HUNGARIAN SHALE GAS – IMPACTS ON THE ENVIRONMENT AND HUMAN HEALTH

AN EXPERTISE FOR MÉLTÁNYOSSÁG POLITIKAELEMZŐ KÖZPONT / CENTRE FOR FAIR POLITICAL ANALYSIS

Final Report

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20 December 2012

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R E P O R T

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ACRONYMS AND ABBREVIATIONS

As	Arsenic
Ba	Barium
Bq	Becquerel
Ca	Calcium
CAS	Chemical Abstracts Service
CH_4	Methane
CO	Carbon Monoxide
CO_2	Carbon Dioxide
Fe	Iron
GHG	Greenhouse Gas
HI	Hazard Index
HQ	Hazard Quotient
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for Conservation of Nature
K	Potassium
LBST	Ludwig-Bölkow-Systemtechnik GmbH
N_2O	Nitrous Oxide
NaCl	Sodium Chloride
$NaHCO_3$	Sodium Hydrogen Carbonate
NMVOC	Non-Methane Volatile Organic Compounds
NORM	Naturally Occurring Radioactive Materials
NO_x	Nitrogen Oxide
Pb	Lead
PM	Dust and Particulate Matter
Po	Polonium
ppm	parts per million
Rb	Rubidium
Rn	Radon
SCI	Areas of Special Conservation Interest
SO_2	Sulfur Dioxide
SPA	Special Protection Areas
Sr	Strontium
Sv	Sievert
TENORM	Technically Enhanced Naturally Occurring Radioactive Materials
Th	Thorium
U	Uranium
WHO	World Health Organization

ABOUT THIS STUDY

The Hungarian company TXM Exploration and Production LLC, headquartered in Budapest, affiliate of Falcon Oil & Gas Ltd. of Dublin, Ireland, have explored a shale gas deposit in Southern Hungary in the Makó area and are currently preparing commercial development of the licence area. Geological analysis of the area started some decades ago and several test wells have been drilled in recent years, some of which involved stimulation through hydraulic fracturing.

TXM has invited Hungarian Non-Governmental Organisations to round table discussions about local shale gas issues. In order to support this process, Méltányosság Politikaelemző Központ (MPK) / Centre for Fair Political Analysis (CFPA) has contracted Ludwig-Bölkow-Systemtechnik GmbH (LBST) to carry out a research study on the possible impacts of shale gas extraction in the Makó area on the local environment and human health. Legal issues are generally excluded from the present analysis, but may play an important role in the comprehensive assessment of the issue.

The aim of the research study is to provide a general risk appraisal by identifying possible impacts of shale gas extraction in the Makó area based on latest scientific knowledge and information provided by TXM. Two workshops for the exchange and discussion of information have been organised and extensive communication by e-mail and phone established. The information received has been evaluated by LBST's independent expert team and checked for consistency and plausibility in comparison to international scientific knowledge and industrial practice. On-site or off-site measurements of any kind have not been carried out by LBST's expert team in the framework of this study.

TXM has made available to the expert team detailed information, both on technical and on environmental aspects of the possible commercial development of unconventional gas extraction in the licence area.

It is important to emphasize, however, that commercial development of the licence area is still under preparation. Consequently, many aspects have been analysed on a general or on a hypothetical basis, and need to be checked against actual commercial planning and development in the future. Most importantly, the commercial field development plan, once established, should be the basis for a thorough environmental impact assessment, as recommended by the International Energy Agency.

The results presented in this study are valid for TXM's production licence area and the specific conditions present there, and under the assumptions specified in the text. The results can therefore not be transferred to other areas or situations. Changes in planning or implementation, or making other assumptions, may lead to significant changes in results.

1 OVERVIEW OF POTENTIAL RISKS AND THREATS

Unconventional gas exploitation implies a higher level of potential risks and threats on the environment and on human health than conventional gas exploitation. The present analysis focuses on the issues that are specific to unconventional gas extraction as follows[1]:

1. Potential risks and threats of drilling on the environment and human health
   - Noise and air pollution
   - Water consumption, potential sources of water (ground water, surface water)
   - Chemicals used in hydraulic fracturing
   - Radioactive materials
   - Waste water disposal
   - Potential contamination of surface waters
   - Hydrogeological aspects including potential contamination of ground water
   - Exploration-induced earthquakes
2. Ecological threats
   - Short and long term ecological threats, including impacts of the linear infrastructure and effects on the local biodiversity
   - Proximity of the local national park Kiskunsagi Nemzeti Park and other protected areas
   - Greenhouse gas balance

According to the International Energy Agency, *"the main reason for the potentially larger environmental impact of unconventional gas operations is the nature of the resources themselves: unconventional resources are less concentrated than conventional deposits and do not give themselves up easily. They are difficult to extract because they are trapped in very tight or low permeability rock that impedes their flow. Since the resources are more diffuse and difficult to produce, the scale of the industrial operation required for a given volume of unconventional output is much larger than for conventional production. This means that drilling and production activities can be considerably more invasive, involving a generally larger environmental footprint."*[2]

[1] See Altmann et al. (2011).

[2] International Energy Agency (2012), p. 19.

TXM production licence area

The commercial development of an unconventional gas field such as TXM's Makó production licence area requires a large number of well drillings, which will be carried out over a long period of time.

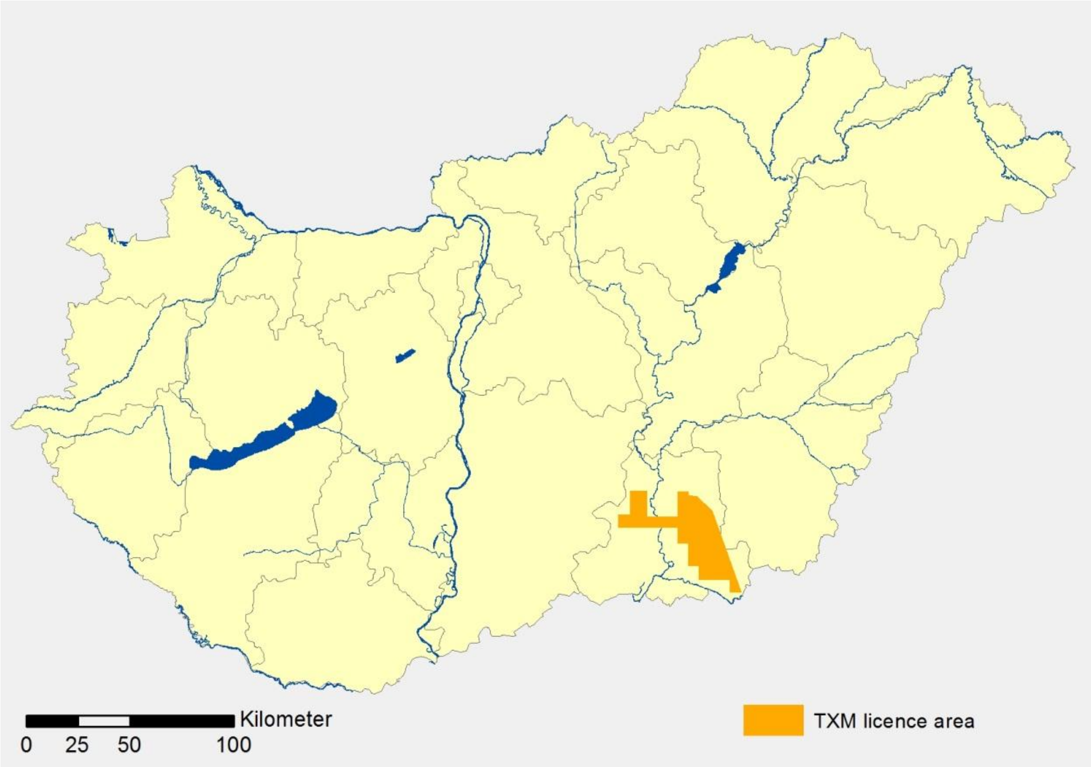

Figure 1: Location of the TXM licence area

TXM's Makó production licence area is located in south-east Hungary covering 994 km^2 mainly in the Csongrad county (Csongrád megye) and to less than 1.5% in the Bekes county (Békés megye). The Romanian border is close to the south-eastern part of the licence area while the Serbian border is close to the south-western part. The entire licence area is part of a plain lowland some 78 – 90 m above mean sea level.

Hypothetical field development

As environmental impacts are cumulative of all wells established the assessment of potential risks and threats requires an understanding of the development of operations over time and area.

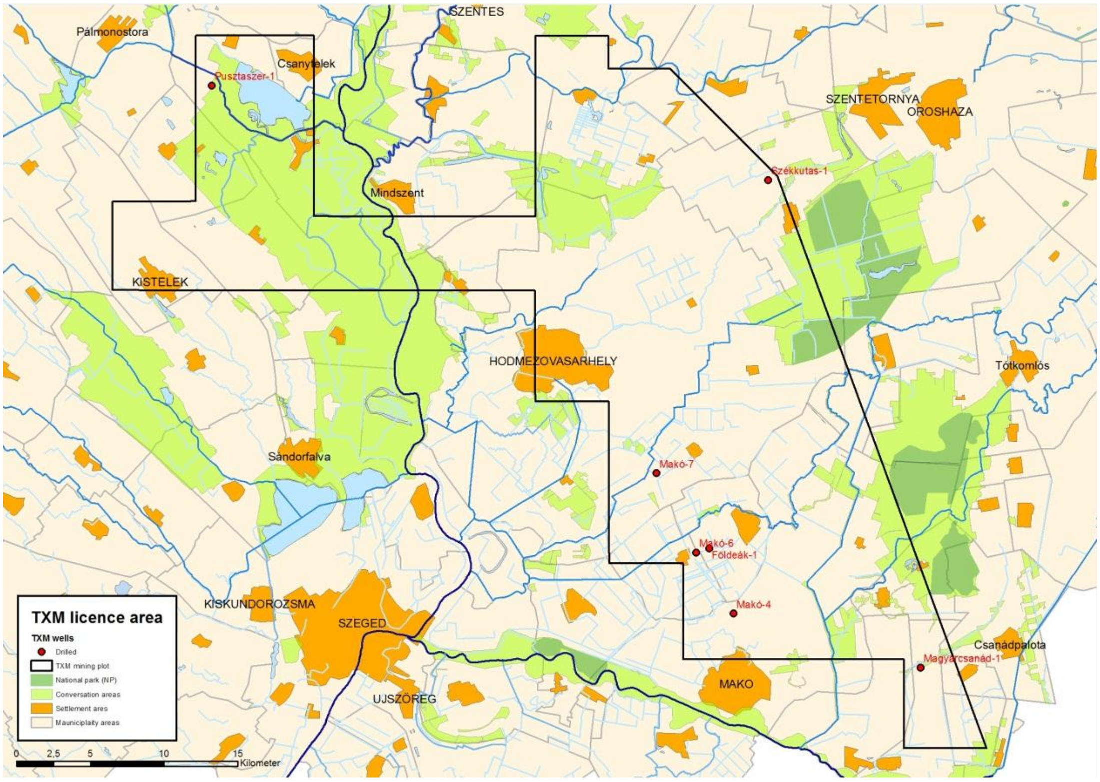

Figure 2: TXM licence area

For this purpose, and in the absence of definite planning by the licence holder TXM, a hypothetical field development plan may have the following characteristics:

- 160 well pads (protected areas excluded from drilling) at about 2 km distance;
- 4 to 8 vertical wells per well pad with 2 horizontal well branches per vertical well, resulting in 8 to 16 well branches per well pad;
- Typical well depths of 3,500 m (Algyö formation) to 5,000 m (Endröd formation);
- Progressive field development with initially one drilling rig, and, based on successful gas production, increase to several drilling rigs so that total field development time is 20-30 years until all well branches will have been drilled;
- Geographical development starting from one well pad and extending successively from there into the entire licence area;
- Gas production of individual fields is expected to extend over a 20+ year timeframe.
- Repeated fracking of well branches after a number of years of production in order to increase declining production is an option, but is not assumed here. Operators in the USA are gaining experience with the effectiveness of repeated fracking. In case repeated fracking would turn out to be effective and sensible in the future in the TXM production licence area, this would increase water consumption and other impacts on the environment.

- Well connection by new below ground gas pipelines towards various existing larger gas pipelines (depending on gas quality).

The following figure shows a hypothetical field development in a certain part of the licence area selected here for illustration purposes only including well pads, gas pipelines, safety distances from settlements of 200 m and from farms of 100 m as well as from surface water bodies, and protected areas.

Figure 3: Hypothetical field development including well pads, gas pipelines, safety distances and protected areas

Based on the characteristics listed above, the following figure shows a hypothetical field development for the TXM licence area.

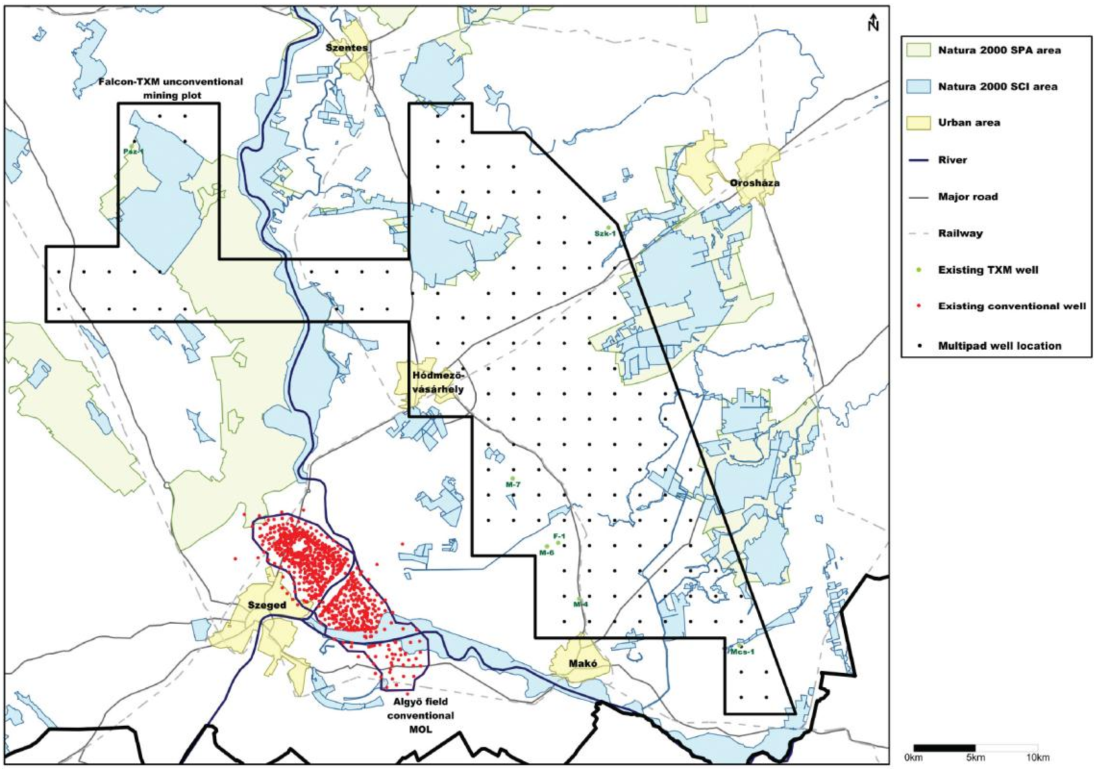

Figure 4: **Hypothetical field development of the licence area (Source: TXM)**

Potential flows of critical substances

Unconventional gas extraction includes a number of potential pathways for critical substances into the atmosphere, surface and ground water bodies as well as the soil.

Critical substances include greenhouse gases, notably carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O); pollutants, notably sulfur dioxide (SO_2), nitrogen oxide (NO_x), particulate matter (PM), non-methane volatile organic compounds (NMVOC) as well as carbon monoxide (CO); liquids, notably chemicals used for fracking as well as flowback fluid containing chemical substances and naturally occurring radioactive materials (NORM) washed out from the geological formations. The following figure shows the potential flows of critical substances. Ground water may be contaminated by

1. fracking fluids flowing through natural or artificially created fractures from the geological formations where fracking is applied;
2. fracking fluids flowing through faulty or improper casings of the well bore;
3. harmful liquids leaking or being spilled from the above-ground operations on the well pad or during road transport of these liquids.

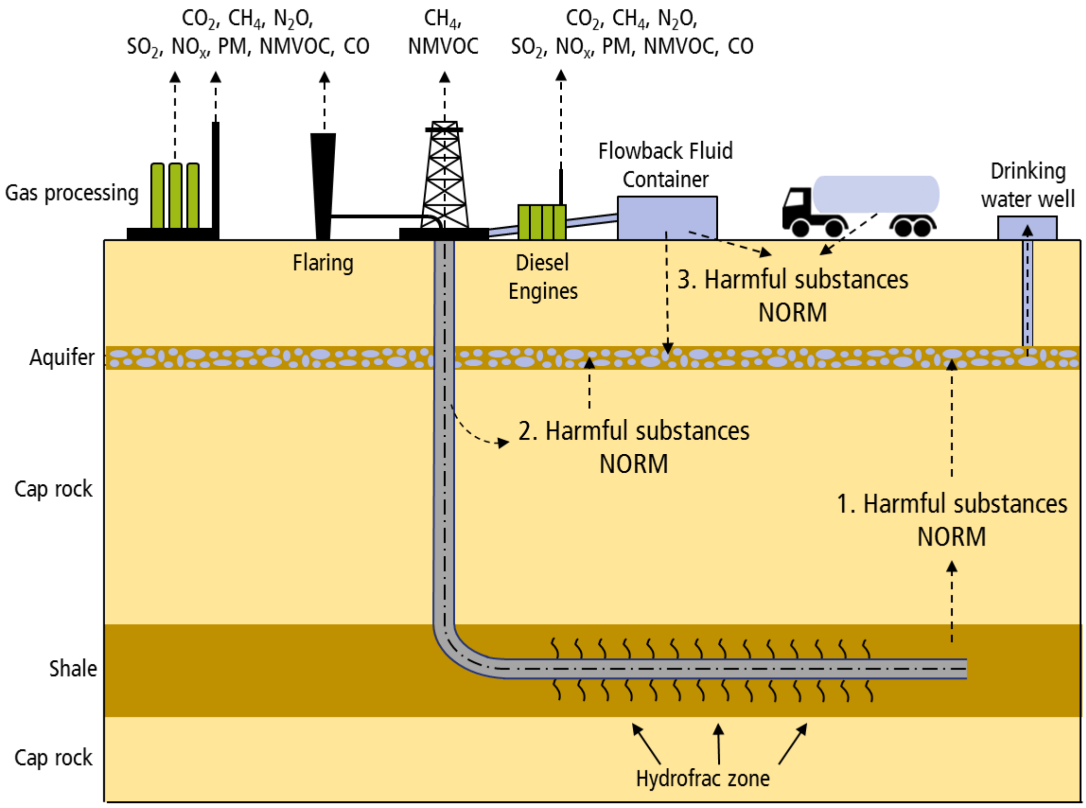

Figure 5: **Potential flows of critical substances; geological strata are not site specific (based on Altmann et al., 2011)**

In the licence area, natural fractures appear to be scarce in the unconventional gas bearing formations and the overlying cap rocks according to preliminary TXM analyses.

The following figure gives an approximate overview of the geological formations in the licence area.

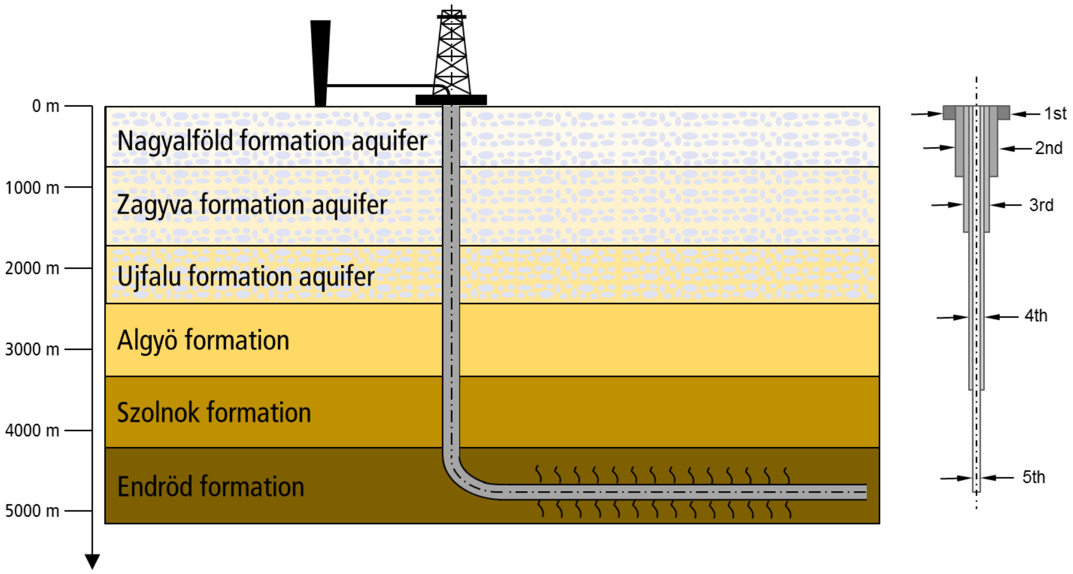

Figure 6: Geological formations and aquifers crossed by the unconventional gas wells; four to five cemented steel casings need to guarantee the integrity of the well.

General Recommendations

A number of public documents present recommendations and best practices for avoiding or minimizing harmful impacts of unconventional gas extraction on the environment and on human health. The most important general recommendations have been compiled by the International Energy Agency in its recent *Golden Rules for a Golden Age of Gas* study (International Energy Agency, 2012).

The most important and fundamental measures recommended by the International Energy Agency (2012) are to establish a "well thought-out field development plan", and to develop a "thorough environmental impact assessment".

In the following box, recommendations are listed together with an indication of the status of implementation by TXM. The following coding is used:

1. implemented by TXM
2. partly implemented by TXM; TXM will continue to adapt as part of best practice
3. considered by TXM for future operations

General Recommendations (International Energy Agency, 2012)	TXM
"Measure, disclose and engage	
▪ Integrate engagement with local communities, residents and other stakeholders into each phase of a development starting prior to exploration; provide sufficient opportunity for comment on plans, operations and performance; listen to concerns and respond appropriately and promptly.	2
▪ Establish baselines for key environmental indicators, such as groundwater quality, prior to commencing activity, with continued monitoring during operations.	1
▪ Measure and disclose operational data on water use, on the volumes and characteristics of waste water and on methane and other air emissions, alongside full, mandatory disclosure of fracturing fluid additives and volumes.	2
▪ Minimise disruption during operations, taking a broad view of social and environmental responsibilities, and ensure that economic benefits are also felt by local communities. […]	2
Be ready to think big	
▪ Seek opportunities for realising the economies of scale and co-ordinated development of local infrastructure that can reduce environmental impacts.	2
▪ Take into account the cumulative and regional effects of multiple drilling, production and delivery activities on the environment, notably on water use and disposal, land use, air quality, traffic and noise.	3
Ensure a consistently high level of environmental performance	
▪ Ensure that anticipated levels of unconventional gas output are matched by commensurate resources and political backing for robust regulatory regimes at the appropriate levels, sufficient permitting and compliance staff, and reliable public information.	2
▪ Find an appropriate balance in policy-making between prescriptive regulation and performance-based regulation in order to guarantee high operational standards while also promoting innovation and technological improvement.	2
▪ Ensure that emergency response plans are robust and match the scale of risk.	2
▪ Pursue continuous improvement of regulations and operating practices.	2
▪ Recognise the case for independent evaluation and verification of environmental performance."	2

General approach to environmental performance

The general approach to environmental performance should be twofold (see Figure 7): In the first place, precautionary measures need to be taken in order to reduce the probability of an event to occur. In the second place, proper actions need to be defined in an emergency response plan that will be taken in case an event with negative impacts does occur. According to TXM, an emergency response plan exists as part of the overall safety management system of TXM.

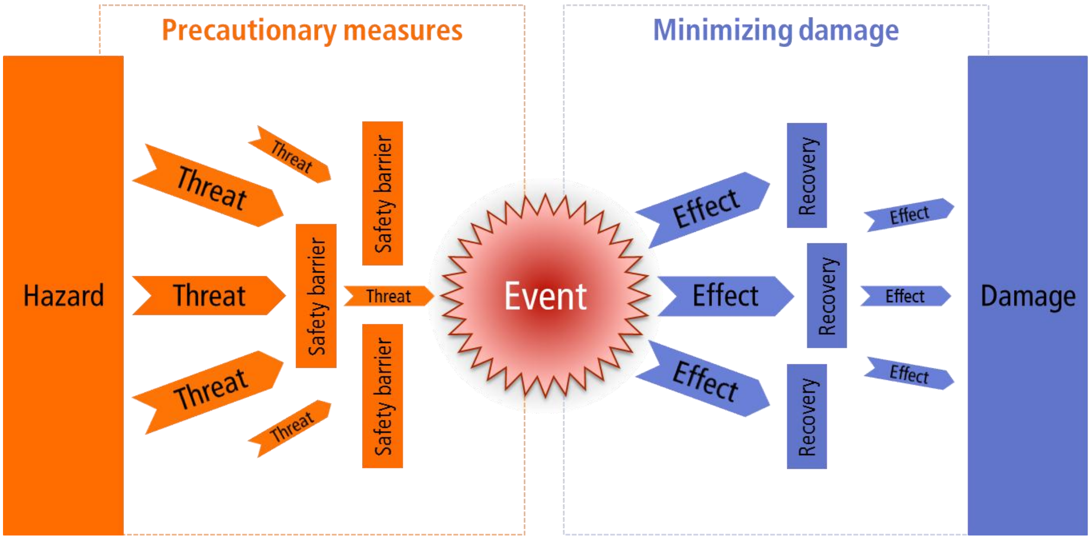

Figure 7: General approach to environmental performance (based on Ewen et al., 2012)

Overview of results

Figure 8 gives an overview of the main results of this study.

Most critical aspects are the chemicals used in hydraulic fracturing (see section 2.3), the potential contamination of surface waters (see section 2.6) as well as the potential contamination of ground water (see section 2.7).

Recommended safety measures and other mitigation options are indicated in the overview, and explained in detail in the respective sections.

Aspects that are assessed to be less critical nonetheless merit attention, with recommended action specified in each section of this study.

The qualitative risk appraisal in the following figure is explained in brief:

- Noise: Required noise abatement measures and tools are readily available
- Air Pollution: Applying best available technology, air pollution should be limited to acceptable levels
- Water Consumption: Based on the specific geology in the licence area and based on extensive water recycling according to TXM planning, water consumption should be limited and uncritical compared to the local underground water availability
- Chemicals: chemicals used in hydraulic fracturing, notably in the USA, are diverse, subject to rapid developments and sometimes extremely hazardous; chemicals to be used in the licence area have not yet been selected; thus, a thorough hazard analysis should be carried out for chemicals selection; risks also depend on good management practices
- Radioactive Material: According to TXM analyses, radioactivity does not display anomalies in the licence area; nonetheless, accumulations of radioactivity in materials and equipment may occur and should be taken care of properly
- Potential Contamination of Ground Water: Potential contaminations of ground water are extremely difficult to remedy while a large number of potential pollution pathways exist; groundwater protection should therefore receive highest possible attention
- Exploration-induced earthquakes: The licence area is part of a very quiet zone, and thus the probability of earthquakes is very low

	Appraisal	Condition/ Mitigation
Noise	Low risk	Planning, distance, noise abatement
Air Pollution	Low risk	Avoid / upgrade unpaved roads, measure emissions
Water Consumption, potential Sources of Water	Low risk	Recycling, water sourcing from deep aquifers
Chemicals used in Fracking	High risk	Public reporting, avoid chemicals with high hazard ranking , monitor, toxicological hazard study
Radioactive Material	Low to Moderate risk	NORM monitoring and control system
Waste Water Disposal	Moderate risk	Recycling, no reinjection into deep aquifers
Potential Contamination of Surface Waters	High risk	Safety distance from water bodies, zero discharge systems
Potential Contamination of Ground Water	High risk	Testing & monitoring of well integrity; detailed inspection of seismic lines for quaternary faults prior to fracking; microseismic control during fracking; safety distances
Exploration-induced Earthquakes	Low risk	Monitoring of seismicity
Ecological Threats (linear Infrastructure, Biodiversity)	Moderate risk	Bio-monitoring, careful site selection, no transport through protected areas
Proximity of Protected Areas	Moderate risk	No drilling in protected areas, saftey distance upstream
Greenhouse Gas Balance	Moderate risk	Methane emission control & monitoring of fracking

Figure 8: Overview of potential risks and threats of unconventional gas extraction in the TXM licence area in the Hungarian Makó area

- Ecological threats: The licence area has a high ecological value as demonstrated by the large number of protected areas; threats are mainly due to the cumulative effect of many drilling sites spread over a large area
- Proximity of Protected Areas: Protected areas are specifically vulnerable to accidents or continuous impacts from nearby drilling and extraction activities; proper risk management plays an major role in risk avoidance and effects mitigation
- Greenhouse Gas Balance: The greenhouse gas balance of natural gas is dominated by the combustion of the gas; during extraction, international experience, notably from the USA, shows that methane emissions after fracking may be high; the application of appropriate technologies allows limiting these emissions and making the overall balance superior to the import of natural gas over long distances.

2 POTENTIAL RISKS AND THREATS OF DRILLING ON THE ENVIRONMENT AND HUMAN HEALTH

2.1 Noise and air pollution

Noise

Noise emissions occur during site preparation, drilling, hydraulic fracturing, site re-cultivation, and various transport activities during all phases. Electric motors are used for drilling supplied by electricity produced by diesel engine generators.

Table 1 shows the expected noise levels from the drilling procedure depending on the distance from the rig and the direction.

Table 1: Predicted noise level from drilling procedures depending on the distance to the rig and the direction (Kötter Consulting Engineers, 2008)

Distance [m]	Predicted noise level [db(A)]							
	N	NE	E	SE	S	SW	W	NW
100	56.1	57.5	60.4	58.8	57.2	55.8	53.5	56.1
200	48.9	50.1	52.1	50.8	50.2	49.6	46.5	49.4
300	44.9	45.8	47.7	46.5	46.1	45.7	42.4	45.4
400	42.1	42.8	44.7	43.6	43.3	42.9	39.5	42.6
500	39.9	40.5	42.4	41.3	41.0	40.7	37.2	40.3

At a distance of 300 m a noise level of 42 to 48 db(A) have to be expected depending on the direction. The top-drive and the mud-pumps add the highest noise to the sound situation (Kötter Consulting Engineers, 2008).

This has to be compared with the relevant noise immission limits in Hungary (see Table 2). For industrial areas these are 60 db(A) at daytime from 6 am to 10 pm and 50 db(A) at night-time from 10 pm to 6 am. For rural residential areas they are 50 db(A) and 40 db(A), respectively (see Figure 9). This indicates that the assumed safety distances from settlements and individual farms of 200 m and 100 m, respectively (see section 1), are not sufficient to comply with the legal noise limits.

Table 2: Noise immission limits in Hungary (KvVM-EüM, 2008)

	Day (6 am to 10 pm)	Night (10 pm to 6 am)
Recreation area	45	35
Rural residential area	50	40
Urban residential area	55	45
Industrial area	60	50

Compliance can be achieved by keeping larger distances, or by applying further noise abatement measures. As the production licence area includes a large number of settlements and dispersed individual farms, keeping larger safety distances may not be possible in many cases. Technical noise abatement systems, however, are available and should easily allow compliance with noise limits.

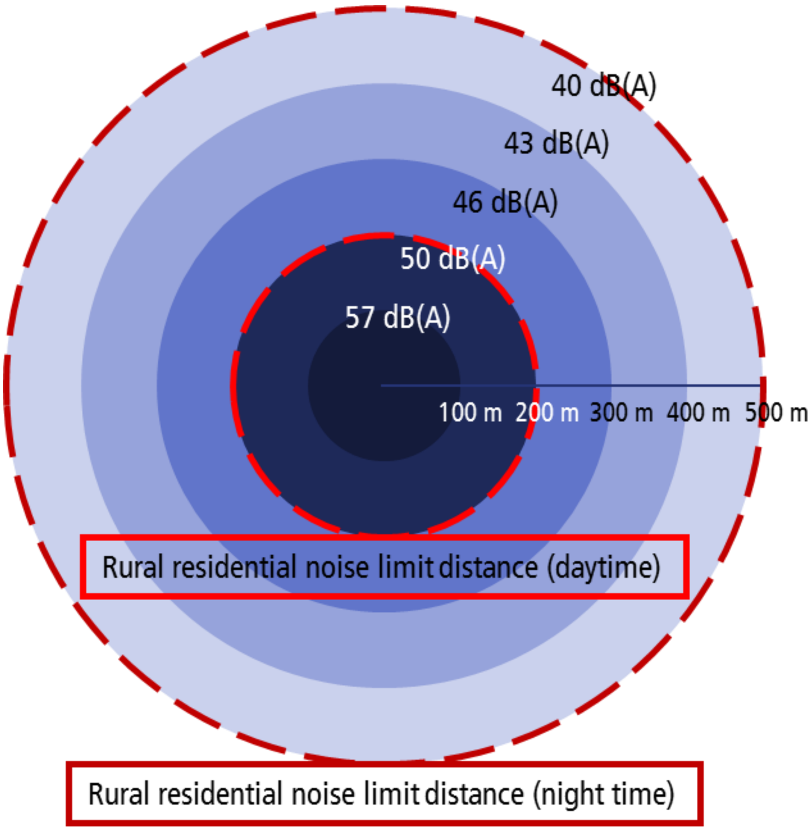

Figure 9: **Noise levels of a typical drilling rig compared to the residential noise limits during daytime and night time, respectively (based on Kötter Consulting Engineers (2008) and KvVM-EüM (2008))**

Furthermore, noise emissions stem from truck delivery of materials and equipment to the well pad. This includes transport of drilling and hydraulic fracturing equipment as well as of materials such as sand, fresh water, waste water, drilling muds, chemicals, cement, steel casings, etc. On average, it is estimated that around two trucks per day will head towards a drilling pad over the entire time of drilling and fracking, which is estimated to extend to one to two years. There will be peaks of transport activity, during mobilization/demobilization of the drilling rig or the fracking equipment, and during fracking procedures, while at other times transport movements will be lower than average. Ewen et al. (2012) under German conditions estimate an average of 7 trucks per day per well pad.

RECOMMENDATIONS ON NOISE AND NUISANCE	TXM[3]
Public exposure	
▪ „In noise control planning, production and water handling facilities should be located as far as practical from buildings or facilities occupied or used by the public." (API, 2009a)	1
▪ "placement of tanks, trailers, topsoil stockpiles or hay bales between the noise sources and receptors" (API, 2011)	1
▪ "orientation of high-pressure discharge pipes away from noise receptors and the addition of noise wall or noise barriers." (API, 2011)	2
Noise abatement of machines	
▪ „Engines and production equipment should be provided with noise abatement measures, if appropriate, to reduce noise levels to the extent practical, considering the local environment." (API, 2009a) this includes "reducing the noise from rig operations by cladding the rig with sound-proof material" (International Energy Agency, 2012)	2
▪ „Flares may need to be provided with noise abatement measures to maintain noise levels compatible with the local environment. The noise intensity, duration, location relative to public areas and natural resources, as well as the flare/vent exit design should be considered, where applicable." (API, 2009a)	2
Reduction/Optimisation of traffic / implementing trucking plans (see International Energy Agency, 2012): "Consideration should be given to minimizing traffic – and thus noise disturbance – in general, particularly in or near urban areas." (API, 2009a) Recommended measures include:	
▪ "route selection to maximize efficient driving and public safety;	2
▪ avoidance of peak traffic hours, school bus hours, community events and overnight quiet periods; […]	2
▪ upgrades and improvements to roads that will be travelled frequently;	2
▪ advance public notice of any necessary detours or road/lane closures; and	2
▪ adequate off-road parking and delivery areas at the site to avoid lane/road blockage." (API, 2011)	2

[3] See section 1 for TXM coding.

Air pollution

The methodology and assumptions used for the calculation of the air pollutant emissions is the same as for the greenhouse gas emissions, which is described in section 3.3.

Overall, pollutant emissions caused by unconventional gas extraction in the production licence area are estimated to be lower or similar to those stemming from imported natural gas. However, pollutant emissions of imported gas mainly take place outside of Hungary, while some of the pollutant emissions of unconventional gas extraction will take place in the production licence area. The area will thus suffer from increased emissions. Nonetheless, local air pollution is estimated to be low.

In addition to the pollutant emission estimates presented in detail below, dust from unpaved roads will be raised and dispersed by truck transport. This will affect local population close to the roads and may be seen as a major disturbance.

Figure 10 shows the emissions of Non-Methane Volatile Organic Compounds (NMVOC) from the supply of unconventional natural gas compared to imported natural gas including transport to Europe. The most important source of NMVOC is the gas processing stage, which for the unconventional Makó gas is assumed to takes place close to the production licence area. NMVOC emissions of imported gas are generally higher, both from gas extraction & processing as well as from gas transport, which means that emissions are mainly taking place outside Hungary.

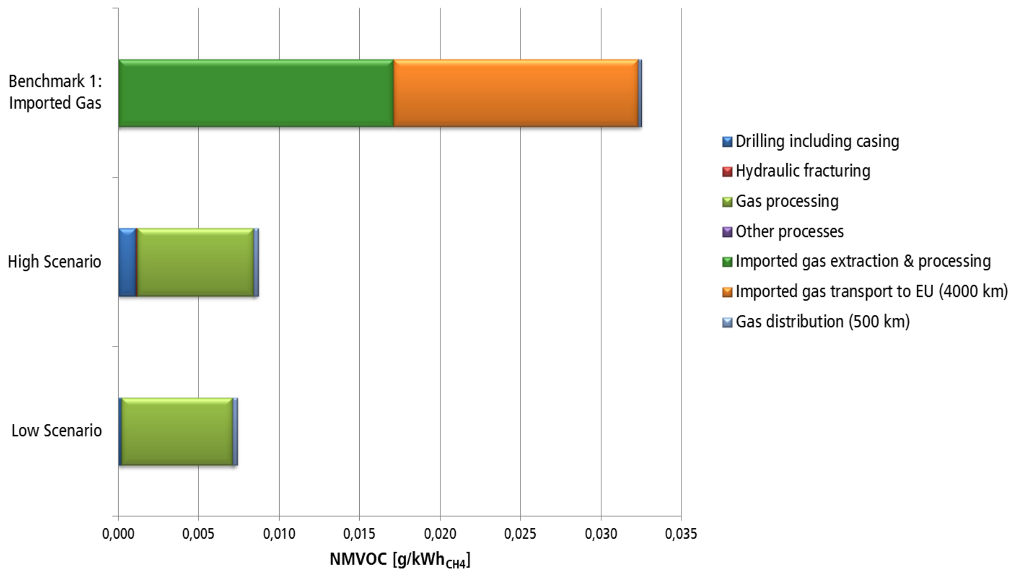

Figure 10: NMVOC emissions from the supply of unconventional natural gas compared to the supply of imported natural gas by process stage

Figure 11 shows the emissions of Nitrogen Oxide (NO_x) from the supply of unconventional natural gas compared to imported natural gas including transport to Europe.

For unconventional gas, the manufacturing of steel tubes used for the well casings (included in the drilling stage) is the major source of NO_x emissions. The majority of the emissions thus take place at the steel tube manufacturing plant, which may be located inside or outside Hungary. For imported gas, the major source of NO_x is the gas compression for long distance pipeline transport, which is thus mainly located outside Hungary. Overall, NO_x emissions of unconventional gas from the production licence area are lower than for imported gas.

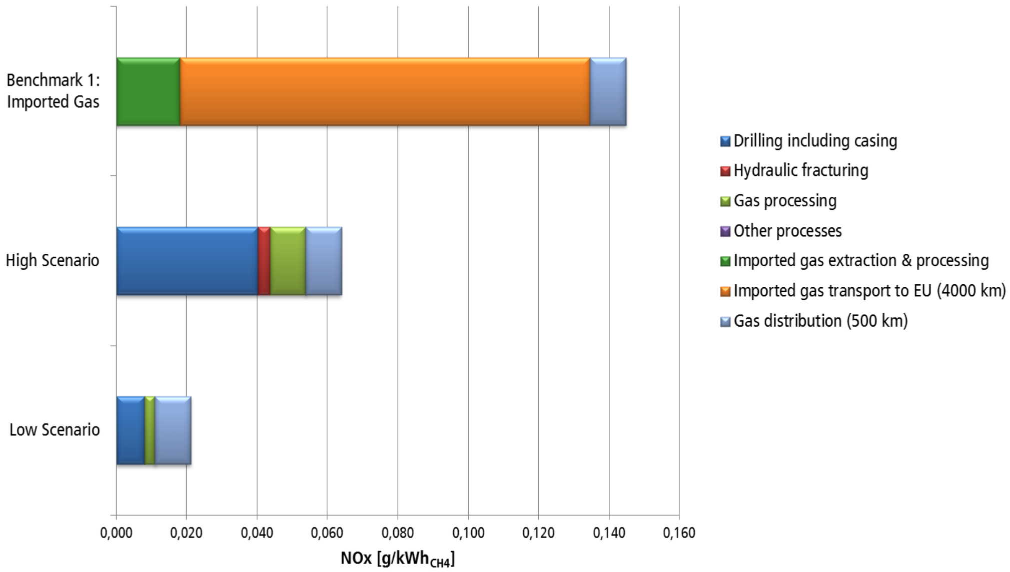

Figure 11: NO_x emissions from the supply of unconventional natural gas compared to the supply of imported natural gas

Figure 12 shows the emissions of Sulfur Dioxide (SO_2) from the supply of unconventional natural gas compared to imported natural gas including transport to Europe.

Also for SO_2 emissions, the manufacturing of steel tubes used for the well casings (included in the drilling stage) is the major source, which may be located inside or outside Hungary. As gas extraction per well branch is very much higher for conventional gas compared to unconventional gas (see section 3.3), the contribution of SO_2 emissions from steel tube manufacturing for well casings is very much lower for conventional gas. For imported gas, gas desulphurization is the major source of SO_2 emissions, which strongly depends on the sulphur content of the extracted gas. Here, a typical gas quality has been assumed, while SO_2 emissions can go down to zero for very clean natural gas resources. SO_2 emissions of unconventional gas from the production licence area may be higher than for imported gas.

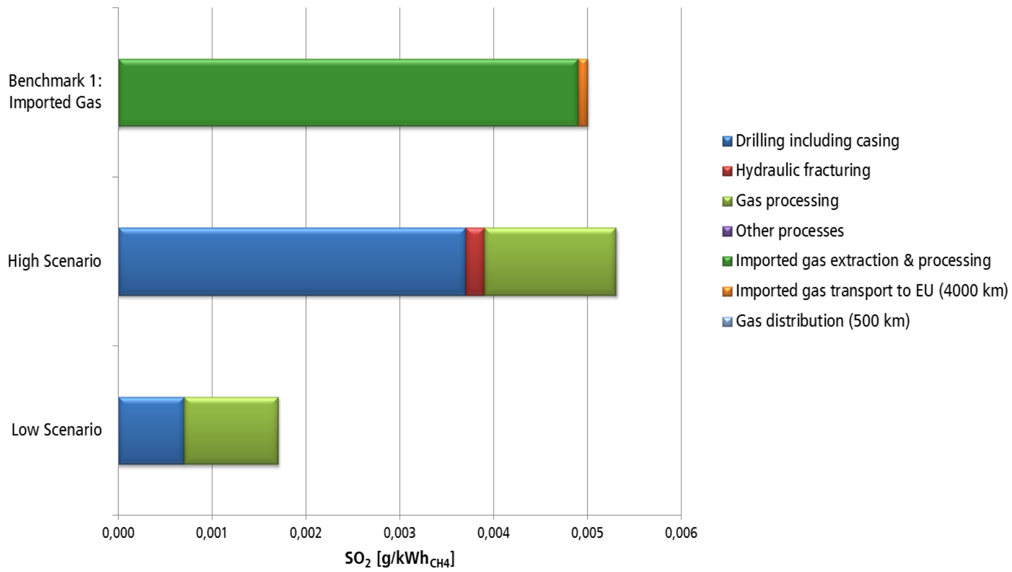

Figure 12: SO_2 emissions from the supply of unconventional natural gas compared to the supply of imported natural gas

Figure 13 shows the emissions of Carbon Monoxide (CO) from the supply of unconventional natural gas compared to imported natural gas including transport to Europe.

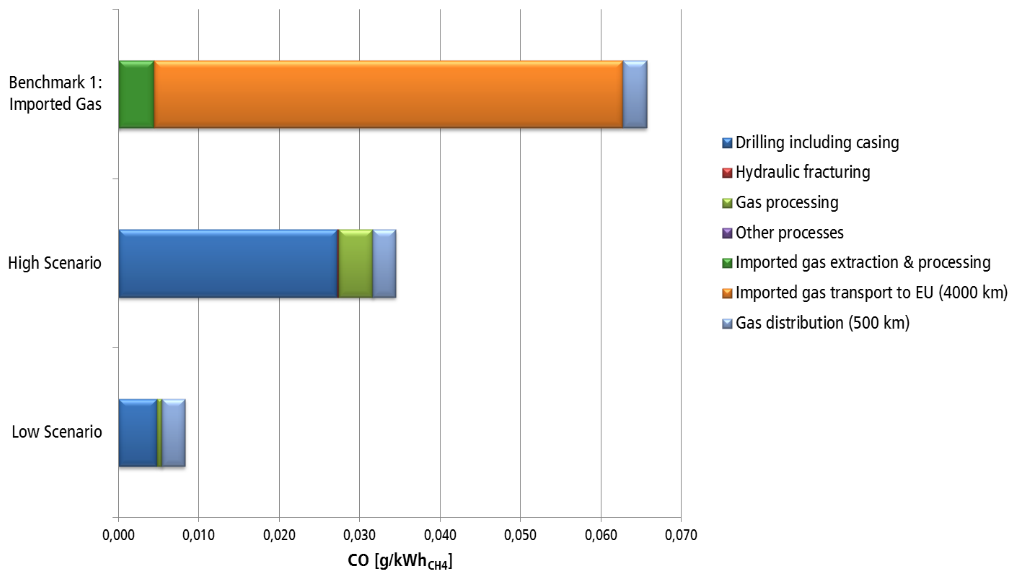

Figure 13: CO emissions from the supply of unconventional natural gas compared to the supply of imported natural gas

Again, the manufacturing of steel tubes used for the well casings (included in the drilling stage) is the major source of CO emissions, while gas compression for pipeline transport is the major source for imported gas. CO emissions of unconventional gas from the production licence area may lower or similar to those of imported gas.

Figure 14 shows the emissions of dust and particulate matter (PM) from the supply of unconventional natural gas compared to imported natural gas including transport to Europe.

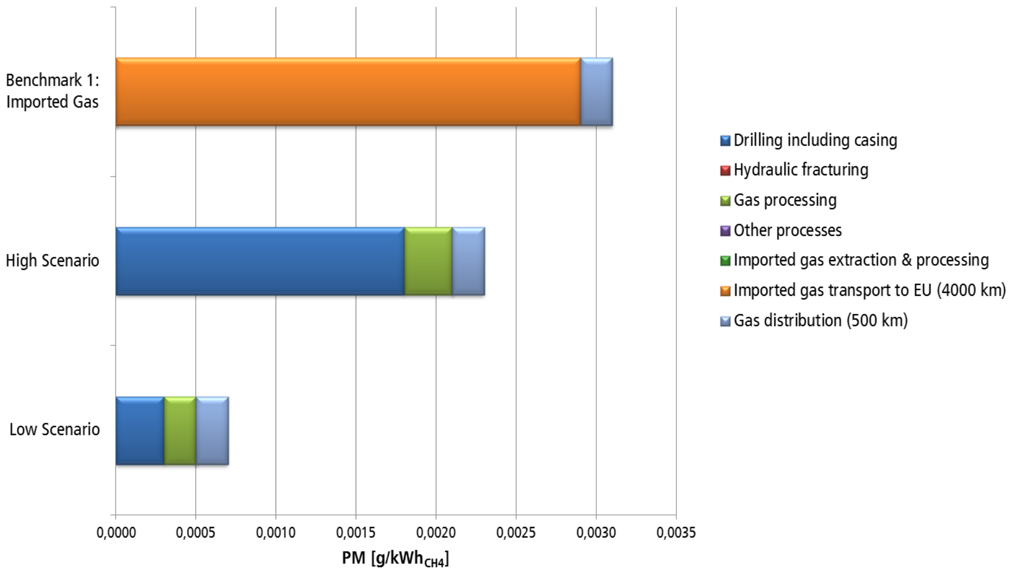

Figure 14: PM emissions from the supply of unconventional natural gas compared to the supply of imported natural gas

The manufacturing of steel tubes used for the well casings (included in the drilling stage) is also the major source of PM emissions, while for imported gas it is the pipeline transport. Overall, PM emissions of unconventional gas from the production licence area are lower or slightly higher than for imported gas.

RECOMMENDATIONS ON AIR QUALITY	TXM[4]
▪ Avoid unpaved roads, or consider to upgrade them if used frequently	2
▪ Measure emissions during operations (International Energy Agency, 2012)	1

[4] See section 1 for TXM coding.

2.2 Water consumption, potential sources of water

Water consumption

The hydraulic fracturing activities in the production licence area will require significant quantities of water over a long period of time.

According to information provided by TXM some 500 m³ of water are required for one single fracking procedure on one well branch, which requires one to six fracking procedures. Thus, water demand for fracking one well branch is 500 m³ to 3,000 m³. This is below water requirements of 20,000 (Ewen et al., 2012) up to 45,000 cubic meters per well (NYCDEP, 2009; see also Altmann et al., 2011, for an overview) cited by international literature sources based on experiences in the USA and in Germany. This low water requirement in the Makó area is estimated by TXM based on the specific geological situation in the licence area.

Repeated fracking of wells after a number of years of production in order to increase declining production is an option, but is not assumed here. Operators in the USA are gaining experience with the effectiveness of repeated fracking. In case repeated fracking would turn out to be effective and sensible in the future in the TXM production licence area, this would increase water consumption and other impacts on the environment.

Table 3: Water demand of TXM hydraulic fracturing activities with and without flowback recycling

Description	Low 80% recycling	Low 70% recycling	High 80% recycling	High 70% recycling	Unit
Number of well pads	160	160	160	160	-
Number of well branches per pad	8	8	16	16	-
Number of hydraulic fracturing procedures per well branch	1	1	6	6	-
Water demand per fracturing procedure	500	500	500	500	m³
Water demand per well branch	500	500	3,000	3,000	m³
Water flowback rate	100%	100%	80%	80%	%
Water recycling	80%	70%	80%	70%	%
Water demand including recycling	6,400	9,600	138,240	168,960	m³/yr

In order to reduce the required water quantities significantly, water recycling has been introduced in recent years in the USA. TXM assumes for the Makó licence area that 70-80% recycling of used frack water is possible, further assuming that 80-100% of the injected water flows back to the surface after the fracking procedure. The latter is based on the specific geological situation in the area and the experience of TXM with the first fracking activities carried out in recent years.

International experience to date suggests a large variance of flowback rates from 80% down to some 20% (Ewen et al., 2012). Recycling levels depend on the flowback handling concept. In principle, flowback can either be treated in sewage plants using different processes depending on the quality required; it should be noted, however, that there are no commercially available solutions that are able to deal with the variety of possible flow back compositions (see Altmann et al., 2012), or re-used without treatment.

Flowback fluid is a mix of fracking fluid and formation water. As a consequence, flowback fluid contains less fracking chemicals than the fracking fluid, and includes chemicals from the geological formation fracked. TXM assumes that recycling will only require making-up fracking chemicals in the flowback fluid without further treatment.

Assuming 80%-100% flowback rate and 70-80% recycling, the water requirements for fracking are reduced significantly demonstrating the importance of water recycling.

In a Low scenario with 8 well branches per well pad and one frack per well branch, further assuming constant drilling activity over the field development time of 20 years, the water requirement is a constant 6,400-9,600 cubic meters per year.

Doubling the number of well branches drilled and fracked from the Low to the High scenario doubles the quantities of water required. In addition, the number of fracking procedures that have to be applied to each well branch is assumed to be between one and six, thus additionally increasing the water quantities sixfold from the Low to the High scenario.

In a High scenario the water requirement is around 140,000-170,000 m^3/yr. Assuming a progressive field development with limited drilling in the beginning and progressively increasing drilling activity (see hypothetical field development plan in section 1), the water requirement increases over the first years and may then be assumed to be sustained over most of the field development time of 20+ years.

Surface water

The climate of south-east Csongrad including the licence area is moderate with annual sun hours of about 2,100 h/a and a mean annual temperature of some 10°C. The hottest month is July with a mean temperature of ~22°C, the coldest is the January with a mean temperature of some -1°C. The mean annual precipitation is around 550 mm/m^2 per year. January-March is the driest period of the year (30-35 mm/m^2/month on average) while the highest amount of rainfall can be expected in June (ca. 70 mm/m^2/month). The average evapotranspiration is about 480 mm/m^2 per year.

Table 4: Significant water bodies in or close to the licence area

River water bodies	Size classification
Büdösszéki-csatorna	Small
Dong-éri-fõcsatorna alsó	Large
Felsõ-fõcsatorna	Medium
Hódtó–Kistiszai-csatorna	Medium
Kenyere-ér	Medium
Kórógy-ér	Medium
Ludas-ér	Small
Mágocs-ér	Medium
Mátyáshalmi-csatorna	Medium
Mûrét-Kistiszai-csatorna	Small
Percsorai-fõcsatorna	Small
Sámson-Apátfalvi-Szárazér-csatorna	Medium
Szárazér-Porgányi-fõcsatorna	Medium
Tisza	Very large
Királyhegyesi-Szárazér-csatorna	Medium
Maros	Very large
Standing water bodies	
Csaj-tó	Medim
Csanyteleki-halastó	Small
Csanyteleki-halastó	Small
Pusztaszeri Büdösszék	Small

The most important water body in the area is the river Tisza – the second biggest river of Hungary – crossing the licence area in north-south direction. The river Maros runs a few kilometres south of the licence area flowing into the Tisza, which some 30 km south-west of the licence area crosses the border to Serbia. In addition to the big rivers numerous small and medium size watercourses cross the mining plot. Some of them are temporary water bodies drying out in drought periods, but most carry water continuously. These are usually modified or artificial channels used for inundation control and water transport for irrigation purposes in agriculture, but they are also important habitats or have recreational uses. All river water bodies in the area are typical of flood planes with a very low gradient and a calcareous catchment area. The watercourses within the licence area have a total length of about 660 kilometres.

In addition to the river water bodies there are numerous lakes within or close to the licence area; most of them are permanent lakes but some are temporary saline lakes drying out in drought periods. They are shallow or of medium depth, calcareous or salinized lakes. The biggest lake is the Csaj lake with an area of over 10 km² – an important wetland habitat and bird reserve.

In the licence area only the direct catchment area of the river Tisza is a surface water protection area running parallel with the river in varying width of 2-10 km.

The riverside areas are exposed to river flood risks typically in spring time, while the inland areas often suffer from inundation caused by heavy rain or snowmelt in the area causing substantial damage to the local agriculture. The area is classified as moderate to medium inland inundation risk (Pálfai et al., 2004).

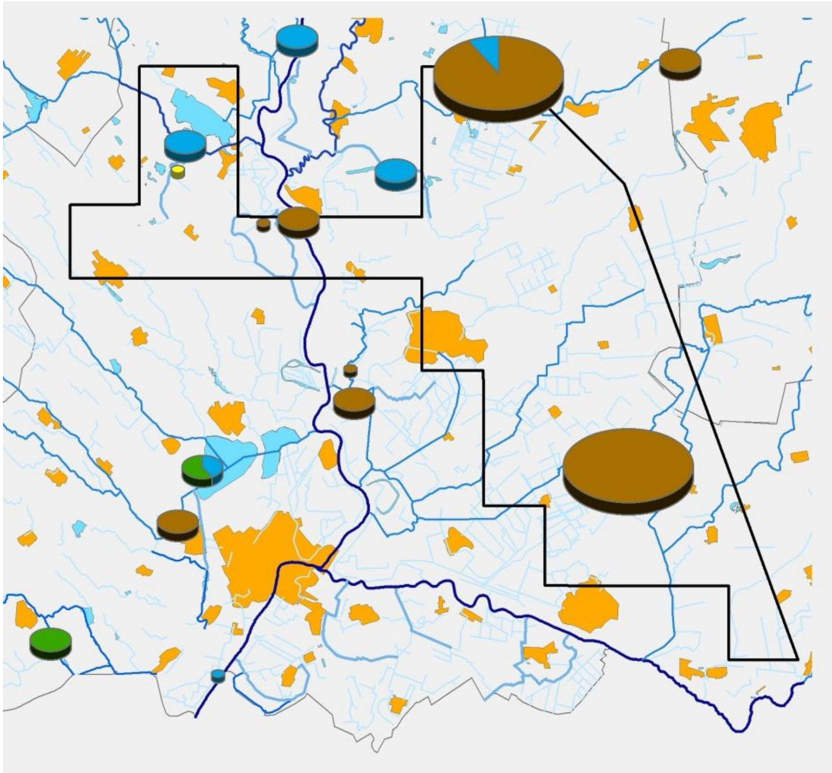

Figure 15: Current surface water use in the area of the licence area (based on VKKI, 2010)

Notes: Use – brown: irrigation, blue: fish breeding, green: ecological purposes, yellow: recreation; Size – small: <100,000 m^3/year, medium: 100,000-1,000,000 m^3/year, large: 1,000,000-10,000,000 m^3/y

Water availability in the area is strongly seasonal. There are periods of water scarcity and of water surplus. In order to bring water demand/surplus in balance; agricultural fields are drained during inundation periods via the channels while in draught periods surface water bodies are used as water sources. The main water withdrawals in the region are shown in Figure 15.

Surface water withdrawal in the area is mainly for agricultural purposes. Only the main rivers and bigger channels Tisza, Kórógy-ér, Mágocs-ér, Királyhegyesi-Szárazér-csatorna provide water quantities sufficient for withdrawals in the area. The typical annual withdrawals are in the order of several million cubic meters per year down to around 100,000 cubic metres per year.

Ground water

Aquifers in the Makó trough are located in Upper Pannonian sedimentary rocks with hydraulic conductivities between 10^{-5} and 10^{-4} m/s. The Upper Pannonian aquifers consist of three lithostratigraphically defined formations with strongly varying thicknesses:

- the Nagyalföld formation aquifer with 300-800 m thick lacustrine and fluvial sediments (Trunkó, 1996),
- the Zagyva formation aquifer with 625 m - 1000 m delta plain facies (Elston, Lantos, & Hámor, 1993; Trunkó, 1996),
- the Ujfalu formation aquifer with thickness ranging from 20 m to 1000 m, most frequently from 200 to 600 m (T-JAM, 2011; Geological Institute of Hungary).

The principal aquifer in the Upper Pannonian is the Nagyalföld aquifer, which overlies the Zagyva and Ujfalu aquifers and which has hydraulic conductivities in the order of 10^{-5} m/s with a high degree of lateral continuity. The upper part of the Nagyalföld aquifer is used as a ground water resource, whereas the Ujfalu aquifer is used for geothermal purposes. The thickness of the Upper Pannonian layers reaches up to 2,500 m in the Makó trough.

The Lower Pannonian sedimentary rocks consist of three formations with considerably lower hydraulic condutivities:

- the Algyö formation with 100 m - 900 m thickness,
- the Szolnok formation with varying thickness, exceeding 1000 m in deep basins,
- the Endröd formation with a total thickness of 100 to 200 m on the average, and a maximum thickness of 700 m (Geological Institute of Hungary).
- The Algyö formation has hydraulic conductivities in the order of 10^{-8} - 10^{-7} m/s. Czauner & Mádl-Szõnyi (2011) consider the Algyö formation as a leaky aquitard[5] with sedimentologic discontinuities and crosscutting fractures and faults as principal hydraulic elements. Czauner & Mádl-Szõnyi (2011) refer to an area some 100 km north of the Makó trough, however given the similar sedimentary facies and similar depth, these data may also apply to the Makó area. The Szolnok formation has hydraulic conductivities in the order of 10^{-7}- 10^{-6} m/s. The Endröd formation in the Lower Pannonian has hydraulic conductivities of 10^{-9} m/s and must be considered as an aquitard. The thickness of the Lower Pannonian layers reaches 2,500 m in the basin center and decreases towards the borders of the trough.

[5] An aquitard has a significantly lower permeability than an aquifer; a leaky aquitard has a certain capacity to release ground water.

Table 5: Lithostratigraphic and hydrostratigraphic units in the Great Hungarian Plain (based on Czauner & Mádl-Szõnyi, 2011).

Age		Lithostratigraphic units		Hydrostratigraphic units
Neogene	Holocene, Pleistocene	Nagyalföld Formation	Upper Pannonian	Nagyalföld Formation Aquifer
	Pliocene	Zagyva Formation		Zagyva Formation Aquifer
		Ujfalu Formation		Ujfalu Formation Aquifer
	Late Miocene	Algyö Formation	Lower Pannonian	Algyö Formation Aquitard
		Szolnok Formation		Szolnok Formation Aquitard
		Endröd Formation		Endröd Formation Aquitard
	Middl3e Miocene, Early Miocene	Sub-Pannonian Formations		Pre-Pannonian Aquifer

Hydraulic conductivities of the Pre-Pannonian aquifers are in the order of 10^{-6} m/s, mainly due to fractures and faults as conductive components (Czauner & Mádl-Szõnyi, 2011).

While the neogene sedimentary layers have a similar facies as in the Makó trough, they are located at depths of less than 2500 m. As the neogene basin fill of the Makó trough is at depths of 2500- 6000 m, these layers will be more compacted than the strata in the area considered by Czauner and Mádl-Szõnyi (2011). Hydraulic conductivities of the neogene formations in the Makó trough should therefore be significantly lower than the data from the study area of Czauner and Mádl-Szõnyi (2011). The neogene layers in the Makó trough can therefore be regarded as aquitards if open fractures are absent.

The database of shallow water wells of the Makó trough shows 10 wells with production depths at 600-500 m, 23 wells producing at 500-400 m, 35 wells at 400-300 m, 46 wells at 300-200 m, 12 wells at 200-100 m and 8 wells at less than 100 m depth.

Average ground water withdrawal in 2007 from shallow wells was 26,598 m^3/day with a population of 172,909 persons, giving a mean value of water consumption of 0.153 m^3/person/day. The production limit of all existing shallow water wells in 2007 is estimated at 110,000 m^3/d, thus around 25% of the existing production capacity is used. Between 2001 and 2011, ground water production in the study area has increased from 22,000 m^3/d to 27,000 m^3/d, still below the production level of 31000 m^3/d, which was reached in 1991. Production from shallow ground water wells in 2011 reaches maximum individual extraction rates of up to 2,800 m^3/d.

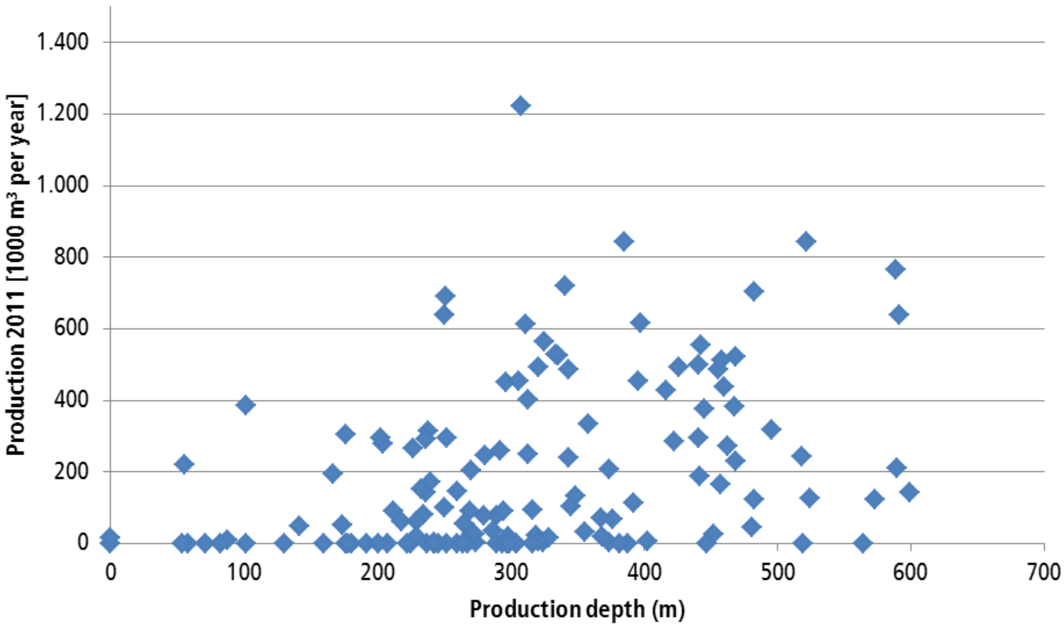

Figure 16: Extraction rates from shallow water wells in the Makó area

Production data from deep wells are not available, however the cumulative yield of 51 wells with top filter depth greater than 600 m is 277,000 m^3/d. As yield rather specifies a possible upper limit for extraction, the actual water production from deep aquifers will be much less. As deep aquifers have a high potential for ground water production, water for fracking operations should be taken from those deeper aquifers in order to keep upper freshwater aquifers exclusively for consumption and irrigation. Due to recent progress in fracking technology, use of freshwater is no longer a necessity. Flowback and naturally occurring produced waters can be used for the fracking process, if modern technology is applied (Brown, 2012).

Appreciation of water consumption and availability

Overall, water availability does not seem to be critical. Both shallow and deep water wells have enough potential for supplying the required water quantities for fracking in the licence area.

Current average ground water withdrawal in 2007 from shallow wells was 26,598 m^3/day compared to a maximum demand for fracking of some 170,000 m^3 per year, or some 460 m^3/day, which would represent a 1.7% increase in water withdrawal if covered entirely from shallow water wells. The production limit of all existing shallow water wells in 2007 is estimated at four times current withdrawal. The yield of deep water wells is significantly higher than that of shallow wells, and competition with other important uses of water is much less. Therefore, deep water wells should be the preferred source of water for fracking.

Surface water withdrawal could be possible in principal based on average availability over the year, but seasonal availability could be critical. Thus, it is recommended not to use surface waters.

RECOMMENDATIONS ON WATER CONSUMPTION	TXM[6]
ICCR & IEHN (2012) report the following best practices, which are relevant here:	
"1. Using non-potable water sources (e.g. saline aquifers, treated industrial waste waters, flowback waters, or other such sources) is the default management choice for fracturing operations. Exceptions can be made to accommodate local circumstances." For the TXM production licence area this means that recycling should be maximised, and that deep aquifers should preferentially be used for fresh water sourcing. Shallow water wells are less preferable.	1
"2. Water sourced for fracturing is reported as part of broader water use reporting under evolving investor disclosure protocols, and is also reported on a jurisdictional (e.g. state) or watershed basis."	2

2.3 Chemicals used in hydraulic fracturing

General introduction

The water injection at very high pressure by hydraulic fracturing enlarges natural or artificial cracks in the shale and allows accessing the natural gas which is trapped in small pores or spaces in the shale layer. When the pressure is reduced a mixture of fracturing fluid, deposit water and the gas reflows to the surface, but at the same time the cracks close again. In order to keep the cracks open during pressure release some propping agents must be added to the injected water which form chocks hindering the cracks to close. However, propping agents (e.g. sand) do not mix with water to form a homogeneous substance. In order to improve the transport of the propping agents the water must be treated with gelling agents giving it a viscous consistency. Friction reducers are added to reduce the energy requirement of the injection process. Surfactants are needed to enhance the surface contact between fracturing fluid and crack walls allowing for improved pressure energy transfer. Biocides keep the injected water and the reservoir water free of bacteria avoiding clumping and sulphur hydrogenation. Anticorrosives

[6] See section 1 for TXM coding.

prohibit the corrosion of the technical equipment. At the end of the fracturing process, breakers help to break down the gel and to enhance the backflow of the injected water.

The fluid properties are designed to optimize the fracturing effect according to the geological rock formation and according to the working step under preparation. For that purpose many different chemicals are tested and the composition of fracturing fluids is optimized over time since the first patents were delivered in the 1940ies.

Many companies keep the composition of the fracturing fluids secret as many of these chemicals show toxic, biocidic and hazardous side effects to environment and humans (Waxman 2011).

Since several years companies look for less harmful substitutes which allow efficient hydraulic fracturing with reduced side effects to the environment. For instance, water purification by UV-radiation helps to reduce the biocide demand, recycling of large amounts of water reduces the overall water demand and biodegradable agrichemicals may substitute harmful chemicals to a certain extent. In spite of many efforts taken the present practice is not free from chemicals.

Chemicals used

TXM plans to use only a few chemical substances in future fracturing activities in the Makó production licence area. The basic chemicals used in these substances are listed in Table 6. According to TXM the concentration of traded chemicals in the injected fluid is below 0.1%. The remainder predominantly consists of water and of propping agents. Assuming concentration levels of 0.1% result in the concentration levels of the individual substances shown in the last column of the table.

Table 6: Basic ingredients of the fracturing fluids to be possibly used in the production licence area

Chemical	CAS	Concentration in the traded chemical fluid	Concentration in injected water
Sodium hypochloride	7681-52-9	10-30%	0.01-0.03%
Sodium hydroxide	1310-73-2	0-2%	0-0.002%
Hydrotreated light petroleum distillate	64742-47-8	10-30%	0.01-0.03%
Terpenes and Terpenoids, sweet orange-oil	68647-72-3	10-30%	0.01-0.03%
Isopropanol	67-63-0	10-30%	0.01-0.03%
Proprietary Component	?	10-30%	0.01-0.03%

Quantitative Estimate

As described in section 2.2, between 0.5 to 3 million liters of water will be injected per well branch, depending on the number of fracturing stages. The total development of 8 to 16 well branches per well pad and 160 well pads results in total injected water of 128 to 3,400 million liters or 6.4 to 170 million liters per year (see section 2.2). TXM assumes a flowback rate of 80%-100% and 70-80% recycling. On this basis, and assuming an average chemicals concentration of 0.02%, the total amount of chemicals would be some 26,000 to 675,000 liters or 1,300 to 34,000 liters per year. Delivering these chemicals to the well pads requires between 1 and 2 annual truck movements if the largest possible tanker trucks are used.

Hazard Potential

Though generally the hazard potential is seen as low and not being worth further investigation when a toxic substance does not exceed the concentration level of 0.2% in a fluid, it seems that such a classification is not adequate for injected fluids with the potential of contaminating surface or ground water levels (Schmitt-Jansen et al., 2012).

In the framework of a comprehensive scientific process carried out in Germany in 2011/2012 financed by ExxonMobil, toxicologists proposed and evaluated a more differentiated scheme which takes care of multiple hazards of a mixture of various substances. One central element in that scheme are the so-called hazard index (HI) and the hazard quotient (HQ) (Schmitt-Jansen et al., 2012).

The hazard quotient relates the lethal dose for exposure to the actual concentration of the chemical. It is calculated as described in the box below.

HQ = expected exposition concentrate / effect concentration

Exposition concentrate = concentration in fracturing fluid

Effect concentration = EC_{50} or LC_{50}

From the available data the HQs of the substances to be used in the licence area at the relevant concentrations (see Table 6) are calculated in Table 7.

Based on this rough analysis it turns out that among the substances planned for use hydrotreated light petroleum distillates are the most critical chemicals. Even though they might be used in a concentration below 300 mg/liter indicated by TXM as the maximum concentration, their hazard potential seems to be significant as the expected exposition concentration is larger than the LC50 concentration.

It must be emphasised that the present analysis is preliminary. It should be seen as a first indicator to identify the most critical substance. For that reason we recommend to perform a more detailed toxicological analysis in a specific study of the issue.

Table 7: Calculated Hazard quotient (HQ) for the Chemicals to be used in the licence area

Chemical	CAS	Exposition concentration mg/l	LC_{50} mg/l	HQ
Sodium hypochloride	7681-52-9	100-300		?
Sodium hydroxide	1310-73-2	0-20	125	<0.16
Hydrotreated light petroleum distillate	64742-47-8	100-300	2.2	45-136
Isopropanol	67-63-0	100-300	4200	0.02-0.07
Proprietary component	?	100-300	??	??

Source for LC_{50} Data: (Schmitt-Jansen, 2012).

Clean Fracturing?

In the past years, a number of chemicals were used in initial hydraulic fracturing activities in the Makó area. Both regulatory changes, most notably the establishment of the REACH Regulation at European level, as well as scientific advances have taken place since then. Decisions of chemicals to be used in fracking in the Makó area in a commercial development have not yet been taken.

The US House of Representatives has published a list of more than 700 chemicals which are used in hydraulic fracturing in the USA (Waxman, 2011). Due to the environmental risks of some of these chemicals and public concerns companies develop and test new mixtures with the goal to reduce and possibly avoid toxic and hazardous substances. Therefore, it is open which fluids will be used in the future. New substances and potentially new techniques might change the present picture.

Details of the chemicals used, their quantities and their concentrations are subject to rapid development. Publicly available information is sometimes scarce and scientific analysis is fragmentary. Often, chemicals are not identified by their CAS (Chemical Abstracts Service) numbers, and concentrations and mixtures are kept confidential so that toxicological analyses are difficult. Public demand for information thus conflicts with commercial interests.

The European REACH Regulation provides for rules for the classification and publication of potentially hazardous chemicals. At present, analyses are ongoing at the European level, of the use of chemicals in hydraulic fracturing in relation to the REACH Regulation. However, legal issues are generally excluded from the present analysis.

In the public discussion some companies draw the attention to the development of environmentally friendly chemicals and techniques for the use in hydraulic fracturing. Research on “clean fracturing” by industry and academia aims at avoiding or substituting hazardous chemicals with biodegradable chemicals. Biocides might be replaced by UV-purging of the injected fluid, recycling will reduce water consumption to lower levels, and biological starch might be used as gelling agent.

At present, it is not possible to judge to which extent the substitution or the avoidance of hazardous chemicals is possible. Taking a responsible approach, developments must be monitored critically[7]. UBA (2012) gives an overview of alternative fracking technologies under development.

Halliburton aims at replacing biocides by ultraviolet (UV) purging of the injected fluid, and has carried out a first frack in Texas, USA, in May 2011. A similar approach is taken by OMV[8] and Montanuniversität Leoben in Austria, combining this with using corn starch as gelling agent, Bauxit as proppant and water as only fracking fluid components. Technical feasibility was scheduled to be demonstrated by 2015, economic viability by 2018/19 according to (UBA, 2012). Other concepts developed are: extreme overbalance perforation, cavitation hydrovibration, fracking using liquefied petroleum gas[9], chemical stimulation using acids, and thermal stimulation. At present, it is not possible to judge to which extent the substitution or the avoidance of hazardous chemicals is possible. However, UBA (2012) emphasizes that even if no chemicals are added to the fracking fluids, the flowback includes formation waters in varying shares, which may contain a variety of hazardous substances.

[7] Where substitution of toxic chemicals is possible, the substitutes may also have unpleasant side effects. Guar beans for instance are used as ingredient in the food industry, but also in fracking. In 2011, the rising demand for guar bean starch for hydraulic fracturing exceeded the demand from the food industry, and guar bean prices in India skyrocketed (BBC, 2012, Reuters, 2012).

Using corn starch as gelling agent is another alternative considered. Present estimates indicate that the share of starch in the injected fluid needs to be higher than 10%. For 500 m³ of water for fracturing the starch harvest from around 10 ha of corn would thus be required.

[8] OMV has stopped unconventional gas activities in Austria. It is unclear in how far this affects „clean fracking „ developments.

[9] consisting of propane and butane in varying shares.

RECOMMENDATIONS ON CHEMICALS	TXM[10]
▪ Avoid fracturing activities with chemicals in water protection areas[11] (surface and ground water) and nature protection areas (see also section 3.1).	1
▪ Publicly report all chemicals used during hydraulic fracturing by specifying the CAS numbers, the quantities per fracture and the hazard potential.	3
▪ Do not use chemicals with high hazard rankings in regions where a contact with surface water cannot be excluded (due to hazards, wrong handling in the bore hole or at the surface during fluid mixing, transport of chemicals or waste water leaks).	3
▪ Baseline monitoring of background chemical levels in groundwater, surface water and air before the start of construction/operation close to well pad sites, pipelines and compressor stations for the most hazardous chemicals used during fracturing including methane and hydrocarbons.	1
▪ Monitor groundwater, surface water and possibly air regarding chemicals used in hydraulic fracturing close to gas infrastructure components and at the closest settlements during operation continuously or in defined intervals.	2
▪ Commission a specific study on the toxicological hazard risks of the chemical substances used in hydraulic fracturing.	3

2.4 Radioactive materials

Naturally occurring radioactive materials (NORM)

Radioactive materials were incorporated in the earth's crust during formation. These exist in different rock formations normally at trace concentrations in the ppm-range (ppm – parts per million). Table 8 gives a short summary of concentrations of major radionuclides in major rock types and in soil for reasons of comparison.

[10] See section 1 for TXM coding.

[11] "Vízvédelmi terület" in Hungarian.

Table 8: Summary of concentrations of major radionuclides in major rock types and soils (IAEA, 2003)

Rock Type	^{40}K		^{87}Rb		^{232}Th		^{238}U	
	%	Bq/g	ppm	Bq/g	ppm	Bq/g	ppm	Bq/g
Igneous Rocks								
Basalt (crustal average)	0.8	0.3	40	0.03	3-4	0.01-0.015	0.5-1	0.007-0.01
Granite	>4	>1	170-200	0.15-0.18	17	0.07	3	0.04
Sedimentary Rocks								
Shale, sandstones	2.7	0.8	120	0.11	12	0.05	3.7	0.04
Beach sand	<1	<0.3	<40?	<0.04?	6	0.025	3	0.04
Carbonate rocks	0.3	0.07	10	0.008	2	0.008	2	0.025
Continental upper crust								
Average	2.8	0.85	112	0.1	10.7	0.044	2.8	0.036
Soils	1.5	0.4	65	0.05	9	0.037	1-8	0.066

Based on TXM's detailed gamma ray spectroscopic measurements the average concentrations of the most relevant radionuclides in the TXM production licence area are as shown in Table 9. Based on these data, the production licence area does not display NORM anomalies, i.e. the radioactivity levels in the geological formations are similar to the average in the earth's crust.

Table 9: Average concentrations of major radionuclides in the geological formation of a specific well in the TXM production licence area

^{40}K		^{232}Th		^{238}U	
%	Bq/g	ppm	Bq/g	ppm	Bq/g
1-2	0.3-0.6	4-12	0.015-0.05	1-3	0.01-0.04

Technically enhanced naturally occurring radioactive materials (TENORM)

The decay of the radioactive elements which are incorporated in the geological facies produces other radioactive elements. Depending on pressure, temperature, acidity and other properties these may be mobile in the subsurface environment and can be transported from the reservoir to the surface with the extracted products. Predominantly, these are radionuclides from the decay chains from Thorium 232 decay and from Uranium 238 decay. From ^{238}U-decay these are Radium 226 (^{226}Ra) which partly dissolves in gas and is transported with gas and water, and further decay products such as Radon 222 (^{222}Rn), Polonium 210 (^{210}Po) and Lead 210 (^{210}Pb). The decay chain stops with the stable ^{206}Pb. ^{232}Th decays via ^{228}Ra, ^{224}Ra (both are transported with water), finally ending at ^{208}Pb.

Typically, NORM accumulates in scale, sludge and scrapings and in gas processing facilities. Since Radium is chemically similar to Barium (Ba), Strontium (Sr) and calcium (Ca) it precipitates with Sr, Ba and Ca scale forming radium sulphate, radium carbonate and sometimes radium silicate (OGP, 2008).

Table 10 gives typical levels of radioactivity which are observed in various stages and waste flows of the gas industry.

Table 10: Levels of radioactivity typically observed in various stages and waste flows of the gas industry

Nuclide	Production Water (Bq/l)	Hard Scales (Bq/g)	Soft/ medium hard scales (Bq/g)	Sludges (Bq/g)	Scrapings (Bq/g)	Gas in Processing Facilities (Bq/g)
^{238}U	0.0003 – 0.1	0.001 – 0.5	0.001 – 0.05	0.005 – 0.01		
^{226}Ra	0.002 – 1,200	0.1 – 15,000	0.8 – 400	0.05 – 800	0.01 – 75	
^{222}Rn						5 – 200,000
^{210}Pb	0.5 – 190	0.02 – 75	0.05 – 2,000	0.1 – 1,300	0.05 – 50	0.005 – 0.02
^{210}Po		0.02 – 1.5		0.004 – 160	0.1 – 4	0.002 – 0.08
^{232}Th	0.0003 – 0.001	0.001 – 0.002	0.001 – 0.07	0.002 – 0.01		
^{224}Ra	0.5 – 40					
^{228}Ra	0.3 - 180	0.05 – 2,800	0.05 - 300	0.5 - 50	0.01 - 10	

The International Atomic Energy Agency (IAEA, 2005) gives a typical average radionuclide concentration in natural gas of 340 Bq/m^3 (^{222}Rn).

Table 11: Observed external radiation levels at the outside of natural gas processing facilities (OGP, 2008)

Processing level	Radiation level (µSv/h)
Downhole tubing	0.1-2.2
Piping, filters, storage tanks, reflux lines	Up to 80
Sludge pits, brine disposal wells, brine storage tanks	Up to 50

Specific aspects of shale gas developments using fracking techniques

As shale gas deposits usually have a low specific hydrocarbon content in the rocks and require large surface contact by opening cracks the probability that radionuclides may be destabilized from the reservoir and enter the fluid and gas cycle is higher than in conventional well developments (Bank et al., 2010; Rowan et al., 2011). The actual levels and the size of radioactive contamination might also increase over time as has been observed in stimulated US gas wells (Haar 2011, NYT, 2011, Resnikoff et al., 2010).

The International Association of Oil and Gas Producers proposes the following NORM action limits (OGP, 2008):

- Soils shall not have a ^{226}Ra contamination above 0.185 Bq/g;
- Equipment, vessels, and clothing shall be considered 'NORM contaminated' if internal or external surface contamination measures double the radiation background level;
- Materials and waste media such as sludge/scale containing NORM at levels below those listed in Table 12 shall be exempted from the requirements of this procedure.

Table 12: NORM exemption levels as proposed by the International Association of Oil & Gas Producers (OGP, 2008)

Radionuclide	Exemption level (Bq/g)	Exemption level (pCi/g)
^{226}Ra	1.1	30
^{228}Ra	1.1	30
^{210}Pb	0.2	5
^{210}Po	0.2	5
^{238}U	5.5	150
Uranium (nat)	3.0	80

The IAEA proposes slightly different exemption activity levels from those listed in Table 12. Recommendations listed below are general recommendations for radioactivity issues related to conventional and unconventional hydrocarbon activities. Proper handling and disposal of equipment and materials as well as recommended monitoring activities should be sufficient to ensure that the general population should not be affected by (TE)NORM and that the work force should be protected as necessary.

RECOMMENDATIONS ON RADIOACTIVITY	TXM[12]
▪ Establish monitoring and control system of NORM contamination and exposure according to OGP recommendations (OGP, 2008).	2
▪ Make control measurements of background radiation levels before the start of construction/operation close to well pad sites, pipelines and compressor stations.	2
▪ If exposure limits are exceeded take action according to OGP and IAEA recommendations (OGP, 2008; IAEA, 2011).	3

[12] See section 1 for TXM coding.

2.5 Waste water disposal

"There are different options available for dealing with waste water from hydraulic fracturing. The optimal solution is to recycle it for future use and technologies are available to do this, although they do not always provide water ready for re-use for hydraulic fracturing on a cost-effective basis. A second option is to treat waste water at local industrial waste facilities capable of extracting the water and bringing it to a sufficient standard to enable it to be either discharged into local rivers or used in agriculture. Alternatively, where suitable geology exists, waste water can be injected into deep rock layers." (International Energy Agency, 2012)

Dealing with waste water from hydraulic fracturing has three main options:

- "The optimal solution is to recycle it for future use and technologies are available to do this, although they do not always provide water ready for re-use for hydraulic fracturing on a cost-effective basis." (International Energy Agency, 2012)
- Waste water can be treated at local industrial waste facilities cleaning the water to a level sufficient for discharging it into local water bodies or for agricultural use.
- The third option is injection into deep geological formations, where suitable.

One of the risks to ground water quality[13] arising from below ground operations occurs from the reinjection of flowback waste water from fracking. It should therefore be avoided as far as possible.

If flowback is injected into deep aquifers, it certainly involves contamination of these aquifers and creates a risk for shallow aquifers, if hydraulic communication between these aquifers occurs. TXM has a permit for reinjection of waste waters in fractured reservoires in the basement in the area of Tótkomlós-Kaszaper. In that case it should be ensured that a vertical safety distance of 600 m to the Upper Pannonian aquifers is guaranteed. On the other hand, TXM claims to use closed loop fluid and solids systems with zero discharge systems since 2005. If a complete closed loop fluid and solids system is used, the problem of injection of waste water in deep aquifers does not exist. If, however, waste water is not recycled entirely, a considerable amount of waste water would have to be injected into those fractured reservoires in the basement. If each well branch fracking produces 500 – 3,000 m^3 of waste water, and all 1,280-2,560 well branches are fracked 1-6 times, a total of 128,000 to 3.4 million m^3 of waste water and mud would have to be injected if 70-80% recycling is assumed. Such amounts will certainly affect possible future use of deep aquifers. Waste water treatment would therefore be an essential necessity of operation, otherwise considerable contamination of deep aquifers would occur due to the large amounts of waste water to be disposed of.

[13] Other risks are discussed in section 2.7.

Reinjection of flowback of fracking fluids in the US locally has caused seismic tremors (Leifer, cited in Brown, 2012). Thoug reinjection of flowback is a common practice in the US, it is not a recommendable method of waste disposal if deep aquifers have to be maintained for possible future use.

Recycling reduces or eliminates the critical issues associated with deep injection of waste water; at the same time it reduces the demand for fresh water, and thus solves two potentially critical issues. This is further discussed in section 2.2.

RECOMMENDATIONS ON WASTE WATER DISPOSAL	TXM[14]
▪ "Recycle and reuse waste water to the maximum extent practicable" (ICCR & IEHN, 2012); recycle all flowback fluids and other waste waters, no reinjection into deep aquifers.	2
▪ The International Energy Agency (2012) suggests "central purpose-built water-treatment facilities: these facilities, allowing closed-loop recycling of waste water, could be linked by pipeline to each pad location. They would reduce the overall water supply required for operations and minimize the need for offsite disposal, thereby reducing total transportation, water and disposal costs."	3

2.6 Potential contamination of surface waters

During the drilling and hydraulic fracturing activities in the licence area the following waste materials occur with a potential of contaminating surface waters:

- Drilling mud (1,000 -2,500 cubic meters per drilling site);
- Flowback fluid (potentially containing chemicals from the fracking fluid and from the geological formations, heavy metals, and NORM).

According to TXM, the drilling mud, which is not specific to unconventional gas extraction, will be treated and disposed of in landfills. The flowback fluid will be collected in closed containers, treated and recycled for further use for hydraulic fracturing; possible deep injection of waste waters is discussed in section 2.5.

Even if all reasonable safety measures are applied, the event of a malfunction or any other kind of accident has to be considered. Because of the large number of 1,280 to 2,560 planned well branches in the mining plot even events with a very low probability can statistically occur. An event with a probability of 0.04% for example will statistically occur in one case out of 2,500.

[14] See section 1 for TXM coding.

From the aspect of the safety of surface water bodies this could be a:

- Spill, i.e. a sudden release of larger quantities of liquids (liquid hydrocarbons, chemicals, flowback fluid) onsite and during transport;
- Leak, i.e. a continuous loss of liquid caused by a defect in liquid tightness of tubings, fittings etc. due to unprofessional handling, old or inadequate equipment etc., which is not detected for a certain period of time;
- Blowout of a well what disperses hydrocarbons, fracking chemicals and NORM in the area of and around the well pad.

If the liquid reaches surface waters (rivers, lakes or channels) the damage and cost of environmental remediation is a multiple compared to a scenario where only soil is contaminated. The possible effects of surface water contamination are:

- Increased speed of dispersion of the pollution via water – the contaminated area is significantly bigger;
- Damage on wetland habitats, including protected species;
- Contamination of irrigation water or fish breeding water with associated economic and ecological damage to agriculture and pisciculture;
- Contamination of drinking water wells;
- Damage to the recreational function of water bodies.

In the licence area only the direct catchment area of the river Tisza is a surface water protection area running parallel with the river in varying width of 2-10 km. This protection area needs to be excluded from drilling activities.

In order to reduce the risk of surface water contamination it is recommended to keep a safety zone between water bodies and drilling sites of at least 100 meters. Even small –at the first glance insignificant or in the summer period dry – channels should be considered as water bodies. This is because in periods of heavy rain or snow melting even these small channels are transporting considerable quantities of water, which in the case of a spill represents a quick and far-reaching transportation pathway for the pollution.

The planned distance of around 2 km between drilling pads should allow keeping these safety distances (see the hypothetical field development plan in Figure 3 as an example).

RECOMMENDATIONS ON SURFACE WATER PROTECTION	TXM[15]
General recommendations:	
▪ No drilling in surface water protection areas.	1
▪ Keep a safety distance from surface water bodies of at least 100 m. Larger safety distances of well pads of 500 m from water bodies where these flow into protected areas within 10 kilometres are kept (see section 3.1).	2
▪ All chemicals and waste waters should be stored in a manner to prevent any kind of leak to the environment; including the sealing of the well pad against leaked fluids from containers.	1
▪ Apply all relevant safety measures in the road transport of critical fluids or substances to and from the well pads.	1
▪ Monitor surface water quality in the vicinity of well pads before and during operation.	1
▪ "Quantity of flowback waters is monitored and chemical composition is tested to assess hazards, inform recycling/reuse/disposal decisions and assure compliance with applicable state waste water management standards." (ICCR & IEHN, 2012)	1

2.7 Hydrogeological aspects including potential contamination of ground water

Two flow regimes in the Makó trough have been distinguished by Toth & Alamasi (2001). The deeper located flow system is charcterized by strong overpressure while at shallow depth a regional flow system exists, which is gravitation- and topography-driven. This is reflected by the fluid potential distribution in the Makó trough, which shows an upper section of the Pannonian sediment fill with low vertical fluid potential gradients of 10 m/1000 m. At depths below 2000 m gradients increase rapidly to 400 m/1000 m due to overpressure in the Lower Pannonian sediments. Given the range of hydraulic conductivities, maximum vertical flow rates may be in the order of few cm/year, except for local vertical hydraulic conducting structures, where vertical fluid flow may exceed such velocities. The presence of upward fluid flow is detectable from the hydrogeochemistry of the lowermost section of the Upper Pannonian basin fill with the Ujfalu and Zagyva formations, containing components of oil field water squeezed out from the deeper clay formations.

[15] See section 1 for TXM coding.

Overpressures in the study area of Czauner & Mádl-Szõnyi (2011) about 100 km north of the Makó trough are in the range of 100-350 bar. The depth of the transition zone to topography driven flow systems varies between 1700 and 200 m below surface and does not coincide with the boundaries of hydrostratigraphic units. In the study area of Czauner & Mádl-Szõnyi (2011), the base of Upper Pannonian sediments is at 600-1,100 m depth. Though overpressures are primarily seen as a result of tectonic pressures and pressure propagation from the Pre-Neogene basement, it cannot completely be ruled out, that overpressure may partially be generated from elevated young sedimentation rates and resulting undercompaction. A similar situation might apply to the Makó trough, although the hydrogeologic section crossing the Makó trough in Toth & Almasi (2001) does not show overpressures in the Upper Panonnian layers. Toth & Almasi (2001) consider hydrostatic pressures in depths of up to 1,400-2,500 m. Overpressure does not linearly increase with depth, a pattern that supports the idea of compaction-induced overpressure generation. Another source of overpressure may be hydrocarbon generation, although Tóth & Almasi (2001) seem to rule out this source of overpressure. Whatever the source of overpressures might be, overpressured sediments may provide a possible engine for driving fluids up from the Lower Pannonian rocks into shallower zones, if preferential pathways exist, which connect overpressured zones with zones of hydrostatic pressure.

The upper flow regime in the quaternary sediments in the Tisza and Makó trough area appears to have an upward component (Toth & Almasi, 2001). Recharge areas of the upper topography driven system are not clearly defined, however they are probably located in the topographically elevated areas of the Makó trough and its neighboring zones. Upward flow usually occurs in ground water discharge areas, while ground water recharge areas have downward directed flow. The Makó trough with upward flow therefore seems to be a ground water discharge area, which reduces possible damage to aquifers in case of ground water contamination from above-ground accidents with fracking fluids.

Hydrochemistry of shallow aquifers (< 600 m depth)

Shallow ground water in the Makó trough has meteoric origin and may locally be enriched by recharge from rivers. The hydrochemistry of shallow ground water is characterized by elevated iron (Fe), arsenic (As) and methane contents. Fe content reaches up to 3 mg/l. Elevated Ar content is a serious quality problem at several shallow water wells. Many wells show arsenic values in the ground water above the limit for drinking water of 10 µg/l; some wells have been shut in due to elevated arsenic contents. In several areas of the Great Hungarian Plain natural arsenic content is above the limit of 10 µg/l (Varsány & Kovacs, 2006), which has been established by the World Health Organization (WHO) as a provisional guideline value for arsenic in drinking water. Ammonium is another problem affecting ground water quality. An unusual aspect of the hydrochemistry of ground water in the Makó trough is its elevated biogenic methane content. Methane contents are in the order of up to 10 Nl/m^3, except for the *Maroslele 28* well with about 20 Nl/m^3. Some wells require fire protection and gas extraction installations. Methane contents of 79,6 Nl/m^3 are detected in the (deep) geothermal water well *Földeak K 52*, which is close to the *Makó 6* gas well. Gas shows in the *Földeak K 52* well were detected prior to TXM drilling operations. *Földeak K 52* produces at about 2000 m depth, so here might already be a thermogenic component of methane.

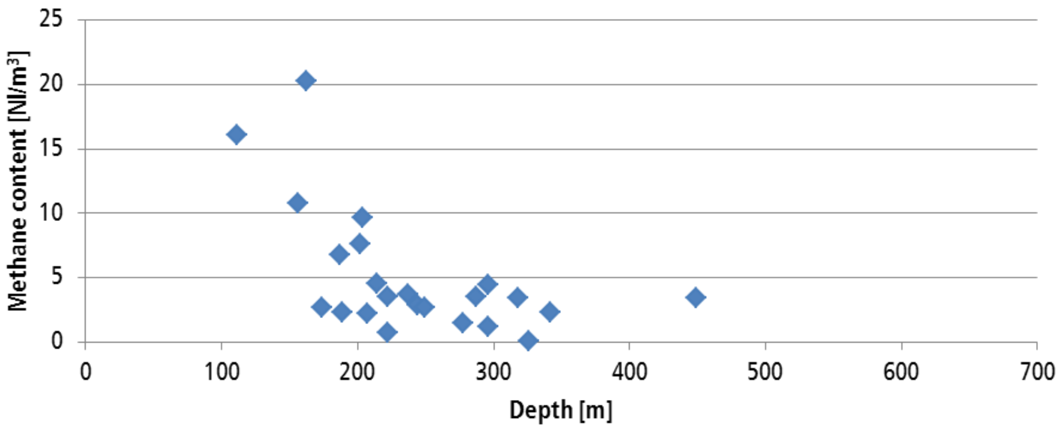

Figure 17: Methane content in selected shallow water wells (data from 2002) in the Makó area

Biogenic methane is derived from the decay of organic matter and occurs at low temperature and shallow burial. Thermogenic methane originates from thermal decomposition of deeply buried organic material. Both can be distinguished from their stable isotope ratio of carbon. The concentration of the stable C^{13} isotope in biogenic methane is lower than in thermogenic methane. A change in isotopic composition of methane in ground water therefore might indicate a possible escape of thermogenic methane from deeper zones towards shallow zones. Therefore, methane content and isotopic composition of ground water should be monitored during unconventional gas extraction in order to detect possible unintended flows of methane from the well towards shallow or deep aquifers.

Hydrochemistry of deep aquifers (600-2500 m depth)

Ground water from deep aquifers is usually not well fitted for human consumption due to elevated temperature and solute content of such waters. Deep ground water is therefore mostly used for geothermal energy. The *Földeak K 52* is such a geothermal ground water well which produces at about 2000 m depth. Waters from deep aquifers in the neighbouring Szeged area have shown isotopic composition of paleometeoric origin with ground water recharge during the last cold period between 70,000 and 12,000 before present (Varsány et al., 1997). Concentration of total dissolved solids reaches more than 6,000 mg/l. Sodium chloride (NaCl) type waters are found above the basement highs such as the Algyö high, and sodium hydrogen carbonate ($NaHCO_3$) type waters are found within the basins. NaCl type waters are mostly formation waters with chloride from marine environments at deposition, while $NaHCO_3$ type waters are paleometeoric waters (Varsány & Kovacs, 2009). Influence of oil field waters has been detected in the deepest aquifers. Kerogen formation at depth may account for the generation of CO_2 and methane. Waters with temperatures above 65° contain natural polycyclic aromatic hydrocarbons (PAH), while thermogenic methane begins to appear at temperatures above 50°.

Methane content in deep aquifers is in the same range as in shallow aquifers, however, there may be thermogenic methane from Kerogene formation at greater depth. Ground water temperature data from shallow and deep wells show a gradient of about 30° at 1 km, which is the average crustal gradient. Dövényi & Horváth (1988) determined the temperature gradient in the Makó trough from the *Hód 1* well at 49,1°/km, which is considerably higher than the average value from ground water wells. Temperature data from wells, however, are prone to measurement errors which may account for the difference to the value given by Dövényi & Horváth (1988).

Fracking risks on aquifers

Fracking risks on aquifers in the Makó trough may originate from below-ground and above-ground operations. They may affect shallow aquifers, which are currently exploited for drinking water and irrigation purposes, and deep aquifers, which might be used for geothermal purposes. Aquifers which are currently not in use also need to be considered. Concerns on increasing contamination of shallow aquifers or increasing water demand might draw attention to deeper aquifers in the future. This might be important as water extraction from shallow wells in the Makó area has increased from 22,000 m^3/d to 27,000 m^3/d between 2001 and 2011.

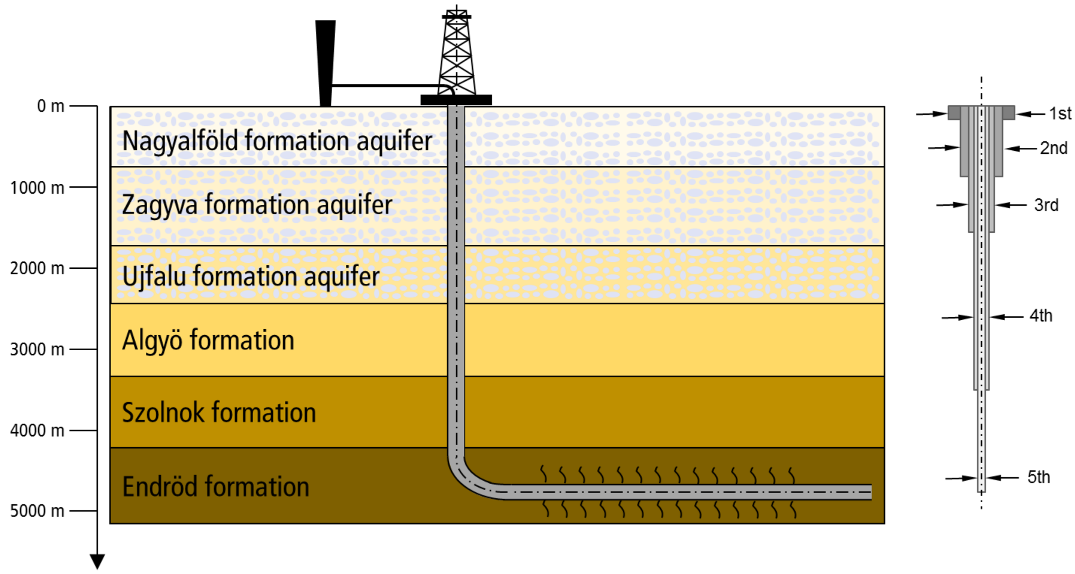

Figure 18: Geological formations and aquifers crossed by the unconventional gas wells; four to five cemented steel casings need to guarantee the integrity of the well.

A principal possible pathway of fracking fluids and natural gas might be the drilling well itself, as it represents an artificial conduit between the surface and the geological rock formations. It is therefore important to apply safety standards and monitoring routines to supervise the integrity of the well and the cementation of the casing. To avoid any contact between aquifers and the fluid moving in the well, the casing needs to be properly cemented. Well integrity during drilling and production needs to be monitored and tested continuously. Casing strings should be properly cemented and inspected. Wells should be completed in such a way, that no section of the wellbore is without casing and cementation. Pressure tests should be performed after cementation in order to check whether the well withstands the fracking pressures. This also applies to abandoned wells, which may be located in the area.

Risks from below-ground operation

Even if a well is safe and aquifers cannot be contaminated directly from the well, a contamination risk from below-ground operations may originate from the injection of fracking fluids into the gas bearing formation, and from the subsequent migration of natural gas from the gas bearing formation into aquifers along fractures that have been created by the fracking process. The creation of such pathways is the principle contamination risk for aquifers, if these pathways provide hydraulic communication and invasion of fracking fluids and natural gas into aquifers. It is therefore essential to control the size, range and propagation of fractures during the fracking process. As fracking is planned for deep seated Lower Pannonian formations, deep aquifers would be primarily affected from the opening of such pathways.

Pre-Pannonian aquifers and Lower Pannonian aquifers in the Makó trough are located at depth of more than 2500 m. The hydrogeochemical properties of their waters will probably not allow for domestic consumption or irrigation purposes. However, other uses such as geothermal purposes might become increasingly important in the future, or even disposal of CO_2 in such deep aquifers might become an issue someday. Deep aquifers should therefore be handled with the same safety measures as shallow aquifers.

The Lower Pannonian formations, which are considered for fracking and gas production, are at vertical distances of several hundreds to thousands of meters beneath the presently used aquifers, so the risk of fracking on aquifers comes principally down to the question whether the range of fractures can technically be controlled to avoid the creation of preferential pathways to these aquifers. If Upper Pannonian sediments were overpressured, propagation of fractures through overpressured zones might be an issue, however, this is apparently not the case in spite of strong sedimentation rates of up to 800 m during the Quaternary.

Davies et al. (in press, cited in Milam, 2012) analysed the range of fractures from fracking events using microseismic field studies. They suggest a vertical safety distance of about

600 m between the fracked formation and the next proximate aquifer. A similar recommendation of a 600 m safety distance has been made by a neutral expert group in Germany in 2012 in their "Hydrofracking Risk Assessment – Study concerning the safety and environmental compatibility of hydrofracking for natural gas production from unconventional reservoirs" (Ewen et al., 2012).

Davies et al. (in press) conclude, that from a single fracking event, the probability of a vertical fracture extending more than 350 m is at 1%. In their field study of various shale gas formations in North America, the maximum range of a fracture was 588 m. However, it remains uncertain in which way repeated fracking events might extend previously created fractures, as these may function as preferred conduits during successive fracks. Two successive fracking events, which each time create 350 m fractures at a 1% probability, might give a 0.1 per mil probability of a prolonged 700 m fracture after the second fracking, if fracture ranges accumulate linearly. The number of longer fractures would have increased, some of them being prolongations of earlier fractures. Depending on the number of fracking events and the number of fractures created at each fracking, the probability of extended fractures might be higher than expected. Repeated fracking in unconventional gas wells in the Barnett shale has shown positive results with regard to production (King, 2012). Obviously, new fracking creates new pathways in the shale and it is difficult to assume that previously created fractures may not have become prolonged during a new fracking event.

With 160 well pads and 8-16 well branches per pad planned, a 1% chance of a fracture reaching 350 m means that a total of about 13-25 well branches will develop fractures reaching 350 m vertical distance from the fracking location. As fracks may have to be repeated as gas production wanes, an important question is whether existing fractures will be extended during successive fracking events, and to which length such fractures will possibly be extended. What is the probability of such an extended fracture to reach a shallow aquifer?

At the present state, a clear answer to this question cannot be given. It is therefore recommended to control the fracking process by microseismic monitoring, and avoid repetition of fracking on such well branches where fractures are detected which have already passed the 600 m safety distance. Microseismic control is of course only a posteriori method to control fracking but not to avoid the growth and extension of fractures.

Especially if natural gas and oil production from the Algyö formation on the slope of the Makó trough (the so called "Upper Play") is performed, microseismic monitoring during fracking will be important, as the Algyö formation is closer to shallow aquifers than the Endröd formation in the center of the Makó trough.

The production license of TXM in the Makó trough is limited to a minimum depth of 2300 m, which is the depth of the base of the Ujfalu formation aquifer in the centre of the basin. As this aquifer is already being used, the safety distance of 600 m should be taken to limit fracking in the Lower Panonnian in the deepest parts of the Makó trough to a minimum depth of 2900 m. If extended fractures occurred during fracking it would primarily affect the geothermal aquifers. Geothermal waters, however, in many cases pose environmental threats themselves and need to be reinjected into the respective aquifers to avoid contact with surface waters or shallow aquifers, so the risk from fracking contamination would be relatively low.

Contamination of shallow aquifers from fracking-induced fractures extending from the Endröd formation has a low probability, as long as the technical safety of the fracking process and the absence of large fracking-induced vertical fractures as preferred pathways for fluids are ensured. However, already existing natural vertical preferred pathways such as faults may pose an additional risk for shallow aquifers. If fracking occurs close to a hydraulic conducting fault, fracking fluids might accidentally invade such a zone and possibly move towards shallower depths. Such a situation has been analyzed by Myers (2012). Therefore, seismic lines in the Makó trough should be carefully checked for faults affecting shallower formations. A horizontal safety distance of 600 m between a fault and the fracking zone should be applied.

Toth & Almasi (2001) assume "a dense network of faults and fractures, created or rejuvenated by intensive Neogene tectonics, has destroyed the regional lithologic integrity of the basin and basin fill, both in lateral and vertical directions" and faults that even reach into Quaternary layers. With regard to this general observation in the Great Hungarian Plain and the strong quaternary subsidence in the Makó trough, the apparent absence of quaternary faults should be veryfied carefully. In other areas such as the western part of the Trans-Tisza area of the Pannonian basin, it has been shown that faults may act as preferential hydraulic pathways, connecting the overpressured sub-Neogene basement with the uppermost aquifer. Czauner & Mádl-Szõnyi (2011) report in their study area about 100 km north of the Makó trough that "faults sometimes dissect the entire rock framework from the sub-Neogene basement to the Quaternary (Rumpler and Horváth, 1988) and compose lithologic discontinuities, which can become highly conductive avenues to porepressure propagation and fluid flow." It should therefore be checked whether similar conditions occur in the Makó trough. Seismic profiles across the Makó trough should be inspected for such patterns as decribed by Toth & Almasi (2001) and Czauner & Mádl-Szõnyi (2011).

Another risk arising from below ground operations occurs from the reinjection of flowback waste water from fracking. This is discussed in section 2.5.

Risks from above-ground operations

Shallow aquifers will mainly have a risk of contamination from above-ground operations during transport, storage and injection of fracking fluids. Another risk arises in the handling and recycling of flowback of fracking fluids after the fracking process. These risks, however, are of technical nature and not primarily a question of hydrogeology as long as waste water is not disposed in aquifers. As a general policy, above-ground operations for fracking should not be performed in ground water protection zones and areas close to surface waters. As the fracking process in deep formations and elevated overpressures is a technical challenge, possible contamination from technical problems during above-ground operations of fracking should be anticipated by sufficient safety measures and exclusion of environmentally sensitive zones.

RECOMMENDATIONS ON GROUND WATER PROTECTION	TXM[16]
▪ Ensure well completion with complete wellbore provided with casing and cementation.	1
▪ Carry out pressure tests after cementation.	1
▪ Continuous monitoring of well integrity during drilling, after fracking and production.	1
▪ Complete or close abandoned older wells in the area.	1
▪ Detailed inspection of seismic lines for quaternary faults prior to fracking.	1
▪ Microseismic control during fracking.	2
▪ Constrain fracking in the deepest part of the Makó basin to below 2900 m depth in order to ensure a vertical safety distance of 600 m to the Ujfalu formation aquifer.	[17]
▪ No successive fracking on well branches where fractures are observed having exceeded a 600 m range.	3
▪ No fracking closer than 600 m to fault or natural fracture zones.	2[18]
▪ No fracking operations in ground water protection zones.	1
▪ Monitoring of methane and stable isotope ratio of carbon in methane from shallow and deep ground water before, during and after gas production.	2

[16] See section 1 for TXM coding.

[17] Not applicable, according to TXM.

[18] Only for faults or natural fracture zones that penetrate into aquifers.

2.8 Exploration-induced earthquakes

Tectonic movement in the Makó trough is dominated by North-northeast – South-southeast (NNE-SSW) oriented compression and contraction as principal strain direction as a result of plate tectonic movements. A NNE directed crustal motion in the order of 1.0 ± 0.3 mm/y with regard to the European plate has been measured. Vertical components are in the order of -1.1 ± 0.5 mm/y, however this subsidence has possibly a non-tectonic component from ongoing compaction of overpressured sediments. The southwestern part of the Makó trough shows land subsidence of up to 50 mm which took place during the last 15 years due to hydrocarbon extraction from the Algyö field (Grenerczy & Tóth, 2007).

Surprisingly, the course of the Tisza river does not reflect the subsidence pattern of the Makó trough. Instead, it crosses the Algyö structural high in spite of ongoing subsidence of the Makó trough. This might be seen as an indication of a generalized subsidence not only in the Makó trough but also in the neighbouring structural highs. This subsidence pattern might also explain the absence of quaternary faults. Apart from ongoing quaternary subsidence there are no signs of recent tectonic activity in the Makó area. According to TXM, seismic profiles in the Makó trough show no quaternary faults. Seismic profiles of parts of the Makó trough described in Mattick, Phillips & Rumpler (1988) do not indicate quaternary faults either.

Strong quaternary subsidence is not accompained by increased seismic acitivity. In the 1995-2004 period seismic events with magnitude 2 and focal depth between 10 and 11 km have been detected (www.georisk.hu). The seismic activity of the area does not indicate anomalies that point to hidden seismic risks. The regional stress field shows directions of maximum principal stress in NNE direction, however residual differential stresses are apparently very low and make the Makó area (historically) a seismic quiet zone with almost no appreciable earthquakes. However, the occurence of unexpected heavy earthquakes in apparently seismic calm areas has been observed in the earthquake in the New Madrid zone in the USA in the 19th century. In the context of fracking, the important issue is the existence of elevated differential stresses, for which no indications are known in the Makó trough. Low differential stresses may also trigger earthquakes, if the state of stress as represented in the Mohr circle[19] is already close to the Mohr-Coulomb failure line[20]. This situation may be the case in overpressured rocks. Fracking induced earthquakes may therefore occur, however earthquakes of significant magnitude as a result of fracking in the Makó trough can hardly be expected.

[19] A measure to show the state of stress of a rock.

[20] A measure that indicates the stress state at which a rock breaks.

RECOMMENDATIONS ON EARTHQUAKES	TXM[21]
▪ Monitoring of seismicity during the exploration and production period to detect eventual changes in earthquake risks.	2

[21] See section 1 for TXM coding.

3 ECOLOGICAL THREATS

3.1 Short and long term ecological threats, including impacts of the linear infrastructure and effects on the local biodiversity

Local landscapes, habitats and important species

The TXM licence area is located within the Alföld geographical region (Great Hungarian Plain) its terrain ranging from flat to rolling plains and containing several mesoregions (‘landscapes’). Three of these mesoregions are part of the licence area: a) the Plains between the Danube and Tisza rivers in the north-western part of the licence area, b) the Lower Tisza Plains crossing the licence area in north-south direction, and c) the Upland between the Körös and Maros rivers forming the major part of the licence area. These contain six geographical micro regions shown in Figure 19: The Csongrádi-sík (rose color), part of the c) Körös-Maros Upland, covers more than 50% of the licence area. The Marosszög (dark brown) and the Dél-Tisza-völgy (light brown), both part of the b) Lower Tisza Plains, represent a relative small part of the licence area, but are located in the flow direction of most rivers or channels passing the licence area. The Dorozsma-Majsai-homokhát (orange) and the Kiskunsági-löszöshát (light grey), both part of the a) Danube-Tisza Plains, only cover small portions of the north-western licence area.

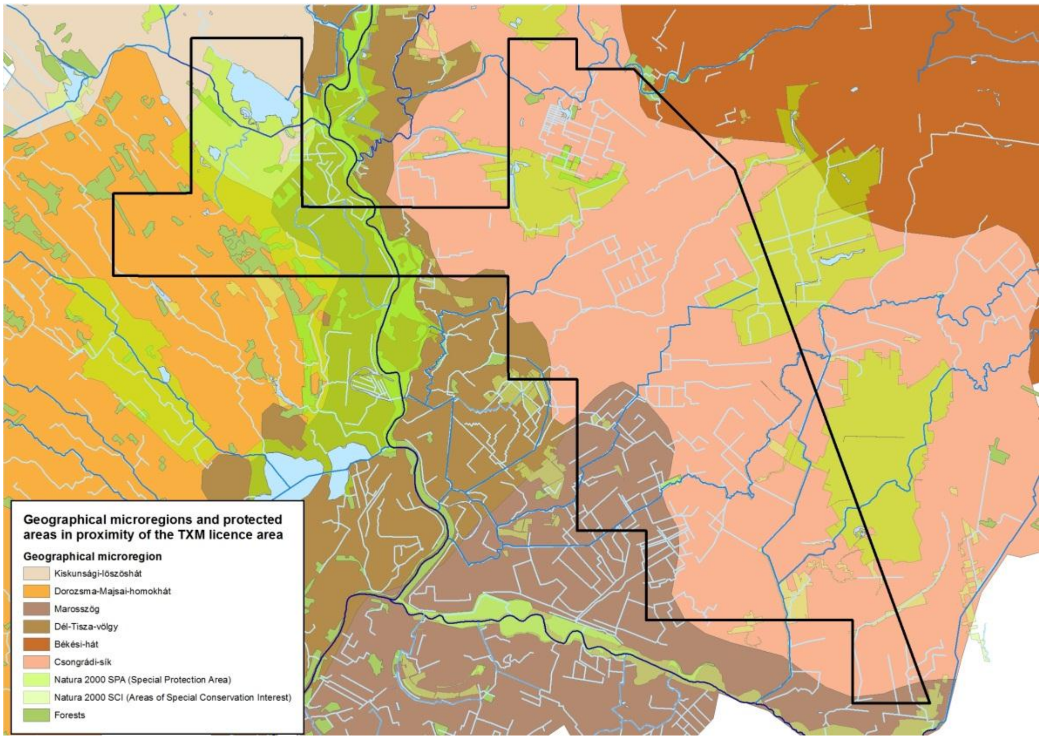

Figure 19: Geographical microregions in proximity of the TXM licence area

The *Csongrádi-sík* is intensively used by agriculture, very little remains of the original habitats. A few species of the original forest vegetation remains at semi-natural oak forest fringes, and some endemic steppe species and fragmented habitats remain, including special habitats located in endorheic depressions. Loess steppe grasslands and solonetz-saline grasslands form unique mosaic habitats here. The high level of biodiversity and high number of endemic species indicate the age of these communities. The vegetation of saline lakes is also unique. Some slow-running or standing water communities are important to mention too. The number of flora species in the area is between 800-1,000, of which some 40-60 are protected (Király et al., 2008), (Deák, J. Á., 2004). Major protected areas here are the Kardoskúti Fehér tó and Csanádi puszták, which are part of the Körös-Maros National Park (see section 0).

The *Marosszög* and *Dél-Tisza-völgy* micro regions are characterized by river sediments. Habitat patterns in this area are a result of interaction of morphology, water management and land use. Adjacent to the rivers, willow-poplar woodlands, marshes with sedges and reeds as well as bogs and moorlands are typical. Outside of the floodplain limited by protective dams, the landscape is dominated by cropland crossed by drainage and irrigation channels; some loess or sand steppe communities can be found. Secondary saline meadows, *Achillea* steppes and a saline steppe-forest can be found in the area. The number of flora species in the area is between 400 and 600, between 20 and 40 of which are protected (Király et al., 2008). The major protected area here is the Körös-Maros National Park, notably the Maros river and floodplain south of the licence area (see section 0).

The north-western landscapes, notably the *Kiskunsági-löszöshát*, are dominated by loess sand soils where grassy steppes and saline grasslands characterise the vegetation; steppe forests have mainly been eliminated. The number of flora species in the area is below 400-800; 20-70 of them are protected (Király et al., 2008). Large shares of the area are used for agricultural purposes. Semi-natural vegetation remains only in deflation-hollows, which can turn into temporal saline swamps at high water coverage, where no crop production or only extensive pasture is possible. A major protected area in the north-western part of the licence area is the *Natura 2000* site *Baksi puszta* with typical habitats and endangered species (see section 0).

Ecological threats including effects on the local biodiversity

Protected areas (see section 0) representing 21% of the licence area are the major locations of important habitats and endangered species in the licence area. Nonetheless, also outside protected areas there are many important semi-natural habitats, which, however, in general are small and fragmented by roads and agricultural activity. Most of the licence area outside protected areas is used for agricultural purposes or covered by settlements.

There are many kurgans (Hungarian: 'kunhalom') in the TXM licence area, which are small hills heaped up centuries ago used as graves, sentries or border marks (Tóth, 2006). These are important flora-fauna habitats as they are obstacles for agricultural machinery, and are sources of archaeological finds. They are protected by law in Hungary.

Unconventional gas extraction poses a number of ecological threats, including a reduction of the number and area of habitats, a further fragmentation of habitats as well as disturbances of or damages to habitats (Standovár & Primack, 2001), (Primack, 2010).

The reduction of habitat number and area by unsuitable siting of the well pads may lead to the reduction of the total population of certain species, which in turn can possibly contribute to critically low levels of population for endangered species, and thus possibly to the expulsion of these species from the region, or to their extinction.

Habitat fragmentation by unsuitable siting of the well pads may lead to the reduction of the gene pool of individual species decreasing the species' adaptation capacity.

Disturbance and damage of habitats at and around well pads and transport routes by noise, air pollution, water pollution, etc. may lead to a reduction of suitable habitat area, a reduced reproduction rate of certain species, acute and chronic poisoning of certain species as well as killed or debilitated individuals.

Some of the impacts described above may be reversible in the short-term. Others may be irreversible, or may take many years or even decades for habitats and individual species to recover.

A number of preventive measures should be taken in order to avoid the above-mentioned threats, or to minimize possible damage.

In order to avoid possible reductions of habitat areas, careful site selection is important. Greyfield or brownfield areas are the preferred site options; agricultural land is second best option, which should include soil sampling and analysis for the determination of the thickness of the humus rich horizon to be removed and stored for later restoration. It is important to note that site remediation cannot stop at the stage of restoring the original soil layers. If the site won't be used by agriculture after the remediation it has to be ensured that endemic or local plants are established and taken care of in the first years at the site in order to prevent invasive species from supressing them.

For sites placed on uncultivated (semi-natural) land, bio-monitoring and soil sampling before site preparation for the identification of important habitats and endangered species is recommended. In case important habitats or endangered species are identified on selected sites, alternative site selection should be considered; where this is not possible, compensation measures should be carried out.

Avoiding sites that cut ecological corridors such as typically hedges, grass verges, ditches, deflation hollows, or patches with soils of low agricultural value or migration routes of protected species such as amphibians will reduce habitat fragmentation considerably.

Noise is an important source of disturbance to certain animal species, notably certain bids, while other species are not noise-sensitive. Safety distances from protected areas where noise sensitive species dwell should be similar to those kept from farms. Mating, nesting and migration seasons may be specifically critical.

Disturbances of and damages to habitats by air and water pollution can be avoided or their impacts minimized if larger safety distances of well pads of 500 m from water bodies where these flow into protected areas within 10 kilometres are kept. Well pads should be designed so as to inhibit any leakages of critical liquids into the ground ("zero discharge").

Furthermore, transport is critical in this respect: Material and equipment transport, notably of dangerous substances, through protected areas, both inside and outside the licence area, should be systematically avoided.

Impact on soil

Soil is an essential and vulnerable natural resource. Its main function is to provide the vegetation with water and nutrients and enable the growth of biomass. The generation of soils is a very slow process; the formation of chernozems (black soils) found in the licence area can take more than thousand years. Soils can be destroyed by erosion, elutriation, or pollution. Soil as a valuable natural resource of Hungary, and its conservation and adequate use is critical for a sustainable development (Stefanovits et al., 1999).

For the non-conventional gas production 160 one-hectare well pads will be established by TXM over a 20 year period. For site preparation, TXM plans to remove the top 20-40 cm layer of the soil. Drilling activities for 8-16 well branches per well pad will take 1 to 2 years. After this 90% of each well pad can be remediated including return of the removed soil. A 1000 m^2 production site will remain until the end of the production lifetime of the site of some 20 years.

In total, about 160 ha of soil will be impacted directly by the field development, not counting possible land use change for new streets and other infrastructure. Using the soil database of (MTA ATK TAKI, 1991), and a hypothetical field development plan (see section 1) where settlements, water bodies and protected areas including safety distances have been avoided (see Figure 20), the affected soil types were identified. Since the final production sites have not yet been selected, the actual values may slightly differ from this analysis.

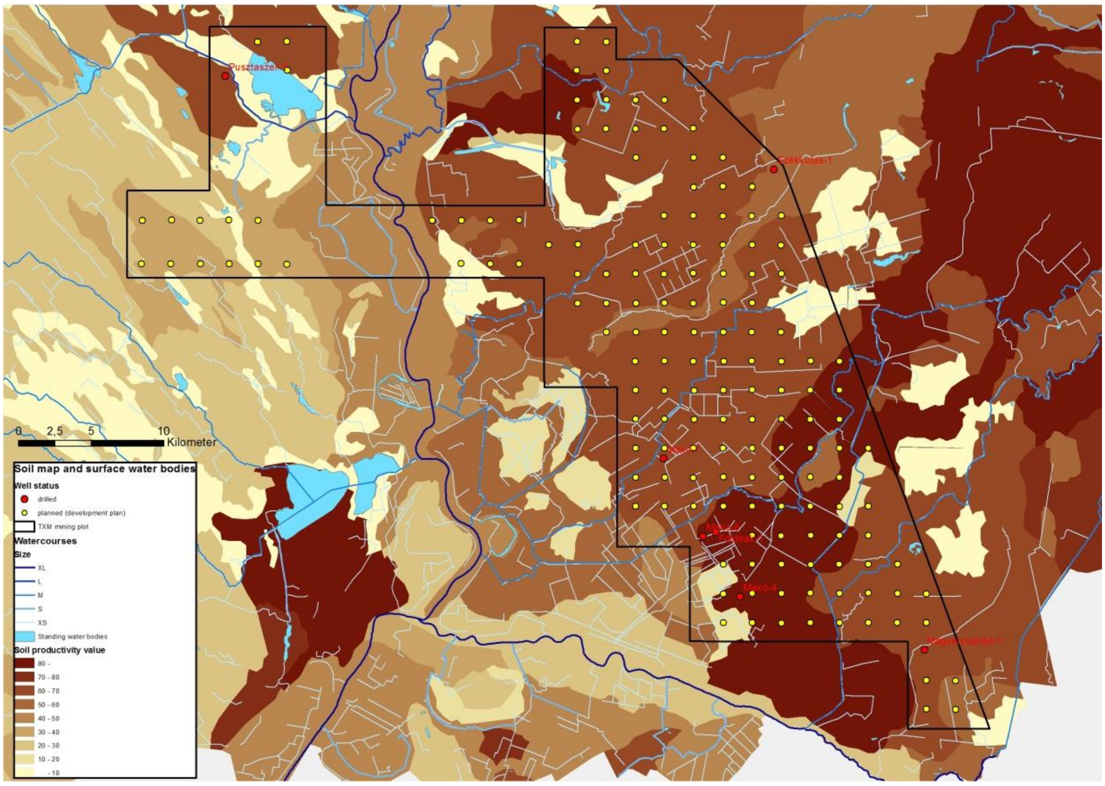

Figure 20: Hypothetical field development plan and soil fertility in the TXM licence area

The quality of soils in Figure 20 is expressed in terms of a productivity value, which is the natural fertility of each soil relative to the most fertile soil (Stefanovits et al., 1999). It is to be expected that about 30 drilling pads will be placed on soils with a fertility value of 80-90%, over 100 pads on soils with a fertility value of 60-70% and less than 30 sites on soils with a fertility values below 60%. About 140 pads will most probably be placed on various kinds of chernozem soils, the remaining 20 pads on meadows, saline or sand soils. The soil column is typically deep in the area with more than 1 in the entire licence area. The soils in question are particularly rich in organic matter (humus, soil carbon), over 130 sites can be expected to be located on soils with an average carbon content of 300-400 t/ha. In the case of inadequate handling the soil carbon can be lost resulting in a loss of soil fertility and substantial greenhouse gas emissions of some 1,100-1,467 t CO2/ha.

For site preparation and remediation the following recommendations are made:

- During site preparation the entire humus-containing top soil 'A' horizon and if necessary also second 'B' horizon should be removed. In the case of chernozems this is typically about 1 m, in the case of meadow chernozems about 0.5 m. Soil samples should be taken before site preparation in order to determine the exact depth of the humus containing horizon to be removed.

- During soil removal and storage it is important to avoid soil compaction, loss of soil structure and most importantly loss of soil by wind and water deflation or erosion; the plantation of fast growing dense-rooting vegetation is thus recommended.
- Many soils in the area have salt accumulations in their deep layers. In order to avoid a loss of fertility these saline layers should not be mixed with fertile top layers.

Impacts of the linear infrastructure

For field development, well pad preparation and gas production, auxiliary infrastructure for the transportation of personnel, material, energy, equipment and the produced gas is necessary. For this purpose, linear infrastructure such as roads, pipelines, and possibly other types are needed with potential impacts on the environment.

Roads are required for the transportation of raw or waste materials, equipment, machinery and personnel to and from the well pads. Csongrad county has a population density of around 100 pop./km^2. There are several municipalities, and a significant number of farms outside the settlement area. The entire area is plain and intensively used by agriculture. Hence, the area is well developed by a dense road network probably allowing reaching most well pads by roads. Many of them, however, may be unpaved roads used for agricultural purposes. The demand for new roads will be low however, upgrading of roads may be necessary. Land use change by establishing new roads will be low, but habitat fragmentation and the increase of impervious surfaces with related consequences are to be expected from road upgrading to a certain extent.

Transport frequency will increase noticeably in some areas such as rural areas where traffic is low to date. Additional transport is estimated at 2 trucks per day over a 2-4 year period for each well pad, with peaks and quieter periods, plus daily transport of personnel. Local dust and particulate matter emissions on dry days could by significant just as other pollutant emissions and noise.

For the collection of raw gas from 160 well pads and its transport to the processing plants in Algyö or Kardoskút an estimated 400-500 km of pipelines will be required. These could be built along the existing pipeline routes (around 75 km in the licence area) or next to existing roads. Gas pipelines will be underground lines. Pipeline construction will thus have associated impacts, while its operation is expected not be be problematic.

In case connection of the well pads to the electric grid is considered (see section 3.3) new medium voltage lines need to be installed. Combining gas pipeline establishment with electric grid connection could reduce reduces related impacts.

RECOMMENDATIONS ON ECOLOGICAL THREATS	TXM[22]
▪ Careful selection of well pad sites based on ecological criteria.	1
▪ Greyfield or brownfield areas are the preferred site options; agricultural land is second best option, which should include soil sampling.	2
▪ Ensure establishment of endemic plants after site remediation.	3
▪ Carry out bio-monitoring and soil sampling on uncultivated areas selected for well pads location. Consider alternative sites in case important habitats or endangered species are affected.	1
▪ Avoid sites that cut ecological corridors.	2
▪ Safety distances from protected areas where noise sensitive species dwell should be similar to those kept from farms. Mating, nesting and migration seasons may be specifically critical.	1
▪ Larger safety distances of well pads of 500 m from water bodies where these flow into protected areas within 10 kilometres are kept.	2
▪ Well pads should be designed so as to inhibit any leakages of critical liquids into the ground ("zero discharge").	1
▪ Material and equipment transport, notably of dangerous substances, through protected areas, both inside and outside the licence area, should be systematically avoided.	1
▪ The entire humus-containing top soil 'A' horizon should be removed.	1
▪ Avoid soil compaction, loss of soil structure and most importantly loss of soil by wind and water deflation or erosion; the plantation of fast growing dense-rooting vegetation is thus recommended.	1
▪ Avoid mixing fertile top soils with deeper soils.	1
▪ Salt accumulations in deep soil layers should not be mixed with fertile top layers.	1

[22] See section 1 for TXM coding.

3.2 Proximity of local national parks and other protected areas

Csongrád county and the licence area have numerous important habitats or protected species. There are 12 protected areas (partly fragmented into several sites) partially or completely within the TXM licence area. The protected areas within the licence area total some 210 km^2, equivalent to 21% of the 994 km^2 of the licence area. Furthermore, there are 10 (partly fragmented) additional protected areas in direct proximity of the licence area.

The protected areas listed in Table 13 are administered by the Kiskunsagi or Körös-Maros National Park Directorates, respectively, even though some are not classified as National Park area. They are mainly NATURA 2000[23] sites classified as either Special Protection Areas (SPA) or as Areas of Special Conservation Interest (SCI). Several sites are classified as Ramsar Convention[24] areas.

Many protected sites in Csongrád county and Békés county belong to the Körös-Maros national park directorate, of which the following three are in the immediate proximity of the TXM licence area:

The Kardoskúti Fehér tó is a valuable lake with a unique hydrologic balance located at the east side of the licence area. The lake and its direct environment is a core national park area, due to its geographical, hydrological, ornithological and biological values as well as a recorded bird refuge according to the Ramsar Convention. The core National Park area (including the Csanádi puszták National Park area) is surrounded by a buffer zone of a NATURA 2000 – SPA Birds Directive site.

As a former branch of river Maros, the area has been subject to a gradual salt accumulation resulting in typical puszta fauna and flora associations on the wetland site, including grasslands and reedbeds. The site has a fundamental role in the passage of thousands of migratory birds such as ducks, geese, cranes, curlews, sandpipers, or whimbrels. On the patches of the ancient loess grasslands very rare plant species grow like the endemic 'apró vetővirág'[25] and saline steppe specialist species 'magyar sóballa'[26]. The surrounding steppes form a reserve for the Hungarian grey cattle and the Hungarian cigája and racka sheep races as well for traditional extensive agriculture.

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[23] The *Natura 2000* network of protected areas is based on the European Habitats Directive adopted in 1992 complementing the European Birds Directive adopted in 1979.

[24] The Convention on Wetlands of International Importance, notably as waterfowl habitat, is an international treaty for the conservation and sustainable utilization of wetlands with the objective of fighting human impacts on and loss of wetlands, recognizing the fundamental ecological functions of wetlands and their economic, cultural, scientific, and recreational value.

[25] Stenbergia colchiciflora.

[26] Suaeda pannonica.

Table 13: Protected areas potentially affected by the extraction activities

Name of area	Classification	Proximity (estimated)	Significant protected species / associations
Kiskunsági Nationalpark	**National park**		
Balastya-Szatymaz környéki homokvidék (sand habitat)	NATURA 2000	1 km	Bird protection area
Közép csongradi szikesek (saline steppes)	NATURA 2000	within	Protected sodic lake
Csólyospályosi földtani feltárás TT	nature reserve	5 km	Geological excavation
Also-Tisza- völgy és hullámtér	NATURA 2000	25% in licence area	River valley, flood plain, gallery forest
Pusztaszeri tájvédelmi körzet	landscape protection area	50% in licence area	Bird protection area
Martélyi tájvédelmi körzet	landscape protection area	20% in licence area	Protected oxbow lakes
Péteri-tó	NATURA 2000	13 km	Salt marshes, Salt steppes Bird protection area
Pusztaszeri Fülöpszék TT	nature reserve	3 km	Protected sodic lake
Baksi puszta	NATURA 2000	within	Salt marshes, Salt steppes
Gáteri fehér-tó	NATURA 2000	2.5 km	Salt marshes, saline lake, bird protection area
Körös-Maros Nationalpark	**National park**		
Kurca	NATURA 2000	within	River, wetland habitat
Szentesi gyepek	NATURA 2000	2 km	Saline steppes and marshes; loess grasslands
Lápistó-fertö	NATURA 2000	20% in licence area	Saline steppes and marshes; loess grasslands
Vásárhelyi kék-tó	NATURA 2000	80% in licence area	Saline steppes and marshes; loess grasslands
T-erdö	NATURA 2000	Within	Hardwood forest, Bird habitat
Mágocs-ér	NATURA 2000	Within	Stream (channel), wetland habitat
Cserebökenyi puszták	NATURA 2000	8-10 km	Saline steppes and marshes; loess grasslands, water habitats
Hódmezövásárhely-környéki es csanádi-háti puszták, including Kardoskúti Fehér tó and Csanádi puszták	National Park / NATURA 2000	30% in licence area	Saline steppes and marshes; loess grasslands, wetland habitats, bird protection area
Száraz-ér	NATURA 2000	Within	Stream (channel), wetland habitat
Maros flood plain	National Park / NATURA 2000	2 km	River water body, wetland habitat
Deszki gyepek	NATURA 2000	12 km	Saline steppes and marshes
Slano Kopovo (Serbia)	**Nature Reserve**	**60 km downstream Tisza river**	**Bird protection area**

Notes: red: within or partly within TXM licence area; blue: outside licence area, but close or downstream; green: far outside licence area and/or upstream.

The Csanádi puszták are at the south-eastern edge of the licence area. They are Holocene formed low-lying, basin-like loess and saline habitats which haven't been strongly affected by the river regulation in the XIX. century. The Csanádi puszták have three sites: the *Kopáncsi-puszta*, a saline habitat, important for example because of its őszi csillagvirág[27] flower population. The *Montág-puszta* is a low-moor with the protected bird's-foot clover[28]. The *Királyhegyesi-puszta* has a diverse microclimate, soil and geo-morphology and therefore diverse vegetation. Ancient saline grassland and moor habitats ensure ideal conditions for rare species of flora and fauna. Due to its closeness to traditional bird migration flyways along the river Tisza, it is not only an important nesting site for birds, but also a roosting and feeding place used frequently during migration. Declining populations of rare birds such as black-tailed godwit[29] classified in the IUCN[30] Red List category[31] 'near threatened', common redshank[32], snipes and peewit[33] nest in areas of temporary marshlands, in autumn wild geese and cranes spend the night on the wetland habitats of the plains. The site also ensures excellent conditions for the reproduction of important amphibian species such as the European fire-bellied toad[34], the Danube crested newt[35] and the European tree frog[36]. Among the mosaics of grasslands a small population of 25-30 individuals of the great bustard[37] classified as 'vulnerable' lives on these steppes.

The Maros river and its floodplain runs about 2-5 km south of the licence are. The right side floodplain of river Maros on its Hungarian section plays an important role in the Hungarian ecological network with its diversified habitats. While the entire floodplain is a

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[27] Scilla autumnalis.

[28] Trifolium ornithopodioides.

[29] Limosa limosa.

[30] International Union for Conservation of Nature.

[31] The *IUCN Red List of Threatened Species* is the internationally acknowledged inventory of the global conservation status of biological species classifying them into the following categories; *Extinct* (EX) – No known individuals remaining; *Extinct in the Wild* (EW) – Known only to survive in captivity, or as a naturalized population outside its historic range; *Critically Endangered* (CR) – Extremely high risk of extinction in the wild; *Endangered* (EN) – High risk of extinction in the wild; *Vulnerable* (VU) – High risk of endangerment in the wild; *Near Threatened* (NT) – Likely to become endangered in the near future; *Least Concern* (LC) – Lowest risk. CR, EN and VU are grouped as "threatened".

[32] Tringa tetanus.

[33] Also known as northern lapwing – Vanellus vanellus.

[34] Bombina bombina.

[35] Triturus dobrogicu.

[36] Hyla arborea.

[37] Otis tarda.

NATURA 2000 Habitats Directive site, a 2852 ha area is a core protection site of the *Körös-Maros* National Park. The river and its floodplain contain wet meadows, arable land, scrub, and woodland. The oxbows offer habitats for amphibians and reptiles supporting a large European otter[38] population and are an important breeding area for various species of waterbirds. Most of the forests are hardwood gallery forests with some smaller communities of softwoods. Very old individuals of black poplar trees can be seen in many parts of the floodplain. Some protected fish species such as Kessler's gudgeon[39], or striped ruff[40] also live here. Raven, black woodpecker, rollers and bee-eaters are among the nesting birds typical of the area. Little ringed plovers nest on open gravel areas near the river, while communities of grey herons, night herons and little egrets nest on undisturbed river islands. The area is one of the most significant habitats of the protected Banat snail[41] in Hungary.

The *Natura 2000* site *Baksi puszta* in the north-western part of the production licence area (see Figure 21) is an important migratory bird protection area. Some of the bird species migrating through *Baksi puszta* are classified in the IUCN Red List category 'near threatened' such as the *ferruginous duck*[42] or the *European roller*[43]. Many are categorized as 'least concern' on the Red List. The autumn migration season is the most critical time of year for ecological impacts. Other protected species include amphibians such as the *European fire-bellied toad*[44], fish such as the *spined loach*[45] (least concern), and mammals such as the *European otter*[46] (near threatened).

In order to ensure the safety of the protected habitats and communities it is crucial that the exploration, production and transport activities will be kept outside the protected areas.

In the case of an abnormal operational event such as a spill or a blow-out, habitats can be irreversibly damaged or destroyed. Protected areas can be affected directly by a pollution from an accident on a nearby drilling pad or the pollution can be transported to the protected area by surface water bodies. In Table 13, protected areas that can be directly

[38] Lutra lutra.

[39] Gobio kessleri.

[40] Gymnocephalus schraetzer.

[41] Chilostoma banatica.

[42] Aythya nyroca.

[43] Coracias garrulous.

[44] Bombina bombina.

[45] Cobitis taenia.

[46] Lutra lutra.

affected by a spill from a well pad, e.g. *Baksi-puszta*, are highlighted in red. Areas to which pollution could be transported by water bodies, i.e. which are located downstream the licence area, e.g. *Szentesi gyepek*, where the *Kórógy*-ditch can be the path of the contamination, are highlighted in blue. Areas highlighted in green are far from well pads or located upstream, e.g. *Gáteri fehér-tó*., and are thus hardly at risk. Figure 21 provides an overview of potential approximate well pad locations as well as protected areas and settlements in and around the TXM production licence area.

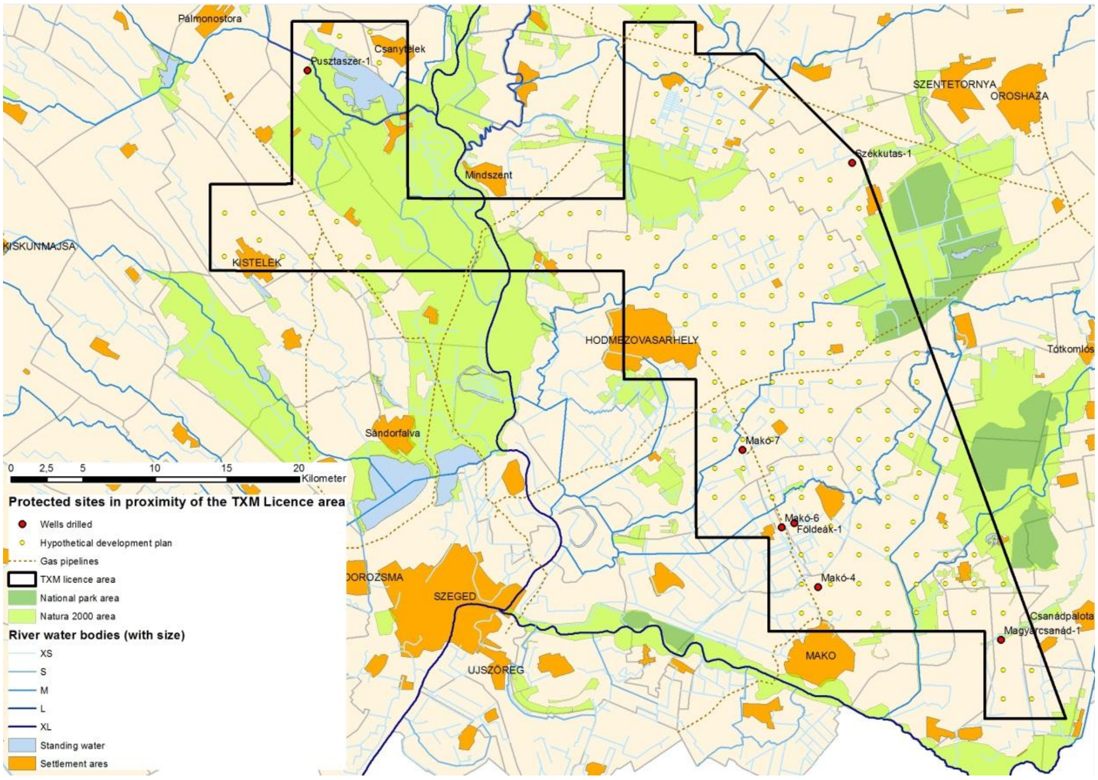

Figure 21: Protected areas and settlements in the TXM licence area showing potential approximate well pad locations

RECOMMENDATIONS ON PROTECTED AREAS	TXM
See section 3.1.	

3.3 Greenhouse gas balance

The greenhouse gas (GHG) balance of unconventional gas extraction is an important aspect of its environmental assessment. Results presented in general scientific studies of the topic vary widely in the results. Over the full life-cycle of the fuel including extraction (drilling, fracking, material and equipment transport etc.), gas processing, transport / distribution and use, the greenhouse gas balance depends on a number of factors significantly affecting the result. Altmann et al. (2011) come to the conclusion that the greenhouse gas emissions of unconventional gas are in a range from the level of conventional, imported natural gas to the level of hard coal. Thus, it is important to calculate the balance for specific conditions, which is done in the following for the TXM production licence area.

Methodology

The greenhouse gas balance calculates all greenhouse gas emissions over the full life-cycle of the gas. This includes gas extraction, gas transport/distribution and gas use. Gas extraction includes site preparation (access road and well pad production), drilling, hydraulic fracturing, well completion, well operation and well abandonment. After transport and distribution to the final user, the gas is combusted for different purposes yielding combustion emissions of 198 g/kWh_{CH4} based on the lower heating value. EC (2012) and Altmann et al. (2011) give good overviews of the GHG balance calculation of unconventional gas activities.

Cumulated GHG emissions are then divided by the total quantity of gas extracted from the well over its entire productive lifetime giving grams of CO_2 equivalents per kWh of methane. Both CO_2 and other GHG emissions have been calculated for this study over the full life-cycle of the gas. Greenhouse gases considered in this study are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O)[47]. The global warming potential of the various greenhouse gases is expressed as CO_2 equivalents calculated using global warming potentials for conversion. Table 14 shows the global warming potentials of the three GHGs considered here for a period of 100 years according to the Intergovernmental Panel on Climate Change (IPCC).

Table 14: Global warming potential of various GHGs (IPCC, 2007)

	CO_2 equivalents [g/g]
CO_2	1
CH_4	25
N_2O	298

The calculations of energy use and GHG emissions are all based on the lower heating value (LHV) of the respective fuels. In general, the European electricity mix has been assumed for all power consumptions relevant here, except for specific processes where dedicated electricity generation is foreseen. These include notably drilling and hydraulic fracturing, where onsite electricity generation in diesel engine generators is assumed.

[47] Other greenhouse gases not relevant in this context are CFCs, HFCs and SF_6.

The energy requirements for and GHG emissions resulting from the construction and decommissioning of facilities, infrastructure and equipment such as power plants, gas processing plants, pipelines, roads, transport vehicles, etc. are not considered.

The well casings, however, consisting of steel tubes and concrete are treated as consumables and consequently are taken into account for the calculation of emissions of GHGs and air pollutants.

The GHG balance of unconventional gas extraction is compared to the benchmark of imported conventional natural gas (JEC, 2011) as well as to a second benchmark assuming methane emissions based on commercial experience in the USA (Altmann et al., 2011). The conventional benchmark of imported gas from Russia represents CO_2 and methane emissions from gas extraction averaged over all gas fields in Russia. This is based on measurements and numerical modelling used in standard calculations on European level (JEC, 2011). Pipeline transport to Hungary over a distance of 4000 km is assumed. Transport emissions stem from the gas consumption for pipeline compressor stations ensuring gas transport as well as from gas leakages through sealings etc.

Assumptions

Natural gas is assumed to be distributed over an average distance of 500 km via the high pressure pipeline grid.

Two scenarios have been assessed in order to cover variations in assumptions for unconventional gas. The 'low scenario' represents best case assumptions such as high methane yield from the well branches based on TXM estimates (100 million Nm^3 CH_4 equivalent per well branch over its entire productive lifetime[48]) and low specific emissions of all relevant processes. The 'high scenario' represents worst case assumptions such as a low methane yield based on TXM estimates (30 million Nm^3 CH_4 equivalent per well branch) and high specific emissions.

As the specific gas yield of a typical well branch is the most crucial parameter for the calculation of specific greenhouse gas emissions these expected yields of 30 – 100 million Nm^3 CH_4 per well branch over their entire lifetime are compared with international data from conventional wells.

The annual average production from a typical gas well in Russia was about 70 million Nm^3/year in 2010, falling off from 80 million Nm^3/year five years earlier, and from 130 million Nm^3/yr in 1990 (Gazprom 2012; Zittel 1997). If on average a Russian well

[48] The extracted gas consists of methane, ethane, propane and butane. The amount of extracted gas is expressed as CH_4 equivalent based on the lower heating value (LHV).

operated some 20 years this would sum up to a total gas production of around 1,400 million Nm^3 per well.

Annual average production from a typical gas well in Germany remained rather stable at 40 million Nm^3/yr in 1997 and 41 million Nm^3/yr in 2005. Since then, however, it has declined to about 26 million Nm^3/yr in 2011 indicating the increasing share of mature wells (LBEG 1997, 2005, 2011). In the USA, annual average production from a typical gas well was already low in 1990 at about 1.9 million Nm^3/yr (Zittel 1997). Until 2010 it further declined by 20 percent to 1.55 million Nm^3/yr (US-EIA 2012). The low average production rate of US gas wells reflects the large share of unconventional gas wells. If on average a US well operated some 20 years this would sum up to a total gas production of around 30 million Nm^3 per well.

Based on TXM assessments, in the 'low scenario' 8 well branches are drilled on each well pad and single stage hydraulic fracturing is assumed, whereas in the 'high scenario', 16 well branches per well pad are drilled, and six stage fracking is assumed.

The production of natural gas from shale gas consists of site preparation, the transport of the drilling rig and the hydraulic fracturing equipment to the site, the drilling procedure including casing and well completion, the hydraulic fracturing procedure, gas production, gas processing, site re-cultivation, and gas distribution to the consumers.

Drilling depths of 3,500 m and of 5,000 m have been assumed for the 'low' and the 'high scenario', respectively, based on TXM input. For the calculation of the energy requirement and emissions from the manufacturing of the casings it has been assumed that seamless cold rolled steel tubes are used. The emissions from the production of steel and from processing of the steel have been derived from (GEMIS, 2002) and (CPM, 2008), respectively. The electricity demand for the drilling and fracturing procedure is generated onsite by diesel fuelled gensets with an electrical efficiency of 39%.

The extracted natural gas is transported to a natural gas processing plant via pipeline. The electricity for the natural gas processing is derived from the EU electricity mix. For the 'low scenario' the CO_2 content of the extracted gas is low (1% by volume) whereas for the 'high scenario' the CO_2 content of the extracted gas is high (13% by volume) leading to high CO_2 emissions at the natural gas processing site. These representative gas compositions are based on TXM measurements of extracted gas from exploratory drilling and hydraulic fracturing in the licence area over the past years, but do not represent the most extreme compositions found.

Based on TXM information, methane emissions from hydraulic fracturing, notably retention of flowback fluid in closed systems, are assumed to be zero. All technical systems have finite, even though possibly very low, emissions. However, closed flowback systems have not yet been analysed scientifically for methane emissions. The U.S. Environmental Protection Agency assumes that capturing 90% of these emissions from the flow back fluid is technically feasible (EC, 2012). In order to test the sensitivity of this zero emission assumption results are compared to a second benchmark. Here, average methane emissions from experiences in the USA have been assumed based on (Horwath et al., 2011; see also Altmann et al., 2011).

Results

Figure 22 shows the GHG emissions from the supply of unconventional natural gas compared to imported gas including transport and distribution; combustion is not included in the figure as combustion emissions of 198 g/kWh_{CH4} do not differ between conventional and unconventional methane.

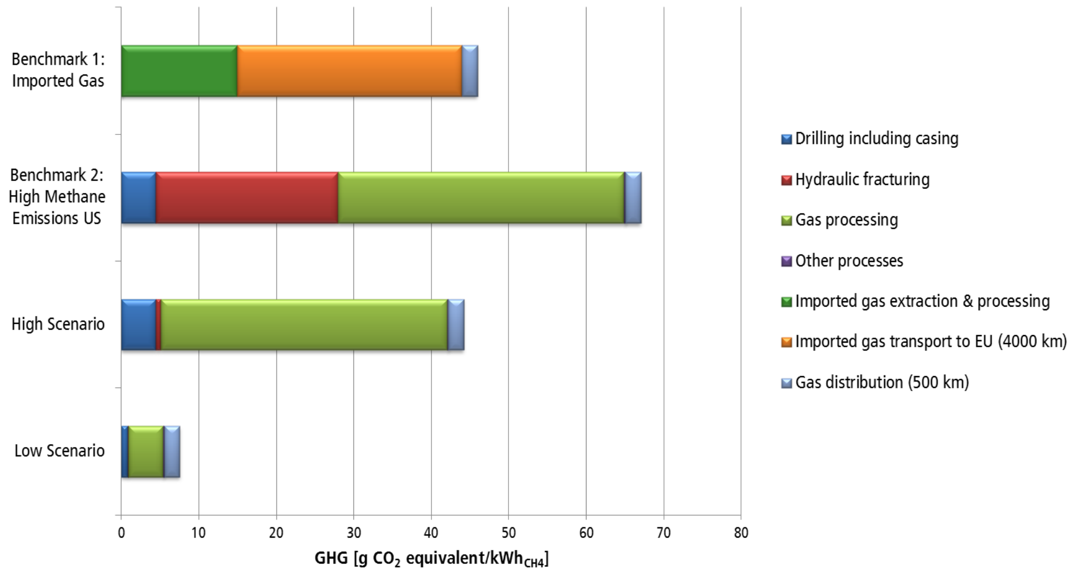

Figure 22: GHG emissions from the supply of unconventional natural gas compared to imported natural gas by process stage

In case methane emissions from the flowback fluid of the fracturing procedure can be avoided entirely as assumed here, the GHG emissions from the supply of unconventional gas are similar to those associated to imported gas even if the worst gas assumptions are applied ('high scenario'). If 'high methane emissions' are assumed, however, unconventional gas has a significantly worse GHG balance than imported gas. In the 'low scenario' GHG emissions are very low.

This is confirmed by the International Energy Agency (2012): *"However, while collecting and processing the [flowback] fluid is standard practice, capturing and selling the gas during this initial flow-back phase requires investment in gas separation and processing facilities, which does not always take place. In these cases, there can be venting of gas to the atmosphere (mostly methane, with a small fraction of VOCs) or flaring (burning) of hydrocarbon or hydrocarbon/water mixtures. Venting and/or flaring of the gas at this stage are the main reasons why shale and tight gas can give rise to higher greenhouse-gas emissions than conventional production. […] The scale of operation would mean that it would be economically viable to have this equipment [test equipment and gas-gathering infrastructure] dedicated to the development, although it remains challenging to estimate expected production rates with sufficient accuracy to ensure that the infrastructure is correctly sized. The early installation of gas-gathering infrastructure would bring forward capital expenditure, but would not increase the net cost, as any additional charges, including interest charges, would probably be offset by the value of the gas captured."*

Emissions of methane can also occur from failures of the well casings due to improper cementation or due to excessive stress during the fracturing procedure. If the casing is not tight the overall GHG emissions of both conventional and unconventional gas extraction can be significantly higher than those shown in Figure 22 and Figure 23.

Another significant source of GHG emissions can be the CO_2 content of the extracted unconventional gas which is released into the atmosphere during natural gas processing. The GHG emissions from natural gas processing strongly depend on the natural gas composition of the extracted natural gas as is evident from Figure 22 with a high CO_2 content of the extracted gas in the 'high scenario' and a very low CO_2 content in the 'low scneario'. The large difference in the GHG emissions of the drilling process between the 'low' and the 'high scenario' is based on the large spread in assumptions on drilling depth, well branches per pad and gas yield. Hydraulic fracturing makes a relatively low contribution to the GHG balance. However, repeated fracking after several years of production as currently carried out in some shale gas plays in the USA in order to increase the gas flow has not been assumed here, and could potentially contribute to higher GHG emissions.

Figure 23 demonstrates the importance of methane emissions for the GHG balance. For imported natural gas, methane losses from the gas extraction and processing stages as well as from pipeline transport make an important contribution to the overall balance. For unconventional gas extraction, emission control of the flowback fluid system is essential shown by the comparison of the 'high methane emissions' and the 'high scenario'.

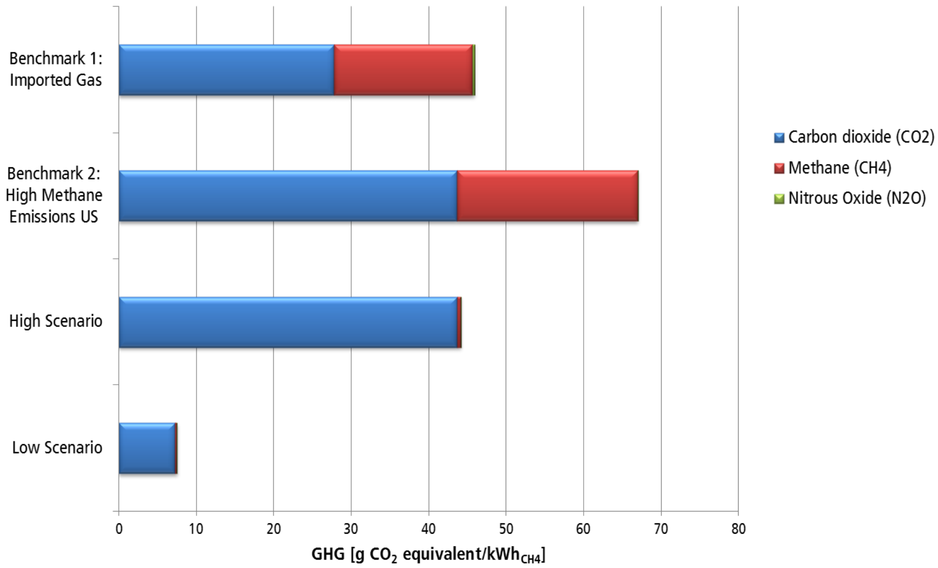

Figure 23: GHG emissions from the supply of unconventional natural gas compared to imported natural gas by greenhouse gas

Instead of onsite electricity generation using diesel generators, grid electricity could be used for drilling and hydraulic fracturing if the existing electric grid were extended to the drilling pads. Depending on the sources of electricity, grid electricity may reduce GHG and pollutant emissions significantly compared to onsite generation, and in addition, noise as well as transport of diesel to the site would be drastically reduced. On the other hand it would mean additional infrastructure construction work for grid extension, preferably using underground cables. In the USA, Chesapeake Energy started considering grid electricity for the development of unconventional gas extraction in north Texas in the Barnett shale field on the area of the Dallas/Fort Worth Airport in 2006 and established the first grid connection for drilling in 2009 (Shipley, 2009). Emission restrictions of the airport would have limited the time that drilling rigs could be operated on diesel fuel. By the end of 2011, Chesapeak had expanded grid electricity drilling from 1 drilling pad to 102 pads spread over its entire Barnett activities, and had demonstrated substantial emissions, noise and cost reductions (Stricklin, 2012).

RECOMMENDATIONS ON CLIMATE PROTECTION	TXM[49]
▪ Check the integrity of the well casings before and especially after fracking as the fracking procedure may compromise the integrity of the casing because of very high pressures applied.	1
▪ Monitor methane emissions from hydraulic fracturing procedures, notably from the flowback fluid system.	2
▪ Consider using grid electricity for drilling and hydraulic fracturing.	3

[49] See section 1 for TXM coding.

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