<td>Podlasie</td>
<td>1325</td>
<td>90</td>
<td>6</td>
<td>1600</td>
</tr>
<tr>
<td>France</td>
<td>Paris</td>
<td>17940</td>
<td>35</td>
<td>4</td>
<td>300</td>
</tr>
<tr>
<td>France</td>
<td>South East</td>
<td>16900</td>
<td>30</td>
<td>3.5</td>
<td>300</td>
</tr>
<tr>
<td>France</td>
<td>South East</td>
<td>17800</td>
<td>47</td>
<td>2.5</td>
<td>630</td>
</tr>
<tr>
<td>Central Europe</td>
<td>Posidonia</td>
<td>2650</td>
<td>30</td>
<td>5.7</td>
<td>365</td>
</tr>
<tr>
<td>Central Europe</td>
<td>Namurian</td>
<td>3969</td>
<td>37</td>
<td>3.5</td>
<td>600</td>
</tr>
<tr>
<td>Central Europe</td>
<td>Wealden</td>
<td>1810</td>
<td>23</td>
<td>4.5</td>
<td>290</td>
</tr>
<tr>
<td>Scandinavia</td>
<td>Alum</td>
<td>38221</td>
<td>50</td>
<td>10</td>
<td>850</td>
</tr>
<tr>
<td>UK</td>
<td>Bowland</td>
<td>9822</td>
<td>45</td>
<td>5.8</td>
<td>530</td>
</tr>
<tr>
<td>UK</td>
<td>Liassic</td>
<td>160</td>
<td>38</td>
<td>2.4</td>
<td>500</td>
</tr>
</tbody>
</table>

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Relevance of Unconventional Gas in Europe

- In Europe about 100 drilling rigs are available.

- An assumed average drilling time of 3 months per well would allow to drill 400 wells per year in Europe at maximum. Further assuming a first month production rate of 1.4 million m³, after 5 years, 2000 wells would have been drilled with a combined output of 900 million m³/month or 11 billion m³/yr.

- These wells would contribute **less than 5 per cent to the European gas production** over the next decades, or 2-3 per cent of the gas demand.

- Even continuing the development rate at that speed (400 additional wells per year) would only marginally increase the production further, as the steep decline rate reduces the production by almost 50 per cent within one year if the development of new wells were be stopped.
IEA: Decline of natural gas production in Europe

Decline of gas natural gas production in the „Golden Age of Gas“ scenario including unconventional gas from 2008 to 2035:

- **OECD Europe**: -1.4% per year
- **European Union**: -3.1% per year

RECOMMENDATIONS
Recommendations (1)

- There is no comprehensive directive providing for a European mining law. A publicly available, comprehensive and **detailed analysis of the European regulatory framework** concerning shale gas and tight oil extraction is not available and should be developed.

- The current EU regulatory framework concerning hydraulic fracturing, which is the core element in shale gas and tight oil extraction, has a number of **gaps**. Most importantly, the threshold for **Environmental Impact Assessments** to be carried out on hydraulic fracturing activities in hydrocarbon extraction is set far above any potential industrial activities of this kind, and thus should be lowered substantially.

- The coverage of the **water framework Directive** should be re-assessed with special focus on fracturing activities and their possible impacts on surface water.

- In the framework of a **Life Cycle Analysis** (LCA), a thorough cost/benefit analysis could be a tool to assess the overall benefits for society and its citizens. A harmonized approach to be applied throughout EU27 should be developed, based on which responsible authorities can perform their LCA assessments and discuss them with the public.
Recommendations (2)

- It should be assessed whether the use of toxic chemicals for injection should be banned in general. At least, all chemicals to be used should be disclosed publicly, the number of allowed chemicals should be restricted and its use should be monitored. Statistics about the injected quantities and number of projects should be collected at European level.

- **Regional authorities** should be strengthened to take decisions on the permission of projects which involve hydraulic fracturing. **Public participation and LCA assessments** should be mandatory in finding these decisions.

- Where project permits are granted, the **monitoring** of surface water flows and air emissions should be mandatory.

- **Statistics on accidents and complaints** should be collected and analysed at European level. Where projects are permitted, an independent authority should collect and review complaints.

- Because of the complex nature of possible impacts and risks to the environment and to human health of hydraulic fracturing consideration should be given to developing a **new directive at European level** regulating all issues in this area comprehensively.
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