TEXTE
53/2014

Environmental Impacts of Hydraulic Fracturing Related to the Exploration and Exploitation of Unconventional Natural Gas, in Particular of Shale Gas

Part 2 – Groundwater Monitoring Concept, Fracking Chemicals Registry, Disposal of Flowback, Current State of Research on Emissions/Climate Balance, Induced Seismicity, Impacts on the Ecosystem, the Landscape and Biodiversity

SUMMARY

For our Environment

Umwelt Bundesamt

TEXTE 53/2014

Environmental Research of the
Federal Ministry for the
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Environmental Impacts of Hydraulic Fracturing Related to the Exploration and Exploitation of Unconventional Natural Gas, in Particular of Shale Gas

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SUMMARY

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1 Introduction

This report builds upon the study entitled "Environmental impacts of fracking in the exploration and production of natural gas from unconventional reservoirs - risk assessment, recommendations for further action and evaluation of existing legal provisions and administrative structures"[1] published in 2012.

Open questions from the 2012 study and further current aspects of the environmental issues associated with shale gas extraction have been addressed in several key topics.

These are:

1. The development of a groundwater monitoring concept;
2. The evaluation of a possible federal fracking chemicals registry;
3. The analysis of environmentally friendly options for flowback disposal;
4. An exposé on the current state of research on emissions/climate balance;
5. The investigation of the potential hazards of induced seismicity;
6. Identification and assessment of the aspects related to land use and of the impacts on the ecosystem, the landscape and biodiversity.

The *goal of this study* is to provide a technical and scientific assessment of the risks associated with the above-mentioned subjects. Open questions and knowledge gaps are clearly indicated and approaches for their resolution discussed.

Methodology: the technical and scientific work on the individual topics was based on extensive national and international literature research. In addition to this, interviews were conducted with subject matter experts, technical and approval authorities, industrial associations and E&P industry representatives.

The study findings and resulting recommendations are summarised in this short version of the full report.

[1] UFOPLAN: Meiners, H. G.; Denneborg, M.; Müller, F.; Bergmann, A.; Weber, F.-A.; Dopp, E.; Hansen, C.; Schüth, C.; Buchholz, G.; Gaßner, H.; Sass, I.; Homuth, S.; Priebs, R. (2012): Umweltauswirkungen von Fracking bei der Aufsuchung und Gewinnung von Erdgas aus unkonventionellen Lagerstätten - Risikobewertung, Handlungsempfehlungen und Evaluierung bestehender rechtlicher Regelungen und Verwaltungsstrukturen. Dessau, Umweltbundesamt.

2 Groundwater monitoring concept

2.1 Scope of work

A groundwater monitoring concept for shale gas exploitation was developed. It envisages the monitoring of all activities that can have an impact on the near-surface groundwater layers. Monitoring of the groundwater composition is a component of the principle of taking precautionary measures. Systematic and regular monitoring allows possible hazards and adverse changes in the groundwater to be identified. The design of the technical systems, such as well pads and boreholes, and of the frac process itself can thus be adapted accordingly.

2.2 Methodology

The development of the monitoring concept is described in the following:

The groundwater horizons in which monitoring bores are being drilled are decisive for obtaining results that

- are meaningful, and also
- reflect a certain proportionality.

For this reason, it is necessary to acquire sufficient knowledge on

- the general hydrogeological conditions of the shallow and the deeper subsurface, and
- the role and properties of barrier horizons.

The above-ground and below-ground risks (failure scenarios) also require detailed consideration. The likelihood and time of their occurrence as well as their potential impacts are of importance in this context.

The subsequent risk appraisal contributes to

- relevance assessment, and
- the selection of the individual groundwater horizons for the monitoring measure.

In addition to this, a groundwater monitoring concept was also developed for the assessment of potential impacts to groundwater resources arising from the technical measures of

- injection, and
- storage of reservoir fluids and flowback in injection horizons.

These monitoring concepts constitute a practical recommendation based on the international knowledge available up to January 2014.

It is recommended to test and appraise the monitoring concept within the framework of demonstration projects or pilot bore drilling operations.

2.3 Current data resources: analyses of the deeper bedrock system

The relationship between the shallow and the deep groundwater must first be examined. The key factors listed below play a major role in the flow of groundwater through bedrock formations:

- The hydraulic gradient;

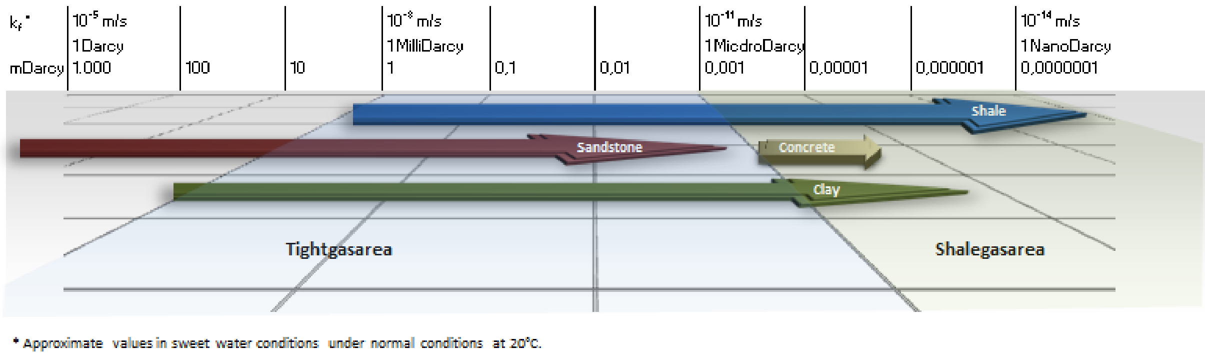
- The direction of the hydraulic gradient;
- The specific permeability properties of the aquifer bedrock material.

The following rule applies in systems with normal hydrostatic pressures:

Groundwater motion is only possible if the water can flow from a high hydraulic potential (high energy potential) to a lower hydraulic potential (low energy potential).

A certain degree of bedrock permeability is required to allow groundwater flow. From a bedrock permeability of $k_f = 10^{-12}$ m/s or 0.0001 millidarcy (mD), advective transport practically ceases (see Fig. 1) and the only major transport process taking place is by diffusion.

Fig. 1: Permeabilities of bedrock and construction materials

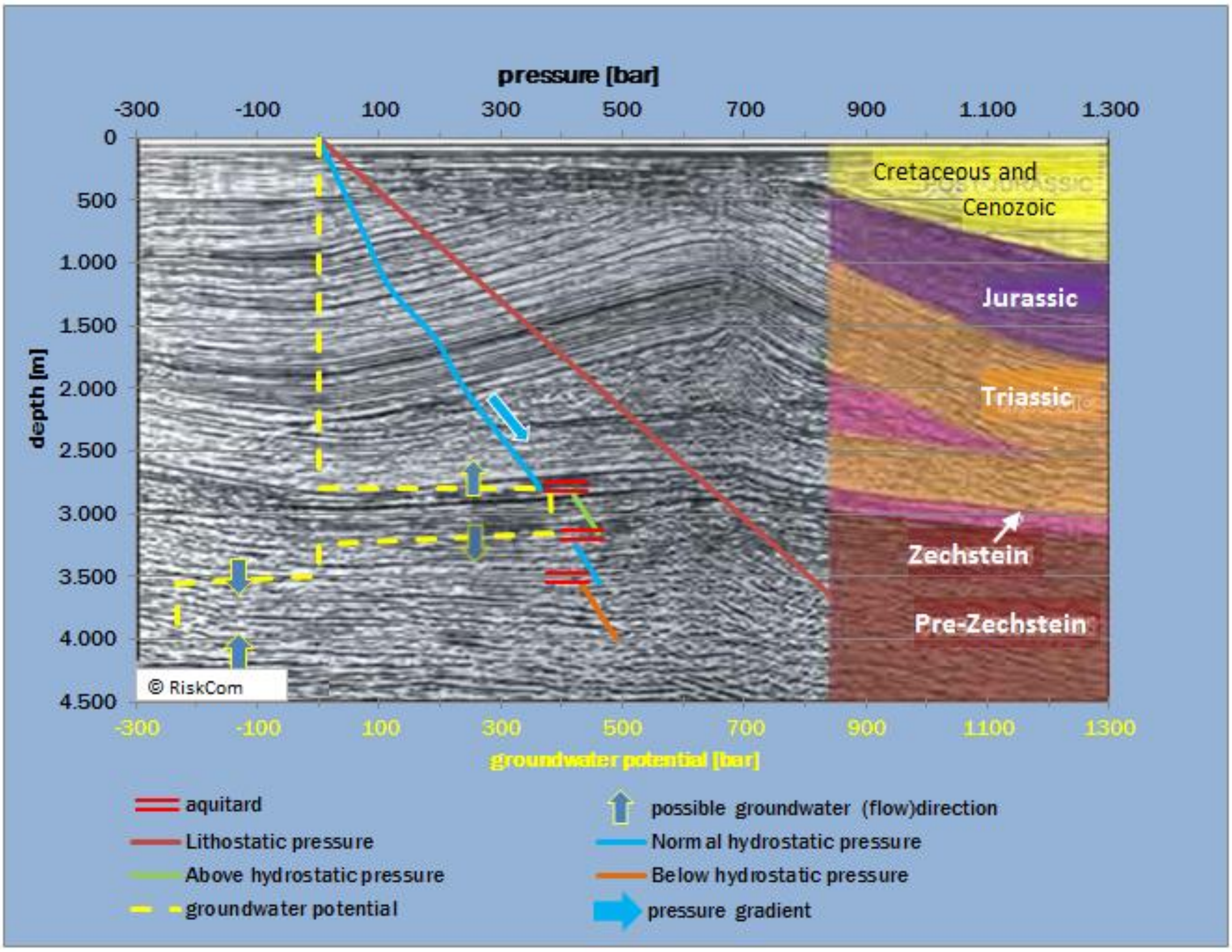


RiskCom GmbH, 2013

The groundwater or pore water present in the deeper bedrock horizons characterised by overpressure or below hydrostatic pressure conditions has in contrast to horizons with hydrostatic pressure due to the extremely low permeability of the barrier horizons no direct connection with the near-surface groundwater. It is therefore not actively involved in the hydrologic cycle.

This is illustrated by Fig. 2 in which the groundwater potential is represented by a yellow line. The vertical progression of the line with increasing depth indicates that there is no upward movement of water between different aquifers in the bedrock. However, this only applies if the geological horizons have no direct contact with the ground surface or the near-surface groundwater. Further explanations, in particular regarding the overpressure zones, are provided in the full version of the report.

Fig. 2: Conceptual presentation of the deeper bedrock system with pressure conditions and groundwater flow directions



©RiskCom GmbH, background: seismic profile of the deeper bedrock system in the North Sea for illustration purposes, Stewart, 2007

2.4 Current data resources: above-ground and underground risks

The treatises published to date show the following: in terms of frequency, the risks arising from above-ground activities conducted in connection with prospecting or extraction drilling are comparable with those performed in connection with numerous industrial processes.

Above-ground risks with varying degrees of impact result from leakages or accidents, for example. They can lead to the contamination of the upper aquifer.

Underground risks during shale gas extraction are mainly caused by:

- Damaged prospecting and extraction boreholes;
- Deficient on-site implementation;
- Possible external weak points such as:
  - Insufficient filling of disused boreholes;
  - Insufficiently-developed geophone boreholes;
  - Incomplete or deficient collection of geological and seismic data during the planning process.

Such factors can lead to the potential contamination of the deeper-lying groundwater.

These issues in particular were taken into close consideration during the development of the monitoring concept.

A temporal analysis of risk impacts shows that there is normally only a short delay between the occurrence of an above-ground risk and its impact. However, in the case of underground risks, there is a considerable delay between the occurrence of an incident and its impact.

Monitoring of the individual aquifers in the different geological horizons must therefore take the following aspects into account:

A significant period of time can elapse between the occurrence of an incident and the detection of a directly-related groundwater contamination. This affects immediate damage mitigation measures on the site.

2.5 Assessment summary and recommendations for further procedures: monitoring concept

The monitoring concept must be specifically adapted to each site, i.e. to:

- The regional and local geological and hydrogeological conditions;
- The size of the investigation area;
- The existing boreholes;
- The parameters to be investigated (for details, please consult the full report).

A geological-hydrogeological site analysis must therefore be conducted prior to the development of a site-specific monitoring concept.

It is furthermore essential to conduct baseline monitoring ("zero" state). This will provide detailed knowledge of the groundwater composition prior to the commencement of the frac process, in particular regarding the substances already present in the groundwater. It will then be possible to demonstrate that the frac chemicals used and also anions, cations and, where applicable, the naturally occurring radioactive substances (NORM) that are typically present in deep bedrock horizons, are not already present in the groundwater prior to the interventions.

It is recommended to conduct a thorough hydrochemical analysis with data collection and a sufficiently long run-up period. This should be performed in:

- existing groundwater wells, where present, and
- possible catchment monitoring wells operated by the water supply services in the greater upgradient and downgradient area.

The baseline monitoring measure should be completed at the latest when construction of the well pad is commenced. As frac measures will already be carried out during the exploration drilling operations it is also recommended to conduct baseline monitoring of the groundwater horizon used for drinking-water extraction (see Tab. 1 below).

It is recommended to conduct continuous surveillance monitoring to document evidence and to perform trend analyses.

- this should take place in particular during the entire frac process, and also
- during the production and demolition phases and later.

Surveillance monitoring should begin at the latest when the extraction borehole is being drilled, whereby a systematic and regular monitoring process must be ensured:

- prior to and during the frac process;
- during the gas extraction process;
- until demolition.

Further control measures are required in addition to this. These apply to the technical instruments such as borehole density measurements, pressure measurements, micro-seismic measurements and others.

As soon as a prospecting area has proven suitable for extraction and the extraction boreholes are being drilled, it must be ensured that qualified groundwater monitoring wells are developed in the following horizons:

Tab. 1: Overview of the aquifers to be monitored for prospecting, extraction and injection

Aquifer	Prospecting and extraction		Injection
	Baseline monitoring	Surveillance monitoring	
Top groundwater horizon (no drinking-water extraction)	X	X	X
Aquifer relevant for drinking-water extraction (drinking-water aquifer)	X	X	X
First aquifer below the last drinking-water aquifer	At present only intended for demonstration purposes.	X	X
Horizon up to approximately 200 m - 300 m above the frac horizon	At present only intended for demonstration purposes.	X	Only for pressure monitoring

The sampling cycle and parameter requirements are presented individually in the full report for

- each groundwater horizon, and
- the respective phase.

These phases include the construction of the drilling site, the drilling, frac, extraction, demolition and post-operation phases.

During monitoring of the above-mentioned groundwater horizons, the analytical parameters oriented to

- the technical substances used for fracking (frac fluid formulations);
- the chemical composition of the water potentially mobilised by the fracking measures and
- possibly released gases (methane).

The requirements for the location and positioning of the geophone boreholes are not addressed in this report. Where possible, geophone boreholes should be combined with the groundwater or monitoring wells.

3 Fracking chemicals registry

3.1 Scope of work

Investigation of the possible creation of a nationwide fracking chemicals registry for the documentation and publication of chemical substances used during fracking.

3.2 Methodology

To fulfil this task, the following procedures were followed:

- For the purpose of this study, the experience gained with comparable registries in Germany and other countries was analysed;
- The purpose and benefits of a fracking chemicals registry were examined;
- In addition to this, a recommendation regarding the requisite contents of such a registry was also drawn up on the basis of the data available;
- Finally, the legal framework in Germany for a legally binding registry was also reviewed.

3.3 Registries currently in use

Different fracking chemicals registries have been operating in European and non-European countries for some years now.

The databases in the USA and Canada are known under the name of FracFocus. In many US states and a number of Canadian state provinces, notification obligations pertaining to fracking measures are regulated by law. However, the publication of fracking measures data in the FracFocus database is only compulsory in a small number of federal states in the USA. Moreover, the volume of the data stored on the individual fracking measures varies due to the differences in legislation at federal and provincial level.

In Europe, the International Association of Oil & Gas Producers (OGP) has been offering the "Natural Gas from Shale Fluid and Additive Component Transparency Service" Internet service (NGS FACTS) since the middle of 2013. The frac industry can use this service to voluntarily publish data on frac measures. As yet, only the data of some few frac measures, such as in Poland, can be called up on the Internet.

In Germany, the natural gas producers can provide information on frac measures conducted in oil and natural gas mining operations via the "Information platform for fracs in Germany" hosted on the website of the German Industrial Association of Oil and Gas Producers (Wirtschaftsverband Erdöl- und Erdgasgewinnung e.V., WEG). All hydraulic borehole treatments performed since 2010 are recorded in the database. As only tight gas drilling has been conducted in Germany since 2010, the data collection does not contain any information on shale gas drilling.

In addition to this, every person in Germany has the legal right to request information on frac measures from the state authorities. This information is furnished pursuant to the Environmental Information Act (Umweltinformationsgesetz, UIG) and the environmental legislation of the federal states. For this purpose, a fee-based application must be submitted to the respective public authority, which usually is the approval authority of the federal state in which the information is being requested. In the opinion of the author, the right to request information under the UIG (Environmental Information Act of Germany) does not contravene business and trade secrets of the company.

The state approval authorities are in possession of different types of information on frac measures. A nationwide, legally binding fracking chemicals registry does not exist, and is also not possible based on the environmental information legislation at national and regional state level.

3.4 Purpose and benefits of the registry

A complete and freely accessible fracking chemicals registry with the above-mentioned contents can:

- Contribute to greater objectivity in the current critical public discussion surrounding the chemicals used in fracking;
- Create greater transparency;
- Ease the workload of the public authorities that are obliged to provide information according to the environmental laws.

According to the jurisprudence of the Federal Constitutional Court, the creation of transparency constitutes an independent legitimate purpose of legislation and contributes to the formation of public opinion.

3.5 Legal requirements

In particular the Federal Environmental Agency, the Federal Institute for Geosciences and Natural Resources, and the Federal Institute for Occupational Health and Safety are possible candidates for the role of registry authority.

The introduction of a nationwide mandatory fracking registry obliging gas companies to provide information would encroach upon the

- fundamental right to freedom of action and also – depending on the legal opinion – on
- the right to freedom of profession and the guarantee of ownership principle.

As a result of the rule-of-law principle set down in Art. 20 Par. 3 of the Grundgesetz (Constitution of the Federal Republic of Germany), the establishment of such a register within the legal framework requires a legal authorisation basis. The federal government is granted legislative powers (economic legislation) under Art. 74 Par. 1 Item 11 of the Constitution in conjunction with Art. 72 Par. 2 Constitution and Art. 74 Par. 1 Item 32 Constitution (water legislation).

EU legislation poses no obstacles to the national regulation of a fracking chemicals registry.

In the opinion of the author, the data to be recorded in the registry do not affect the legally protected interests of the frac fluid manufacturers or frac companies. In particular, publication of the above-mentioned data does not constitute a breach of business or trade secrets.

Even if business and trade secrets were affected, publication of the data would be permissible according to the regulations set down in Section 9 Par. 1 Sentences 1 and 2 UIG (Environmental Information Act).

3.6 Recommendations

3.6.1 Legal form of registry

Against the background of this legal situation in Germany, the introduction and maintenance of a federal mandatory fracking chemicals registry by a federal authority on the basis of an independent federal law or an amendment of the Wasserhaushaltsgesetz (Federal Water Act - WHG) with free access for everyone via the Internet is to be recommended.

Alternatively, a trial voluntary registry could also be taken into consideration. The following conditions must be met for this purpose:

- The companies must be prepared to voluntarily provide the complete data requested for publication on an ongoing basis;
- Validation of the data by a public authority is required.

The willingness of the company to provide the data must not diminish and the data must be made available completely. This must be kept under observation for control purposes.

3.6.2 Registry content

The following information should be included in both the mandatory and the voluntary database:

- Name of the gas company and frac fluid manufacturer;
- Information on the fluid medium and the propping agents used;
- Precise designation of the chemicals used according to substance name and CAS Registry number;
- Quantity and percentage of chemicals in the frac fluid;
- Hazardous properties of the chemicals according to the EU CLP directive;
- The water hazard class of each chemical;
- Substance condition at time of injection;
- A presentation of the different fracking phases;
- Location of frac measure, and
- Details on flowback.

4 Flowback – Best practise for disposal, material flow balances

4.1 Scope of work

This report examines the extent to which environmentally friendly treatment and disposal of flowback and produced water (wastewater flowing to the surface after flowback) from shale gas extraction is possible. It furthermore puts forward proposals as to how this process can be embedded in a comprehensive water management concept. Concrete recommendations on the monitoring and balancing of water and material flows are intended to allow accurate and reliable balancing of the chemicals and water quantities used.

4.2 Methodology

To fulfil this task, the following procedures were followed:

The first step consisted of an extensive literature study to summarize the current state of knowledge on the following topics:

- Treatment of flowback and produced water;
- Waste and residue disposal;
- General water management in natural gas production.

In the second step, open questions were discussed with operators, authorities and the public.

The findings made it possible to derive conceptual and procedural recommendations for the treatment and disposal of flowback and produced water as well as for an overall water management concept. This was ultimately made possible by the many years of experience of the Institute of Sanitary Engineering and Waste Management in the fields of industrial wastewater treatment, waste management and process monitoring.

4.3 Flowback constituents

When flowback reaches the surface, depending on shale formation, it consists of the following components:

- Frac fluid;
- Formation water;
- Condensed water vapour above ground level.

In addition to additives used in fracking, flowback may also contain:

- Reaction products formed from additives during the fracking process;
- Mobilised solutes and solid products from the formation.

4.4 Classification of flowback according to different phases and treatment concept

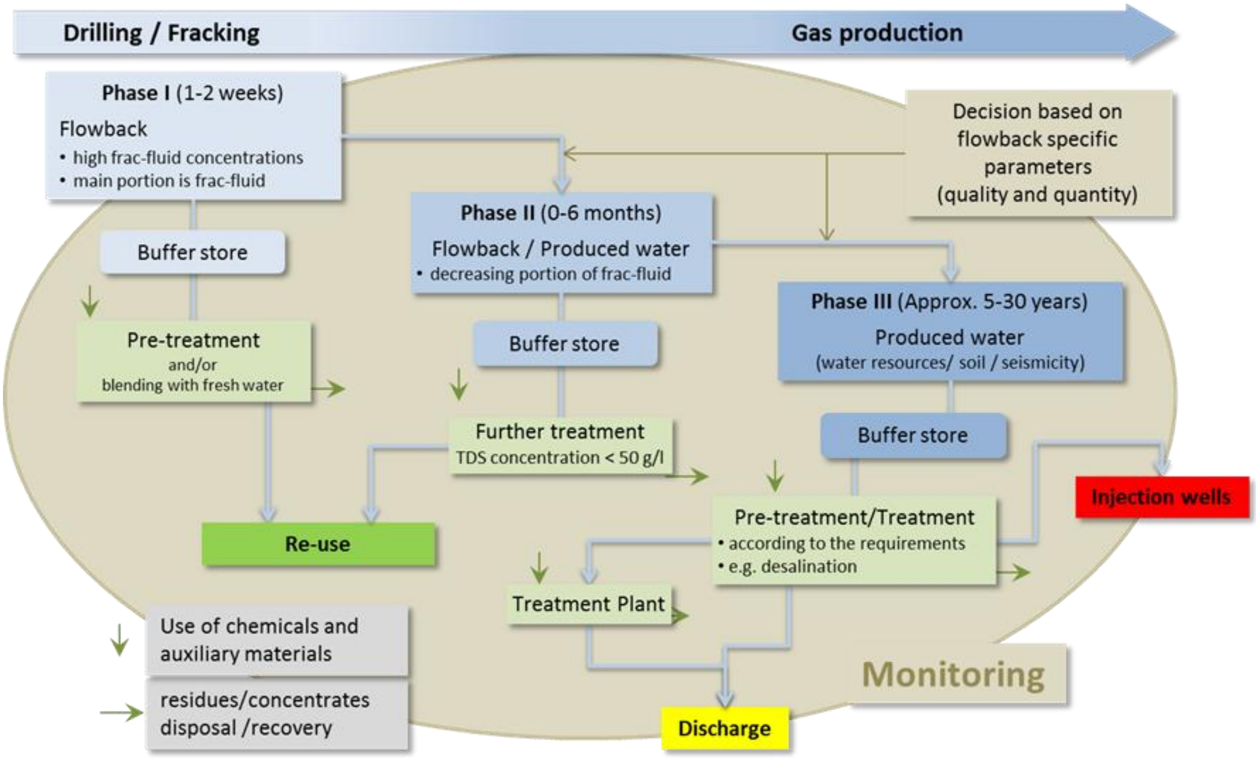
A comprehensive approach should be developed for flowback treatment. For this purpose, the entire volume of returned water should be divided into three different phases:

- Phase 1 “Flowback”;
- Phase 2 “Transitional phase”;

- Phase 3 "Produced water".

In addition to this classification, Fig. 3 also shows the proposed treatment paths for the wastewater flows in the individual stages (flowback/produced water).

Fig. 3: Classification of total volume of returned water in flowback and produced water, together with the proposed treatment options.



ISAHH, 2013

The temporal extension of the phase 2 "transitional phase" could differ according to situation, as this phase is influenced by a variety of factors. It is therefore recommended to define a parameter that will allow a clear description of the transition from the exploration stage to the production stage.

The return water can thus be clearly identified as either flowback or produced water. This can be carried out by means of an accompanying analysis.

Laboratory and pilot studies are required for the identification of such a parameter. The applicable legal framework must also be considered, particularly in terms of proof of obligation, permission and monitoring.

4.5 Treatment methods and goals

Numerous technical methods can be used for flowback treatment. Within the framework of this report, the applicability and availability of these approaches were examined.

According to the current state of knowledge, the treatment method should be capable of meeting the goal of the treatment. The treatment goals are as follows:

- Recycling;
- Discharge;

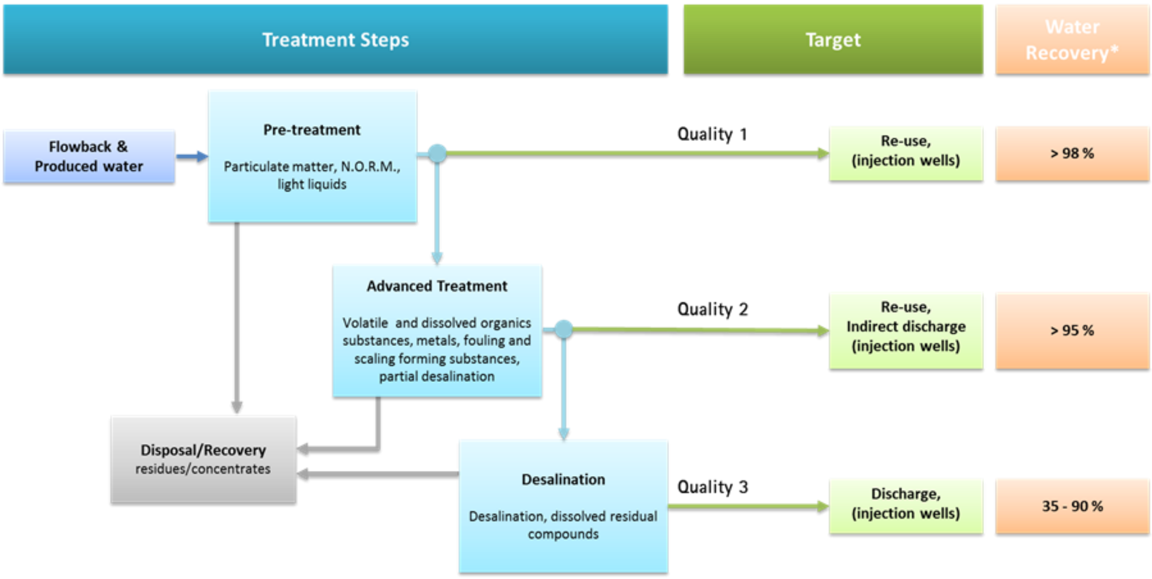
- Disposal (for example through injection wells).

The costs of a treatment system can vary considerably, depending on the quality of treatment required. Adequate treatment can only be achieved by a combination of different processing technologies.

The treatment goals and options for flowback management (i.e. recycling, discharge, and disposal) determine which treatment is to be applied. The different processing stages involved must be agreed with the authorities. This applies in particular for:

- Clustered flowback and produced water substances;
- The treatment of incurred residues and concentrates (see Fig. 4).

Fig. 4: Selection of flowback and produced water treatment steps according to the recycling and disposal target



From Acharys & Wilson, 2012

At present, no process chain can be regarded as a state-of-the-art method in regard to flowback and produced water treatment and disposal.

The state-of-the-art technology should be defined by setting down the requirements to be made of parameters that must be adhered to, for example, in an appendix to the German Wastewater Ordinance.

Recycling of the wastewater produced and replacement of freshwater should take priority over disposal. However, the amount of recovered water decreases with increasing treatment goals.

The costs, benefits and environmental impacts must be weighed up against each other according to the principle of proportionality.

4.6 Water management and monitoring concept:

The treatment and disposal of flowback and produced water can be only be achieved within the context of a comprehensive regional water management concept. Every development of a shale gas formation and every individual fracking activity should be accompanied by a comprehensive well-site and regionally-specific monitoring programme to allow reliable balancing and long-term documentation of water and material flows. This includes, for example, an analysis plan, defined sampling, an electronic logbook and much more. Regulatory supervision can also be integrated.

The exploration of natural gas from shale deposits is always conducted on a large area. For this reason, the following factors must be taken into account for the entire exploration area:

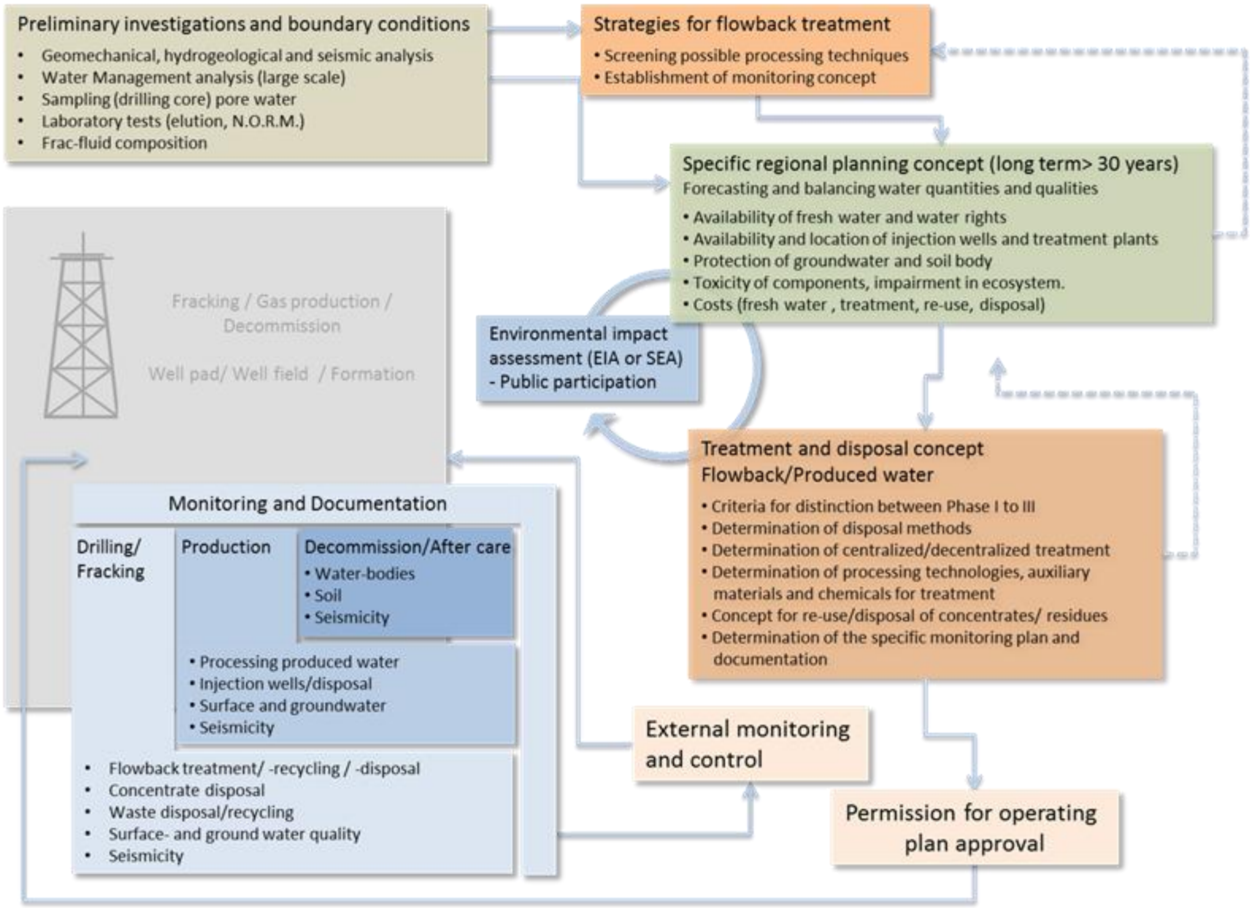
- Provision of input material;
- Treatment and disposal of wastewater and waste;

The preliminary investigation should include research on:

- A regional planning concept for the formation;
- An associated surface and groundwater catchment area.

Fig. 5 illustrates the relationships and procedures involved in the development of flowback treatment and disposal concepts. This includes the management of the relevant water and material flows. The figure demonstrates the crucial role of a comprehensive monitoring programme in regard to security and surveillance, which should be organised, conducted and managed in line with the groundwater monitoring programme.

Fig. 5: Relationships and procedures in the development of specific flowback treatment and disposal concepts. The importance of a comprehensive monitoring plan for security and surveillance is also illustrated.



ISAHH, 2013

4.7 Recommendations

To ensure an appropriate legal framework for the oil and gas extraction industry and the regulators, the following steps are recommended:

- A state-of-the-art flowback and produced water treatment cannot currently be defined. It should be defined by developing a sector-specific solution in the form of a separate appendix to the German Wastewater Ordinance which could be integrated at European level into a BREF document;
- A comprehensive database must first be created to allow an appendix to the German Wastewater Ordinance or a BREF document to be drawn up;
- In a first step, the appendices for wastewater from other sources with similar pollutant loads/load patterns must be referred to.

Research and development required by the recommendations:

- Within the framework of demonstrations, pilot tests on the treatment and recycling of flowback and produced water should be conducted. This should allow valid scientific insights to be obtained and a "state-of-the-art" approach to be developed;
- Systematic process selection and specification can doubtlessly be conducted beforehand. However, this should be scientifically backed by pilot or field tests with real wastewater and waste materials;
- This also applies to the ongoing monitoring of flowback and produced water treatment and disposal which should also be systematically studied by means of a demonstration project. The knowledge thus gained can be used to ensure compliance of the monitoring programme with the requirements of the supervisory authorities.

5 Compilation of scientific knowledge on GHG emissions and climate balances

5.1 Scope of work

This chapter presents the energy and climate balances of shale gas in comparison to conventional natural gas and oil and for the electricity generated from the respective fuels.

In a second step, shale gas electricity is compared with the German national mix, electricity from imported coal and oil sands.

5.2 Methodology

The analysis is based on calculations for a new combined-cycle (CC) power plant for electricity generation from gas and oil, and a new steam-turbine power plant for imported coal.

The key data for conventional production, processing and transport as well as the data for the power plants are taken from the GEMIS Version 4.9 database[2] which takes extraction, processing, transport, manufacturing of all processes, auxiliary energies and auxiliary material inputs into consideration.

The climate balance was determined on the basis of greenhouse gases emissions (GHG), primarily CO_2 and CH_4 emissions[3]. The fossil energy sources to be compared with shale gas include natural gas from Germany (conventional production mix), Norway and Russia as well as the supply mix in Germany. For oil and imported coal, the average German supply mix for the respective supply year was used.

The time horizons used to calculate the life cycles were the year of 2010 (as a fictive base year) and the year of 2020 (as a scenario).

The life-cycle balances for German shale gas were detailed as follows:

- The quantification of GHG emissions due to additional work required for drilling (exploration and extraction of shale gas) based on existing studies and assumptions on the implementation of future shale gas projects in Germany;
- The role of methane leakage during shale gas exploration and production as far as it differs from conventional natural gas.

Shale gas processing and pipeline transport are not different from the respective conventional natural gas processes and were, therefore, taken to be equal.

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[2] GEMIS = **G**lobal **E**missions **M**odel for **i**ntegrated **S**ystems, an energy and material flow model (see www.gemis.de or http://www.iinas.org/gemis-download-en.html)

[3] The CO_2 equivalents given here also include other GHG emissions (N_2O, F gases). The GEMIS can show the individual contributions of all GHG emissions.

5.3 Settings for shale gas extraction

The analysis of GHG balances for shale gas is based on the assumption of four types of situations (settings) applying to North German sites[4]:

- "low" describes favourable geological situations (shallow depth, large reservoir volume), low exploration requirements (high success rate of exploratory drillings, short horizontal drilling length) as well as low CH_4 emissions during extraction and no post-production emissions;
- "med" represents less favourable geological and exploratory conditions and also excludes post-production emissions;
- "high" stands for very unfavourable geological and exploratory/production situations, and excludes post-production emissions as well;
- "hi2" indicates the "high" case plus CH_4 emissions from the post-production phase.

A hypothetical production scenario for Germany first uses the "low" settings and later also the "med" and "high" settings.

All settings considered here are based on the assumption of the complete capture and use of solute CH_4 from flowback. This is significantly different to existing production in the USA. A sensitivity analysis for all settings therefore also takes the uncontrolled release of CH_4 from the flowback into consideration.

The "hi2" setting describes the risk of CH_4 escaping through geological rifts or fault lines subsequent to shale gas extraction. Through ground water contact and subsequent release it enters into the atmosphere. As with the calculations of the respective CO_2 equivalents,

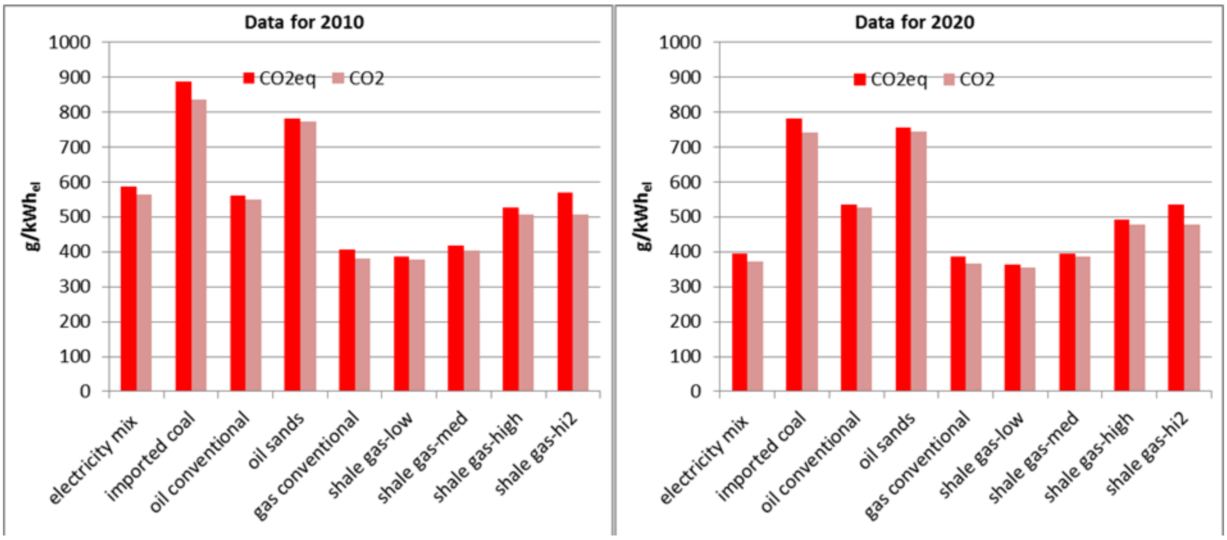
- a 100-year time horizon is used;
- a residual share of 25% of the original production volume is assumed;
- the release of 1% of the residual inventory within the time horizon is assumed as an upper boundary.

Result 1: Comparative Balances of Shale Gas and other Energy Sources

Fig. 6 shows the comparative GHG emission balances results for electricity from various energy sources in 2010 und 2020.

[4] Potential sites in Southern Germany were excluded from the analysis, as agreed with BMUB and UBA.

Fig. 6: Comparison of GHG Emissions of Electricity Generation from Shale Gas and other Electricity Supply Options in 2010 and 2020



Source: IINAS calculation with GEMIS 4.9; CO_2 equivalents for GWP_{100} based on IPCC (2007)

Results:

- For the "low" and "med" settings in the year of 2010, electricity from shale gas has roughly the same GHG emissions as electricity from the German natural gas mix;
- The "high" setting generates approximately 30% more GHG emissions, the "hi2" setting generates even 40% more;
- These relations are valid also for the year of 2020, though all electricity generation options show slightly lower GHG emissions;
- The GHG emissions from electricity generation from shale gas in 2010 roughly equal those of the German electricity mix. However, in 2020, they are 30% ("high") to 40% ("hi2") higher than the respective emissions, as the 2020 electricity mix has significantly lower GHG emissions than in 2010;
- Compared to electricity from imported coal and oil sands, electricity from shale gas has lower GHG emissions for all settings, which are roughly on the same level as electricity from light oil.

Result 2: Sensitivity Analysis of the Settings

Extreme variation of the drilling length in the shale gas settings has only very small impacts on the results for electricity from shale gas. The definition of the settings in regard to drilling length can therefore be considered sound.

An extreme variation of the diffuse CH_4 emissions also has a very small impact on the resulting GHG emissions, so that the definition of the settings with regard to this parameter can also be considered as sound.

The results calculated here are valid also if – as a sensitivity case – the CO_2 equivalents are determined for a 20-year rather than a 100-year time horizon. The resulting higher weighting of CH_4 increases the GHG emissions of electricity from natural gas and shale gas, but this is also the case for electricity from coal and oil as well as for the electricity mix.

The GHG emissions from electricity from coal and oil are therefore also higher than those from natural gas or shale gas for shorter time horizons.

In addition to this, the calculation of the sensitivity case of a complete release of CH_4 from the flowback shows that for the 100-year time horizon, the GHG emissions of electricity from shale gas increase substantially, but are still lower than those from imported coal and oil sands.

If the GHG balance is calculated for the 20-year time horizon, the GHG emissions of electricity from shale gas with complete CH_4 release from the flowback are higher than those from oil sands, but still lower than from imported coal.

5.4 Summarizing evaluation and recommendations

The presented climate balances for shale gas and the comparison with respective balances for other fossil energy carriers were conducted for each specific unit (MJ_{gas}, kWh_{el}). These simplified comparisons are subject to the following substantial limitations which influence their validity:

- In real supply situations, the settings for shale gas will have different percentages, similar to conventional oil and oil sands for example. Future shale gas use would presumably first make use of "low" setting sites. With increasing shale gas production, the more GHG-relevant sites according to the settings "med" and "high" would, however, have to supply increasingly larger percentages, and could – over the total scenario time horizon – dominate the integrated absolute emissions;
- Furthermore, shale gas development does not necessarily lead to a reduction of coal use for example. In the national energy mix of the USA, coal was replaced by shale gas in recent years, but low-cost coal was exported to Europe with the consequence of rising emissions from increased coal use there. The international substitution effects therefore need to be considered to determine the global total emission balance and, consequently, the effective climate impacts of shale gas;
- Moreover, there is competition for investment capital for low-GHG energies: the IEA projects possible investments for unconventional gas extraction of approximately seven trillion US$ by 2035 (IEA 2012). These funds would therefore not be available for developing renewable energies and energy efficiency (UNEP 2012);
- A comprehensive analysis of the indirect substitution effects and investment funds competition for shale gas for Germany is not available. Such an analysis should be carried out to complement the simplified GHG balances presented here.

6 Scoping analysis of the climate balance in Germany

6.1 Scope of work

This chapter analyses:

1. The framework that a scientifically sound data collection would need to evaluate the climate balance of shale gas for German production conditions;
2. The requirements for such an endeavour and the financial resources needed;
3. The question of whether the existing methods of the IPCC as the basis for the national and European emission reporting are sufficient for reporting on GHG emissions from shale gas production or whether they need further development. For this purpose, findings from an IPCC Expert meeting were also consulted.

6.2 Methodology

The existing data were first collected and evaluated regarding suitability, validity and completeness. An analytical concept was then developed on this basis and respective recommendations derived.

6.3 Results and evaluation for 1. and 2.

The following data must be collected to allow valid GHG balances for shale gas in Germany:

- Data on the energy input for vertical and horizontal drilling for shale gas production as well as for the success rate of exploratory drillings, with respective information on the estimated ultimate recovery (EUR).

Requirements: the requirements for this are minimal as these data are disaggregated by the industry so that only the statistical collection and the reporting systems require adjustment. The requirement for statistically differentiated collection is estimated at 1 - 2 person/s-month.

- An inventory of technologies for CH_4 reduction in share gas exploration and production on the level of individual enterprises and drilling sites.
- The attribution of atmospheric CH_4 concentrations measured spatially disaggregated at the individual share gas production sites through respective measurement campaigns and recalculation using atmospheric dispersion models.

Requirements: the inventory would require a few working days and could be included in the collection of the data on drilling activities. The measurement campaigns and subsequent atmospheric modelling could be carried out for a some ten thousand Euros per production site if immediate access to the data on the technology inventory of the site is possible.

- The empirical collection of potential CH_4 releases after conclusion of shale gas production (post-production) is possible through intense monitoring of the groundwater bodies (see chapter Groundwater monitoring concept in this study). The groundwater monitoring should be complemented by periodic monitoring of atmospheric CH_4 background concentrations (see below).

- Collection of spatially disaggregated data on CH_4 background emissions to verify the technology inventories and to allow future site-specific monitoring of potential post-productions emissions against respective baselines.

Requirements: this would require some ten thousand euros per site and monitoring year. It should be noted that significant cost reductions for CH_4 measurement are expected in the coming years.

6.4 Results for 3.

- The UN reporting formats for national GHG inventories and the national inventory reports contain some data on the GHG emissions of the energy sectors. The current reporting disaggregation for energy carriers should be extended to the respective extraction technologies and applied GHG reduction technologies.
- The IPCC Guidelines for national GHG inventories offer generic data for natural gas extraction but there are no specific data or methods for shale gas. The respective disaggregated Tier-1 emission factors for shale gas production should therefore be developed. Methodological references for Tier 2 and 3 data should also be provided which should indicate the different gas constituents depending on the geological situation. Furthermore, existing data on emissions from flaring should be improved and more efficiently differentiated; depending on the details of the extraction technology and operation, very different emissions can occur.
- With regard to the negotiations for a post-Kyoto climate regime for 2020, a revision of the IPCC Guidelines is considered appropriate in the coming years. Respective preparatory work should be started immediately.
- EU Member States must annually report their national GHG emissions to the European Commission. From these figures, the European Environment Agency prepares a publication of the GHG emissions of the total EU using further data from EUROSTAT. Other reporting obligations exist for companies subject to the European Emission Trading System (ETS). These mechanisms build on the IPCC Guidelines and do not provide further information on GHG emissions from shale gas production.

A differentiation of the international reporting obligations under the UNFCCC with regard to extraction technologies is required, especially with acknowledgement of the increasing proportions of oil sands in Canada and shale gas in the USA, and expected developments for shale gas in countries such as China. The respective preparatory work should be followed-up and supported by Germany. This would allow more adequate and transparent GHG reporting for unconventional fossil energy carriers to be implemented internationally.

7 Induced seismicity

7.1 Scope of work

- The topic of induced seismicity addresses the extent to which an additional seismic risk arising from the production of shale gas is to be expected;
- The question of whether the existing technologies are generally controllable was examined against this background;
- Finally, the resulting risks were identified and guidelines on how to deal with them formulated.

7.2 Methodology

This study analyses the experience gained from fracking activities both in Germany and abroad. It was shown that the project phases of drilling, fracking, production and disposal of flowback/produced water must be considered separately in an investigation of induced seismicity. Other technologically related methods from the energy resources mining sector were included in the study, for example, the exploitation of hard coal, conventional oil and gas as well as geothermal energy.

7.3 Current database resources

Within the context of shale gas extraction, induced seismicity is considered a primary risk. A hazard is considered to exist if exploration or production, according to mining legislation, cause seismic events and vibrations which are:

- considerably stronger than the background of local natural seismicity;
- exceed the state-of-the-art thresholds set down for possible damage.

However, if an event is merely noticeable, this does not mean that it may cause damage.

As with any other interference with the subsurface, drill-based mining may cause vibrations. The threat in the case of shale gas production is small, also when compared to other mining methods.

This minor threat applies in particular to the project phases of

- drilling;
- fracking;
- production;
- closure of all installations.

During the project phase of fracking, noticeable seismic events are extremely rare. Only two events among the hundreds of thousands frac operations have been reported. No damage was reported in either of these two cases. For the project phase of flowback/produced water injection, however, a seismic threat cannot be categorically excluded. Disposal well reports are available from abroad on the injection of wastewater from shale gas mining projects and technically comparable measures such as wastewater injection from other sources or the reinjection of thermal water in the geothermal industry. In all these applications, measures must be considered to make this operation phase (disposal phase) controllable in regard to the seismology aspects.

In general, seismic events can be classified as follows:

- Seismic events too small to be noticed by people, for instance caused by shearing of the drill bid, which occur all the time;
- Rare events that may be noticed by people or – in very few cases- may cause minimal damage such as small plaster fractures in buildings;
- Structural damage, damage to public property, infrastructural damage or even personal damage is statistically-very unlikely.

Massive shale gas production will of course increase the number of registered events. However, this increased number of events will be distributed over a larger area so that an increase in the magnitude of the events is not to be feared. For an analysis of the threat in a certain location (location of emission), concentrated gas extraction in the surrounding area would have no influence, as the PGV values (peak ground velocity) decrease quickly with increasing distance from the source.

7.4 Controllability and controlled operation

There is no doubt that every technology includes risks. These risks must be mitigated or minimised by technical and non-technical measures, but a degree of risk will always remain in any case. This makes the term ‘controllability’ relative. A technology cannot first be deemed controllable only if the residual risk can be completely eliminated.

Minimising the risk and consequently increasing controllability may be achieved by:

- reducing the occurrence probability of an event;
- reducing the maximum possible damage of an event.

In some cases, these two factors are interconnected, the probability of occurrence will therefore depend on the strength of the event. For the case of induced seismicity examined in this report, the Gutenberg-Richter-relation and its variants confirm these relationships.

Measures to control the technology of shale gas production from a seismological viewpoint must monitor and modify the influencing factors. They are summarised in the main report under the term of ‘controlled operation’ which essentially includes:

- The selection of suitable locations for disposal wells;
- Seismic monitoring with appropriate monitoring station networks;
- Reaction plan (traffic light system control);
- Technical consultant support.

These measures can help ensure that the seismicity caused by natural background activity does not increase and that no damage is caused.

7.5 Legal regulations

Experience shows that the existing legal regulations are sufficient. The application of the proposed measures is mandatory for example during operational planning in the geothermal industry.

The following also applies:

- The seismic risk alone does not necessitate amendments to the existing legislation or binding environmental impact assessments (EIAs);
- Operators must compensate any damage incurred if they cannot show that they did not cause the damage;
- Proof is usually furnished by showing that the guidance values defined by the state-of-the-art have not been exceeded. This is generally demonstrated by means of a suitable monitoring well network.

7.6 Recommendations

The following recommendations allow the general controllability of shale gas exploitation. Seismic events that may cause damage are extremely unlikely if these guidelines are followed.

- All projects concerning gas production from shale deposits should be accompanied by a seismological baseline study as part of the EIA. This baseline studymust be provided by an independent seismological expert. The expertise must be continuously updated during the entire project within the framework of a technical-consultant supervision of the project with ongoing integration of the newest data and facts available;
- This applies in particular to disposal wells. The seismological, tectonic and petrological findings must be taken into consideration for the selection of suitable locations. Sufficient injectivity, the exploration of pre-existing faults, the estimation of the local stress field and the evaluation of the natural seismicity are essential;
- Areas to be excluded for disposal wells include “Zone 3” earthquake areas and areas in which tectonic stress along recently active faults is known of. Areas of reduced pressure (i.e. below hydrostatic pressure) from abandoned oil/gas deposits may, in contrast, be particularly suitable;
- ‘Controlled operation’ measures that have been successfully tested by the geothermal industry must be made obligatory in all operation phases of shale gas projects. The individual components must be adapted to shale gas extraction if they differ from geothermal applications.
- This procedure essentially consists of:
    - Monitoring;
    - Reaction plan (that can be adopted from geothermal projects for shale gas extraction);
    - Planned start-up of system over a suitable period of time (for example also a system for flowback injection);
    - Technical consultant support.

- To improve transparency within a controlled and controllable activity, additional non-technical measures could include:
    - Formal communication with authorities;
    - Public presentations of data in the Internet;
    - Neutral ombudsman to settle disputes;
    - Supervisory team including members of the public;
- Changes to laws are not necessary from a seismological viewpoint. Regulations on a sub-law level beyond existing standards such DIN 4150 or GTV 1101 are also not urgently required. Existing mining legislation and its attendant operation plan procedure are sufficient for seismicity control. This has been proven by geothermal projects;
- Research in many of the areas mentioned must be conducted as a scientific contribution. This applies in particular to demonstration projects.

8 Competing uses and environmental protection

8.1 Scope of work

In this key topic, the spatial impacts of exploration and unconventional extraction of shale and tight gas are assessed. These assessments are then evaluated under the aspect of possible conflicts with competing uses and environmental protection interests.

8.2 Methodology

For the purpose of this study, the following procedure was applied:

A comprehensive international literature review was first performed to provide the foundation for the study.

The competing uses, environmental impacts and risks associated with unconventional gas extraction can only first be recognised by the large-scale analysis of a development area in its entirety, as the individual activities involved act cumulatively together. They cannot be adequately judged from a consideration of individual well sites. For the assessment of possible conflicts, three scenarios were developed. The starting point was a hypothetical catchment area with an assumed area of 260 km^2 (approximately 16 x 16 km) and varying well-pad densities.

The analysis addressed the following six topics:

1. Housing and traffic structure;
2. Agriculture and forestry;
3. Water management/water protection;
4. Further types of underground space utilisation;
5. Recreational use, landscapes and townscapes;
6. Species and habitat conservation.

An evaluation was carried out only insofar as this was possible independently of location.

8.3 General characteristics of shale gas production

The exploration and production of natural gas by fracking and multiple horizontal boreholes (high-volume hydraulic-fracturing) differs significantly from conventional gas production. The latter is carried out at discrete sites that directly puncture the reservoirs and is clearly divided into separate temporal phases.

High-volume fracking as in the USA, however, is characterised by diverse and temporally overlapping activities. This results in a growing number of spatially distributed well pads and individual boreholes. Moreover, the areal development of a production area by means of fracking is associated with a significant increase in the consumption of resources. Decommissioning is rare during extraction phases, at least in the USA. In the case of a rapid fall in yields, the option of re-fracking or re-drilling should be left open. Possible consequences include:

- Directly conflicting uses caused, for example, by surface loss;

- Indirect effects on uses and environment, for example by permanent disturbance effects in the vicinity, pollutant release, fragmentation of natural areas.

8.4 Housing and traffic structure

Germany is comparatively densely populated. For this reason, substantial utilisation conflicts can be expected in the extensive development and production of shale gas. In particular in regard to:

- Living quality;
- Infrastructure;
- Health;
- Material goods.

The development phase in particular is associated with the following impacts:

- Risk of leakages due to numerous handling operations and transport of large volumes of chemicals, hazardous substances and fluids;
- Substantially increased heavy goods traffic;
- Operating noise (especially from diesel motors in the pumps and from delivery traffic);
- Light emissions.

Air pollution and particle emissions are also to be expected in the immediate vicinity of the well pad. These are caused by mixing processes, equipment operation and drilling-related gas emissions.

Emissions can cumulatively pose health hazards due to reduced air quality in concentrated areas.

To protect against emissions and accidents it is therefore recommended to only permit well pads in substantial precautionary distances to residential areas.

Land use may also indirectly affect living quality. This can be caused by the increased utilisation and construction of new access roads and pipelines. The transport infrastructure of rural towns can be overstrained by the significant increase in heavy transport traffic.

8.5 Agriculture and forestry

- In the area of the well pads, access roads and utility lines, a loss of soil functions and plant population is to be expected;
- The use of large amounts of water during fracking can lead to competing regional uses, for example with farming or with drinking water;
- The probability of accidental discharges of toxic substances into agricultural and forestry areas increases with the growing number of boreholes, transports and utility lines, for example by spillage during pipeline transport of flowback and produced water;
- In the United States, cases of livestock and game contamination have become known in connection with open flowback tanks.

The following areas are therefore considered to be unsuitable sites:

- Ecologically important forest biotopes;
- Forest research sites;
- Seed stock areas.

8.6 Water resource management/water protection

The water requirements of a well pad depend primarily on the number of frac operations performed during the field development and stimulation phase. Extensive well-pad development can lead to the following overall effects for water management and protection:

- Regional drawdown of groundwater levels;
- Changes in the hydrodynamics of groundwater and surface waters;
- Changes in flow velocity, temperature and oxygen conditions including significant ecological consequences.

The risk of groundwater and surface water contamination exists:

- on the surface due to improper transportation, storage and handling of chemicals and flowback or produced water;
- in the subsoil due to gas migration and hydraulic short-circuiting.

The disposal of large amounts of flowback and produced water involves additional risks. Due to the potential environmental risks, the following measures must also be prohibited in a number of areas:

- Development of well pads;
- The construction and use of access roads;
- The construction of pipelines for the transport of water endangering substances.

These prohibition areas primarily include:

- Drinking water protection areas;
- Medicinal spring protection areas;
- Areas of mineral water sources;
- Floodplains.

In addition to this, a sufficient vertical and horizontal precautionary distance must be maintained to protected areas.

8.7 Further types of underground space utilisation

Unconventional, tight and shale gas production competes with other underground uses. This depends on the local and regional geology. Competing uses are:

- Extraction of raw materials such as coal mining, oil and gas extraction;
- Geothermal energy;
- Energy storage;

- Carbon Capture and Storage (CCS);
- Underground waste storage.

Possible risks are posed, above all, by corresponding pathways and seismic events. The proximity of inadequately sealed old wells, for example, poses the risk of accidental releases.

Hydro-geothermal use, CCS deposits and energy storage (for example in salt caverns and deeper aquifers) occur in regions that could also be used for the shale gas production. This gives rise to an increased risk and potential for conflict. The three-dimensionality of the subsoil may require the maintenance of both vertical and horizontal distances.

Note, the Federal Mining Act of Germany (BBergG) does not set down regulations governing total spatial planning and cross-project subsoil utilisation. However, the problem is increasingly being receiving attention in individual regional development plans.

8.8 Recreational use, landscapes and townscapes

Conflicts with recreational use and adverse effects on the landscape are to be expected for the reasons mentioned under "Housing and traffic structure". They are frequently possible due, above all, to the cumulative character of well pad development.

The main areas affected are:

- Spa areas;
- Health resorts;
- Camping, weekend and holiday home areas;
- Protected landscape areas such as national parks and nature reserves;
- Biosphere reserves.

Indirect effects such as landscape dissection by roads and pipelines must be expected in addition to the above-mentioned direct adverse effects.

Fracking normally clearly clashes with the goals specifically defined for many recreational areas, in particular national parks, nature and biosphere reserves.

8.9 Species and habitat conservation

The development and operation of well pads, access roads and pipelines also affect species and habitats beyond the actual development area itself. Adverse effects caused by noise, transport activities or pollutants are common examples.

Indirect adverse effects on the flora and fauna, for example due to changes in the water regime, are also possible. Due to the extensive spatial development of a production area, the disturbance radii to be maintained around well pads, access roads and pipelines often lead to a significant loss of habitat functions. They are therefore at odds with species protection and with the objectives of protected areas.

In this context, outstanding consideration must be given to:

- Explicitly designated sites pursuant to Section 20 et seqq., Federal Nature Conservation Act of Germany (BNatSchG);

- Specific natural areas and landscapes pursuant to Section 30, Federal Nature Conservation Act;
- The habitats of particularly protected species pursuant to Section 44, Federal Nature Conservation Act.

The status of different types of protected areas conflicts with the extensive spatial development and production of shale gas. These areas must be excluded from development and production operations. The following areas in particular are affected:

- Biosphere reserves;
- Nature and wildlife sanctuaries;
- Nature reserves;
- National parks;
- Natura 2000 areas.

Due to the disturbance radii, the precautionary distances should be checked and adhered to. The following sites are also areas that need to be protected:

- National natural monuments;
- Natural monuments;
- Protected landscape areas;
- Legally protected biotopes.

In some cases, however, adverse effects can be avoided by appropriate site selection. In potential areas of unconventional natural gas production, nature conservation legislation frequently does not take the possibility of conflicts with mining projects into consideration. Until now this has largely not proved necessary. To protect rare and sensitive species and habitats, the legal aspects of these regulations should be checked again.

8.10 Summarized assessment and recommendations for further procedures

As regards the extraction of natural gas by fracking, diverse cumulative effects on environmental resources and land uses are to be expected. Significant environmental and use conflicts can be expected in all the scenarios. The requisite taboo areas and safety distances will limit the potential areas considerably. The main conflict issues include the fracking fluids and the risks of improper transportation and handling of environmentally hazardous additives, the large amounts of water consumed by operations, the risks due to possible defects in well construction and the handling and disposal of large quantities of highly contaminated wastewater.

9 General recommendations

The general recommendations ensuing from the overall context of the study are presented in the following.

- Each development of a shale gas deposit and also each individual frac measure should, in principle, be accompanied not only by monitoring of the aquifers that are relevant for the drinking water, but also by a comprehensive well-pad and regionally specific monitoring programme (initial state characterization, analysis plan, sampling, electronic logbook, etc.) that can be tracked and checked by the authorities. Sound accounting and long-term documentation of water and material flows must be ensured and also integrated into the authorities' supervisory measures.
- The cumulative environmental effects described must be evaluated within the framework of the Environmental Impact Assessment (EIA) that was already recommended in the preceding study (UFOPLAN 2012). In addition to this, the performance of a Strategic Environmental Assessment (SEA) is also recommended.
- Against the background of the energy turnaround and the climate targets set down by the Federal Government of Germany, the climate impact of shale gas exploration in Germany must be determined. Adequate data for detailed GHG balances must therefore be collected. It is also recommended to collect spatially specified data on CH_4 background emissions for a future monitoring programme.
- The establishment and maintenance of a legally binding national fracking chemicals registry is recommended. It should be managed by a federal agency and, based on a separate federal law governing this registry, grant every person free access to information over the Internet.
- It is recommended to perform scientifically supported field tests, as without such testing measures, further scientific findings on the risks and opportunities of fracking technology are limited. In this connection, the following issues must be investigated:
  - Whether and how fracture propagation can be controlled in the shale gas deposits;
  - Whether and how the groundwater situation can be kept under control. This requires comprehensive monitoring;
  - How systematic method selection and specification of the treatment and recycling of flowback and produced water together with the real wastewater and waste can be scientifically substantiated. Sound scientific insights should be obtained as a result, and a "state of the art" developed.
- For all shale gas production projects, a seismological baseline report is to be provided. The report must be included as a component of the EIA and compiled by an external independent seismologist. Above all in respect to the injection of flowback and produced water, the seismic hazard must be monitored. When choosing a location, the seismological, tectonic and petrological aspects must be taken into account.

Risk assessment

- We recommend the performance of an ex-ante risk assessment for all frac projects (also for field testing measures) as an indispensable part of the EIA and the SEA.
- As documented repeatedly within the framework of this report, the borehole constitutes the actual weak point of shale gas exploration and extraction. With the help of the recommended risk assessment, the integrity of the borehole must be assessed by means of the following steps:
    - Comparison and evaluation of the risks of fully cemented gas boreholes and partially cemented gas boreholes with annulus pressure monitoring in the uncemented sections;
    - Review of the current practice of not monitoring low pressure wells (<5 bar head pressure), in particular in regard to the risk of gas migration;
    - Definition of minimum requirements for permissible gas or fluid leakage rates and the related metrological requirements.
- To evaluate the risk, it is essential to develop standardized procedures, targets and verification methods and document them in a risk registry. Only in this way can the risk profile of oil and gas production be sustainably reduced. To ensure continuous improvement of exploration and production activities, we recommend ex-post analyses of the identified risks and their countermeasures, and also the registration of near accidents and incidents that have actually occurred and their notification to the relevant mining authorities as a supplement to the risk register. By processing such data, future safety standards that remain to be defined can be significantly augmented.
- It is suggested that a quantitative risk assessment (QRA) be performed ex-ante by clearly presenting the risks, their probability and impacts as well as the risk-minimizing measures for each specific well pad. Suitable quantitative assessment standards regarding occupational health and safety, individual risks, social risks, financially tolerable loss levels and the permissible residual risk thresholds ("As Low As Reasonably Practicable, ALARP") must be worked out in detail, in particular for the permissible residual risk.
- The recommendations for risk assessment put forward in this report comply with the new standards set down by the EU[5] in 2011 for the safe performance of off-shore oil and gas drilling operations.
- For large-scale field developments, the cumulative effects must be reflected appropriately within the framework of an SEA.
- A quantitative risk assessment allows a costs-benefit analysis as recommended by the European Commission.[6] A QRA allows the costs and benefits of a specific project to be analysed, assessed and illustrated by means of an appropriate communication strategy.

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[5] From: Directive 2013/30/EC of the European Parliament and Council dated 12 June 2013 on the safety of offshore mineral oil and natural gas operations amending Directive 2004/35/EC.

- As a by-product of the risk calculations, a calculation of the safety measures taken by the exploration and production companies to be able to remediate or contain possible adverse changes can also be carried out. In Germany, in accordance with Section 56 Par. 2 BBergG (Federal Mining Act of Germany), the responsible mining authority can make the approval of an operating plan dependent on the provision of a security, for example in the form of a bank guaranty or insurance policy deposited with the LBEG (Federal Authority for Mining, Energy and Geology of Germany), comprising an insured sum to be determined in each individual case. For details, please refer to LBEG (2013).
- The findings obtained within the framework of the risk assessment must be communicated appropriately to the addressees.

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[6] See E.G. "Guide To Cost-Benefit Analysis of Investment Projects", July 2008: http://Ec.Europa.Eu/Regional_Policy/Sources/Docgener/Guides/Cost/Guide2008_En.Pdf
From: Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Energy infrastructure priorities for 2020 and beyond - A blueprint for an integrated European energy network