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Environmental Impacts of Hydraulic Fracturing

Related to Exploration and Exploitation of
Unconventional Natural Gas Deposits

Short Version



Federal Ministry for the
Environment, Nature Conservation
and Nuclear Safety

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Environmental Impacts of Hydraulic Fracturing Related to Exploration and Exploitation of Unconventional Natural Gas Deposits – Short Version



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**Environmental Impacts of Hydraulic Fracturing Related to Exploration
and Exploitation of Unconventional Natural Gas Deposits –
Risk Assessment, Recommendations for Action and Evaluation of
Relevant Existing Legal Provisions and Administrative Structures**

SHORT VERSION

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1 Introduction

1.1 Current situation, and objectives

The exploration and exploitation of unconventional gas deposits especially as it involves hydraulic fracturing ("fracking") has been generating intensive public discussion. Such discussion has focused especially on the potential impacts on the environment and on human health – in particular, on how the techniques and substances used in fracking can affect the environment and human health. The Federal Environment Agency (UBA) has published a statement report on shale gas exploitation in Germany.¹ A number of the aspects that the Federal Environment Agency statement report has introduced have since been detailed and scientifically analyzed in the framework of an extensive study. The study has focused especially on substances used in fracking, which are toxic for humans and for aquatic organisms, on the potential impact pathways and on the relevant legal framework. The present short version of that study summarizes its results and recommendations.

The study describes the potential environmental impacts of fracking, and the potential risks for people, along with the additional findings and knowledge that are needed in order to properly assess such impacts and risks. In addition, it describes the existing applicable provisions under (the German) mining law, environmental law and – especially – water law, and analyzes those provisions with regard to areas in which they agree, areas in which they differ and areas they fail to address. The objectives of the overall project include:

1. Assessing the risks of exploitation of unconventional gas deposits (especially of such exploitation via fracking) from scientific, technical and legal standpoints.
2. Describing the available technical alternatives.
3. Developing recommendations for action and procedures that legislative authorities and enforcement authorities can implement as a basis for managing the risks entailed in exploitation of unconventional gas deposits. This also includes development of suitable criteria for public participation in the framework of environmental impact assessment (EIA).

1.2 Procedure, and structure of the study

A well-founded risk analysis will be based on a precise description of the existing relevant system (its sensitivity), of the impacts related to the project (intervention) and of the relevant cause-and-effect relationships. The existing system and its sensitivity must be assessed site-specifically.

The nature, extent and duration of the project's environmental impacts can vary in keeping with the possible combinations of types of deposits and the technologies used to exploit them. As a result, the two subsystems "environment" and "technology" have to be considered first; then, the two can be combined in useful ways for systematic, comprehensive analysis of the possible cause-and-effect relationships.

1.3 Structure of the study

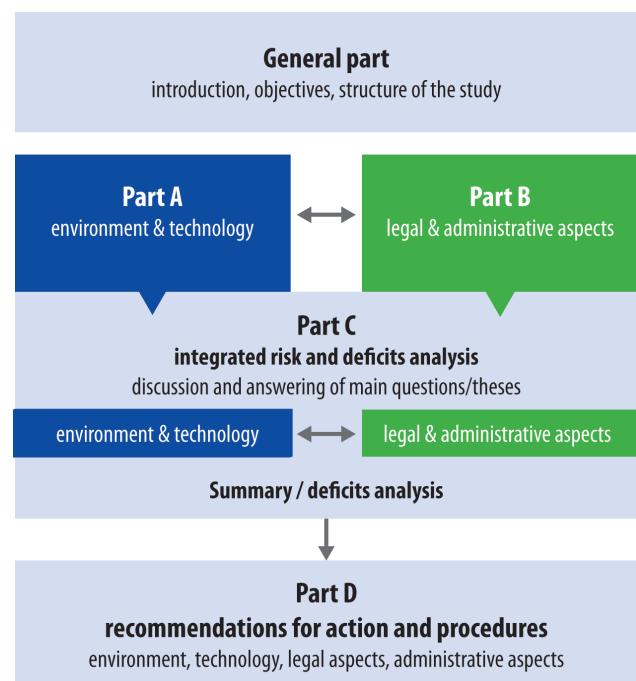


Fig. 1: Structure of the study (long version)

The structure of the present study is shown schematically in Figure 1. Following a general introduction, the long version of the study is divided into four parts: Description of the physio-geographic, technical and substance-related factors involved in fracking (Part A), applicable legal frameworks and administ-

¹ http://www.umweltbundesamt.de/chemikalien/publikationen/stellungnahme_fracking.pdf

relative structures (Part B), risk and deficit analysis (Part C) and derivation of recommendations for action and procedures (Part D).

This study was prepared mostly on the basis of openly accessible information and data. To assess the risks related to fracking, we had to rely on the extensive range of relevant literature available internationally (such as US EPA 2004, US EPA 2011, Tyndall Centre 2011) and on information provided by this country's national authorities and operating companies. In Germany, extensive experience with fracking has been obtained in connection with tight gas deposits (primarily in Lower Saxony). To our knowledge, no systematic study of the types, quantities, behavior and fate of the substances employed in those deposits has been carried out, nor have the relevant environmental impacts been monitored specifically and systematically.

2 Unconventional gas deposits in Germany

The following types of unconventional gas deposits are differentiated:

- **Tight gas:** Tight gas is gas that has moved from a parent rock formation into sand or limestone formations with very low permeability. In Germany, such formations normally occur at depths greater than 3,500 m. The productivity of a given tight gas deposit depends on its permeability and porosity and on the way the gas is distributed throughout the rock.
- **Shale gas:** Shale gas is thermo genic gas created via cracking of organic matter at high temperatures and pressures. Under such processes, the gas is absorbed into the parent rock in various ways. The exploration and exploitation techniques used with such gas involve breaking the relevant bonds and creating suitable pathways for gas migration. While some shale gas deposits in Germany are presumed to lie at relatively shallow depths, beginning at about 500 m (overlying alum shale in the Rhenish Massif), many of the deposits are known to be at considerably greater depths.
- **Coal bed methane (CBM):** Coal bed methane is formed via coalification of organic matter in coal deposits. Such deposits are found at a number of different depths in Germany. The pressure of the formation water in such deposits binds the gas to the surface of the coal. Consequently, before gas can be extracted from them, such deposits first have to be drained of water. It remains to be seen whether gas exploitation from such deposits always requires hydraulic stimulation (fracking).

In Germany, unconventional gas deposits are thought to be present in a number of different types of geological formations. Table 1 presents an overview of

Tab. 1. Potential unconventional gas deposits in Germany

Type of deposit	Most promising deposits	Regions
Coal bed methane (source rocks)	Seam-bearing Upper Carboniferous	Northern Ruhr region / Münsterland Basin (NRW)
		Ibbenbüren (NRW)
		Saar Basin (Saarland)
Shale gas (source rocks)	Tertiary clay formations (e.g. Fischschiefer)	Molasse Basin (BW)
	Posidonia Shale (Black Jurassic) *	Northwest German Basin (e.g. Lünne) (NI)
		Molasse Basin (BW)
		Upper Rhine Graben
	Wealden clay formations (Lower Cretaceous) *	Weser Depression (NRW / NI)
	Permian clay formations (e.g. black shale („Stinkschiefer“), copper shale)	Northeast German Basin (NI / SA)
	Carboniferous and Devonian clay formations e.g. alum shale (Lower Carboniferous) *	Northern edge of the Rhenish massif (NRW)
		Northwest German Basin
		Harz Mountains (NI / SA)
Tight gas (deposit rocks)	Silurian slates	Northeast German Basin
	Cambro-Ordovician clay formations („alum shale“)	(not yet studied in detail)
	Red sandstone	Northwest German Basin (NI / SA)
	Permian sandstones (Rotliegend) and carbonates (Zechstein)	Northeast German Basin (e.g. Leer) (NI)
	Permian sandstones (Rotliegend) and dolomite (Stassfurt series) sandstones (Triassic)	Thuringian Basin (TH)
	Upper Carboniferous sandstones	Northwest German Basin (e.g. Vechta) (NI)

* = relevant potential shale gas deposits pursuant to the Federal Institute for Geosciences and Raw Materials (BGR; 2012)

potential target geological formations for exploration of unconventional gas deposits in Germany, broken down by the different types of unconventional gas deposits involved. It also lists the deposits that are currently thought to offer the greatest promise for exploitation.

According to current estimates (BGR 2012), the technologically recoverable gas reserves (assumption: 10 % of the gas in place (GIP) are technologically recoverable) present in shale gas deposits in Germany amount to about 700 to 2,300 Bill. m³. The GIP in coal bed methane deposits is estimated to exceed 3,000 Bill. m³ (GD NRW 2011). The technological recoverability of coal bed methane reserves in Germany has not yet been analyzed.

Most of the hydrocarbon provinces known in Germany already contain approved or applied-for exploration fields for exploration of, and exploitation from, conventional and unconventional oil and gas deposits. Figure 2 shows the areas that contain (planned) activities for exploration for unconventional gas deposits in Germany (BGR 2012). To our information, no permits have yet been issued for exploitation of natural gas from unconventional shale gas and coal bed methane deposits. Furthermore, we have not yet seen any specific planning detailing such exploitation.



Fig. 2:
Mining authorizations in Germany
(= yellow, last revision: 31. December 2011)
for exploration for unconventional hydro-
carbon deposits (ochre = regions with the
basic geological conditions for formation of
shale gas)

(source: BGR 2012)

3 Scientific and technical parameters, and risk assessment

3.1 System analysis, impact pathways and risk analysis

3.1.1 System analysis

Unconventional gas deposits are parts of larger geo systems, which differ in terms of their geology and hydrogeology. As a result, exploration methods and exploitation strategies have to be locally specific. Also the methods and strategies have to be assessed specifically, using suitably differentiated perspectives, in terms of their environmental impacts and risks. A “geo system” within the meaning of the present study is a large-scale unit that forms a geological and hydrogeological system (e.g. Molasse Basin, etc.). To understand local flow systems within such a geo system, in the context of a site-specific consideration, and to assess the pertinent risks, one must understand/analyse the large-scale system involved.

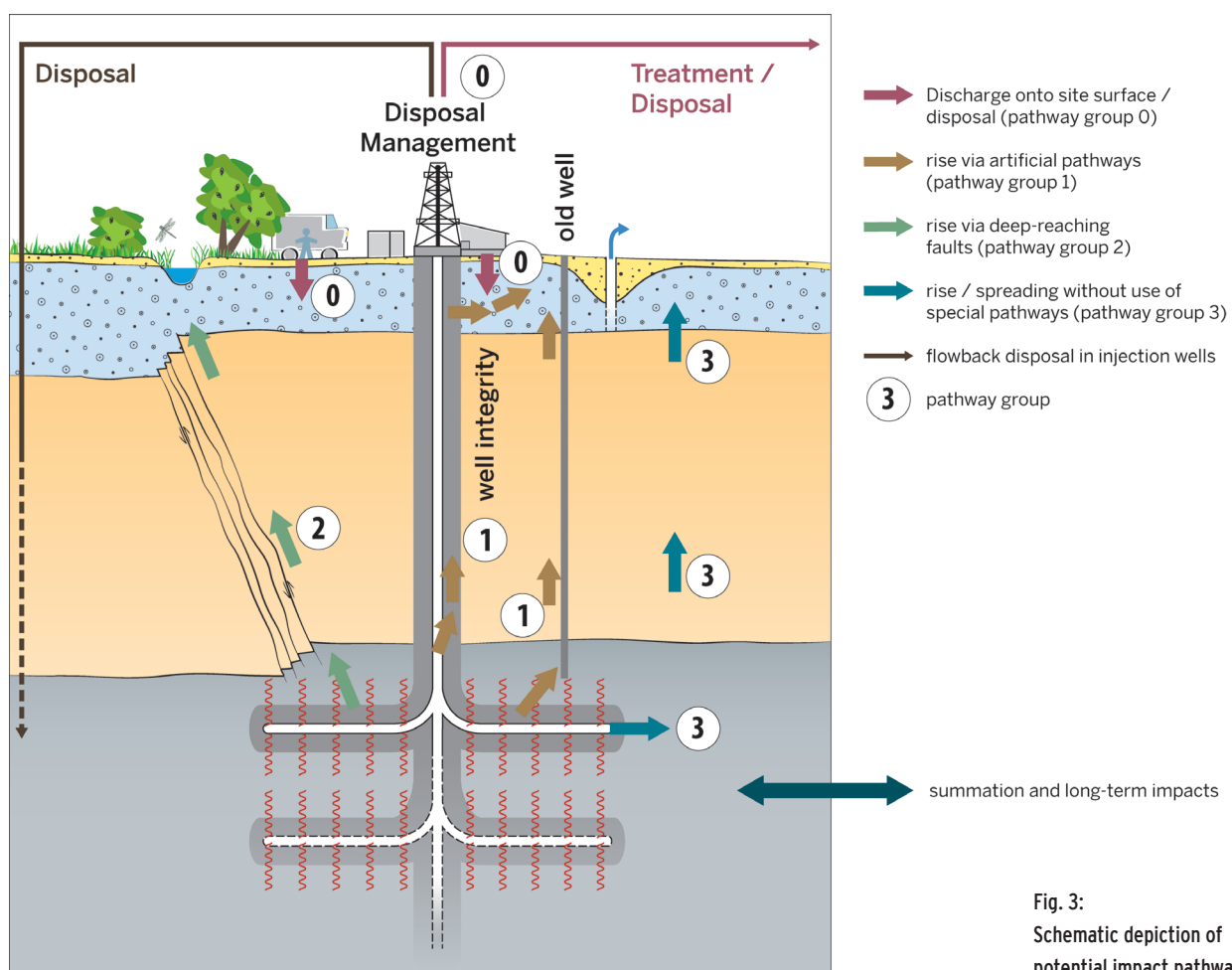
In the long version of the study, selected sample geo systems and their possible unconventional gas deposits are described and analyzed with regard to the specific issues they present for risk assessment (cf. Tab. 2).

3.1.2 Impact pathways

Potential water-related impact pathways resulting from exploration and exploitation of unconventional gas deposits via fracking are shown schematically in Figure 3. Both technical impact pathways (such as failures of well casings) and geological impact pathways (such as faults) have to be considered. For a geological impact pathway to be relevant, it must entail both, permeability and a potential difference (pressure difference), the two factors needed for a directed

Tab. 2. Special issues to be considered in risk analysis relative to selected geo systems

Type of deposit	Region	Subsystem	Special issues to be considered in risk analysis
Tight gas	Northern German Basin	Deposits overlying Zechstein	Other geological barriers Existence of continuous faults Permeability of covering strata Distribution of regional groundwater flow systems
		Deposits underlying Zechstein	Barrier function / effect of Zechstein deposits Other geological barriers
Coal bed methane gas	Münsterland Basin	Central Münsterland	Permeability of Emscher marl (including naturally formed gas rises) Permeability and potential deposits of Cenoman/Turon limestones Existence and relevance of continuous faults Impacts of exploratory wells from hard-coal mining
		Mining zone	Scenarios for further use of water resources (development of mine water management, etc.) and its impacts on the hydraulic system Hydraulic connections to mine-water-management areas
		Perimeter areas of Münsterland	Impairment of source lines Permeability and potential deposits of Cenoman/Turon limestones
Shale gas	Molasse Basin	Western area	Structure of regional groundwater flow systems Groundwater flows ascending from deeper aquifers Existence of continuous faults Competing uses – for example, geothermal uses
	Harz Mountains		Position of target horizons Existence and permeability of continuous faults Rise of brine



flow. Whether or not the two factors are present will depend on a) the relevant natural conditions and b) the nature and scope of the intervention involved.

Pathway group 0

Pathway group 0 refers to (pollutant) discharges that occur directly at the ground surface, and especially in handling of fracking fluids (transport, storage, etc.) and in management of flowback (not including disposal; see below). Often, such discharges will be preceded by a failure of the equipment being used. Pathway group 0 is relevant especially during the fracking phase, when handling of fracking fluids and of flowback – including transport, storage and disposal – is most intensive. Pollutant discharges at the ground surface can occur via accidents, disruptions or improper handling.

Pathway group 1

Pathway group 1 refers to potential (pollutant) discharges and spreading along wells, i.e. to artificial underground pathways. With regard to the impact

pathways involved, a distinction has to be made between production wells and old wells, such as wells from other exploration and uses. Options for controlling and monitoring fracture formation in fracking play an important role with regard to old wells (cf. section 3.2.2), since fractures can open up sudden hydraulic connections to old wells.

In production wells leakages can occur during the fracking process that can lead to undesired entry of fracking fluids into the annulus or into the neighbouring rock; in addition, failures of cementations and/or casings can become impact pathways in the long term.

Pathway group 2

Pathway group 2 comprises all impact pathways along geological faults. Significantly, the permeability along any given fault can vary, section-wise. Whereas deep-reaching, continuous faults can often be monitored, since the near-surface locations of their outcrops are usually known, faults that affect only parts

of the overburden are difficult to monitor. Options for controlling and monitoring fracture formation in fracking play an important role also with regard to pathway group 2 (cf. section 3.2.2), since fractures can open up sudden hydraulic connections to faults.

Pathway group 3

Pathway group 3 comprises extensive rise, as well as lateral spreading, of gases and fluids through geological strata (for example, via an aquifer), without preferred pathways similar to those described for pathway groups 1 and 2. Impact pathways in pathway group 3 depend primarily on the prevailing geological and hydrogeological conditions.

With regard to fracking, the phases actually involving fracking itself – at the depths > 1,000 m that are currently being discussed – are considered to be too short to be able to directly impair near-surface groundwater resources via this pathway. During exploitation, uncontrolled rise of gases via these impact pathways would be the primary relevant factor. These impact pathways are also considered significant for post-operational phases, subject to the condition that there are sufficient permeabilities and groundwater potentials.

Summation and combination of different impact pathways and long-term impacts

Summation and combination of the aforementioned impact pathways play a role in all operational phases considered, and they must be appropriately taken into account. Since many flow processes in the deep underground take place very slowly, the relevant long-term impacts have to be estimated – also in connection with effects that must be summed. Such estimation is possible only on the basis of an extensive understanding of the geological and hydrogeological conditions prevailing in deep underground layers. In our view, for no geo systems are data currently available, along with corresponding numerical forecast models, that would suffice to support such estimation.

Flowback disposal via disposal wells

Operators currently refer to injection options as an important parameter for (cost-effective) exploitation of unconventional gas deposits. From the perspective of the study authors, flowback disposal via deep-underground injection can entail risks. For this reason, so our view, any deep-underground injection calls for site-specific risk analysis and monitoring.

3.1.3 Risk analysis

Along with direct environmental impacts (noise, land use, substance emissions, etc.) exploration and exploitation of unconventional gas deposits present

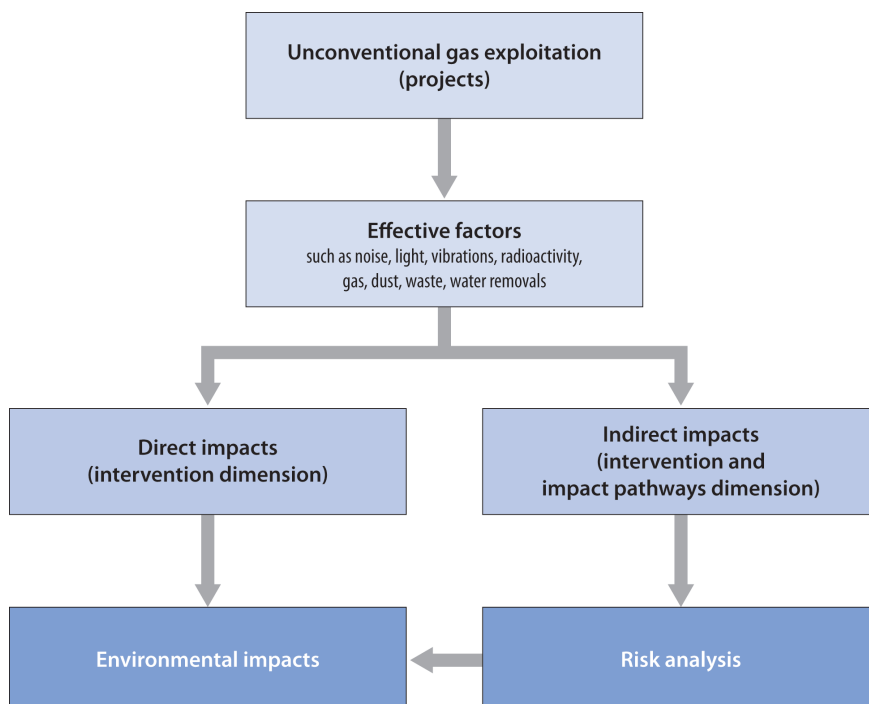


Fig. 4:
Assessment of environmental
impacts via effective factors

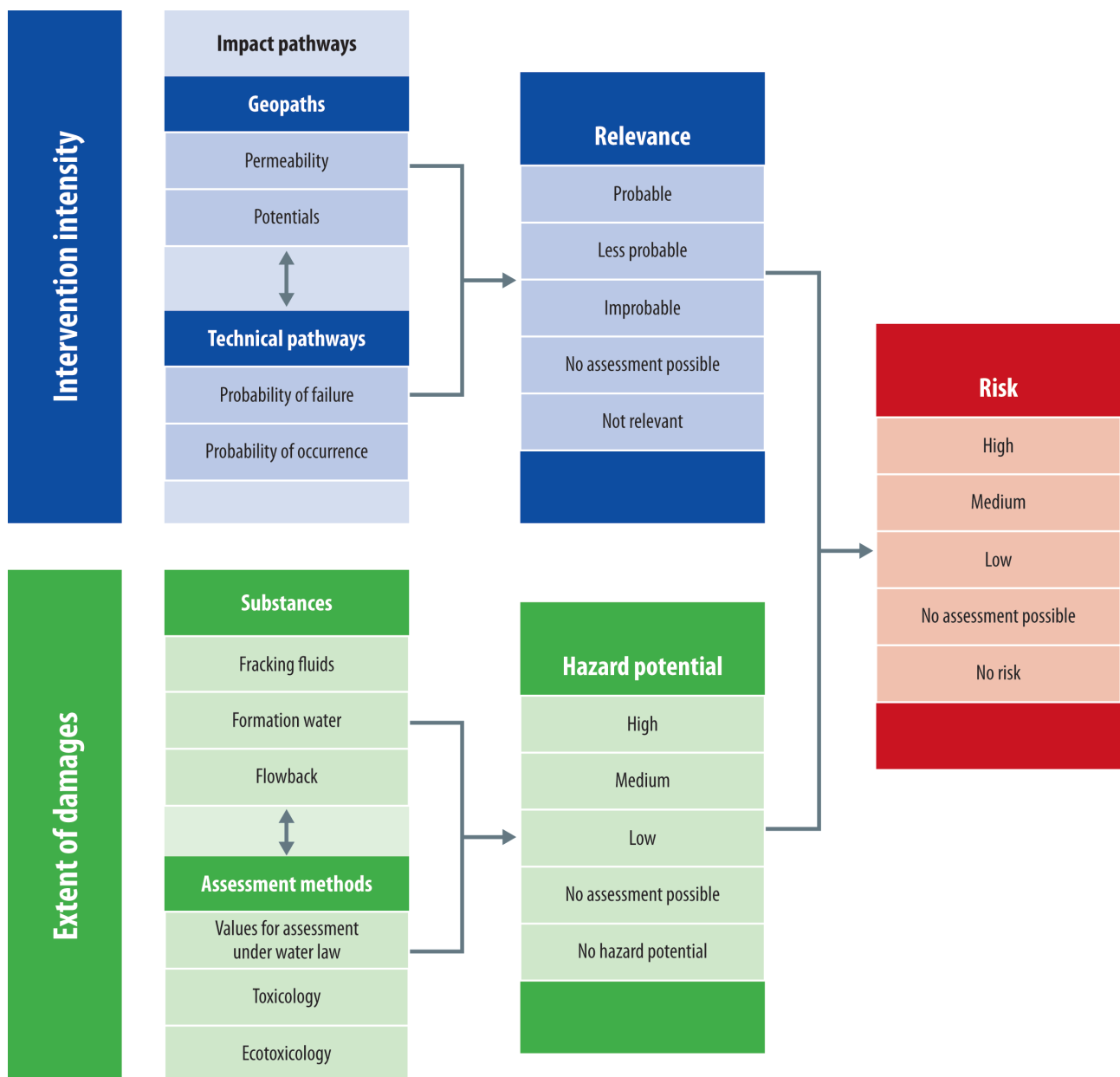


Fig. 5: Structure of risk analysis for assessment of unconventional gas exploitation

(like any technical-plant operations) a range of other, delayed and spatially separated risks for humans and the environment (indirect environmental impacts) (cf. Figure 4). Such risks include, for example, gas rise and groundwater contamination via rising fluids.

In the present case, involving exploitation of unconventional gas deposits, it is difficult to determine the relevant risks – primarily as a result of the paucity of available data. On the one hand, key basic data, especially data relative to geology and hydrogeology, are lacking; on the other, while some experience has

been gained in Germany with tight gas exploitation, no concrete experience has been gained in Germany with exploitation of shale gas and coal bed methane. For this reason, we propose that the (site-specific) risk analyses required at the present time be carried out using a combination of various risk-analysis methods (cf. Fig. 5).

Impact pathways (intervention intensity)

In consideration of the risks that exploitation of unconventional gas deposits can pose for exploitable groundwater resources, impact pathways are consi-

dered instead of intervention intensity (see above) (cf. section 3.1.2). The reason for this is that a risk can lead to actual damage only if the pertinent impact pathway is relevant.

For technical impact pathways, substantiated probabilities of occurrence or failure can be determined if adequate data are available. Geological impact pathways depend on the geo systems involved. They are defined primarily via the two parameters permeability and hydraulic potential (referred to below as “potential”). Without suitable numerical quantification, the relevance of any impact pathways can only be approximated, with great uncertainties.

Hazard potential

Suitable methods for assessing the hazard potential of fracking fluids, of formation water, of flowback and, if relevant, of applicable mixtures, are described in section 3.3. In the component-based methods used, assessment is based on the toxicological and ecotoxicological effective concentrations of the individual substances involved. Since specific fracking-fluid recipes, and formation-water and flowback constituents, can be suitably assessed only site-specifically, the hazard potential of such fluids, water and flowback is assessed in the following via a generic, i.e. overarching, site-independent approach. To differentiate between low, medium and high levels of hazard potential, in any scientifically sound way, one must use exposure scenarios for specific resources/assets, such as scenarios developed with the help of numerical models.

Flowback, and the fluids that can be released via pathway groups 1, 2 and 3, consist of variable mixtures of fracking fluids and formation water. Since the fractions in such mixtures vary by site and over time, it is assumed that the hazard potential of such fluids is determined by the higher hazard potential of the initial components of such mixtures, namely fracking fluids and formation water.

Risk assessment

Consideration of the hazard potential of fluid-water mixtures focuses on near-surface groundwater resources. Mixing with formation water (for example, following migration of such water from deeper layers) is not considered to be dilution that would lower the hazard potential, since formation water normally has negative impacts on near-surface groundwater resources. The risk is then obtained by considering the relevant pathway(s) (intervention intensity) together with the hazard potential of the pertinent fluids (frack-

ing fluids and formation water). As Figure 5 shows, the risk can then be divided into different categories of degree – for example, in a five-part scale.

3.2 Equipment and techniques

The entire process of exploration of, and exploitation from, unconventional deposits includes the following phases, inter alia:

- Exploration,
- Selection and preparation of the drilling site,
- Drilling and completion of the well,
- Stimulation,
- Exploitation,
- Retreat from the drilling site / renaturation.

With regard to techniques used, the key fracking-specific aspects to consider include specifications for site layout and design (single well or clusters of wells); the manner in which frac propagation is modeled, controlled and monitored; and the long-term integrity of wells (cementation and casing).

3.2.1 Site layout and design

Selection of drilling sites forms part of the authorization procedure, under mining law, for approving operational plans for exploration for, and production of hydrocarbons. In comparison to gas production from conventional deposits, however, exploitation of unconventional deposits requires a significantly greater number of wells (and, thus, of drilling sites). Generally several wells are drilled from a single well-pad. This is done by moving the drilling rig to different starting points within a well-pad (cluster drilling).

To protect surface water and groundwater from any pollutant spills above ground, the drilling site – and especially those areas where substances hazardous to water are stored and handled – has to be sealed. Rainwater has to be collected and treated in conformance with applicable laws (WEG 2006).

Drilling techniques and drilling-site layouts/design are subject to a range of standards and legal provisions. These include the federal state ordinances on deep-drilling (Tiefbohrverordnungen der Bundesländer – BVOT) and various technical guidelines and industry standards (WEG 2006). In our view, the issue of the extent to which such standards and regulations can be applied to the new requirements involved

(such as cluster drilling, multilateral drilling, etc.), or may need to be supplemented, has to be reviewed.

3.2.2 Modeling, control and monitoring of fracture propagation

Fracking processes are used to create pathways (normally, fractures) in deposits with low permeability, in order to increase permeability for fluids (liquids and gases). Prior to actual fracking, fracture formation can be modeled with the help of coupled hydraulic-mechanical models (cf. also BGR 2012). For such modeling, one requires a detailed knowledge of the geomechanical properties of the target formation and of the stresses prevailing underground.

The primary risk connected with “uncontrolled” fracture formation is that it can form an (undesired) connection to a hydraulically active element (old well, fault, permeable rock layer), thereby creating the possibility of gas and fluid rise.

While simulations of fracture formation can be carried out prior to fracking, such simulations are subject to some uncertainties, in keeping with the parameters selected; it is not possible to predict fracture propagation precisely (cf. also US EPA 2011).

The fracking process is controlled primarily through the pressure applied via the fracking fluid, while monitoring of fracture formation is carried out geophysically, with the help of geophones. However, there are no binding requirements specifying the degree of accuracy with which the position and orientation of fracs is to be predicted and determined.

Overall, the authors of the study see a need for improvement in modeling, control and monitoring of fracture propagation, since the position and size of created fracs can be key factors in determining the relevance of the impact pathways of pathway groups 1 through 3, and in derivation of pertinent “safety distances” (cf. also US EPA 2011).

3.2.3 Long-term integrity of wells

Cementing of the casing in a well provides the key barrier against contamination of aquifers via migration/penetration of hydrocarbons, formation water or fracking fluids. In addition, the cement used for this purpose shields the casing from corrosive formation fluids, and it considerably enhances the stability of the well.

No specific binding technical requirements exist regarding well completion for exploitation of unconventional gas deposits via hydraulic stimulation – for example, requirements specifying the strength of well casings and their connections. The dimensions of casings and well cementation are determined on the basis of existing regulations, taking account of the stresses caused by the applied fracking pressures (WEG 2006). In some cases, operators apply their own safety standards in this area. No consistent, binding (national) requirements and standards are yet in place.

There continues to be a lack of reliable data on the long-term stability of cementations, especially data relative to the thermal and hydrochemical conditions prevailing at the depths at which unconventional gas deposits in Germany are encountered.

3.3 Fracking fluids

3.3.1 Overview

The hydraulic medium used to apply pressure to the rock strata inducing fracture formation is referred to as “fracking fluid”. With the fracking fluid, proppants (such as quartz sand) are generally injected into the created fractures in order to keep fractures from closing under the pressure of the surrounding rock and thus to ensure that the pathways created remain accessible for gas migration during the production phase. Fracking fluids also contain other additives, with functions such as facilitating transport of proppants into fractures; preventing formation of precipitates, microbiological growth, formation of hydrogen sulphide and swelling of clay minerals within the frac horizon; preventing corrosion; and reducing fluid friction at high pump rates. Table 3 provides an overview of the functions of certain additives.

Tab. 3. Functions of additives in fracking fluids (based on UBA 2011, Tyndall Centre 2011)

Additive	Function
Proppants	Keeping the fractures created open under the pressure of the surrounding rock and allows gas/fluid to flow to the well bore
Scale inhibitors	Preventing deposits of poorly soluble precipitates, such as carbonates and sulphates
Biocides	Preventing bacterial growth, biofilm formation and formation of hydrogen sulphide by sulphate-reducing bacteria
Iron control	Preventing iron-oxide precipitation
Gelling agents	Improving proppant transport
High-temperature stabilizer (temperature stabilizer)	Preventing gel decomposition at high temperatures within the target horizon
Breakers	Reducing the viscosity of gel-containing fracking fluids for depositing proppants
Corrosion inhibitors	Protecting against equipment corrosion
Solvents	Improving the solubility of additives
pH regulators and buffers (pH control)	Controlling the pH of fracking fluids
Crosslinkers	Increasing viscosity at higher temperatures, to improve proppant transport
Friction reducers	Reducing friction within fracking fluids
Acids	Pretreating perforated sections of the well, and cleaning them of cement and drilling mud; dissolving acid-soluble minerals
Foams	Supporting proppant transport
H ₂ S scavengers	Removing toxic hydrogen sulphide to protect equipment against corrosion
Surfactants	Reducing surface tension of fluids
Clay stabilizers	Reducing swelling and migration of clay minerals

Based on the extensive studies on fracking additives used in the U.S. (US EPA 2004; US EPA 2011; Waxman et al. 2011; Tyndall Centre 2011; NYSDEC 2011) information on the fracking fluids and additives used to date in Germany were compiled. A method is presented for assessing the hazard potentials of the fracking fluids employed with regard to groundwater, especially with regard to human use of groundwater as drinking water and to aquatic organisms. Selected fracking fluids used in Germany and possible new improvements of such fluids are assessed.

3.3.2 Fracking fluids used in Germany

To obtain information on the fracking fluids used in unconventional deposits in Germany, we relied primarily on publicly accessible data; only in some cases we were able to obtain information from non-publicly accessible sources (ExxonMobil 2011; BR Arnsberg 2011). The information presented below on the composition of the fracking fluids used is based mainly on analyses of safety data sheets of the commercial products used to prepare fracking fluids. We found that these safety data sheets are often the only

available source of information on the identity and the concentrations of the additives used. For approval authorities, this situation creates considerable uncertainties and lack of knowledge regarding the additives that are actually injected in the well and the loads involved.

In the following, we discuss the prepared fracking products (products produced by services companies that are sold under brand names and that usually are mixtures of various chemicals) and fracking fluids (the fluids that are injected into the well; they are usually prepared by combining several products with water). “Fracking additives” refers to all substances that are mixed with a carrier medium and injected, as part of the fracking fluid, into the well.

Quantities used

Information on fluid quantities was available for a total of 30 fracking fluids used in various unconventional deposits (and in one conventional deposit) in Germany between 1982 and 2011. Most of the deposits involved were tight gas deposits in Lower Saxony.

The quantities used varied considerably, depending on the type of fracking fluids and the characteristics of the deposits. The quantities of fracking fluids used per frack ranged from less than 100 m³ to more than 4,000 m³. With the modern gel fluids used since 2000, an average of about 100 t of proppants and about 7.3 t of additives (of which usually less than 30 kg were biocidal products) were injected per frack. The quantities used can be quite large especially with multi-frack stimulations and/or use of slickwater fluids: for example, a total of about 12,000 m³ of water, 588 t of proppants and 20 t of additives (of which 460 kg were biocides) were injected into the Damme 3 well in three frack operations in 2008.

Commercial fracking products

According to the available information, at least 88 different products have been used to prepare fracking fluids in Germany. However, since data are available on only 21 fracking fluids (corresponding to about 21 % of the some 300 fracks carried out in Germany), it must be assumed that other products have also been employed.

For 80 of the 88 products, the study authors were able to obtain manufacturers' or importers' safety data sheets that were either current or valid at the time the fracks were carried out. Evaluation of the available 80 safety data sheets revealed that

- 6 products are classified as toxic,
- 6 are classified as dangerous to the environment,
- 25 are classified as harmful,
- 14 are classified as irritant,
- 12 are classified as corrosive and
- 27 are classified as non-hazardous

according to Directives 67/548/EEC or 1999/45/EC, respectively. Several products are classified in more than one hazard class. According to the information in the safety data sheets,

- 3 preparations are classified as severely hazardous to waters ("Wassergefährdungsklasse 3"),
- 12 preparations are classified as hazardous to waters ("Wassergefährdungsklasse 2"),
- 22 preparations are classified as low hazardous to waters ("Wassergefährdungsklasse 1"),
- 10 preparations are classified as not hazardous for water.

A total of 33 of the safety data sheets available to the study authors provided no information on the "Wassergefährdungsklasse" (water hazard class) of the product.

Fracking additives

Information on the fracking additives used was available to the study authors for 28 fracking fluids. Those fluids were used in about 25 % of the some 300 fracks carried out in Germany.

Evaluation of those 28 fracking fluids showed that, overall, at least 112 substances / substance mixtures have so far been used in Germany. For 76 of the 112 substances / substance mixtures, either unique CAS numbers¹ were provided or it proved possible to correct or determine the CAS number on the basis of a unique given substance name. A total of 36 substances / substance mixtures could not be uniquely identified, either because their composition was unknown or because the available safety data sheets referred only to unspecific chemical group names (such as aromatic ketones, inorganic salts, etc.).

3.3.3 Hazard potentials

Assessment method

Under water law, the key requirement to be applied in assessing releases of substances into the groundwater is that releases must not adversely affect the water quality (Art. 48 (1) Federal Water Resources Management Act (WHG)). An adverse effect on the quality of near-surface groundwater – i.e. of the exploitable groundwater that is integrated within natural cycles – has occurred, if water quality has worsened more than slightly.

An adverse effect on the water quality of groundwater must be assumed if relevant legal and sub-legal limit values, guide values and maximum values, and especially the "Geringfügigkeitsschwellenwerte" (de minimis thresholds) of the Federal/Länder Working Group on Water (LAWA 2004), are exceeded in exploitable groundwater. Those de minimis thresholds² are based primarily on the maximum permitted concentration specified by the Ordinance on Drinking Water (TrinkwV), and on toxicologically and eco

1 The CAS number (Chemical Abstracts Service) is an international standard for identification of chemical substances. Every chemical substance known in the open scientific literature has a unique CAS number.

2 The de minimis threshold (Geringfügigkeitsschwelle – GFS) for a substance is the maximum concentration of the substance at which, in spite of an increase in groundwater with respect to regional background values, no relevant eco toxicological effects can occur, and conformance with the requirements of the TrinkwV, or with pertinent derived values, is still assured (LAWA 2004).

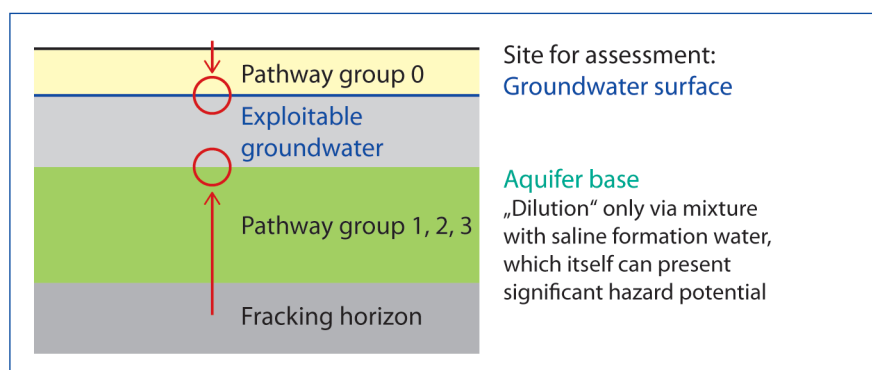


Fig. 6:

Substance concentration to be assessed at the surface or base (red circles) of a near-surface, exploitable aquifer (blue) when substances enter via input pathways from the surface (pathway group 0) and via migration from the fracking horizon (pathway groups 1-3)

toxicologically established effect thresholds, in order to ensure that groundwater remains available as drinking water for human consumption, and remains intact as a habitat and as part of natural cycles.

For the majority of the substances used as fracking additives, no de minimis thresholds, or other water-law-based assessment values, are available. For such substances, therefore, hygienic guidance values³ or health orientation values⁴ and eco toxicologically established PNEC values⁵ were researched, or derived using published methods, following the concept of LAWA (2004).

In the case of substance discharges at the surface (pathway group 0 in Fig. 6), the relevant substance concentration for assessment must be considered at the groundwater surface (seepage water). By analogy, in the case of a possible release from the fracking horizon (and related migration via pathway groups 1 through 3), the concentration at the base of the exploitable aquifer should be used for assessment (cf. Fig. 6).

The relevant substance concentrations can properly be assessed only site-specifically, for possible migration and exposure scenarios, using suitable models that take account of all relevant hydraulic and geo-

chemical transport, mixing, decomposition and reaction processes along the underground flow pathways. No such models are available at present that have the necessary resolution. As long as suitable models are lacking, we propose to assess hazard potentials on the basis of substance concentrations in (undiluted) fracking fluids and formation water. Based on the current state of knowledge, we consider it not suitable to presume a considerable reduction of their hazard potential due to dilution along the underground flow pathways, because along the flow path dilution occurs mainly by mixing with saline groundwater, which can have considerable hazard potential of its own; thus, mixing with such water would not necessarily reduce the hazard potential of fracking fluids.

The pertinent hazard potentials of the fluids are assessed on the basis of the individual constituents. This is achieved by calculating substance-specific risk quotients of substance concentrations and assessment values (de minimis threshold (GFS), GVDW, HOV or PNEC)):

$$\text{Risk quotient} = \frac{\text{Substance concentration in the fluid}}{\text{Assessment value}}$$

When a substance has a risk quotient < 1, no hazard potential is expected, while a risk quotient ≥ 1 represents a toxicological or eco toxicological hazard potential. In the present study, a risk quotient > 1,000 is assumed to represent a high hazard potential. This value is given as an example and has not been scientifically established; it needs to be site-specifically reviewed on the basis of exposure scenarios – for example, using numerical models.

Since recipes for fracking fluids are normally tailored to specific deposits, the hazard potentials of each fluid need to be assessed individually. In the present

3 The health-related guidance value for drinking water (GVDW) is the maximum concentration of a substance in drinking water that can be tolerated for a lifetime without suffering adverse effects on health.

4 The health orientation value (HOV) is a precautionary value for substances that cannot (or can only partially) be toxicologically assessed (UBA 2003).

5 The PNEC value (Predicted No Effect Concentration) is the maximum concentration of a substance at which no effects on organisms of an aquatic ecosystem are expected (EC TGD 2003).

Tab. 4: Fracking fluids that have been used in, or would be suitable for, unconventional deposits, and that were selected for assessment of their hazard potential

Tight gas			
Söhligen Z16 Rotenburg district (Wümme), Lower Saxony	9 Fracs in 2008 Final depth: 6,872 m Dethlinger sandstone (late rotliegend)	Gel: Water: Proppants: Additives:	 824 m ³ 170,100 kg 38,079 kg
Shale gas			
Damme 3 Vechta district, Lower Saxony	3 fracs in 2008 Wealden clay formation 1,045 to 1,530 m	Slickwater Water: Proppants: Additives:	 12,119 m ³ 588,000 kg 19,873 kg
Coal bed methane			
Natarp Warendorf district, North Rhine – Westphalia	2 fracs in 1995 Seam-bearing Carboniferous 1,800 to 1,947 m	Gel: Water: Nitrogen: Proppants: Additives:	 121 m ³ 81,750 kg 41,700 kg 1,230 kg
Future improvements			
Slickwater Figures of Exxon Mobil (Last revised 04 Feb. 2012)	Planning	Slickwater Water: Proppants: Additives:	 1,600 m ³ unknown 5,600 kg
Gel: Figures of ExxonMobil (Last revised 04 Feb. 2012)	Planning	Gel: Water: Proppants: Additives:	 1,600 m ³ unknown 6,530 to 7,080 kg

study, detailed assessment was carried out of a fluid used recently in a tight gas deposit in Lower Saxony, and of the only two fluids used to date in shale gas and coal bed methane deposits in Germany (Tab. 4). Planned improvements were taken into account by assessing two fracking fluids mentioned by an operator as potentially being suitable for shale gas deposits and, possibly, coal bed methane deposits (improvements of slickwater and gel fluids, Tab. 4).

Results

The assessments of the fluids listed in Table 4 find that the selected fracking fluids have high, or medium-to-high, toxicological and ecotoxicological hazard potentials. The two improved fracking fluids are also expected to have a high hazard potential, primarily because of their high concentrations of a biocide and the lack of available data for assessing that biocide.

Current developments aiming at reducing the numbers of additives used, at finding substitutes for substances that are highly toxic, carcinogenic, mutagenic or toxic for reproduction and at reducing or replacing biocidal agents, point to potential progress in the development of environmentally compatible fracking fluids. However, the study authors can currently not evaluate the feasibility or progress of such efforts.

The replacement of three hazardous additives that were still being used in 2008 by substances with considerably lower hazard potentials must be critically evaluated, since it highlights the fact that additives used in the recent past were found to be replaceable or improvable within just a few years. Since the underlying database for assessing those additives has been available for years, it is necessary to review whether, in the past, service companies, operators and/or authorities have adequately considered the possibilities for finding substitutes for hazardous additives.

3.3.4 Possible fracking procedures that use no chemical additives

Along with efforts to find substitutes for individual additives, efforts are being made to develop fracking fluids that are completely free of certain additive groups. For example, UV light is being tested as a technique for inhibiting growth of microorganisms and thereby reducing application of biocides.⁶ Another research project is testing a process that relies solely on water, bauxite and corn starch.⁷ As such examples indicate, while various techniques are currently being developed and tested, much more research will be required before fracking processes become available that do completely without chemical additives. The present study can only cite the current relevant development, since we were currently unable to assess such projects in terms of their practicability.

Fracking without chemical additives would eliminate the hazard potential of the substances employed. However, it would not reduce the hazard potential of the formation water and the flowback. The risks presented by formation water, along possible impact pathways, are always site-specific and depend primarily on the water's chemical composition and mineralization.

3.4 Flowback

3.4.1 Quantities and composition

After pressure has been applied to the gas-bearing formation, some of the injected fracking fluids are recovered along with the gas and formation water that is extracted from the well; the majority of the proppants used remains in the fractures. The fluid that usually has to be extracted and disposed of throughout the entire gas-production phase is known as “flowback”.

Flowback consists of varying proportions of injected fracking fluids and co-extracted formation water. Initially, fracking fluids account for the larger share of flowback; later, formation water begins to predomi-

nate. As a result of various hydro geochemical processes that can occur within the deposit horizon (Fig. 7), flowback can contain a number of other substances in addition to fracking additives and formation water constituents.

At the high pressures and temperatures prevailing in the target horizon, injected fracking additives may undergo chemical transformation and decomposition reactions in the presence of saline formation water. Microbiological decomposition reactions may occur as soon as the effects of the injected biocides diminish. In the process, stable metabolites can form that can pose toxicological and ecotoxicological risks that can even exceed the risks posed by the parent substances that were injected.

Because the characteristics of formation water are always deposit-specific, and because the proportions of extracted fracking additives vary, the characteristics of flowback have to be individually assessed for each site and pertinent time. Little information is available about the constituents of formation water in tight-gas, shale-gas and coal-bed-methane deposits in Germany, such as information about primary, secondary and trace components, dissolved gases, organic substances and NORM⁸; regional and depth-oriented data is often missing.

Assessments of flowback from the Damme 3 well carried out by Rosenwinkel et al. (2012), concluded that only 8 % of injected fracking fluids were being recovered as part of the flowback. Even though that percentage can be expected to increase as production continues, it seems certain that a substantial proportion of the fracking additives injected remain underground.

As noted, flowback is a mixture of fracking fluids, formation water and possible reaction products. At present, there is a lack of the reliable analyses and mass balances that would allow for quantification of the variable mixing fractions, the fraction of the extracted fracking fluid and possible reaction products. To date, no systematic measurements have been carried out for the purpose of identifying transformation and decomposition products in the flowback.

Fracking additives that remain underground pose a risk for near-surface (exploitable) groundwater, if there is a possibility (probability of occurrence) that they could migrate into near-surface (exploitable) ground-

6 <http://www.halliburton.com/ps/Default.aspx?navid=93&pageid=4184&prodid=PRN%3a%3aKWTBF215&TOPIC=HydraulicFracturing>

7 http://www.wirtschaftsblatt.at/home/boerse/bwien/omv-will-mega-gasvorrat-im-weinviertel-ab-2020-foerdern-504947/index.do?_vl_pos=r.1.NT

8 Naturally Occurring Radioactive Material.

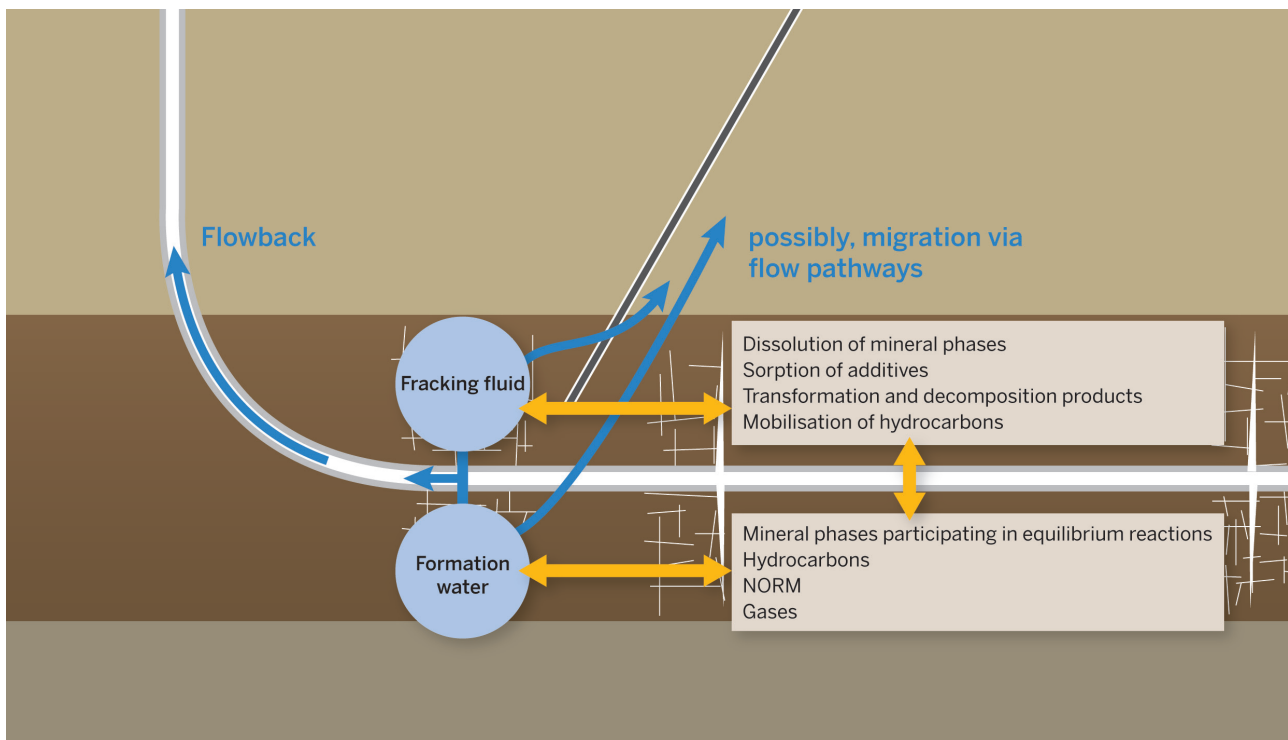


Fig. 7: Schematic depiction of flowback formation via mixing of fracking fluids and formation water in connection with hydrogeochemical processes

water via one or more of the aforementioned impact pathways, and if they result in a significant deterioration of the groundwater quality. The question of whether, and to what extent, substance transport in the direction of exploited groundwater resources occurs thus depends on the relevant, site-specific, geological and hydrogeological conditions, as well as on the sorption properties of fracking additives and the surrounding rock.

3.4.2 Disposal pathways

As noted, flowback composition is always deposit-specific, because (i) fracking additives are selected site-specifically and (ii) the quality of the formation water is also site-specific. Possible technical processes for treating flowback are described in Rosenwinkel et al. (2012). Rosenwinkel et al. (2012) conclude that none of those flowback-treatment processes, at present, qualifies as “best available technology” within the meaning of the Federal Water Resources Act (Wasserhaushaltsgesetz). In general, the following options are available for disposing of / recycling of flowback:

- Injection via disposal wells,
- Treatment, for discharge into surface water,
- Treatment, for discharge into the sewer system,
- Reuse in future fracks,
- (Atomization / evaporation / agricultural irrigation).

At present, formation water and flowback are commonly disposed of via injection wells / disposal wells in those regions in which conventional and unconventional gas production are already taking place, usually in depleted oil or gas deposits, or other rock horizons with the necessary permeability and capacity.

Flowback can present significant hazard potentials. In the view of the study authors, flowback disposal via injection into underground horizons can pose risks that can be analyzed and assessed solely in the framework of site-specific risk analyses. To our knowledge, the binding requirements that would be needed to assure such analysis are lacking.

Treating flowback in industrial wastewater-treatment facilities is seen by operators as an option that is technically feasible but not economically feasible. Therefore, the disposal via injection and disposal wells is currently preferred.

The question of whether, and to what extent, it would be technically feasible to reuse/recycle flowback can be answered only after analysis of the characteristics and concentrations of the recovered fluids.

4 Legal regulations and administrative structures

The legal section of the study considers issues of water protection and water-pollution control related to procurement, handling, use and disposal of injected and extracted fluids. The key regulations applying to such activities include provisions of mining and water law, along with regulations relative to environmental impact assessment. The study focuses especially on use of substances during actual fracking and on handling and disposal of flowback. In addition, it considers legal requirements pertaining to procurement, storage and transport of fracking fluids.

The present short version of the study includes a summary of the deficits seen, from a legal standpoint, with regard to applicable regulations and administrative structures, also in light of the prevailing scientific and technical parameters and of relevant risk assessment.

4.1 Mining law

Mining law establishes central requirements for fracking projects, including prerequisites for approvals of operational plans, and the Länder ordinances on deep-drilling (Tiefbohrverordnungen der Bundesländer – BVOT). Such requirements mandate that precautions must be taken to guard against risks, in conformance with generally accepted rules for safety technology and with special requirements, in ordinances on deep-drilling, designed to prevent damage.

At the same time, mining law does not have a “concentration effect” (blanket effect with regard to approvals). Neither does it take precedence over water law. In fact, requirements under water law have to be reviewed either as part of review of whether harmful impacts (for the public sphere) must be expected (Art. 55 (1) No. 9 Federal Mining Act (BBergG)) or as part of review of whether approval of the relevant operational plan would conflict with predominating public interests (Art. 48 (2) Sentence 2 BBergG).

Where an approval procedure under water law is required, water-law aspects must be given priority in review within the procedure. This results from general jurisdiction on delineation of parallel authorization procedures. On the other hand, for deep-drilling, mining authorities have not, to date, routinely carried out approval procedures under water law.

4.2 Water law

Applicable water law requires the execution of an approval procedure under water law for drilling of wells for which fracking is planned (for some future date), for fracking itself and for injection of flowback.

Discharging of substances directly into groundwater, in connection with fracking or with flowback injection, is deemed to constitute a “real use” (“echte Benutzung”) that is subject to permit requirements. Discharging of substances into geological formations in which groundwater is not directly encountered is deemed to constitute an “artificial use” (“unechte Benutzung”) that is also subject to permit requirements. On the one hand, applicability of permit requirements can result in that an indirect adverse effect on groundwater in the immediate or wider surroundings of the deepest point of the well cannot be ruled out with a sufficient degree of certainty. On the other hand, the Water Framework Directive requires such applicability, since that directive allows the introduction of substances into geological formations only when the relevant conditions have been found to be suitable for such introduction (Art. 11 (3) Letter j WFD). Under German water law, the suitability of the prevailing conditions must be determined as part of the relevant approval procedure under water law.

In the case of wells drilled for later fracking, the applicability of permit requirements results in that all drilling introduces substances into groundwater (drill bits, drilling fluid, casing, cement), as well as in that the planned fracking poses a risk of substance discharges into groundwater via failure of the sealing function of the casing and cementation. To ensure that groundwater is properly protected, the applicable requirements for casing and cementation have to be reviewed, and defined, in a water-law procedure carried out prior to the insertion of the casing.

A permit under water law may be issued only if no adverse impacts on groundwater must be expected (principle of prophylactic water protection, Art. 48 Federal Water Resources Management Act (WHG)). The principle of prophylactic water protection applies to both “real” and “artificial” uses.

No adverse impact on groundwater is deemed to be present if the de minimis thresholds derived from applicable maximum permitted levels, and via toxicolo-

gical and eco toxicological standards, are not exceeded in exploitable groundwater integrated within natural cycles.

Groundwater is subterranean water in the saturation zone that is in direct contact with the ground or with underground regions. It includes deep groundwater containing salt or pollutants. With regard to deep groundwater containing pollutants, the “suitability for protection”, i.e. any presence of an adverse effect, must be determined on an individual-case basis. For such groundwater, exceeding of the de minimis thresholds developed for exploitable groundwater integrated within natural cycles does not directly constitute an adverse impact on groundwater.

The principle of prophylactic water protection accepts not even the smallest possibility of water contamination; i.e. it requires that such contamination be completely improbable in light of human experience. The law is extremely stringent in this area. In any individual case, all circumstances must be considered. This extends to the possibility of disruptions / incidents, improbable developments and extensive and long-term impacts.

And even when all permit requirements are fulfilled, the decision on whether a permit under water law is actually granted is subject to management discretion. Under such management discretion, residual risks for the safety of the drinking water supply, and for the quality of groundwater, may be considered apart from specific precautions with regard to adverse impacts on groundwater and weighed against the economic benefits of gas exploration and exploitation.

To be sure, these stringent requirements under water law have been upheld by jurisdiction. And yet, water law, like mining law, contains many hazy legal concepts that leave room for interpretation, latitude that can be exploited – and is exploited – by the competent authorities, in various ways. It can be argued that, in practice, such interpretive latitude can lead to a considerable neglect of various aspects of water law. For this reason, the aforementioned situation should be clarified, in the interest of consistent interpretation of water law and of assuring the necessary groundwater protection. This should be accomplished in connection with mining-sector projects, at a suitable level – i.e. either via amendment of federal or Länder law or simply via internal administrative regulations or directives of authorities.

4.3 Handling of fracking fluids and flowback

With regard to above-ground handling of substances, a distinction has to be made between a) procurement and handling of water and additives, and of the fracking fluids formed by mixing them, and b) handling of flowback.

Procurement of water is subject to the normal requirements, under water law, applying to removal of groundwater and surface water, except in cases in which the water is obtained by other means. Procurement and handling of additives are subject to requirements under laws on chemicals and substances (REACH Regulation, laws on biocides), mining law (ordinances on deep-drilling), water law (facilities for handling substances hazardous to water) and occupational health and safety legislation (mining ordinances, Ordinance on Hazardous Substances (Gefahrstoffverordnung)). Pursuant to requirements under laws on chemicals and substances, for each substance and each mixture involved, it must be determined whether a general or special prohibition on use, a constraintment on approval, a registration obligation or an obligation to prepare a safety data sheet or a use-based safety study applies. For many substances, provisions on transitional periods and on exemptions apply (for example, below certain concentration levels).

Handling of flowback is subject to requirements under legislation on mining waste and on wastewater. Where they are radioactive residues, sludge and deposits fall under legislation on radiation protection, except where compliance with legally defined monitoring limits is assured. Flowback is both liquid mining waste and wastewater, since flowback – recovered water – contains both (unaffected) formation water and injected water that has been affected via human use – addition of additives, injection, mixing with formation water and extraction.

4.4 Coordination and integration of authorization procedures under mining law and water law

To date, mining law and water law contain no provisions on coordination of parallel procedures. All authorization procedures for mining projects should be completely coordinated – as has been accomplished for legislation on authorization of industrial plants – in order to ensure that before any project commences all relevant conditions for authorization have been met and all required authorizations have been

issued. In addition, minimum requirements pertaining to submitted application documents should be established.

The procedure for approval of operational plans should be redesigned, via a federal-level legislative amendment, as an integrated project-approval procedure under environmental law. This would ensure that comprehensive review, under water law, is always carried out, without creating the need for an additional approval procedure to achieve that aim. Compliance with requirements under water law should be ensured either a) by making the mining authority, which serves as the environmental and water-quality authority, subject to the specialized supervision of the highest-level water authority, or b) ensuring that approvals may be issued only with the consent of the water authority.

4.5 Development of general standards

The key deficits applying to execution of authorization procedures under mining law and water law, for fracking projects, include a lack of specific material standards – especially with regard to requirements under water law – and discrepancies in the stringency of co-existing requirements under mining law and water law.

The applicable requirements level under mining law is the level of generally accepted rules and principles of sound engineering practice. By contrast, under water law, discharges of substances into groundwater are subject to the principle of prophylactic water protection, without any weakening via clauses pertaining to equipment/technology/engineering. Under wastewater law, the higher requirements level of the “best available technology” applies.

The differences between the requirements levels of mining law and of water law have practical implications in that requirements under mining law are detailed via pertinent technical regulations, while either no specifications, or only very general specifications, exist with regard to the principle of prophylactic water protection, relative to groundwater protection, and to “best available technology” requirements for wastewater-treatment equipment used in connection with mining projects. This complicates the task, for mining and water authorities, of reliably assessing requirements under water law. Requirements under mining law (which tend to be less stringent) are easier to apply.

To eliminate this deficit, use of “best available technology” should be made a standard condition for approval under mining law, as it already is under legislation on authorization of industrial plants.

4.6 Water protection areas

At present, ordinances on protected areas usually contain constraints on approvals for drilling and for certain uses of substances hazardous to water. They also contain prohibitions on discharges of substances hazardous to water, and of wastewater, into underground regions. Normally, such regulations should already mean that drilling and operation of wells for fracking and for injection are prohibited, in general, in water protection areas and may be approved only via special exemptions.

Legislative deficits apply to fracking projects within water protection areas in that actual drilling is subject only to certain constraints on approval, while fracking is only prohibited insofar as it is carried out using substances hazardous to water. Currently, it cannot be concluded, with sufficient certainty, that the risks posed by fracking using no substances hazardous to water would be significantly lower than those posed by fracking with substances hazardous to water. For this reason, all fracking – even fracking that uses no substances hazardous to water – should generally be prohibited in water protection areas.

4.7 Environmental impact assessment (EIA) and public participation

Under German national law, EIA obligations currently apply solely to projects, subject to obligations to prepare operational plans, oriented to gas exploitation at daily production levels greater than 500,000 m³. That scope violates the provisions of the EIA Directive, however. That directive mandates that EIAs be carried out for deep-drilling, and for above-ground facilities for gas production, even for projects below that threshold, taking account of certain selection criteria. Pursuant to the jurisdiction of the European Court of Justice (ECJ), such projects may not be completely exempted from EIA obligations. What is more, so the ECJ, the applicable selection criteria must be applied either directly via the thresholds or via (supplementary) individual-case review. Since the German EIA ordinance for the mining sector (UVP-V Bergbau) does not fulfil those requirements, the EIA Directive already applies directly, because it takes precedence.

For each individual case, it requires that preliminary review be carried out to determine if the specific project involved, at the site in question, is subject to EIA requirements.

Apart from that requirement, the EIA Directive has to be transposed via directive-conformal redefinition of EIA obligations for fracking projects. According to current findings, it cannot be denied that such projects could have extensive, lasting and irreversible adverse impacts on the drinking water supply and on the natural environment. In light of the precautionary and preventive-action principle, this indicates that the threshold for EIA obligations should be set very low for the time being, i.e. that general EIA obligations should be introduced for fracking projects. To ensure they are able to take pertinent new findings into account, the Länder could be given the option, for certain projects carried out under certain geological conditions, of imposing EIA obligations only following preliminary review in individual cases.

In general, EIA obligations should be oriented to drilling and operation of wells in which fracking takes place or flowback is injected. And EIA obligations should apply even to set-up and operation of drilling sites with a single well (for example, an exploration well). Furthermore, the obligations should apply to all drilling and auxiliary facilities taking place / used at a drilling site.

Another central deficit in current legislation is that thus far it has been possible for fracking projects to be carried out without any public participation. Introduction of EIA obligations would immediately eliminate this deficit, because public participation forms part of any procedure involving environmental impact assessment.

Mining projects differ from many other types of environmentally relevant projects in that their environmental impacts are very difficult to predict before the projects actually commence. The potential environmental impacts of such projects will become easier to assess in advance as knowledge and findings in this area advance. On the other hand, such orientation to advancing knowledge is somewhat at odds with the objective of any EIA, namely to ensure that the relevant impacts on the environment are taken into account, in keeping with the EIA results, and as early as possible, in the relevant authorization procedure.

We recommend that advancement of knowledge relative to fracking projects be taken into account by

providing new possibilities for public participation in such projects. In addition, it should be ensured that renewed authorization and EIA obligations, following preliminary review in individual cases, arise not solely through project changes that can have significant environmental impacts, but also through adverse changes in key parameters (such as new findings) significant to assessment of a project's environmental impacts.

Site-related environmental impact assessment is inadequate to the task of reviewing plans for exploration and exploitation of unconventional gas over large areas, via numerous wells, i.e. plans for systematic, complete-coverage drilling. Due to their above-ground implications, and the need they create for coordination with other area-related planning, such plans should ideally be subject, and may even need to be subject, to regulations at the regional-planning level. The state-wide zoning plans and regional plans of the Länder are suitable instruments for achieving such regulation.

4.8 Responsibilities

In various ways, as defined by the relevant Länder laws in each case, mining authorities are responsible not only for permits under mining law, but also for central monitoring tasks under water law and other environmental legislation. In general, this is to be welcomed; it is in keeping with modern practice in environmental protection legislation, which seeks to have a single authority function as a “fence authority” (“Zaunbehörde”), i.e. be responsible for all tasks of relevance for environmental protection. This approach prevents fragmentation of responsibilities.

On the other hand, mining authorities tend to be organized as part of ministries for industry and economics, and this is problematic. The core tasks of such authorities include promoting business interests. Only in some areas – in keeping with applicable Länder law, within the framework of tasks entrusted to them under environmental law and, especially, water law – are mining authorities subject to the detailed supervision of the supreme environmental authorities (ministries of the environment). In light of the significant environmental relevance of mining projects, and of environment ministries' responsibility for enforcing environmental legislation, it should at least be ensured that all environmentally relevant decisions, i.e. all decisions relative to approvals under

water law, and to environmental impact assessments, and execution of supervisory measures under environmental law, be completely subject to the detailed oversight of environment ministries. Only environment ministries have the necessary competence relative to environmental protection, and environmental protection law, for such oversight.

In addition, we recommend that overall approval and monitoring of mining projects, with regard to environmental and safety legislation, be assigned to the portfolios of environment ministries. Such assignment would be in keeping with the way such tasks are assigned with regard to industrial facilities. Decades ago, responsibilities for monitoring such facilities, with regard to environmental legislation, were transferred from economics ministries to environment ministries, in connection with removal of emission-protection law from the sphere of commercial/industrial law. This was done in order to assure proper enforcement of environmental law.

Careful, impartial review and monitoring of environmental impacts, by the competent authorities, plays an especially important role in connection with publicly controversial projects – such as fracking projects. Without public confidence and trust in such review and monitoring, even detailed study of pilot projects' environmental impacts will hardly be likely to meet with sufficient public acceptance.

5 Recommendations for action and procedures

Only in combination with technical and geological impact pathways, the substance-related hazard potentials of fracking projects related to exploration and exploitation of unconventional gas can become risks for the environment. We have found that in various geological systems several of such impact pathways can occur. No reliable data are currently available that would provide a basis for the reliable exclusion of risks to near-surface water resources. Because of the lack of reliable data, the relevant tools and methods available at present (such as numerical groundwater models) can yield only approximate results.

In our view there is great lack of basic information that would be needed for any well-founded assessment of the pertinent risks and the degree to which they can be controlled by technical means. Examples of such information include information regarding the structures and properties of deep geological systems (permeabilities, potential differences), the identities of the fracking additives used and the chemical and toxicological properties of such additives. There are several reasons for this lack of information and data: (a) the information and data are not (openly) accessible, (b) the information and data have not yet been evaluated, and/or (c) there are gaps in our knowledge that can be closed only through additional studies and research.

Mining law and water law establish legal requirements that apply to fracking projects, with regard to groundwater protection. Under water law, fracking projects and flowback injection have to be reviewed in order to determine whether any risks of adverse impacts on groundwater can be ruled out. Such review must be carried out in the form of an approval procedure under water law. Because the EIA Directive takes precedence over the German EIA ordinance for the mining sector (UVP-V Bergbau), all fracking projects are already subject to the requirement that preliminary review must be carried out, in each individual case, to determine if an EIA is required. Enforcement to date in this area exhibits shortcomings. Regulatory deficits are found in implementation of requirements under the EIA Directive, and in the uncertainties seen in application of water law (definition of “groundwater”, applicability of permit requirements, fulfillment of permit requirements).

The following recommendations for action and procedures are based on the results of our studies, which are described in the previous sections.

We expressly note that stimulation in connection with development of deep geothermal deposits was not considered in the present context, and that thus our recommendations cannot be directly applied to techniques for geothermal stimulation.

5.1 Overarching recommendations

In light of the current situation as described, and on the basis of our assessments, we have developed the following overarching recommendations:

- (1.1) The risks of exploration and exploitation of unconventional gas projects can be reliably analyzed only insofar as reliable information on the relevant geological systems (and potential impact pathways) is available, along with information about the characteristics of the deposits in which the pertinent gas reserves are found. We thus recommend that exploration of gas deposits be combined with exploration of the relevant geological systems, in order to place the resulting site-specific information in a larger, regional context. In our view, mining authorities and gas companies should routinely consult with each other regarding the issue of what information is required. The information should be largely publicly accessible, in order to enhance public acceptance. In our view, in each case the authorities and gas companies should communicate clear information regarding the geological systems involved, the gas deposits involved and the planned exploration strategies (including their potential impacts).
- (1.2) We recommend that the many relevant data that are available and that have not yet been evaluated (cadaster of old wells, cadaster of disposal wells, etc.) be evaluated and that the results be published. Pertinent experience should also be so evaluated and published. At the same time, we maintain that without new data it will not be possible to answer the questions of whether, and where, economically exploitable unconventional gas reserves are present in Germany and of what technology (with or without fracking) could be used to develop them. We thus could support the idea of carrying out further exploration, including exploration involving deep drilling (but without fracking), and carrying out targeted research in the above-described framework, for the purpose of answering those questions.
- (1.3) We recommend that further actions be taken step-by-step: clear criteria should be established for deciding whether or not fracking should be allowed, at a later time, in wells. Such criteria should cover both the hazard potential of fracking additives and the availability of reliable information about the geological and technical impact pathways involved. We maintain that it should go without saying that both exploration and any later production should be subject to clear criteria for approval. A catalogue of criteria for approval should be developed step-by-step. In this area as well, we recommend that transparent approaches be applied, possibly approaches involving the interested public.
- (1.4) In light of the sketchiness of the currently available data, and of the fact that environmental risks cannot be ruled out, the study authors recommend, from the standpoint of water-resources management, that above-ground and below-ground activities for unconventional gas exploitation should not be approved, for exploration and exploitation companies that use fracking, in water protection areas (classes I through III), in water-extraction areas for the public drinking water supply (even if not set aside as water-protection areas), in mineral spa protection zones and near mineral water reserves, and that the aforementioned areas be made off-limits for such activities. As better data become available, this recommendation on denial of approval should be reviewed. In areas known to have unfavourable – with regard to potential environmental impacts – geological and hydrogeological conditions (groundwater potentials and pathways), no exploration and exploitation of unconventional gas (via deep-drilling and fracking) should be carried out.
- (1.5) We recommend that research and development be intensified in areas such as enhancement of the long-term integrity of wells; improvement of techniques for forecasting the widths and lengths of fractures caused by fracking; and development of fracking fluids with lower hazard potential. Practical application of the relevant research findings should be monitored scientifically.

- (1.6) Site-specific risk analyses should be carried out with regard to any future drilling with fracking, and to drilling and use of disposal wells for injection of flowback. Such analyses should take account of all relevant fluids, whether introduced or encountered (fracking additives, formation water and its reaction products, and flowback), and of the relevant geological (and technical) impact pathways. In addition, risk analysis involving both overarching and site-specific approaches should be carried out. We recommend that use of toxicologically and eco toxicologically hazardous fluids, and flowback disposal in disposal wells – also in the tight gas deposits in Germany that have already been exploited for many years – be reassessed.
- (1.7) With regard to EIA obligations, we recommend that fracking projects be subject to general federal EIA obligations, and that such obligations include an „opening clause“ to allow Länder participation. The public participation required under EIA legislation should be expanded to include a project-monitoring component, since many findings regarding projects' potential environmental impacts cannot be obtained until the projects are actually underway. Careful review of requirements under water law should be assured, via clarification of pertinent requirements, and via a) introduction of an integrated project-approval procedure to be directed by an environmental authority subordinate to the Ministry for the Environment, or b) integration of mining authorities within the environmental administration.
- (1.8) In our view, the following two aspects are of central importance with regard to any continuation of exploration and exploitation of unconventional gas in Germany, regardless of the procedures applied: all work processes and results should be fully transparent, and all stakeholders should exercise trust in their dealings with each other. Efforts to further these aims should include the establishment of a publicly accessible cadastre listing all fracking measures carried out, along with the quantities of fluids used and the compositions of the fluids used. To our knowledge, such a database is currently being prepared, in Lower Saxony, with the participation of Lower Saxony's state office for mining, energy and geology (Niedersächsisches Landesamt für Bergbau, Energie und Geologie – LBEG) and of the Wirtschaftsverband Erdöl- und Erdgasgewinnung (WEG) German oil and gas industry association. The study authors were unable to view that database by the time the present study was completed, however.
- (1.9) In our view, it would be useful to carry out a comparative analysis of the studies carried out to date in Germany with regard to the risks of exploration and exploitation of unconventional gas, in order to identify the areas in which the studies agree, and the areas in which they differ, with a view to finding strategies for resolving the latter. In addition to the present study, such comparative analysis should especially cover the studies undertaken as part of the information and dialog process initiated by ExxonMobil and the study prepared under commission to the state (Bundesland) of North Rhine – Westphalia (ahu AG et al. 2012). Furthermore, the comparative analysis should also cover, if possible, any available (interim) results of the study announced by the U.S. EPA (US EPA 2011).

5.2 Special recommendations

In the following sections, we have developed special recommendations with regard to further steps relative to the issue of exploitation of unconventional gas in Germany. The focus of the recommendations is on the next phase of pilot exploration, especially exploration in geological systems for which no information, or very little information, is yet available about unconventional gas deposits they may contain. The objectives of our recommendations include:

- Closing gaps in pertinent findings and knowledge (sections 5.2.1 through 5.2.4),
- Identifying hydro geologically problematic areas, and possible impact pathways, at an early stage, and proposing measures for ongoing monitoring (section 5.2.1),
- Making pertinent drilling and handling techniques safer (section 5.2.2),
- Reducing the hazard potential of the substances used, or making it possible to assess such hazard potential (section 5.2.3), and
- Suitably shaping and structuring legal and organisational procedures in this area (section 5.2.4).

5.2.1 Special recommendations with regard to the area of environment / geological systems

The cause-and-effect relationships between deep-reaching and near-surface groundwater flow systems are of particular importance with regard to the water-related environmental impacts of unconventional gas exploitation projects (impacts on people, flora and fauna). To properly assess such water-related risks, and even quantify them, one must have a detailed understanding of the hydrogeological systems involved.

Analyses of selected geological systems have shown how widely sites can differ in terms of their specific geological and hydrogeological characteristics and parameters. In many cases, the information required for such analyses can be obtained only through consultation of many different sources. The information has to be compiled and studied, and then assessed from an overarching perspective. Such efforts should include the following main steps:

- (2.1.1) Conceptual hydrogeological models should be prepared that support reliable risk analysis for all potential impact pathways. The scope of such conceptual models should be large enough to support assessment of the impacts of exploration and exploitation of unconventional gas – via fracking – both for the specific sites involved and with regard to the large geological systems involved.
- (2.1.2) For areas in which water-related environmental impacts cannot be ruled out (as shown by risk analysis), numerical groundwater-flow models should be prepared/refined with which the pertinent risks can be quantified. As a rule, this will entail preparing a regional-level model that can then serve as a basis for local models within and around the actual gas-production area.
- (2.1.3) Normally, the work mentioned under (2.1.1) and (2.1.2) will necessitate additional evaluations and terrain studies (system-oriented exploration).
- (2.1.4) The aforementioned models have to be continually verified and calibrated on the basis of data and information obtained through monitoring (both preliminary and during the project). For monitoring to be effective, it must be based on an adequate understanding of the system involved (see above). At the same time, the understanding of the system involved (conceptual or numerical model) can be improved with the help of data obtained via monitoring.
Monitoring-based project control requires meaningful indicators (derived directly from measurements and/or calculations) for which an evaluation system is available. Ultimately, options must be available for stopping, limiting or reversing any undesired developments, to ensure that no damage occurs and that risks do not increase.
The models resulting from the aforementioned work steps provide an important basis for competent authorities' decisions regarding the general authorizability of submitted projects and design and structuring of ancillary provisions (under water law) for specific projects.
- (2.1.5) The necessary regional and local models must be prepared by the relevant mining companies, in the framework of authorization procedures under mining law and water law, and in keeping with the requirements imposed by the competent mining and water authorities. In the current early phase of use of fracking technology, however, the competent mining and water authorities should first develop the requirements applying to such models. And such development should be carried out step-by-step. In our view, a fracking project may be approved only when enough pertinent knowledge has been gained, and adequate precautions have been taken, to rule out the possibility of an adverse impact on groundwater.

5.2.2 Special recommendations with regard to the area of equipment / techniques

The current key regulations applying, in Germany, to drilling equipment and techniques for developing conventional gas resources, and for developing unconventional gas deposits, result from the provisions of the Federal Mining Act (BBergG) and its secondary legislation – such as ordinances on deep-drilling (Mining ordinance on deep-drilling, underground storage areas and on resources extraction via wells (Bergverordnung für Tiefbohrungen, Untergrundspeicher und für die Gewinnung von Bodenschätzen durch Bohrungen – BVOT); such ordinances differ slightly between states – and from other relevant environmental provisions specified in the permits for such operations.

In addition, within this legal framework there are numerous different implementation provisions that may be applied by gas-production companies.

Companies choose exploration and production strategies on an individual-case assessment. Criteria they take into account are the equipment and techniques to be used, the specific geological and hydrogeological characteristics of the site's deposits and, not least, their own experience in developing the deposits in question (companies' internal standards).

- (2.2.1) Approval authorities should apply implementation provisions consistently and logically (and, in each individual case, in keeping with the prevailing geological and technical parameters).
- (2.2.2) The international drilling standards established in the gas-production sector (API standards, guidelines of the Wirtschaftsverband Erdöl- und Erdgasgewinnung (WEG) German oil and gas industry association, etc.) are technically adequate in terms of the current state of the art in drilling technology. Nonetheless, efforts should be made to reconcile operators' own internal safety standards, which in some cases are quite stringent, and to mandate a binding safety level. Inter-Länder coordination of such efforts should be sought.

- (2.2.3) In order to enhance safety, particular attention should be given to ensuring compliance with applicable guidelines for wells and casings, and to ensuring that casings are fully cemented. In addition, – and this is also in keeping with standard practice – we recommend that completed wells be inspected and checked for pressure-tightness in light of the fracking pressures expected in them.
- (2.2.4) The existing requirements applying to the leak-tightness of cementations should be reviewed, and further detailed if necessary, in light of the specific requirements applying to fracking. Such review should also include suitable studies and monitoring procedures for ensuring the long-term integrity of wells (casing and cementations).
- (2.2.5) For cases involving hydraulic stimulation, we recommend that frac propagation be monitored via suitable procedures. Further research is required in this area as well, i.e. with a view to improving modelling and monitoring of frac propagation, and inter-Länder coordination should be carried out with a view to achieving relevant consistent, suitable standards and minimum requirements.

5.2.3 Special recommendations with regard to the area of substances

Assessment of selected fracking fluids used in unconventional gas deposits in Germany, along with the available information on the characteristics of flowback, have revealed that injected fluids, and fluids requiring disposal, can pose considerable hazard potentials. In light of the gaps in knowledge, uncertainties and data deficits identified via the research and assessment for the present study, the following recommendations for action are seen as important:

- (2.3.1) Complete disclosure of all substances used, with regard to substance identities and quantities.
- (2.3.2) Assessment of the toxicological and ecotoxicological hazard potentials of substances used, and provision of all physical-chemical and toxicological substance data required by the applicants. If relevant substance data are lacking, the gaps in the data must be eliminated – if necessary, via suitable laboratory tests or model calculations. In the process, the effects of relevant substance mixtures must be taken into account.
- (2.3.3) Substitution of unsafe substances (especially substances that are highly toxic, carcinogenic, mutagenic or toxic for reproduction), reduction or substitution of biocides, reduction of the numbers of additives used, lowering of concentrations used.
- (2.3.4) Determination and assessment of the characteristics of site-specific formation water, with regard to constituents of relevance to drinking-water quality (salts, heavy metals, Naturally Occurring Radioactive Material – NORM, hydrocarbons).
- (2.3.5) Determination and assessment of the characteristics of site-specific flowback, with regard to constituents of relevance to drinking-water quality (salts, heavy metals, NORM, hydrocarbons), and with regard to additives used (primary substances) and their transformation products (secondary substances); determination and assessment of the proportion of fracking fluids recovered with the flowback.
- (2.3.6) Determination of the behavior and fate of substances in the ground, via mass-balancing of the additives used.
- (2.3.7) Modeling of substance transport, for assessment of possible risks to any exploitable groundwater, from any ascending formation water and fracking fluids.
- (2.3.8) Technical treatment and “environmentally sound” disposal of flowback, including description of all technically feasible treatment processes and of the possibilities for reusing substances. In cases involving injection into disposal wells, site-specific risk analysis, and description of the impacts on water resources that accumulate spatially and over time.
- (2.3.9) Monitoring and system-oriented examination (cf. also section 5.2.1), including installation of near-surface groundwater measuring stations to determine the reference condition with regard to additives and methane; if appropriate, installation of deep groundwater measuring stations to determine the characteristics of formation water and the relevant hydraulic potentials.

5.2.4 Special recommendations with regard to the area of legislation / administration

The deficits analysis carried out with regard to the applicable legal framework was based on the working hypothesis that existing basic concerns about adverse impacts on groundwater could be eliminated in the framework of required authorization procedures – at least for a significant number of sites and projects, and, if necessary, after issue of specifications relative to technical implementation and to monitoring of environmental impacts. In sum, the following specific recommendations for action have resulted:

- (2.4.1) Already under currently applicable laws, preliminary, individual-case review of fracking projects must be carried out to determine whether an environmental impact assessment is required. This results from the direct applicability of the EU EIA Directive. The German EIA ordinance for the mining sector (UVP-V Bergbau), and mining authorities' existing practice, based on that ordinance, of not requiring a preliminary review of EIA requirements, do not conform to requirements pertaining to implementation of that directive as specified by the European Court of Justice.
- (2.4.2) The EIA Directive must be properly transposed. To that end, EIA obligations should be introduced from which only minor cases would be exempted. At the same time, the Länder should be empowered to determine, for all or parts of their territories, that EIAs for certain types of projects (to be determined), are required only if so indicated by the results of a general or site-specific preliminary review of EIA requirements, or may be waived if such results lie below certain thresholds (to be determined). In the short term, EIA obligations should be established via amendment of the German EIA ordinance for the mining sector (UVP-V Bergbau). In the medium term, they should be established via amendment of the Environmental Impact Assessment Act (UVPG), with integration of provisions on EIA obligations for mining projects in the list in Annex 1 of the Environmental Impact Assessment Act.
- (2.4.3) The decision on whether an EIA is required, in a given case, should be made by the mining authority, in keeping with the pertinent assessment by environmental authorities, if the mining authority is not also the environmental authority and is subject to the detailed supervision of the highest environmental authority. This assignment of responsibilities should be defined at the federal level.
- (2.4.4) Both a) establishment and operation of drilling sites intended to be used later for fracking, and b) establishment and operation of self-contained drilling sites with injection wells for flowback, should automatically be deemed projects subject to EIA obligations. EIA obligations should also apply even to set-up and operation of drilling sites with a single well. And they should apply to all wells drilled and operated from a single drilling site. Furthermore, as necessary in keeping with a relevant company's project concept, they should also apply to set-up and operation of drilling sites linked as part of a single project. Injection wells intended solely as ancillary facilities for a unified fracking project should also be subject, as parts of the project, to EIA obligations.
- (2.4.5) Where EIA obligations apply, EIA requirements dictate that public participation is required. For fracking projects, public participation should be expanded to include ongoing participation during the project, to ensure that the public is informed about whether, and to what extent, the assumptions are confirmed, in the course of further site exploration, that were made in the EIA carried out prior to the setting-up of the drilling site (for example, assumptions regarding the lack of any faults), and to enable the public to ensure that the competent authority addresses new risks properly as they emerge. To that end, the possibility should be provided of establishing monitoring groups modeled after the „Asse-II Monitoring Group“ (Asse-II-Begleitgruppe; focusing on radioactive waste stored in the Asse II former salt mine); such groups would include representatives of municipalities and municipal organizations, of environ-

mental groups and of citizens' initiatives, and would engage in ongoing dialog with the relevant mining company and mining authority in each case. In addition, it should be ensured that renewed authorization and EIA obligations, following preliminary review in individual cases, arise both through project changes that can have significant environmental impacts and through adverse changes in key parameters (such as new findings) significant to assessment of a project's environmental impacts.

- (2.4.6) With regard to the definition of „groundwater“, which determines the scope of application of water law, it should be clarified that water in deep geological formations is groundwater within the meaning of the Federal Water Resources Management Act (WHG), regardless of the depth at which it occurs, regardless of any hydraulic connections to near-surface groundwater and regardless of its quality. Such clarification is required especially with regard to the issue of salt content, because mining authorities sometimes deem water law to be inapplicable when water salt-content levels justify classification as brine.
- (2.4.7) At the same time, it should be clarified that an adverse effect on deep groundwater may be deemed present only for water that qualifies for human uses or that is part of the biosphere's natural systems. „Water that qualifies for human uses“ should refer not only to uses that are cost-effective at present, but also to possible uses under changed framework conditions. The de minimis thresholds used to evaluate whether an adverse impact on near-surface groundwater has occurred thus cannot be used, in the same way, for assessment of changes in deep groundwater.
- (2.4.8) In any case, for fracking wells and wells for flowback injection, review, under water law, should be carried out with regard to casing and cementation, as well as with regard to discharges of substances in connection with fracking and with injection.
- (2.4.9) Preferably, such review under water law should be carried out in the framework of an integrated project-approval procedure, and should have a concentration effect relative to water law. In addition, it should be carried out under the direction of an environmental authority subordinate to the Ministry of the Environment. For introduction of such procedures, the Federal Mining Act would have to be amended.
- As long as applicable laws have not yet been suitably amended, it should be clarified that review with regard to water law must be carried out within an approval procedure under water law, in agreement with the water authority.
- (2.4.10) The conditions for a permit under water law should be defined via general standards for required preliminary exploration, for the design of technical components, for knowledge of the systems involved and for monitoring of impacts on groundwater. Where such standards cannot be derived at an abstract regulatory level, due to a lack of relevant knowledge, they should be developed, via a coordinated process, in the framework of pending individual authorization procedures.
- (2.4.11) An integrated project-approval procedure should also be required by law for facilities for treatment of flowback, and for pipelines for transport of flowback, where the project-approval procedure for the relevant drilling site does not automatically extend to such facilities. As long as such a project-approval procedure is not required by law, it should be ensured that conformance with requirements under wastewater law is reviewed within the relevant procedure under mining law, if no separate approval procedure under wastewater law is carried out.
- (2.4.12) In general, drilling and operation of fracking and injection wells should be prohibited within water-protection zones and mineral spa protection zones. At the same time, it should be possible, in individual cases, and in connection with overriding reasons of the public interest, to issue an exemption if a proce-

dures with environmental impact assessment and public participation has been carried out. If it becomes clear that fracking technology is to be used on a large scale, as a precautionary measure, all fracking projects and projects for flowback injection within a certain radius (to be defined) of a protected area should be made subject to a constraint on approval, in keeping with all available findings at that time, via amendment of the relevant protected-area ordinances or via individual-case decisions.

(2.4.13) In accordance with a step-by-step procedure, water-law permits for pending fracking projects should be issued first for relatively low-impact projects, in areas of relatively low sensitivity, and such permits should be tied to comparatively stringent requirements relative to preliminary study, technical design and ongoing monitoring, as long as concerns regarding adverse impacts on groundwater cannot be eliminated for other projects or in other areas. While requirements applied to approved projects should primarily have the purpose of eliminating concerns regarding projects' adverse impacts on groundwater, they should also be evaluated as a basis for assessing comparable future projects.

(2.4.14) In accordance with a step-by-step procedure, water-law permits for specific fracking projects should be structured, via suitable provisions and ancillary provisions, so as to ensure that measures about which concerns regarding adverse impacts on groundwater cannot immediately be eliminated are approved only if assessment of the execution and monitoring of authorisable, safe measures (such as measures with lower pressures, of shorter durations, or with lower pollutant concentrations or quantities) has shown that measures with potentially greater impacts also give no cause for concern.

(2.4.15) In the framework of management discretion under water law, the (provisional) denial of a permit under water law may be justified if relevant concerns falling into the „boundary area“ between concerns that would automatically lead to denial of a permit and the remaining residual risks cannot be eliminated, in light of the most recent relevant findings. In this „boundary area“, management discretion allows weighing of the economic interest in development of unconventional gas deposits against the economic interest in assuring the drinking water supply. In this framework, it may also be taken into account whether, and to what extent, the gas supply is assured via imports. That criterion may only be considered, however, if in a relevant concrete case a residual risk for the drinking water supply indeed cannot be ruled out. In this framework, it may also be taken into account whether findings from ongoing (pilot) projects will, in the foreseeable future, provide a better basis for assessment, and reconsideration of the decision on whether to issue a permit should be postponed until then. Where approval for exploration and exploitation projects is to be denied for reasons other than considerations related to water-resources management, or if such approval is initially to be limited to just a few test or demonstration projects, the possibility of amending the Federal Mining Act should be considered (for example, for introduction of management discretion under mining law).

(2.4.16) As long as no integrated project-approval procedure has been defined by law, the authorization procedure under water law, and the operational-plan procedure under mining law, could be completely coordinated, in the manner used for parallel authorization procedures for industrial facilities. Operational-plan approvals for relevant measures subject to permit requirements under water law – specifically, drilling wells and furnishing them with casings; fracking; and flowback injection – should not be issued until it is clear, from the status of the relevant procedures under water law, that there is no cause for concern regarding adverse impacts on groundwater and thus a permit under water law may be issued.

- (2.4.17) For purposes of review under water law, a project's required application documents must include a detailed description of the project (specific technical design, full disclosure of the substances to be used, description of the relevant operational procedures and of the boundaries of the operations to be authorized). The permit issued for a project must specifically define the content of the approved measure. For that purpose, it does not suffice simply to refer to general legal requirements or to general provisions of technical regulations, without including a precise description of the specifically approved measures.
- (2.4.18) While legal provisions, or secondary legislation, are not absolutely necessary for implementation of most of these recommendations for action, such provisions and legislation are useful. They can be implemented, without regulatory overhead, in the framework of applicable laws, via suitable implementation by the competent mining and water authorities. We recommend at least that these matters be regulated via directives of the highest water authorities (Länder environment ministries), ideally in cooperation with the highest mining authorities (usually the ministries of economics of the Länder; in Baden-Württemberg and Hesse, they are also the environment ministries, however). In the medium term, requirements pertaining to fracking projects should be defined via an integrated procedure under mining law and water law. This should be achieved via supplementation of the mining ordinances on deep-drilling, underground storage areas and on resources extraction via wells (Bergverordnungen für Tiefbohrungen, Untergrundspeicher und für die Gewinnung von Bodenschätzen durch Bohrungen – BVOT), to provide for relevant water-law regulations at the Länder level, or via introduction of an integrated BVOT at the federal level.
- (2.4.19) For the legislation level, we recommend that safety requirements under mining law be integrated within environmental law, in an approach similar to that used in the 1970s in integrating legislation on authorization of industrial plants within environmental protection legislation, in order to assure effective, efficient environmental protection.
- (2.4.20) With regard to responsibilities, we recommend that, overall, approval and monitoring of mining projects, under environmental and safety legislation, be sited in keeping with the approach used in integration of trade oversight within environmental administration – i.e. be assigned to the portfolio of environment ministries, in order to assure effective, efficient environmental protection and to functionally and organizationally separate business-promoting tasks of economic ministries from efforts to foster trust in authorities' oversight, which trust is an indispensable basis for public acceptance of fracking projects. As long as responsibilities have not been so assigned, mining authorities should take all important environmentally relevant decisions in keeping with decisions of the primarily responsible environmental authorities, except in cases – as in North Rhine – Westphalia – in which they are themselves environmental authorities and, as such are subject to the instructional authority of the environment ministry.

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„Mindful also of its responsibility toward future generations, the state shall protect the natural foundations of life and animals by legislation and, in accordance with law and justice, by executive and judicial action, all within the framework of the constitutional order.“

Basic Law for the Federal Republic of Germany, Article 20 a