2022 Annual report Mining Impact Knowledge Programme (KEM)

KEM Scientific Expert Panel (KEM panel)

August 2023

Content

Summary

This is the 5e annual report of the Mining Impacts Knowledge Programme (KEM). The report covers substantive activities and results carried out up to December 2022. The annual report is not an annual financial report. In accordance with the letter to the House (Parliamentary paper 32849 no. 80) from the Minister of Economic Affairs, this report includes: (1) progress of the substantive research programme, (2) knowledge assurance and exchange and (3) work of the KEM scientific expert panel (KEM panel). It also discusses the KEM evaluation carried out in 2022. The annual report is a report of the KEM panel and provides the KEM panel's interpretation and conclusions.

The KEM research programme. This continued to progress well in terms of content in 2022. In the opinion of the KEM panel, the quality of most projects is good and the impact is meaningful. In 2022, besides long-term seismicity Groningen, most attention was paid to effects of other mining activities, such as underground storage and geothermal energy, which are relevant to the energy transition. The priorities indicated in the report "Towards a (national) research agenda and risk toolbox in the Netherlands" are still leading in this respect.
The project deliverables delivered in 2022 or early 2023 are: two Groningen gas field studies on post-liquefaction effects (KEM-19) and the effect of fluid injection (KEM-24), a literature review on mining-related sources of infrasound, as well as their propagation and monitoring (KEM-31) and improvements to the public seismic threat and risk analysis model (SDRA) Groningen (KEM-35 and KEM-43) and to the SDRA's open test environment that allows sensitivity analyses to be carried out (KEM-09).
The projects on seismicity risks in geothermal energy near fractures (KEM-15), on modelling multiple subsidence (KEM-16), on monitoring methods for large-scale CO_2 storage (KEM-27), on hydrogen storage in clusters of salt caverns (KEM-28) on infrastructure vulnerability in larger quakes (KEM-34), on the 3D ground motion model for Groningen (KEM-36) and on the safe bandwidth of storage of gases other than methane (KEM-39) worked on in 2022 will be delivered in 2023.
Knowledge assurance and exchange. The KEM website publishes KEM research questions, project results and evaluations of project results and recommendations. The website had about 2450 visitors in 2022, who visited more than
28,000 pages (40% more than in 2022) viewed, mainly the KEM project pages. To meet the demand for more readable technical information, a link to interpretation information from EZK and SodM and the presentations of the KEM-DeepNL colloquia has been added for each completed KEM project from 2022.
The KEM panel advised in 2018 that knowledge assurance can best be shaped by the deployment of public tools for the analysis and representation of mining threats and risks. The first version of TNO's public Groningen SDRA model was commissioned in spring 2021. Thereafter, improvements and the implementation of different sub-models and improved versions of this model chain were worked on, on which the KEM subpanel also advised SodM and EZK in 2022. The KEM panel believes that the development and use of public threat and risk models for other mining activities and types of risks deserve the same approach. Communication by the KEM is going well towards science, with the joint KEM- DeepNL colloquia, where KEM results and research topics are discussed, and KEM's participation in the DEEP-NL stakeholder meetings. Biweekly interaction with policy and supervision, or EZK and SodM, is intensive. Communication to governments and citizens in the regions was limited in 2022.
KEM panels. The KEM panel met four times in 2022. The scientific expert role with regard to demand articulation, project guidance, project evaluation and interpretation of studies was efficiently and well fulfilled in 2022. At the end of 2022, the KEM subpanel, established for this purpose, advised SSM on the SDRA model version proposed by TNO for the operational strategy of the Groningen gas field. In early 2023, the KEM subpanel advised on the proposed additional model developments for the Groningen SDRA. The advice, together with that of SSM, will be used by the Ministry of Economic Affairs to flesh out the model development of the SDRA within the research programme with TNO.

KEM evaluation and future. At the end of 2022, the second three-year term of the KEM ended. An independent evaluation of KEM took place in 2022. This involved testing the extent to which the intended objective and goals (public and independent knowledge development into mining effects and connection to international top researchers in this field) of the KEM were achieved. It also evaluated whether results of KEM reach professionals at SSM, EZK, Dutch knowledge institutes and universities, and how they are valued and used. It was concluded that KEM is largely effective and efficient. As a result, EZK and SodM decided in late 2022 to continue KEM for the next five years (2023-2027). The evaluation also identified shortcomings and made recommendations. An improvement plan was drawn up for this at the end of 2022, to be implemented in 2023.

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1. Introduction

This is the 5e annual report of the Mining Impact Knowledge Programme (KEM). The report covers activities carried out and results achieved up to December 2022. In line with the 2016 parliamentary letter from the Minister for Economic Affairs (see Annex A), the report covers the developments of:

1. *Research.* Strategic developments (chapter 2) and development of research questions and projects in KEM classified by risk type (chapter 3);
2. *Knowledge assurance and dissemination.* Strengthen platforms for knowledge assurance, knowledge sharing and agenda-setting of: KEM website, public Seismic Threat and Risk Analysis tool (Chapter 4);
3. *Scientific expert panel and subpanel.* Progress in review and articulation of research questions, quality control and interpretation of results and public threat and risk analysis (DRA) model development (Chapter 5).

This annual report also reports the results of the KEM evaluation conducted in 2022 and the resulting recommendations and improvement actions (chapter 6). Chapter 7 is devoted to conclusions and recommendations.

2. Strategic development 2017- 2022

First period (2017-2019)

KEM started drafting a strategic framework in 2017, describing the objectives, the process of research and the initial research agendas coming from EZK, SodM, NCG and the broad knowledge platform subsoil meeting in 2017 in Groningen. The strategic framework and initial research agenda 2017-2019 formed the basis for strategic development in the first period (section 2.1). Priority in 2017, 2018 and 2019 was given to research questions on seismic threat and risk associated with mining activities, mainly gas production in Groningen, and the development of publicly available threat and risk tools to quantify these risks independently. An important starting point in the strategic framework is that the research results of individual research questions and projects should contribute to the better handling of named mining impacts or risks in different mining sectors. More specifically, it aims to contribute to validating and improving publicly available risk tools for quantifying mining risks and the effects of possible management strategies, as well as improving, where necessary, practices and protocols used in practice and thus safeguarding knowledge gained. The urgency for research is determined by estimating the extent to which answering the knowledge questions contributes to reducing existing uncertainties in threat and risk quantification and improving risk management, partly prioritised by timeliness. The state of risk knowledge (see, for example, SSM publications on the state of the mining sectors) and the need for publicly available risk tools are therefore taken into account in the prioritisation.

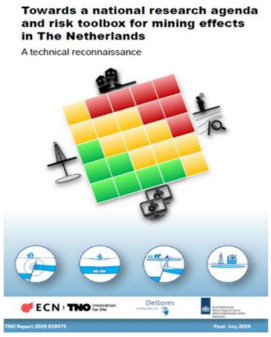
Mining Activities vs Risk types	Seismic risks	Soil subsidence risks	Leakage risks	Physical integrity installations at risk	Abandoning risks
Oil and gas production	**KEM-02, KEM-04, KEM-05, KEM-07, KEM-08, KEM-11, KEM14,** KEM-20, *KEM-21, KEM-22*		**KEM-18**		**KEM-18, KEM-19**
Geothermal production	**KEM-06,** KEM-12, **KEM-15**	***KEM-16***	**KEM-06, KEM-18**	**KEM-06**	**KEM-06, KEM-18**
Storage and disposal	**KEM-01, KEM-24**		**KEM-24**		
Salt caverns		**KEM-17**		**KEM-13**	
Former coal production					
Public HRA instruments	**KEM-03, KEM-09, KEM-10**	***KEM-16***			
Bold: off; Bold Italic: running; Normal black: in planning, Normal grey; no go		**Not applicable**	**Public knowledge and tools available**	**Public knowledge and tools limited**	**Public knowledge and tools insufficient**

The dashboard figure (left) indicates the 24 research questions (and projects) from the first research agenda, against a background of the level of availability of public knowledge and threat and risk analysis tools. All research from this period, which have been approved by the KEM scientific expert panel, are completed or in the process of [illegible]essed as unnecessary and 2 studies (KEM- 21 and KEM-22) are of lower priority.

This has led to new results, insights into short- and longer-term mining effects (mainly gas production and gas storage) and to the first publicly available public seismic threat and risk analysis tool for the Groningen natural gas field, developed by TNO. As a result, the publicly available knowledge in the Netherlands regarding threat and risk caused by mining activities has been significantly increased and strengthened. Stakeholders, including, among others, the Groningen Subsoil Platform, and the Technical Platform Earthquakes (TPA), as well as university researchers, value the KEM results.

Second period (2020-2022)

The report "Towards a national research agenda and toolbox for mining effects in The Netherlands" (result of the KEM-03a project) and new research questions put forward by EZK, SodM and third parties form the main input for the second research agenda (2020-2022) in the second period. Also in 2020, additional research questions were raised by stakeholders and regional authorities during the open meeting of the Subsoil Platform in Groningen autumn 2019 and additionally by some interest groups elsewhere (such as Stichting Bescherming Historisch Harlingen, SBHH) and from the Technical Committee on Soil Movements, Tcbb. Some of the research questions raised were taken up by KEM and some were assessed as already investigated or not a priority . In summary, in the second period, 2020-2022, more attention was paid to salt extraction, geothermal energy, fluid storage (H_2, N_2, CO_2, CH_4), leakage risks, infrasound and abandonment issues.



At the same time, attention continued to be paid to the seismic risks from other mining activities and to finalising the remaining research questions from The 2017-2019 strategic agenda.

This strategy period also saw work on improving publicly available mining effects threat and risk analysis tools, or the public threat and risk analysis tool (pSDRA) Groningen, a subsidence threat analysis toolkit, and sharing results with scientists and the public in the Netherlands.

Mining Activities vs Risk types	Seismic risks	Soil subsidence risks	Leakage risks	Physical integrity installations at risk	Abandon risks
Oil and gas production	***KEM-24b*** **,** KEM-32, ***KEM-34*****,** **KEM-35,** **KEM-36,** KEM-41, KEM-46	KEM-38, KEM-47		**KEM-31**	***KEM-19b*****,** **KEM-33**
Geothermal production				**KEM-31**	
Storage and disposal	**KEM-39**	KEM-47, KEM-48	***KEM-27, KEM-28***	**KEM-31,** KEM-29, KEM-30	***KEM-27, KEM-28***
Salt caverns	KEM-40	KEM-25, KEM-26, KEM-44, KEM-45			
Former coal production					KEM-41, KEM-44
Public HRA instruments	KEM-32, **KEM-35, KEM-43**	***KEM-16b*****,** KEM-37, KEM-38			
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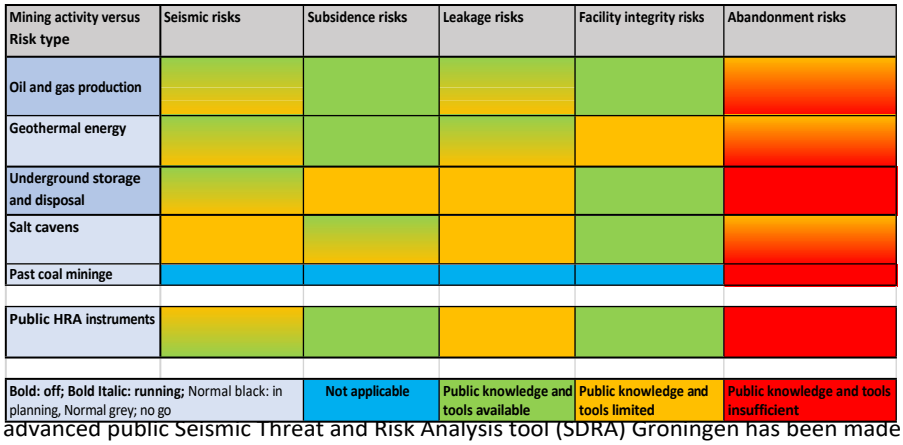
There are 24 new research questions on the agenda by the end of 2022 (KEM-25 to KEM-48). The dashboard figure opposite shows at which area of research, these research questions and projects relate to. Most concern long-term effects of gas extraction, storage and disposal and subsidence threats and risks. There were relatively few questions related to geothermal energy. On the one hand, this is caused by the fact that a lot of (practical) research for geothermal energy takes place alongside the KEM, such as the SCAN programme, the research to arrive at a seismic threat and risk analysis for geothermal energy conducted by TNO and EBN, and in the TNO-AGE work plans for SodM and EZK. On the other hand, few explicit questions coming from citizens and lower authorities have been put on the agenda, perhaps due to the relative unfamiliarity with the possibility of this within the KEM programme and the fact that no meeting specifically for geothermal energy has been organised. Furthermore, there is relatively little research in the area of underground leakage threats and risks and an initial development of threat and risk analysis tools in this area took place.

Strategic dashboard at the end of 2022

The aim of KEM was to achieve, by the end of 2022, that knowledge of *seismic and subsidence* threat and risk in the past period would be greatly improved. In addition, there would be a good fit with international knowledge in these areas, and independent, public threat and risk analysis tools would be available, or become available.



The degree of availability of public knowledge and threat and risk analysis tools in the areas of seismicity and subsidence has significantly improved by the end of 2022 (illustrated by changed background colours compared to 2017 in the dashboard figure opposite).

Meanwhile, the advanced public Seismic Threat and Risk Analysis tool (SDRA) Groningen has been made publicly available. The knowledge of and public tools for seismic threat and risk analysis for other mining activities (small fields, geothermal or CO_2 storage) are under development outside KEM but are also becoming publicly available. KEM calls for attention to make full use of the 'state of the art' knowledge developed for the Groningen earthquakes, and to include damage in addition to safety (as these can also lead to socio-economic risks). In addition, KEM advocates a uniform approach for the various mining activities. The tools developed in KEM-16 are a good first step for subsidence threat analyses. Attention is drawn to enabling the quantification of the various damage risks of all mining activities in a region - in addition to safety risks (which in many cases are zero) - with public DRA tools.

In the field of underground *leakage* threat and risk analysis tools, initial steps have been taken. A continuation of fundamental, such as DeepNL, and applied research, such as KEM, is considered necessary, especially in light of the use of the subsurface for energy transition. For mining risks where knowledge, expertise and public threat and risk tools are state of the art and available, incorporating advancing insight and incremental improvements will suffice.

The initiated course of research by national parties alongside or together with internationally renowned research groups, as takes place in KEM or EU projects, will be able to make the knowledge position of the Netherlands in the field of operational and long-term effects mining unquestionable for the Netherlands and contribute to confidence in it.

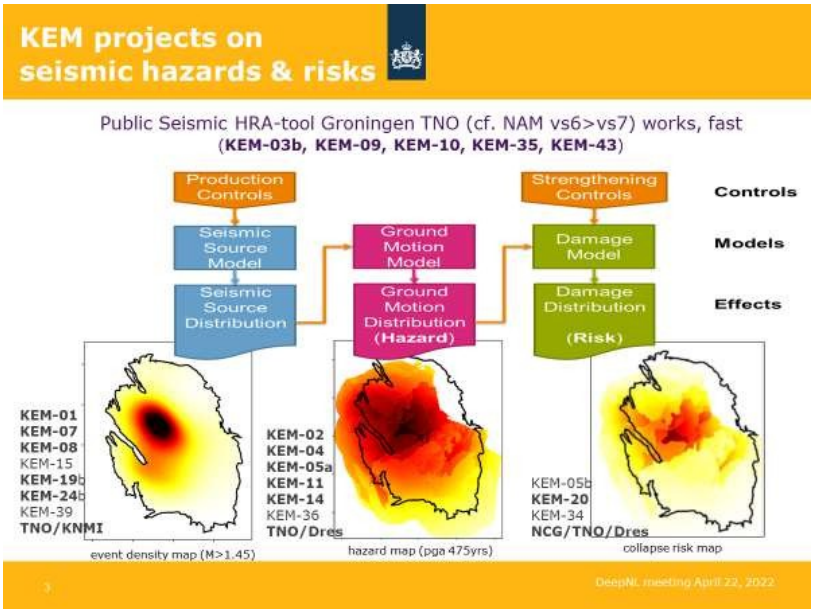
3. KEM survey: status and results

The actual research starts with research questions, which are reviewed by the KEM panel, sometimes better articulated scientifically, and provided with a recommendation of the best international groups that could carry out the work. Thereafter, research projects are tendered, initiated and supervised by the Ministry of Economic Affairs and SSM and monitored by the KEM panel. Finally, the KEM panel evaluates the project results for content quality and potential impact. The status of all research questions and projects at the end of 2022 can be found in Annex C. Sections 3.1-3.4 report on research on the four different threats and risks from mining activities: seismicity, subsidence, leakage and physical integrity risks. Specific research on post-abandonment threats - longer-term impacts - are included in these sections.

3.1 Seismic-acoustic risks

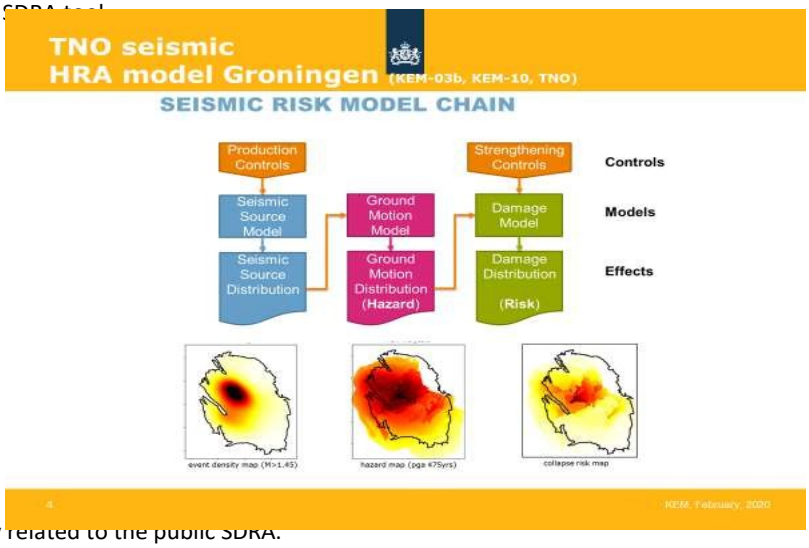
Status of research questions on seismic risks

Many research questions from KEM (KEM-02, KEM-3b, KEM-04, KEM-05a, KEM-05b, KEM-08, KEM-09, KEM-10, KEM-11, KEM-14, KEM-19, KEM-24, KEM-35, KEM-36, KEM-43) deal with knowledge about the seismic threat and risks associated with gas production in Groningen. They are specifically aimed at answering research questions on the processes and their uncertainties and the method of calculating seismic threat and risk in Groningen in order to further validate and improve the SDRA Groningen model train.
In addition, two research questions were conducted relevant to earthquake threat and risk at smaller gas fields (KEM-07, KEM-11) and two research questions were conducted on seismic risks associated with geothermal energy (KEM-06, , KEM-15) and three research questions were conducted focusing on seismic risks in gas storage (KEM-01, KEM-24, KEM-39) and none for any seismic risks associated with salt.
All these research projects have now been tendered, started and (almost) completed (NB KEM-05b has been taken up by NCG and TUDelft). The results of these research projects are available on the KEM website. The results of KEM-15, KEM- 36 are expected to follow in 2023. Some five research questions were rejected with arguments by the KEM panel and referred, not considered or held.



Status research questions on public SDRA models
Some four KEM projects have been carried out to set up public seismic threat and risk assessment (SDRA) toolbox for Groningen (KEM-03b, KEM-10, KEM-35 and KEM-43).

The KEM subpanel (see section 5.3 and Annex B) advises the Ministry of Economic Affairs on further model developments of the resulting public SDRA tool for Groningen at TNO and to SSM on the use of validated versions by government or third parties. The KEM subpanel has delivered opinions on model version status and model development programme respectively in recent years. In December 2022, the advice on model version status for SDRA 2022 was provided to SSM. The advice to EZK on SDRA model development 2023 was delivered in early February 2023. The members of the KEM subpanel also supervise some other KEM research projects (a.o. KEM-09, KEM-36), which are strongly related to the public SDRA.



Results and impact of seismic threat and risk survey through 2021

The KEM panel believes that by the end of 2022, compared to 2017, major strides have been made in public knowledge development regarding seismic mining risks. Some specific outcomes and impacts of KEM research related to seismic risks are (**2022 results in *italics***):

- 2018: A better understanding of the minimum and maximum reservoir pressures to be applied and the maximum storage and production rates for storing gas in former gas fields has been achieved. Seismic risks are thus minimised. This prescription has now been incorporated into practical guidelines (KEM-01).
- 2019: An alternative physics-based evaluation methodology has been developed and demonstrated for calculating seismic risks in small gas fields. Based on this, an understanding has emerged that a denser network of seismological data and a more complete set of reservoir data are needed for more reliable predictions with current or alternative methodologies. This is already affecting seismological monitoring requirements at all mining operations and the basic seismic monitoring network in the Netherlands (KEM-07).
- 2019-2020: Partly due to its use in some KEM surveys, it was identified that some of the (former) ground acceleration measurements in Groningen were problematic. KEM-11 has given an impetus to improving the quality of Groningen's seismological network and earthquake catalogue.
  KNMI takes results into account in improving the network and catalogue (KEM-11).
- 2020: Suggestions have been made for possible improvements in the (seismological) models, which predict the occurrence of quakes. These will be considered for further development of the Seismological Quake Model, SSM, in the public (TNO) seismic threat and risk analysis tool (KEM-08).
- 2020: TNO has provided a publicly available SDRA tool for Groningen that allows the seismic threat and risks for a given production scenario to be calculated 100 to 1,000 times faster than before and independently (KEM-03, KEM-10, KEM-35). The TNO SDRA tool was compared with the results of with NAM's vs6 HRA calculations. With equal assumptions and parameters, the results are almost the same. The TNO SDRA tool was used by the government in 2021 to underpin the operational strategy of the Groningen gas field for gas year 2021-2022. A sensitivity analysis takes place in the KEM (KEM-09), the outcome of which was delivered in 2022.
- 2020-2021: Two studies investigated the cumulative effect of multiple quakes on the settlement behaviour of shallow soils (KEM-05a) and the potential for softening (KEM-14) of shallow soils in Groningen. The conclusion is that some soil types are more sensitive than others, but that there are no additional risks for gas production in Groningen.
- 2020-2021: It has been shown that ground acceleration measurements in Groningen are affected by local variations in the subsurface to a greater extent than can be described by current models. The KEM-02 and KEM-04 studies show that the spatial variability in ground motions due to

heterogeneity in the subsurface are relatively small (presence of Peel gullies, variations in the thickness of the Zechstein) or relatively large (due to topography, the Holocene weak subsurface layers immediately below the surface, due to the presence of salt domes). These acquired insights into the effect of very low seismic wave sections in the very shallow soft subsurface layers and attenuation at slightly greater depths,are important and will be included in the next ground motion model GMM (V7). In this model, mounds, with very low seismic wave velocities, are included as separate objects.

- 2021-2022: The in researched and developed improvements in the SDRA versions (KEM-35) concern (1) the calibration with more and better data, (2) seismic source model (a.o. based on KEM-08 insights), the ground motion model (a.o. based on KEM-02, KEM-04 insights) and consequence model (in line with KEM subpanel advice). The developed test framework allows TNO to compare the alternative (sub)models and calibrations before they are included in a new version. In 2021, mainly seismic source models were tested.
- *2021-2022: A comprehensive sensitivity analysis study was completed in 2022, which provided insight into the most determining parameters and model assumptions in the risk calculations of the SDRA Groningen (KEM-09). The sensitivity analysis showed that the most sensitive and determining parameters for the seismic source model are the maximum magnitude distribution (Mmax) and the relationship between the number of quakes and the magnitude (Magnitude-frequency relationship). These, with some other parameters in the ground motion model and consequence model, are the most decisive for the SDRA outcomes and ranges of uncertainties. A test infrastructure was developed for the sensitivity analysis in 2021. This developed test infrastructure enables TNO to compare and assess alternative (sub)models and calibrations before their possible inclusion in formal versions of the Groningen SDRA model instrumentation. With this testbed and capabilities for sensitivity analyses developed in KEM- 09, the Groningen SDRA model will be improved more purposefully in the future. By 2022, this test infrastructure has been further improved and sensitivity analyses have been performed again.*
- *2020-2022: The KEM-19 project investigating long-term pressure equalisation and fluid flow in and around the Groningen gas field was completed in 2022. This project further investigated the long-term ground motion effects (subsidence and seismicity) after closure of the Groningen gas field. The results provide more clarity on location and nature of likely soil movements after production ceases in Groningen. The study concludes that the probability of soil subsidence and seismicity around the Groningen gas field will increase slightly but will be limited. In addition, the rate of subsidence and seismicity above the Groningen reservoir will decrease. A follow-up study (KEM-19b) in the southwestern part of the study area is recommended. In addition, long-term fluid leakage or migration effects were also considered. The probability and magnitude of gas leakage risks due to gas extraction in Groningen were calculated and considered small.*
- *2020-2022. The KEM-24 project, which studies the effect of gas injection to influence reservoir pressure (stopping or reversing pressure drop) and its effect on seismic risks, was completed by the end of 2022. Unfortunately, the project - partly due to the innovative modelling approach adopted - did not provide unambiguous answers to the research questions. It is proposed to follow up this project using existing and proven reservoir modelling tools and the SHRA Groningen tool (KEM-24b).*
- *The project KEM-39 to investigate the geomechanical and geochemical factors that determine the probability of shifts along existing fractures during pressure build-up and cycles of underground storage of CO_2, H_2 and N_2 storage was started and completed in 2022. It concluded that the same method of safe range for reservoir pressures can be used for these gases as for methane (see also results of KEM-01). The study also notes that knowledge in the literature on geochemical effects at fractures for N_2 and H_2 is still very limited and requires more fundamental research.*
- *2021-2022. Based on previous KEM research (KEM03/10/35), TNO has developed a tool that can quickly and independently analyse the seismic threat and risk for a given production scenario in Groningen. The improvements examined and developed in KEM-43 in 2022 concern (1) calibration with more and better data, (2) alternative seismic source model (based on KEM-08 insights, among others), the ground motion model (based on KEM-02, KEM-04 insights, among others) suitable for risk analyses after production ceases (3) GMMV7 ground motion model and consequence model (in line with KEM subpanel opinions). The results of developments and calculations of TNO's SDRA instrument are almost identical to the results calculated from with NAM's HRA V6 or V7, under equal assumptions and parameters.*

All project results, including the evaluation by the KEM panel can be found on the KEM website. In 2022, the results of KEM-02, KEM-05a, KEM-11, KEM-14 and KEM-35 were shared with national governments and scientists at universities and knowledge institutes, in the Netherlands in the joint KEM-DeepNL colloquia.

Ongoing seismic threat and risk study in 2022

Several major projects were ongoing in 2022, contributing to public knowledge development regarding seismic mining risks in 2022. In addition, new research questions were articulated and approved by the KEM panel and in the start-up phase by the end of 2022. These include the following projects:

- 2020-2022: A study, KEM-15, has been ongoing since 2021, focusing on an improved understanding of geomechanical effects due to cold water injection in geothermal systems. It has looked at parameters and combinations of parameters, both geomechanical and operational, that play a role in possible induced seismicity. The risk of seismicity when fractures are within the sphere of influence of the geothermal system was also specifically considered. A probabilistic seismic threat analysis was developed as part of the project. KEM-15 has since been completed. The evaluation of this project will be finalised after which it will be published by SSM and made available simultaneously via the KEM website.
- 2021-2022: Literature review on monitoring methods of underground CO_2 storage offshore (KEM-27) started in 2022. Many borehole and geophysical methods have been used and validated in various CO_2 storage projects worldwide. A technical review is being conducted on best practice for monitoring CO2 injection and, in addition, new techniques are being evaluated. The results should help sharpen monitoring guidelines for CO_2 storage in the Netherlands.
- 2021-2022: Research and risk analysis of underground hydrogen (H_2) storage in conglomerates of salt caverns (KEM-28) started in 2022. It investigates the physical and chemical processes and parameters that play a determining role in the dynamics of caverns and between caverns and the topsoil. The results should enable better quantification of possible threats and risks to H_2 storage in salt caverns.
- 2020-2023: KEM-34, a contribution to a large EU project, focuses on being able to quantify the vulnerability of various infrastructures to more severe earthquakes (I>V). The project also focuses on accelerating risk communication with national or regional safety teams. KEM-34 focuses on the Groningen case, targeting rapid threat information (KNMI) and risk information on dykes, bridges, locks and similar infrastructural works.
- 2020-2022: The KEM-36 project (a follow-up to KEM-04) focuses on the qualitative and quantitative validation of GMMV7 of TNO's public seismic HRA tool through expert study and with 3D seismic model calculations, respectively.

The research questions of the projects, which have been started, can be found on the KEM website.

Other research questions, rejected or reserved

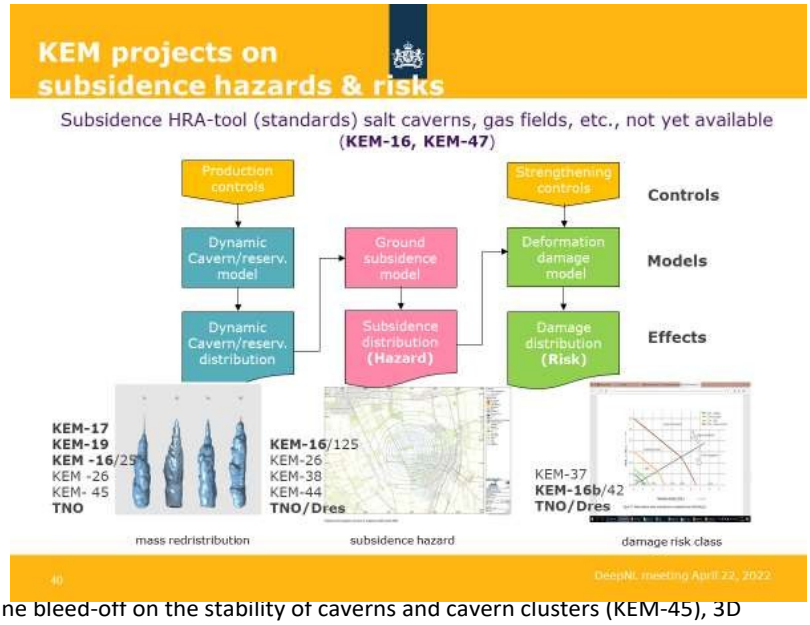
Some of the research questions identified for 2022 have been rejected, not prioritised or held by the KEM panel for various reasons, waiting for final decisions:

- KEM-21 and KEM-22 aimed at predicting - using AI - the probability of earthquakes in the short term (since 2020). Current monitoring and signalling using seismic activity and density parameters is considered adequate.
- KEM-11c and KEM-42 on seismological monitor networks will not continue as KEM projects. The research questions will be taken up by KNMI. However, the KEM panel will be kept informed about developments.
- Natural and induced seismicity both offshore in the Q quadrant and onshore in North Holland and Utrecht. These are regions where mild quakes have occurred and new mining activities are expected. The question is whether there is a natural component in the observed quakes (KEM-46).

3.2 Soil subsidence risks

Status of research questions on subsidence risks

The KEM contains eight research questions related to subsidence risks. A number of research questions related to salt caverns (KEM-17, KEM-25, KEM-26). One research question is about subsidence after abandonment of the Groningen gas field (KEM-19). There is also a research question on the accumulation of subsidence due to a combination of various deep mining and shallow other causes (KEM-16). In addition, subsidence is also frequently addressed in seismic studies.



KEM-17 has been completed and its results are available. KEM-19 has also been completed and resulted in insight of the naile limited subsidence (around the Groninger field) and soil rise (above the Groninger field). The first two pilots of KEM-16 report in 2023. The decision to take up research questions KEM-25 and KEM-26 has been held until KEM-16, second phase, is completed.
In 2022, several research questions related to subsidence were discussed in the KEM panel: Local subsidence gradients and building damage (thresholds (KEM-44), The influence of controlled brine bleed-off on the stability of caverns and cavern clusters (KEM-45), 3D modelling of subsidence from multiple mining activities and heterogeneous geological subsurface and validation 1D/2D subsidence instruments (KEM-47) and the investigation - partly at the request of residents - of cumulative effects of multiple mining activities (gas extraction and storage) and multiple risks (seismic, subsidence, leakage) in the area around the Grijpskerk gas storage facility (KEM-48). Some will lead to KEM projects in 2023.

Status of research questions regarding public land subsidence risk models

There is a research question, which includes the evaluation and design of the public threat and risk analysis tool for subsidence (KEM-16). Together with stakeholders, three subprojects for KEM-16 have been shaped where there is a cumulation of subsidence from different mining activities, a combination of deep and shallow causes and a combination of subsidence with damage to buildings. In these subprojects, public subsidence threat analysis tools are deployed and delivered. KEM-16 hereby published the first public tools suitable for determining multiple subsidence (TNO2022_R11962 report).

Results and impact study soil subsidence threat and risk through 2021

Compared to 2017, the KEM panel believes that by the end of 2022, further steps have been made in knowledge development with regard to subsidence risks from mining. It concerns (**2022 results in *italics***):

- 2019: The insight has emerged that better consideration must be given to the best method for abandoning - especially more than 1,000 metres deep - salt caverns after the end of the extraction period, without future soil subsidence or leakage risks. This will allow preconditions for new gas storage in salt caverns and the method of abandonment of existing salt caverns to be adjusted in order to control subsidence and leakage risks (KEM-17).

- *2020-2022: The KEM-19 project investigating long-term pressure equalisation and fluid flow in and around the Groningen gas field was completed in 2022. This project further investigated the long-term ground motion effects (subsidence and seismicity) after closure of the Groningen gas field. In addition, long-term fluid leakage or migration effects were also considered. The results provide more clarity on location and nature of likely soil movements after cessation of production in Groningen. The study concludes that the probability of subsidence and seismicity around the Groningen gas field will increase slightly but will be limited. In addition, the rate of subsidence and seismicity above the Groningen reservoir will decrease. The probability and magnitude of gas leakage risks due to gas extraction in Groningen has been calculated and is considered small.*

The project results, including the evaluation by the KEM panel can be found on the KEM website. In 2022, the results of KEM-19 were shared with national governments and science, universities, knowledge institutes, in the Netherlands in the joint KEM-DeepNL colloquia.

Ongoing research on subsidence threats and risks through 2021

Some major projects were ongoing in 2022, contributing to the public knowledge development with respect to subsidence risks in 2023. In addition, new research questions were articulated and approved by the KEM panel and in the start-up phase by the end of 2022. These include the following projects:

- 2021-2022: The KEM-16 project focuses on the development and integration of public subsidence threat and risk analysis tools (KEM-16). One subproject concerns subsidence quantification for a combination of shallow causes and deep causes, and a second subproject concerns subsidence for an area with multiple deeper causes (multiple gas recoveries). The project is largely complete and results in best practices and robust subsidence DRA tools for multiple deep and shallow subsidence. The third subproject focusing on the relationship of subsidence with surface buildings has been delayed and will be specified in 2023 (KEM-16b).
- 2021-2022: A research question on local subsidence gradients and construction damage (thresholds) has been approved. This project was due to start in 2022 (KEM-44) but was not prioritised with arguments from SSM.
- 2022. The influence of controlled brine bleed-off ("controlled brine bleed-off") on the stability of caverns and cavern clusters (KEM-45).
- 2022. 3D modelling of subsidence with heterogeneous geological substrates and comparison with existing 1D/2D subsidence tools to determine at which heterogeneity the existing modelling is inadequate (KEM-47).
- 2022. Investigating - partly at the request of residents - cumulative effects of multiple mining activities (gas extraction and storage) and multiple risks (seismic, subsidence, leakage) in the area around the Grijpskerk gas storage facility (KEM-48).

The research questions of the projects, which have been started, can be found on the KEM website.

Other research questions

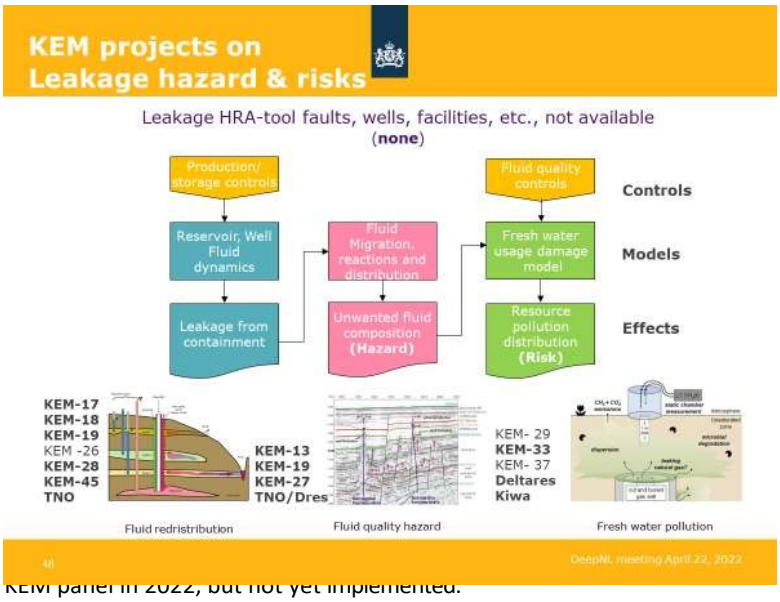
Some of the research questions identified for 2022 have been rejected, not prioritised or held by the KEM panel for various reasons, waiting for final decisions:

- 2020: The KEM-25 research question was rejected as it does not require further investigation after KEM-16 and the KEM-26 research question was retained. This concerns the interference of multiple activities on subsidence and modelling the sinkhole process. These may be taken up later, after the ongoing KEM-16 project is completed.
- The research questions retained earlier by Tcbb regarding subsidence (including *subsidence damage*, impact of (cyclical) settlements on subsidence (KEM-37) will be reviewed - taking into account the results of KEM-16 and other subsidence projects and after coordination with IMG/CM - in terms of research question and funding.

3.3 Leakage risks

Status of research questions on leakage risks

The KEM contains 5 research questions related to leakage risks around wells (gas, geothermal and underground storage of gas and carbon dioxide in gas fields and aquifers and hydrogen in salt caverns: KEM- 17, KEM-18, KEM-19, KEM-27 and KEM-28. KEM-17, KEM-18 and KEM-19 have been completed and their results are available. New research questions have been formulated and projects started in 2022 on leakage of salt caverns (KEM-45),monitoring of underground stored carbon dioxide offshore (KEM-27) and storage of hydrogen in conglomerates of salt caverns (KEM-28). The latter two projects (KEM-27 and KEM-28) will report in 2023. KEM-45 was approved by KEM panel in 2022, but not yet implemented.



Status of research questions on leakage risk tools

No research question for a public leakage risk toolbox is yet planned. Project KEM-18 did produce relevant knowledge for that purpose. In KEM-19, a modelling workflow became available for estimating the risks of leaks from wells in gas fields.

Results and impact study leakage threat and risks

Compared to 2017, the KEM panel believes that by the end of 2022, the first steps have now been made in the development of knowledge with regard to 'leakage risks from mining'. Some specific outcomes and impacts of KEM studies in this area are (**2021 results in *italics***):

- 2019: The insight has emerged that much better consideration must be given to the best method for abandoning - especially more than 1,000 metres deep - salt caverns after the end of the extraction period, without future soil subsidence or leakage risks. With this, besides preconditions for gas storage in salt caverns and the method of abandonment of salt caverns can be adjusted in order to control subsidence and leakage risks (KEM-17).
- 2020-2021: The study on long-term leakage risks along boreholes and wells, which have been abutted (KEM-18) is completed in 2021. This thorough study has identified the main risk factors for leakage through and along capping cement plugs based on global experience and insights. With this, a qualitative risk scan and monitoring of all abandoned wells in the Netherlands can be shaped and their management in relation to future subsurface use improved.
- *2021-2022: Research on the effect the possible long-term horizontal (in gas and aquifer formations) and vertical migration (along wells) of fluids after abandonment of gas fields has started. Results indicate that communication between gas fields is slow and vertical leakage is limited (KEM- 19).*
- *2021-2022: A literature review is underway on monitoring methods of underground CO_2 storage offshore (KEM-27). Many borehole and geophysical methods have been used and validated in various CO_2 storage projects worldwide. A technical review is being conducted on best practices for monitoring CO2 injection and, in addition, new techniques are being evaluated. The results should help sharpen monitoring guidelines for CO_2 storage in the Netherlands*

- *2021-2022: A study and risk analysis of underground hydrogen (H_2) storage in conglomerates of salt caverns (KEM-28) was initiated in 2022. What are the physical and chemical processes and parameters, which play a determining role in the dynamics of caverns and between caverns and the topsoil? The results should enable better quantification of possible threats and risks to H_2 storage in salt caverns.*

The project results, including the evaluation by the KEM panel can be found on the KEM website. In 2022, the results of KEM-19 were shared with the national governments and university world in the Netherlands in the joint KEM-DeepNL colloquia.

Ongoing leakage threat and risk assessment through 2022

Some major projects were ongoing in 2022, contributing to the public knowledge development regarding leakage risks in 2023. In addition, new research questions were articulated by the KEM panel, approved and ready to start up by the end of 2022. These include the following project:

- 2021-2022: The influence of controlled brine bleed-off on the stability of caverns and cavern clusters (KEM-45).

The research questions of the projects, which have been started, can be found on the KEM website.

3.4 Plant integrity risks

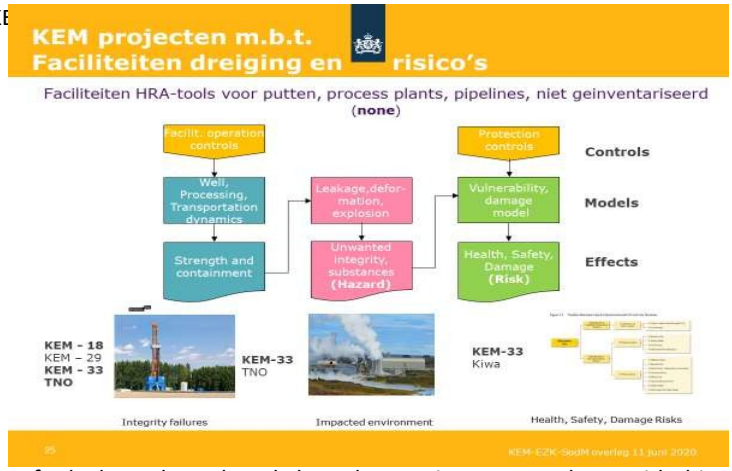
Status of research questions on facilities risks

The amount of research questions in the area of facility integrity risks (resulting in potential hazard, nuisance and environmental damage) has so far been limited in line with the KEM focus so far (see §2 and the figure on the next page).

Results of research

Some specific outcomes and impact of KEM studies in this area are (**2022 results in *italics***):

- 2017: The investigation into the risks of drilling through salt stringers has been completed and has led to the recommendations for adjustments in the methodology applied, including via the need for related 3D seismic preliminary investigations (KE 13).
- 2019: The study on Brent platform decommissioning was conducted and reported in 2029 (KEM-33). The opinion helped determine the Netherlands' position on the issue.
- 2020-2021: The study on the sealing effect of cement at boreholes and wells, especially in the long term (KEM- 18) is completed in 2021. In this thorough study, based on global experience and insights identified the main risk factors for leakage through and along the capping cement plugs. With this knowledge, qualitative risk analyses, monitoring and management of abandoned wells in the Netherlands can be improved.



- *2020-2021: The study on infrasound coming from the subsurface and mining facilities (KEM-31) has for the first time systematically listed infrasound sources of mining activities, forms of propagation and nuisance effects. It is clear that infrasound occurs, can have various causes and, due to a lack of monitoring, cannot always be traced. SSM is considering a follow-up.*

There are currently no research questions or investigations ongoing in this focus area. The research question relating to transport of hydrogen through existing gas pipelines (KEM-29) was discussed in 2021 and was not prioritised at SSM's request.

4. Knowledge assurance and - dissemination

In the 2016 room letter (see annex 1), KEM and the KEM panel were instructed that the agenda-setting of knowledge questions and the mining risk knowledge developed in KEM studies should be secured and shared through knowledge exchange platforms. In 2022, work on this was also carried out on three fronts:

1. Information sharing via kemprogramma.nl, the KEM website
2. Knowledge assurance in public DRA models, such as SDRA Groningen.
3. Communication with the environment regarding various mining risks;

4.1 Information sharing via kemprogramma.co.uk

The Mining Effects Knowledge Programme started in 2017. October 2018, the English-language version of the KEM website came online. The Dutch version followed in January 2019. First of all, the website contains general information about the KEM (the mission, the strategic framework and knowledge agendas, the working method of the scientific expert panel) and the current status of research questions and studies (including evaluations of the KEM panel and link to reactions from EZK and SodM). In addition, the KEM annual reports are published and there is an opportunity to provide feedback on the KEM.

The most visited part of the website is the information on individual research projects under consideration (question, description, results, impact, etc.). The evaluation made by the scientific expert panel after the conclusion of the KEM studies is part of the information. In 2022, results of 6 ongoing projects have been added and the final reports and evaluations of three project results and evaluations have been added. In addition, 4 new approved research questions have been added.

Experience from past years shows that the website is now well found. The website had about 2450 visitors in 2021, who viewed more than 28,000 pages (40% more than in 2022), mainly the pages of the various surveys. Findability could still be improved by more links from other websites. Since 2021, the website has been designed slightly more audience-friendly, but not yet at the desired level of user-friendliness.

4.2 Knowledge assurance in public DRA- models

The KEM panel started in 2017 t o more sharply frame, prioritise and focus KEM and steer the development and improvement in the independent, publicly available mining risk toolbox, starting with seismicity Groningen. The proposal for setting up public mining risk toolboxes and the contribution to it from the KEM has been embraced by the Ministry of Economic Affairs and SSM. A process has started from 2018 to help TNO develop the public seismic risk toolbox for Groningen through the KEM. In 2020, the first version the public Seismic Threat and Risk Analysis tool (public SDRA) was realised by TNO and compared with NAM HRA vs5 and made available for use from 2021.
This version was put into use as of 2021. A KEM subpanel, affiliated to the KEM scientific expert panel, has been set up to provide technical-substantive advice on the further developments of this instrument (see section Annexes B and D). In 2022, several improved or alternative functionalities were added to the public SDRA by TNO in addition to the NAM V6 and V7 models. In 2022, the KEM subpanel provided substantive advice on TNO's proposed SDRA Groningen model versions 2022 and 2023 and the development plan of (parts of) the public SDRA Groningen for 2023.

A first draft of the test and sensitivity analysis framework recommended by KEM subpanel was realised by TNO in 2021 (including in the KEM-09 project). This test framework was completed in 2022. The test framework allows transparent understanding of the outcomes, differences and uncertainties of different (components of) seismic threat and risk models. Meanwhile, this is the basis for evaluating the quality of modules and versions of the public SDRA developed by TNO and allows easy testing of alternative models and modules.

The KEM panel expects that by making public, independent risk tools available, knowledge will be best secured and applicable. In this way, trust can grow in the government's choices analysed and substantiated with these tools regarding the Groningen dossier and, in time, all dossiers related to effects mining.

This approach deserves to be used also for seismicity from other mining activities and other risk types, such as subsidence and underground leaks.

4.3 Communication with the environment

Communication with the environment takes place in 3 forums; the scientific community, professionals at public institutions such as EZK, SodM, NCG and institutes like TNO, Deltares and KNMI, and the authorities and citizens in the regions.

There has been intensive contact with other mining-related research programmes in the Netherlands through the secretary of the KEM panel and through participation in each other's meetings, namely:

- Scientific research programme DeepNL, through which KEM research is shared and discussed in colloquia and vice-versa;
- Colloquia have been organised jointly with the NWO programme DeepNL since 2021 in response to KEM research results, with the aim of sharing and discussing results of (inter)national KEM research and researchers with Dutch DeepNL researchers. The projects KEM-01, KEM-02, KEM-04, KEM-05, KEM-09, KEM-10, KEM-11, KEM-14, KEM-17, KEM-19, KEM-35 and KEM-43 are to 2022 in the colloquia have already been discussed. These presentations have been added to the project information on the KEM website, making them available to the interested public.
- Contributions are made to scientific symposia and publications (KNGMG, NAC). Meanwhile, the list of publications from the KEM studies is growing (see Annex D);
- The conduct of several KEM studies by internationally renowned groups also brings Dutch researchers and policymakers into contact with this network. Examples are: KNMI collaborates with Norsar and GfZ, Fugro collaborates with Italian universities, Deltares and KNMI are affiliated to the EU Turnkey network, etc.

In addition, professional contact with key institutions in the field of securities mining will continue in 2022:

- Public toolbox team at TNO and sister institutes, consolidating knowledge from KEM studies into risk tools; additional contacts have been made with TNO as part of the public SDRA;
- Initiatives under top sector innovation programmes, such as the Geo-energy programme and Geothermal platform and EBN;
- Other policy and research staff at EZK, SodM and NCG, not through KEM have made presentations in the KEM panel consultations.

Contact with the regions or regional authorities and citizens is limited.

- Via the secretary of the KEM panel, because of corona, there was predominantly e-mail contact with mining risk platforms, such as: (1) interested parties regarding seismic risks Groningen and NCG; (2) knowledge platforms Building and strengthening and Livable and Promising Groningen; (3) Tcbb and TPA; (4) interested parties subsidence, c.q. Harlingen Soil Subsidence; (5) stakeholders in geothermal energy via the Platform Geothermal Energy (via EBN/EZK) and (6) stakeholders in coal mining via the counter na- ijlingseffecten mijnbouw Limburg (via SodM). These contacts are ad hoc and not regular. In a number of cases, these contacts also led to the sharing of new knowledge questions and existing knowledge in 2022. Many questions raised did not require additional research to answer them. In those cases, referrals were made to bodies that take on the answering.
- The secretary of the KEM panel together with the University of Groningen provided several introductory presentations and workshops on seismicity and subsidence for NCG employees, employees of the Groningen safety region and employees of the municipality of Het Hoogeland involved in the reinforcement task.

- EZK and SodM are the main link with regional authorities for the KEM panel. Questions from the region come to the KEM panel through them. Meanwhile, there are also KEM questions set up jointly with regions, such as KEM-48.

5. Activities of the KEM panel and subpanel

KEM research is guided by the KEM scientific panel (KEM panel). The KEM subpanel guides and advises on the development of TNO's public seismic threat and risk analysis model of Groningen. This chapter explains the activities of both panels.

5.1 Activities KEM- panel

The independent KEM Scientific Expert Panel (KEM Panel) is responsible for ensuring the scientific quality and independence of KEM. The panel assesses the research questions; advises on their articulation; recommends parties suitable to carry out the studies and evaluates the scientific quality and interpretation of the research results. The KEM panel was complete as of early 2019, according to the insights at its inception in 2017. In 2021, panel member Prof Margot Gerritsen from the University in Berkeley, USA, was replaced by Prof Inga Berre from the University of Bergen in Norway. Appendix D shows all members of the KEM panel. The KEM panel has considered expanding in terms of expertise, but for the time being given the limited number of questions in other areas (structures, external safety) and the possibility of bringing in ad hoc experts, this has not been chosen. So far, no permanent need has emerged for a second larger ring of domain experts outside the KEM panel.

After the two-day kick-off meeting in May 2017, the KEM panel has had two physical (except in 2020 due to Covid19) and two conference call meetings every year. The secretary of the KEM panel prepares the meetings in consultation with the coordinators from EZK, SodM and NCG (until mid-2021), as well as interim email contacts between them. There are fortnightly meetings with these coordinators. The KEM panel usually works efficiently and well, and panel members are willing to carry out (demand articulation, project evaluation) actions outside the meetings.

Planning treatment of research questions and projects
Each research question was reviewed by the expert panel and refined where necessary.

Of the 24 research questions in the first four tranches of the first strategy period 2017-2019, 21 were deemed highly relevant for research, of which four focused on tool development and have since been (almost) completed. Three questions were not pursued for various reasons.

Tranche	Status	Numbers
1 (2017)	The 9 research proposals in the 1e Tranche were handled entirely by the KEM panel between October 2017 and January 2018. All concern seismic risks. They were discussed and reviewed by the panel and adjusted and fine-tuned where necessary in cross-communication with the proposers. The panel also advised by which parties the proposed investigations can best be carried out. These survey questions have now all been implemented. Only KEM questions 5a and 5b were not in tender after a year.	KEM-01 to KEM-07
2 (2017)	A second tranche of 6 research proposals was handled by the KEM scientific expert panel between November 2017 and March 2018 and concern seismic risks. Five of the six research questions were completed, in progress or under tender after 1 year. KEM-11 is extended twice (KEM-11b, KEM-11c).	KEM-08 to KEM-12
3 (2018)	A third tranche of 8 research proposals was considered between January and July 2018 by the scientific expert panel and all but 1 was settled by the panel at the end of June 2018. All projects have been completed or will be completed by 2022.	KEM-13 to KEM 20
4 (2018)	One research question (KEM-23) was rejected with arguments by the KEM panel. The remaining 3 questions in this fourth tranche were assessed as relevant between March and July 2018. Two studies (KEM-21 and KEM-22) have not been prioritised.	KEM-21 to/KEM 24

NB. Sometimes 1 KEM project number covers a number of projects, E.g. KEM-03a, KEM03b and KEM-03c (see Appendix C).

The second strategy period (2020-2022) started in 2019. Of the 24 research questions in the fifth to tenth tranche, 10 have since been deemed highly relevant and launched, including 2 toolbox developments. Eleven

research questions require further discussion among the KEM panel, EZK and SSM. Three questions were not pursued for various reasons.

Tranches	Status	Numbers
5 (2019)	Questions related to soil movement and salt (KEM-25, KEM-26). Both are held until after completion of KEM-16.	KEM-25 to KEM-26
6 (2019)	First questions related to energy transition. These are questions related to hydrogen and CO_2 storage (KEM-27-29), infrasound (KEM-31), abandonment of facilities (KEM-33) and seismic risk alert for infrastructure (KEM-34). KEM-32 awaits completion of KEM-11. The other have been completed or are ongoing.	KEM-27 to KEM-34
7 (2019)	KEM-35 developing the seismic DRA tool Groningen vs 6 has been completed. KEM-36 awaits final activities around the GMM V7 in 2022.	KEM-35 to KEM-36
8 (2020)	A number of new questions raised in the 2 0 1 9 Groningen platform underground meeting and contributed by Tcbb, These concern part additional questions related to subsidence (KEM-37, KEM-38 and KEM-40) and gas storage (KEM-39, follow-up KEM-01) and the FCM model in the pSDRA (KEM-41). A question related to local subsidence effects KEM-42) a.o. in former coal mining or caverns. Most of these research questions were pending in 2021 .	KEM-37 to KEM-42
9 (2020)	KEM-43 focused on improving the pSDRA tool, KEM-44 focused on local subsidence gradients and KEM-45 on pressure control in caverns by brine extraction. These projects have not yet been approved and started in 2021.	KEM-43 to KEM-45
10 (2021)	New questions regarding offshore seismicity (KEM-46), 3D subsidence calculations (KEM-47 and cumulative effects in the Lauwerszee area.	KEM-46 to KEM-48
11 (2022)	External questions on InSAR for subsidence (KEM-49), salt extraction Frisia (KEM-50), the Review of the Groningen vibration tool (KEM-51)	RQ-49 to RQ-51

In 2022, 5 projects were completed (KEM-09, KEM-19, KEM-24, KEM-39, KEM-43). 6 projects were still ongoing from previous years (KEM-15, KEM-16, KEM-27, KEM-28, KEM-34, KEM-36) and 3 projects were approved and/or started in 2022 (KEM-45, KEM-47, KEM-48,) of which the last four are still in the tendering phase.

5.2 KEM activities subpanel

From 2020, the KEM panel is complemented by the subpanel for model development of TNO's public seismic threat and risk assessment (SDRA) tool for Groningen (see also Annexes B for Terms of Reference and Annex F for composition). The KEM subpanel includes scientific experts on seismic threat and risk tools. The KEM subpanel provides its advice to the Ministry of Economic Affairs and Climate and the State Supervision of Mines through the KEM panel.

Specifically, the KEM subpanel advises substantively on the functional development of TNO's public seismic Threat and Risk Analysis models and tool and the responsible use of new functionality to be used versions of TNO's public seismic Threat and Risk Analysis tool.

Specifically, in each year, this means advice on two plan documents to be delivered by TNO:

- The TNO SDRA Status Report containing a proposal for the official public SDRA model version to be used for evaluating the plan of the upcoming gas year or alternative scenarios, if any.
- The TNO SDRA Development Plan, proposing new functionality to be developed and validated, which could potentially be included in an official version of the public SDRA.

For its opinions, the KEM subpanel has defined a number of criteria on which the proposed proposals are assessed for content and usability. These include the following criteria: reproducibility of results, testability and robustness of the code, quantification of uncertainties in outcomes, transparency of the model and test results and openness of the code.
These criteria assess annually, based on proposals provided by TNO, whether proposed (functionality of) model versions are ripe for use and estimate when proposed newly developed functionality can be used in an official version.

Planning SDRA advisory activities

The KEM subpanel started in small format (2 members) in late 2020 with the first advice. From February 2021, the full KEM subpanel started its work. The KEM subpanel meets around 2-3 times to arrive at each requested advice.

Two opinions have been issued for the 2021 gas year, November 2020 (TNO Status and model version report 2021) and May 2021 (TNO model developments report 2021), respectively.
In December 2021, the advice on the TNO Status and model version report 2022 was delivered. The advice on the 2022 development plan proposed by TNO has - partly at SSM's request - been postponed. However, some proposed activities related to finalisation transfer NAM and functionality needed for modelling post-pile effects, which advised the KEM subpanel regarding model development in 2021, have been initiated.
An advice has been issued to SSM for gas year 2023 and December 2022 respectively (TNO Status and model version report 2021) and an advice (TNO model developments report 2021) to EZK is scheduled for February 2023. Below is the list of opinions so far:

Plan year	Advisory question, advice and impact	Status
2021	Status report pSDRA model version 2021. Two members of the KEM subpanel recommended positively on the SDRA version for 2021.	Started: October 2020 Delivered: November 2020
2021	TNO pSDRA development plan 2021. In about four meetings, the KEM subpanel arrived at an opinion come. Some of the prioritised development activities have been i n c l u d e d in the TNO plan. Some of the development was not.	Started: February 2021 Delivered: May 2021
2022	Status report pSDRA model version 2022. In about four meetings, the KEM subpanel arrived at ee opinion. Part of the functionality proposed by TNO was deemed good by the KEM s u b p a n e l , while another part needed more validation. The Ministry of Economic Affairs decided - partly on the advice of SSM - not to want to use any new functionality in the model versions for the pSDRA 2022.	Started: October 2021 Delivered: December 2021
2022	TNO pSDRA development plan 2022. This trajectory has been delayed after an initial start in January. Nevertheless, developments have started at TNO based on a mandate from the Ministry of Economic Affairs.	Started: January 2021 To be delivered: 2022 (not)
2023	Status report pSDRA model version 2023. The KEM subpanel advised positively on the SDRA version for 2021 to SSM, with some recommendations....	December 2022

The documents from TNO, KEM subpanel advice, SSM advice and assignments EZK are published at:
https://www.rijksoverheid.nl/documenten/publicaties/2022/06/17/modelversies-publieke-sdra-groningen
The appendices show the KEM subpanel opinions and how they were used in the choice of model versions to recalculate extraction plans and initiate new developments at TNO.

5.2 Procurement and finance

The call for tenders for the surveys has been placed with EZK's Procurement IUC (incl. queries from SSM and NCG). On 24 July 2017, consultations took place with EZK's Procurement Department and its substantive advisor (special professor of procurement law). Based on the latter's advice, it has become clear that the procurement of KEM research does not fall under European procurement rules as long as it concerns scientific research. However, a number of other conditions do apply that must be taken into account in the tender.

Most of the studies (ca.20) are, until the end of 2022, mostly international, marketed through Bureau Procurement. Some (ca.5) have been included in the work programmes of TNO, KNMI and Deltares. In addition, there were ca.6 SDRA development projects at TNO The experiences so far have been positive.

The research costs of the KEM studies so far amount to a maximum of 4 million euros per year divided between the Ministry of Economic Affairs and SSM (including the development costs of the public SDRA tool for Groningen). It is not well possible for the KEM panel to provide the financial statements as financial control is not part of the Terms of Reference (that responsibility lies with EZK and SodM).
What is clear is that, due to capacity prioritisation, financial spending on projects in 2022 at SSM lagged significantly behind that of the Ministry of Economic Affairs. In 2022, no projects were started at SSM and a number of research questions were withdrawn. EZK is struggling with internal budget limits, which moderate the progress of KEM.

A similar effort to 2021 and before is envisaged for subsequent years.

6. KEM evaluation and follow- up

6.1 KEM evaluation AEF

An independent evaluation of KEM took place in 2022. First, the extent to which the intended objective and goals (public and independent knowledge development into mining effects and connection to international top researchers in this field) of the Mining Effects Knowledge Programme were achieved was tested. Secondly, it tested whether results reach professionals at SSM, the Ministry of Economic Affairs, Dutch knowledge institutes and universities, and how they are valued and used. The overarching question is to what extent KEM has been able to contribute to public confidence in mining risk management in the Netherlands. Finally, it evaluated how the current set-up and organisation has worked and to what extent improvements are still possible and desirable.

It was concluded that KEM is largely effective and efficient. Professional stakeholders who were consulted indicated the project results reach them well, value them positively and there is impact. Citizens who were also consulted recognised this to a lesser extent.

The evaluation also identified shortcomings and made recommendations. These concern:

- Sharpening the mission. This was followed up in parliamentary letter of December 2022 (parliamentary paper 32849, no. 213).In this parliamentary letter, the goals were reformulated: (1) Conduct independent applied research to increase understanding of the potential impacts and uncertainties of mining activities, (2) Compile knowledge into methods and tools to quantify impacts, which can be used for policy and monitoring in the energy transition and (3) Contribute to knowledge of and confidence in mining activities by communicating to experts and other stakeholders (including residents) about KEM projects.
- Better reference documents for strategy and implementation and appointment policy panels.
- More transparent process of demand identification, articulation and decision-making thereon.
- Better communication about KEM and KEM project results to professionals and the public.
- Explore how KEM can be complemented by research on non-physical, societal impacts.

A plan for this was drawn up by the end of 2022 and will be implemented in 2023.

6.2 Reflection on evaluation and recommendations

The results of the evaluation were discussed with EZK-SodM and KEM chairman in December 2022. The KEM panel, EZK and SodM are satisfied with the evaluation and agree with the recommendations. As a result, EZK, with the agreement of SodM, decided at the end of 2022 to continue KEM for at least 5 years (2023-2027). See Parliamentary letter (Parliamentary Paper 32849, no. 213).

6.3 KEM future and improvement actions

Meanwhile, there is a draft KEM strategy 2023-2027, which addresses the first three identified shortcomings. This document now guides KEM in 2023-2027.
Actions remain concerning improvement in broad-based communication, how non-physical, social impacts can be picked up within or alongside KEM and contributing to a national strategy. First steps will be taken in these areas in 2023.

7. Conclusions, improvement actions and recommendations

7.1 KEM strategy and research

KEM is running well in terms of content. In the opinion of the KEM panel, the quality of the majority of projects is excellent and the impact meaningful. There is a shift from research on seismicity Groningen to other impacts of mining related to the energy transition from 2020, in line with the priorities

stated in the report "Towards a (national) research agenda and risk toolbox in the Netherlands" (TNO_R10375). KEM has now been active for 5.5 years and the second period expired at the end of 2022.

KEM was evaluated by an independent agency (AEF) in 2022 at the request of all stakeholders (EZK, SodM and KEM panel). It concluded that KEM is largely effective and efficient. This helped lead to KEM being approved, or provided with an associated budget, for a new five-year period, 2023-2027. The review also identified shortcomings and made recommendations. Actions to address these were agreed by the end of 2022 and will be implemented in 2023.

Attention strategic:

- Actions following the KEM review have been agreed and should be largely implemented by 2023. The updated strategy and modus operandi document is now available. In it, the demand identification and decision-making process has also been clarified. Areas of focus are:
    - the scope and appointment policy of the KEM panels (change and check on expertise) and the examination of the need for the establishment of a socio-economic research panel
    - A decision on the intended target audience of the KEM website.
- Both KEM panels believe that a unified approach in quantifying mining impacts is needed. A long-term view desirable on the need for DRA tools for other mining activities or hazards and the role of the government. Essential are that not only to hazard, but also impacts/risks are quantified along with it (even if they are sometimes small). Furthermore, a probabilistic approach is considered important to include uncertainties. Finally, the KEM panels advocate the development and acceptance of public and independently verifiable hazard and risk instruments. Coordination and harmonisation deserve more attention, given the various unconnected developments (SRA geothermal, CO2 storage, small gas fields).
- The KEM scientific expert panel, together with NWO's scientific research programme on seismicity Groningen (DeepNL), advocated in a widely supported letter note in 2022 for a national, coordinated research strategy, for long-term (beyond 2022) independent scientific (NWO) and applied research (KEM and JTIs) and the development of public DRA tools, for the responsible use of the Dutch subsurface, as deemed required for the energy transition. KEM, meanwhile, is pleased that the PEGA and cabinet response and EZK response support such a strategy.

Issues operational:

- The budget for KEM research in 2022 was broadly similar to previous years, and will remain needed at this level in 2023. However, there was a clear difference in 2022 between the number of projects and spending at the Ministry of Economic Affairs and SSM: most projects ran through the Ministry of Economic Affairs' budget. Due to capacity problems or other prioritisations at SSM, several investigations were slow to be completed and new investigation requests were not developed and tendered (through KEM). The KEM panel has concerns about the progress of and focus on KEM research at SSM.
- An operational aspect that continues to require attention is lead time. That lead time is now 3-6 months for demand articulation (with exceptions of 1 year or more), the tender takes 3-6 months and the evaluation and publication of results afterwards also takes 3-6 months. Capacity at SSM in particular, and to a lesser extent EZK, for demand articulation and project supervision seems tight. The turnaround time of projects themselves is usually on schedule. Sometimes the evaluation from KEM takes too long. Added to this, the period of interpretation by SSM sometimes exceeds 6 months. This means that answers to most research questions are sometimes publicly available a year later than might be possible.

7.2 Knowledge assurance and - dissemination

For sharing the design, results and evaluations of KEM studies, the KEM website, kemprogramme.co.uk has been set up since October 2018. This is functioning well. In particular, people are increasingly aware of the research information and the annual reports. The website had about 2450 visitors in 2022, who visited more than 28,000 pages (40% more than in 2022) viewed, mainly the KEM project pages. It was decided not to make the interpretation of research results for policy and supervision part of the KEM website. Links are only made to with interpretation information on the SSM website or explanations requested by EZK on nlog.nl.

The KEM promotes the development of public mining effects toolboxes for mining risk tools, specifically the public SDRA Groningen. In 2020, it managed to complete the development of the first version of TNO's public seismic threat and risk analysis tool and move to a more controlled management situation, with the KEM subpanel providing content advice. The decision to freeze versions for practical use lies with the Ministry of Economic Affairs, where other arguments count in addition to substantive ones. The interpretation of other public threat and risk analysis tools is still under discussion. Clear vision and frameworks for this can be further developed by the EZK, SSM with lower authorities.

The connection with NWO's scientific research programmes, or DeepNL, went well in 2022. This also applies to contacts with professionals at EZK, SodM and key knowledge institutions TNO, KNMI, Deltares and research groups involved in KEM projects. Communication with regional authorities and citizens also remained limited in 2022.

Points of interest are:

- The findability of the kemprogramma.co.uk website was further improved in 2021. There is also a greater need for more user-friendly technical information. KEM currently refers to sites of EZK, SodM and TNO for that. A thorough update of the website, linked more to risks than to project progress, could be considered, but awaits more clarity on communicating together in line with the PEGA recommendation 9 and cabinet response measure 49.
- Regarding the assurance in public threat and risk tool Groningen, there are still some points of attention, namely: clarity on the criteria for determining model versions and choices in model developments for TNO's public SDRA tool, the independence of the further development and quality assurance of the SDRA (currently, the relationship or alignment with NAM model developments still seems to be leading).
- Intensifying contacts between professionals. First, re-establish ties with NCG and collaborate with research parties and partners participating in setting up a national strategy, Cabinet response Measure 49.
- Intensifying and communicating more personally with stakeholders in various regional governments of mining regions and with various interest platforms on the results of KEM research and picking up any new research questions has been limited in 2022. Primarily, this task lies with EZK or SSM. More clarity on the (limited) role of the KEM panel is desirable.

7.3 KEM panel and subpanel

The KEM scientific expert panel met twice digitally and twice physically in 2022; the scientific expert role in question articulation (five research questions), project guidance (six projects), project evaluation (six final reports) and interpretation worked efficiently and well in 2022.
From the end of 2020, the KEM subpanel plays a role in guiding the model development of the public SDRA at TNO. Five opinions have since been issued by the KEM subpanel.

Focal points for the KEM panels are:

- The KEM panel realises that it has limited expertise in the area of facilities/infrastructure (external safety, environmental risks). The KEM panel considered recommending expanding on this, but has not chosen to do so for the time being, given the limited number of questions in these areas especially as NCG supervises a lot of research in this area and there is a possibility to hire ad hoc experts.
- The KEM panel realises that it has limited expertise in socio-economic sciences (risk perception). The KEM panel has considered expanding with these areas of expertise, but believes that this would make the KEM too broad and that a second similar but affiliated panel with socio-economic scientists is the right solution.
- The planning of the KEM subpanel's advisory work on SDRA model developments 2022 has gone differently than anticipated. A clear annual schedule and possible merging of the two annual advisory requests could be an improvement.

Annex A Kamerbrief 2016 on Knowledge Programme Effects Mining

Ministerie van Economische Zaken

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Ons kenmerk
DGETM-EO / 16093912

Datum 24 juni 2016
Betreft Kennisprogramma effecten mijnbouw

Geachte Voorzitter,

In het rapport 'Aardbevingsrisico's in Groningen' concludeerde de Onderzoeksraad voor Veiligheid (OVV) dat de kennisontwikkeling omtrent de risico's van gaswinning tekort is geschoten. De OVV stelde dat er meer behoefte is aan inzicht in de risico's en de onzekerheden rond gaswinning. Daarnaast heeft de OVV aanbevolen om het onderzoek onafhankelijk uit te laten voeren en meer aandacht te geven aan multidisciplinaire regie en integratie van kennis. De OVV constateerde dat dit in brede zin geldt en dus ook voor andere vormen van mijnbouw. Het kabinet heeft naar aanleiding hiervan aangegeven een voorstel te ontwikkelen voor de wijze waarop de kennisontwikkeling rond de mogelijke risico's van het gebruik van de ondergrond beter vormgegeven kan worden. Met deze brief informeer ik uw Kamer op welke wijze ik van plan ben hieraan invulling te geven.

Kennisprogramma effecten mijnbouw
Ter uitwerking van bovenstaand punt uit de kabinetsreactie op het OVV-rapport werk ik aan het inrichten van een kennisprogramma dat specifiek gericht is op het vergroten van de kennis over en het begrip van de effecten van mijnbouwactiviteiten. De doelen van dit kennisprogramma effecten mijnbouw zijn:

- Versnelling inhoudelijke voortgang van de kennisontwikkeling met betrekking tot de mogelijke effecten van mijnbouw;
- Intensivering van (multidisciplinaire) samenwerking tussen kennisinstellingen;
- Ontwikkeling van onafhankelijke, toegankelijke en gezaghebbende kennis.

Op basis van deze uitgangspunten is voor het kennisprogramma effecten mijnbouw een aantal samenhangende elementen gedefinieerd:

1. Het feitelijke onderzoeksprogramma effecten mijnbouw;
2. Een platform voor kennisuitwisseling effecten mijnbouw;
3. Een wetenschappelijke adviescommissie kennisontwikkeling effecten mijnbouw.

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Hieronder licht ik deze elementen toe.

1. *Onderzoeksprogramma effecten mijnbouw 2017*

Samen met Staatstoezicht op de Mijnen (SodM) heb ik een concept onderzoeksprogramma opgezet dat gericht is op de effecten en risico's van mijnbouw in Nederland. Hierbij heb ik zo goed mogelijk de zorgen en vragen meegenomen die naar aanleiding van diverse mijnbouwactiviteiten aan mij zijn voorgelegd. Een belangrijk onderdeel van het kennisprogramma zal zijn het realiseren van de mogelijkheid om de onderzoeken die door NAM worden uitgevoerd in het kader van gaswinning Groningen over de gehele breedte onafhankelijk te kunnen toetsen. Zowel bij het ontwikkelen van het concept onderzoeksprogramma als voor het vaststellen van het definitieve programma vindt afstemming plaats met de Nationaal Coördinator Groningen (NCG) om te bewerkstelligen dat ook vragen over de effecten van mijnbouwactiviteiten van de kant van NCG onderdeel uitmaken van het programma.

2. *Platform voor kennisuitwisseling*

Ik hecht er belang aan dat het onderzoek aansluit bij de vragen die leven in de samenleving. Ik ga dit onder andere faciliteren door een platform voor kennisuitwisseling in te richten. Dit platform zal zorg dragen voor periodieke (wetenschappelijke) bijeenkomsten waarin de resultaten van recent onderzoek met de wetenschap en met regionale stakeholders worden gedeeld. Anderzijds moet dit platform ook ruimte gaan bieden voor het maatschappelijk debat over zowel de vraagstelling als de uitkomsten. Verder zal er een interactief digitaal platform gecreëerd worden waarop vraag en resultaat bij elkaar komen.

3. *Wetenschappelijke adviescommissie kennisontwikkeling effecten mijnbouw*

Ik acht het van belang dat bij de beschreven kennisontwikkeling zowel de wetenschappelijke kwaliteit alsook de onafhankelijkheid van de onderzoeken goed geborgd zijn. Om te bewerkstelligen dat het onderzoeksprogramma daadwerkelijk bijdraagt aan kennisontwikkeling zal ik een wetenschappelijk gezaghebbende en onafhankelijke commissie van deskundigen aanstellen. Naast kwaliteitsbewaking is dit ook nodig om het draagvlak voor het programma en de resultaten van de onderzoeken te vergroten en om te zorgen voor een versnelling van de kennisontwikkeling op het gebied van effecten mijnbouw.

Van de wetenschappelijke adviescommissie verwacht ik dat zij (1) advies uitbrengt over de concept onderzoeksvragen met als doel de wetenschappelijke articulatie van de kennisvragen te verbeteren; (2) aangeeft welke wetenschappelijke disciplines nodig zijn in het onderzoek en daarbij bij voorkeur een voorstel doet over de instituten en/of universiteiten (nationaal en internationaal) die bij het onderzoek betrokken zouden moeten worden; en (3) jaarlijks rapporteert over de voortgang van de kennisontwikkeling, de onafhankelijkheid van het onderzoek en de meerwaarde daarvan voor kennis met betrekking tot mogelijke effecten van mijnbouw. De wetenschappelijke adviescommissie heeft daarmee een cruciale rol in de ontwikkeling van het kennisprogramma effecten mijnbouw.

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Ons kenmerk
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Op het ogenblik ben ik zowel nationaal en internationaal aan het inventariseren welke onafhankelijke wetenschappers beschikbaar zijn voor deelname aan de wetenschappelijke adviescommissie. Omdat het van groot belang is ook aansluiting te houden bij andere nationale onderzoeksprogrammering, hecht ik eraan dat de verbinding met NWO ook verankerd wordt in de commissie.
De criteria waaraan de leden moeten voldoen zijn:

- Gezaghebbend in de (internationale) wetenschappelijke wereld;
- Internationaal netwerk;
- Onafhankelijke positie ten opzichte van de industrie;
- Goed ingevoerd in de effecten van de mijnbouw;
- Actueel beeld van de kennisbehoefte van de overheid;
- Bereid en in staat de overheid op maat te adviseren.

De wetenschappelijke commissie zal ondersteund worden door een wetenschappelijk secretaris. De organisatie en logistiek rondom de feitelijke uitvoering van de projecten binnen de randvoorwaarden als gesteld door de wetenschappelijke commissie zal belegd worden bij TNO-AGE.

Naast de wetenschappelijke adviescommissie zal ik en ook SodM, waar nodig en indien gewenst, binnen de eigen verantwoordelijkheid gebruik blijven maken van nationale en internationale deskundigen.

Planning
Ik streef ernaar om de adviescommissie in het vierde kwartaal van 2016 te installeren. Daarmee zal ook het onderzoeksprogramma effecten mijnbouw in het vierde kwartaal van 2016 formeel kunnen starten.

(w.g.) H.G.J. Kamp
Minister van Economische Zaken

Annex B Terms of Reference KEM scientific expert panel and KEM subpanel model development

Terms of Reference

International Expert Panel on Mining Effects

MEA, October 2020

Objective and scope
The International Expert Panel on Mining Effects advises the Directorate Energy and Environment of the Dutch Ministry of Economic Affairs and Climate (MEZK), the Regulator for natural resources extraction Staatstoezicht op de Mijnen (SodM) and the Groningen crisis organisation Nationaal Coördinator Groningen (NCG) on the development and implementation of research projects related to the use and associated risks of Natural Resources extraction.

The role of the panel is to ensure that specifications of research requests coming from MEZK, SSM, NCG and other public bodies meet criteria of relevance and completeness in the context of issues they are supposed to address and to advise on which parties are best qualified to carry out the proposed research.

Specific tasks include:

- Assess and advise on the scientific description of the proposed research questions
- Indicate which scientific disciplines should be involved in the individual research projects
- Give advice on which national and international institutes and/or universities could best be involved in the research projects
- Assess progress and impartialness of knowledge development and its fitness to address questions concerning mining effects and associated risks.
- Identify and report knowledge gaps, e.g. important research request not raised by MEA, SSM or NCG
- Report any suggestions how KEM can help in improving management of Mining Risks
- Scientific sounding board on Mining risk assessment protocols (for SSM) and publicly available Mining risk quantification instruments (for TNO c.s.)

The Expert Panel was installed by the Minister of Economic Affairs in Q2 2017.

Context and mission
In their report on induced seismicity risks in Groningen (2015) the Netherlands Safety Investigation Council (OVV) ascertained shortcomings in the knowledge development concerning the risks of natural gas production. Specific recommendations were:

- Improve the insights into the risks and associated uncertainties
- Conduct the research independent from the mining industry
- Stimulate multidisciplinary research projects and put more effort in integrating research results of the various scientific disciplines.

The OVV stated that these recommendations should also apply to mining activities other than natural gas production.

Knowledge programme on the effects of Mining

To meet these recommendations the Dutch Government decided to initiate a knowledge development program specifically aimed at mining activities and associated risks. The goals of this program (Kennisprogramma Effecten Mijnbouw, KEM) are to:

- Accelerate and intensify research concerning mining effects and associated risks
- Enhance the multidisciplinary collaboration between research centres and universities

- Develop independently authoritative knowledge which can be

verified Elements of KEM are:

- The actual research framework and programme (the research projects)
- A knowledge exchange platform to both initiate and stimulate scientific debate within the scientific community and to consolidate and exchange scientific results with society
- A scientific panel on mining effects, as described in this document, that ensures quality, relevance, completeness, fitness and independence of the conducted research.

Composition
The panel consists of a chairperson and 4-6 members, appointed for periods of three years. The panel and its members will have an outstanding scientific reputation, function independently and will also be perceived as such; they will have no relationship with the mining industry in general and are not involved in research commissioned by the Dutch oil and gas industry in particular. The individual members act without a mandate or instruction from their organisations. They are selected on the basis of their expertise and scientific reputation.

The main areas of expertise to be covered by the panel are:

- Induced seismicity
- Subsidence and uplift
- Containment and confinement
- Long-term effects of mining activities
- Technical aspects (pipelines, construction aspects)

The panel may be assisted by sub-panels or guest experts in case additional expertise is required.

Reporting line
The panel reports to the Directorate Energy and Environment of the Ministry of Economic Affairs; the Dutch Regulator for Natural Resources Staatstoezicht op de Mijnen (SodM); and the Nationaal Coördinator Groningen (NCG).
At least once a year, the panel chair will inform the Minister of Economic Affairs about the State of The Programme.

Working method
The panel will have four formal meeting moments in any given year. The panel is expected to meet physically twice a year in The Netherlands. Due to the current situation (Covid-19) this requirement cannot be met. Instead of the in-person meetings, online meetings (spread over two days) are arranged. The two other meetings and any ad hoc meetings are expected to be conducted by video/teleconferencing apart from usual email correspondence. The panel is supported by a secretariat. The members receive a remuneration and compensation for travel time and expenses.

Confidentiality and communication
The members of the panel can communicate about the jointly approved status of the KEM research framework and programme. The KEM panel will not disclose any information on ongoing research requests and projects. The outcome of the research projects will only be communicated by panel members after informing the Ministry of Economic Affairs. The outcome of all projects will become publicly available through the KEM-website.

KEM subpanel on model development

From 2021 onwards the yearly probabilistic seismic hazard and risk analysis for gas production of the Groningen gas field, previously performed by the operator of the Groningen gas field (NAM), will be performed by TNO using the model chain which TNO has developed under the umbrella of the KEM program.

Additionally, the Study and Data acquisition plan of NAM finishes in 2021, meaning that NAM will cease to develop new model versions to be used in the yearly probabilistic seismic hazard and risk analysis from 2021 onwards.

Recognising that:

1. seismicity in Groningen is decreasing but still occurring,
2. gas production will only cease from 2022, barring limited gas production for security of supply,
3. the strengthening programme will continue,
4. Damages may still occur due to ongoing earthquakes,

EZK recognised a need to further develop the models for the yearly analysis as well as a need for a decision on model versions to be used in the yearly risk analysis. For this reason, a KEM-subpanel is formed to:

1. advise on model development for the models included in the model chain developed by TNO (called public SDRA Groningen).
2. give input to the advise of SSM on the versions of the models to be used in the yearly public seismic hazard and risk analysis.

Reporting line

The KEM subpanel gives advice on the further SDRA model development, yearly in November. The advice is presented to the KEM panel who will send the advice, with an accompanying letter to the Directorate Energy and Environment of the Ministry of Economic Affairs.

Additionally the KEM subpanel gives input to the Dutch Regulator for Natural Resources, Staatstoezicht op de Mijnen (SodM) for their yearly advice on the model versions to be used in the yearly public seismic hazard and risk analysis.

Working method

The KEM subpanel will have two formal meeting moments in any given year on the SDRA model development. Additionally, online meetings will be arranged as needed to advise on model development. The subpanel reports once a year to the full KEM panel in the meeting in November. The subpanel is supported by a secretariat (the same as the KEM panel). The members receive a remuneration and compensation for travel time and expenses.

Specific tasks

Specific tasks of the KEM sub-panel include:

- Review of studies with a view on further model development:
    - KEM studies (ongoing)
    - DEEP-NL studies (first results expected in 2021)
    - SDAP studies (NAM research programme, ends in 2020, perhaps some limited activity in 2021)
    - Scientific publications in peer reviewed journals
- Advice on proposed SDRA model train development in November of each year. In the advice, the KEM- subpanel:
    - will review the annual public SHRA model train roadmap development reports of TNO, specifically focusing on their scientific quality
    - can propose new research questions and activities on SDRA model train development within the KEM programme;
    - can propose new implementations of SDRA model train components into the SDRA model train framework, typically carried out by TNO.
- Every six months a meeting on SDRA model train development, to inform the KEM-subpanel on model development. Participant will be the KEM-subpanel, TNO, SodM and EZK as well as other parties which have recently finished research on parts of the models included in the SDRA model train.
    - Beginning of October
        - Start of advice on the further SDRA model train development,
        - TNO will present their public SHRA model train development and implementation plan,
        - other presentations on model development (if applicable)
    - April
        - TNO will present work program current calendar year
        - discussion on model development and planning
        - other presentations on model development (if applicable)
- Two additional online meetings for the advice on model roadmap development in autumn of each year.
- input to SSM for the model versions to be implemented for the public SHRA for the next calendar year;

- Submit request for review of (parts of) new models to other experts with complementary expertise

Composition
The KEM subpanel on public SDRA Groningen model development consists of 4-6 members, appointed for a period of three years. The members will have an outstanding scientific reputation, function independently and will also be perceived as such. The individual members act without a mandate or instruction from their organisations. They are selected based on their expertise and scientific reputation. Two KEM- panel members will also be member of the KEM SDRA subpanel.

The main areas of expertise to be jointly covered by the KEM subpanel are:

- Geological/reservoir model
- Seismological model
- Ground motion model
- Fragility and consequence model
- Probabilistic hazard and risk methodology

The subpanel may be assisted by guest experts in case additional expertise is required. The necessary funds will be arranged by MEZK.

Confidentiality and communication
The members of the subpanel can communicate with the KEM panel, the Directorate Energy and Environment of the Ministry of Economic Affairs and to the Dutch Regulator for Natural Resources, Staatstoezicht op de Mijnen (SodM) about the SDHR model development.
The KEM-subpanel and its members will not disclose any information from ongoing research and projects and or their concept advice to other parties than mentioned above. The advice will only be communicated by the KEM-panel to other parties after the decision of the Ministry of Economic Affairs on SDRA model development. The advice will become publicly available on the KEM-website.

Annex C Status of KEM research questions at end 2022

The table below shows the status of all research questions and projects at the end of 2022. The period from enquiry to end of project is indicated. The KEM projects in bold were active in 2022.

In 2022, 5 projects were completed (KEM-09, KEM-19, KEM-24, KEM-39, KEM-43). 6 projects were still ongoing from previous years (KEM-15, KEM-16, KEM-27, KEM-28, KEM-34, KEM-36, red bold) and 6 projects were approved and/or started in 2022 (KEM-45, KEM-47, KEM-48, KEM-19b, KEM-24b, red).

T	KEM no	Source	brief description	Period	Status
1	KEM-01	SSM	Safe injection pressure and speed of gas storage tanks	2017-18	Ready
	KEM-02	NCG/EZK	Influence inhomogeneous shallow subsurface 'site response'	2018-20	Ready
	KEM-03a	KEM/SodM	Public HRA Toolbox inventory and research questions	2018-19	Ready
	KEM-03b	EZK/KEM	Reconstruction NAM vs2 in public Groningen model train	2018-19	Ready
	KEM-03c	EZK/SodM	NJG publication survey seismicity Groningen	2018	ready
	KEM-04	NCG/EZK	3D wave propagation effects on seismic signature	2018-20	ready
	KEM-05a	NCG/EZK	Effect of repeated earthquakes on soil settlement	2020-21	ready
	KEM-05b	NCG/EZK	Effect of repeated earthquakes on buildings	2021	ready, not KEM (NCG)
	KEM-06	SSM	Risk analysis UDG/EGS (geothermal energy)	2018-20	ready
	KEM-07	SSM	Induced seismicity small gas fields	2018-19	ready
2	KEM-08	SSM/KEM	Next generation of earthquake models	2019-20	ready
	KEM-09	NCG/EZK	Review propagation uncertainties in risk model train	2021-22	ready
	KEM-10	EZK/KEM	Development of public seismic HRA model train, vs5	2019-20	ready
	KEM-11a	SSM	Review catalogue Earthquakes Netherlands	2018-19	ready
	KEM-11b	SSM	Seismological data quality	2019-20	ready
	KEM-11c	SSM/KEM	Upgrade seismic catalogue earthquakes Netherlands	2021	ready, not KEM (KNMI)
	KEM-12	SSM	Advice on outsourcing review Warmtestad QRA	2018	no go (additional risks)
3	KEM-13	SSM	Risk of puncturing carbonate stringers in salt	2018-19	ready
	KEM-14	NCG/EZK	Risk of softening due to induced quakes	2020-21	ready
	KEM-15	**SSM/EXT**	**Seismic risk water injection geothermal energy**	**2020-21**	**90% complete**
	KEM-16a	**EZK/KEM**	**HRA Model train subsidence**	**2020-21**	**90% complete**
	KEM-17	SSM/NCG	Stability of salt caverns	2018-19	ready
	KEM-18	SSM/EXT	Risks geothermal drilling, well integrity	2020-21	ready
	KEM-19	**NCG/EZK**	Risks of leaks and ground movements after gas extraction	2020-22	ready
	KEM-20	NCG/SodM	Alignment of impact models in risk assessments	2019	No go (no exam.)
4	KEM-21	KEM/SodM	Seismicity & damage warning systems	2021	in planning
	KEM-22	EXT/SodM	Data-driven models for seismicity in space, time	2021	in planning
	KEM-23	EXT/SodM	Risk reduction seismicity through fault generation	2019	no go (additional risks)
	KEM-24	EXT/EZK	Risk reduction seismicity by 'fluid' injection	2020-22	ready
5	KEM-25	EXT/SodM	Determining subsidence cumulative mining activities	2019	no go (no exam.)
	KEM-26	EXT/SodM	Sinkhole development, quantifying threats and risks	2021	in planning
6	**KEM-27**	**EZK**	**Monitoring requirements for offshore CO_2 storage in gas fields and aquifers**	**2021**	**25% finished**
	KEM-28	**EZK**	**Risk analysis of hydrogen storage in conglomerates of salt caverns**	**2021**	**25% finished**
	KEM-29	SSM	Evaluation additional risks when transporting H_2 or CO_2 in existing gas transport networks	2021	in planning
	KEM-30	SSM	Classification safety culture, impact on mining risks	2019	no go (no expertise)
	KEM-31	SSM	Infrasound generation, threat and (health) risks	2020-22	ready
	KEM-32	NCG/EZK	Optimisation strategy monitoring ground vibrations	2021	no go (KNMI)
	KEM-33	SSM	Review Brent decommissioning plan and 'second opinions'	2019	ready
	KEM-34	**EXT/EZK**	**Earthquake information infrastructure**	**2020-22**	**90% complete**
7	KEM-35	EZK/KEM	Development of SDRA tool Groningen TNO, vs6	2020-2021	ready
	KEM-36	**NCG/EZK**	**KEM-04 update for version 7 SDRA tool Groningen**	**2022**	**10% finished**
8	KEM-37	EXT/EZK	Soil subsidence impact models in DRA tool and data	2021	in planning
	KEM-38	EXT/SodM	Optimisation strategy monitoring soil subsidence/rising	2021	in planning
	KEM-39	EXT/EZK	Fracture behaviour at pressures in CO_2, H_2, N_2 storage (see KEM-01)	2021-22	ready
	KEM-40	EXT/SodM	Mechanical softening due to cyclic loading storage	2021	in planning
	KEM-41	EXT/EZK	Model/data alignment DRA tool and NPR (cf. KEM-20)	2021	in planning
9	KEM-42	EZK/TCbb	Soil subsidence risks former coal mining Limburg	2021	in planning
	KEM-43	EZK	Development PSHRA vs7	2021-22	ready
	KEM-44	SSM	Local subsidence, the potential for damage	2022	no go, cancelled
	KEM-45	**SSM**	**Risk of 'salt-bleed off' salt caverns**	2022	to tender
10	KEM-46	SSM	Seismicity of offshore Q quadrants offshore, H-Holland and Utrecht	2022	in planning
	KEM-47	**EXT/EZK**	**Impact of heterogeneities on subsidence over producing gas fields**	2022	to tender
	KEM-48	**EXT/EZK**	**Cumulative mining effects, generic and in the Grijpskerk region**	2022	to tender
	KEM-19b	**NCG/EZK**	**Southwest aquifer depletion and seismicity, KEM-19 follow-up study**	2022	to tender
	KEM-24b	**EXT/EZK**	**Risk reduction seismicity using 'fluid' injection, follow-up study**	2022	to tender
11	KEM-49	EXT/EZK	Subsidence in the area Twente measured by satellites (InSAR) and coupling with salt caverns	2023	in planning
	KEM-50	EXT/SodM	Salt creep questions Harlingen	2023	in planning
	KEM-51	EXT/EZK	Quality assurance of Groningen seismic vibration tool	2023	in planning

Annex DList of KEM reports and publications

KEM reports

The following is the list of reports and publications of all started and approved KEM projects up to 2022. The KEM projects in red were active in 2022. Of these, the projects in **bold did** not yet have final reports at the end of 2022. Using the blue links, reports of projects can be found quickly.

Webpage	Risk	Mining	Year	Authors	Title	Report	Consortium
KEM-01	Seismic (SSM)	Gas storage	2018	Ferronato, M., Franceschini, A., Isotton, G., Janna, C., Teatini , P., Tosatto, O., Zoccarato, C.	Safe operational reservoir pressure bandwidth for underground gas storage (3 reports)	Link to final report	University of Padua
KEM-02	Seismic GMM)	Gas production	2020	Besseling, F, Bougioukos, A., Greef de J., Pruiksma, J., Tsouvalas, A.	Evaluation, validation and improvement of the site amplification component of the Groningen HRA model	Link to summary report	Witteveen & Bos, TNO, TUDelft
KEM-03a	All	All	2019	Dost, B., Gessel, van, S., Hoogendoorn, B., Huijgen, M., Marsman, M,. Pluymaeker, M., Thienen-Visser, K.,	Towards a national research and HRA toolbox for mining effects in The Netherlands: a techinical reconnaisance	Link to final report	TNO, Deltares, KNMI
KEM-04	Seismic GMM)	Gas production	2020	Ameri, G., Dijkstra, O., Mazzieri, I., Ozcebe, A.G., Paolucci, P., Piunno, G. , Smerzini, C, Vanini, M.	Data-driven study on seismic 3D structural features of Groningen ground motions	Link to final report	Fugro, Politecnica Milano, Seister, Hanzehogeschool, GR8-Geo, CM-consultation
KEM-05a	Seismic GMM)	Gas production	2021	Meijers, P., Korff, M. et al.	Cumulative effect of repetitive earthquakes on soil settlement	Link to final report	Deltares
KEM-05b	Seismic GMM)	Gas production	2021	Not KEM	Cumulative effect of repetitive earthquakes on buildings	Link to final report	TUD
KEM-06	All	Geothermal	2020	A'Campo, Y.W.L., Baisch, S., Besselink, F., Butter, E.L., Laenen, B. Slob, S.	Risk assessment for UDG and EGS and an inventory of preventive and mitigation measures	Link to main report	Witteveen & Bos, Q-Con, VITO
KEM-07	Seismic GMM)	Gas production	2018	Baisch, S., Voros, R.	Geomechanical study - Small gas fields in The Netherlands	Link to final report	Q-Con
KEM-08	Seismic GMM)	Gas production	2020	Dahm, T., Hainzl, Kühn, S., D., Oye, V., Richter, G., Vera Rodriguez, I.	Review, alternatives and future seismogenic source models for HRA model Groningen (3 reports)	Link to last report	GfZ Potsdam, Norsar
KEM-09	Seismic (All)	Gas production	2021	Pluymaekers et al.	Sensitivity analysis public seismic hazard and risk model train Groningen	Link to final report	TNO
KEM-10	Seismic (All)	Gas production	2018	Breunese, J., Kraaijpoel, D., Osinga, S.et al	Public Seismic Hazard and Risk Assessment model train Groningen, vs5 (3 reports)	Link to final report	TNO
KEM-11	Seismic (GMM)	Gas production	2019	Goertz-Allmann,B., Kühn,D., Langet,N., Lindholm, C., Meslem, A., Oye, V.	Review of the KNMI induced earthquake catalogue from the Groningen gas field (2 reports)	Link to final report	Norsar
KEM-11b	Seismic (GMM)	Gas production	2020	Christensen, J.M., Dando, B.D.E. , Dichiarante, A.M., Ghione, F., Kühn, D., Langet, N., Oye, V.	Review of the KNMI induced earthquake catalogue from the Groningen gas field, continued phase 2A	Link to final report	Norsar (KNMI)
KEM-11c	Seismic (GMM)	Gas production	2021	Kühn, D., Oye, V. et al.	Review of the KNMI induced earthquake catalogue from the Groningen gas field, continued phase 2B		Norsar (KNMI)
KEM-13	Leakage (LSM)	Facility	2017	Heege ter, J., Zijp, M., Huijgen, M., Bouroul-lec, R., Wilpshaar, M.	Drilling in carbonate stringers occurring in salt formations	Link to final presentation	TNO

KEM-14	Seismic (GMM)	Gas production	2021	P. Meijers, P., Korff, M. et al.	Liquefaction (settlement, damage) risk quantification risk module	Link to final report	Deltares
KEM-15	Seismic (SSM)	Geothermal	2021	Dijkstra, O. et al.	Optimal thermal production regime for prevention of the generation of seismicity during water injection given faults and production		Fugro, GfZ Potsdam
KEM-16	Subsidence (All)	Gas production	2021	Pluymaekers et al.	Subsidence risks due to gas/oil production (new subsidence model train), phase 1		TNO, Deltares
KEM-16b	Subsidence (All)	Gas production	2021	Pluymaekers et al.	Subsidence risks due to gas/oil production (new subsidence model train), phase 2		TNO, Deltares
KEM-17	Leakage (LSM)	Salt mining	2019	Baumann, T., Brouard, J., Kaus, B., Schmatz, J.J., Clover, Popov, A., Urai, J.L.	Over-pressured salt solution mining caverns and possible leakage mechanisms: review and modelling on pore, cavern and salt dome scales (5 reports)	Link to final report	Microstructures and Pores GmbH, Brouard Consulting, Smart tectonics
KEM-18	Leakage (LSM)	Gas production	2021	van Oort, E.	What are the long-term sealing risks associated with (geothermal) wells and what are the typical loss of containment risks	Link to final report	EVO
KEM-19	Leakage (LSM)	Gas production	2021	Bottero, S. et al.	Post reservoir abandonment long term fluid migration hydromechanical risks and monitoring strategy	Link to final report	TNO. Deltares
KEM-19b	Leakage (LSM)	Gas production	2021	Bottero, S. et al.	Post reservoir abandonment long term fluid migration hydromechanical risks and monitoring strategy, extended		TNO. Deltares
KEM-20	Seismic (FCL)	Gas production	2018	No project	Why and how are risk assessment Groningen model for buildings different from assessment using building standards (NPR)	KEM comments	None
KEM-24	Seismic (SSM)	Gas storage	2021	Dijkstra, O. et al.	Seismic risk reduction by fluid injection and pressure maintenance	Link to final report	Fugro et al.
KEM-24b	Seismic (SSM)	Gas storage	2021	Dijkstra, O. et al.	Seismic risk reduction by fluid injection and pressure maintenance, extended		TNO
KEM-27	Leakage	CO2 storage	2022	Raddatz Bob, A., Strijbos, F. et al.	Monitoring requirements for CO2 storage sites on the Dutch continental shelf		DNV et al
KEM-28	Leakage	Hydrogen storage	2022	Clover, J., Brouard et al.	Risk assessment of hydrogen storage in a conglomerate of salt caverns in The Netherlands		Brouard, MAP, Pondera, Smart Tectonics, Geo-structures cons.
KEM-31	Sound	Gas	2021	Evers, L. et al.	Infrasound generation and observation	Link to final report	KNMI, RIVM
KEM-33	Leakage (LSM)	Facility	2019	Ash van, D., Eftekari, A.A., Feilberg, K., Nick, H,M.	Review, evaluation of Brent spar decommissioning plan and second opinions	Link to final report	DTU et al
KEM-34	Seismic (FCL)	Gas production	2021	Martinelli, M. et al.	Enhancing information flow on impacted infrastructure after seismic events	Link to EU reports	Deltares et al
KEM-35	Seismic (All)	Gas production	2020	Breunese, J., Kraaijpoel, D., Osinga, S.et al	Public Seismic Hazard and Risk Assessment model train Groningen, vs6	Link to final report	TNO
KEM-36	Seismic	Gas production	2022	Pauluci, P, Ameri, G., Dijkstra, O. et al.	3D modelling the Groningen seismic wave field conforming GMMv7, follow up of KEM-04		Fugro, Politecnica Milano, Seister,
KEM-39	Seismic	Gas storage	2022	Ferronato, M., Franceschini, A., Isotton, G., Janna, C., Teatini , P., Tosatto, O., Zoccarato, C.	Geomechanical/chemical factor determining fault criticality du-ring pressure (non)cycling of underground $_{CO2,H2,}$ $_{N2}$ storage	Link to final report	University of Padua

KEM-43	Seismic	Gas production	2022	Puymaekers et al.	Development and validation of new submodels in the seismic Groningen HRA model		TNO

Scientific publications from (black) and following KEM projects (grey) General (with KEM as sponsor)

Netherlands Journal of Geosciences, Special issue (2018) *Induced Seismicity in the Groningen Gas Field, the Netherlands*, Volume 96 - Special Issue 5 - December 2017. DOI: 10.1017/njg.2017.39

KEM-01

Teatini, P., Ferronato, M., Franceschini, A., Frigo, M. and Janna, C., Zoccarato, C., Isotton, G. (2019) *Gas storage in compartmentalised reservoirs: a numerical investigation on possible "unexpected" fault activation*, - 53rd US Rock Mechanics/Geomechanics Symposium. Paper Number: ARMA-2019-1991

Teatini, Pietro & Zoccarato, Claudia & Ferronato, Massimiliano & Franceschini, Andrea & Frigo, Matteo & Janna, C. & Isotton, Giovanni (2020) *About geomechanical safety for UGS activities in faulted reservoirs*. Proceedings of the International Association of Hydrological Sciences. DOI: 10.5194/piahs-382-539-2020

KEM-02/KEM-05

van Ginkel, J. (2022). *Seismic site response in the Netherlands: impact of the shallow subsurface composition on earthquake ground motion amplification*. University of Groningen. DOI: 10.33612/diss.211424759

KEM-03a

TNO-Deltares-KNMI (2019), *Towards a National Research Agenda and Risk Toolbox for Mining Effects in The Netherlands*, TNO report TNO_R10375

KEM-04

Paolucci, R, Mazzieri, I, Piunno, G, Smerzini, C, Vanini, M, Özcebe, A. *Earthquake ground motion modeling of induced seismicity in the Groningen gas field*. *Earthquake Engineering Structural Dynamics.* 2021; 50: 135- 154. DOI: 10.1002/eqe.3367

Ameri, G., Martin, C, Oth, A. *Ground-Motion Attenuation, Stress Drop, and Directivity of Induced Events in the Groningen Gas Field by Spectral Inversion of Borehole* Records, July 2020, *Bulletin of Seismological Society of America 110(5)*. DOI: 10.1785/0120200149

KEM-06

Buijze L, van Bijsterveldt L, Cremer H, Paap B, Veldkamp H, Wassing BBT, van Wees J-D, van Yperen GCN, ter Heege JH, and Jaarsma B. (2019) *Review of induced seismicity in geothermal systems worldwide and implications for geothermal systems in the Netherlands*. Netherlands Journal of Geosciences, Volume 98. DOI: 10.1017/njg.2020.9 **KEM-07**

K. van Thienen-Visser, J.A. Roholl, B.M.M. van Kempen, A.G. Muntendam-Bos (2018) *Categorising seismic risk for the onshore gas fields in the Netherlands,* Engineering Geology, Volume 237, Pages 198-207.DOI: 101190/tle34060664.1

Muntendam-Bos, A., Hoedeman, G., Polychronopoulou, K., Weemstra, C., Van der Zee, W., Bakker, R., Roest, H. (2021) *An overview of induced seismicity in The Netherlands.* Netherlands Journal of Geoscience. DOI: 10.1017/njg.2021.14

KEM-08

Kühn D, Hainzl S, Dahm T, Richter G, and Vera Rodriguez I. (2020) *A review of source models to further the understanding of the seismicity of the Groningen field.* Netherlands Journal of Geosciences, Volume 101. **KEM-09**

TNO (2022), KEM-09: *Cumulative propagation effect of Groningen risk model component uncertainties on hazard and risk predictions.* TNO2021 R12442.

KEM-03/KEM-10

TNO (2020) *Probabilistic Seismic Hazard and Risk Analysis, TNO Model Chain Groningen* TNO: TNO2020_R11052

TNO (2020) *IT platform for the TNO Groningen Model Chain PSHRA calculations* TNO: TNO2020_R10474

TNO (2020) *Final report Status of the TNO Model Chain Groningen per October 1, 2020 and recommendations for the public Seismic Hazard and Risk Analysis 2021* TNO: TNO2020_R11464

TNO (2021) *Proposed research activities for model development in the public SHRA Groningen* TNO: TNO2021_R10153

TNO (2021) *Status of the TNO Model Chain Groningen per October 1, 2021 and recommendations for the public Seismic Hazard and Risk Analysis 2022* TNO: TNO2022_R11742

TNO (2021) *Cumulative propagation effect of Groningen risk model component uncertainties on hazard and risk predictions* TNO: TNO2021_RR12442

KEM-11

Kühn, D., Heimann, S., Isken, M. P., Ruigrok, E., Dostal, J. (2020): *Moment tensor inversion testing report on hydrocarbon-induced seismicity in the Groningen gas field, the Netherlands*, GfZ report. DOI: 10.5880/GFZ.2.1.2020.003

Gabriele Ameri, Christophe Martin, Adrien Oth (2020) *Ground-Motion Attenuation, Stress Drop, and Directivity of Induced Events in the Groningen Gas Field by Spectral Inversion of Borehole Records*. *Bulletin of the Seismological Society of America*. DOI: 10.1785/0120200149

KEM-14

Korff, M., Meijers, P. , Wiersma, A., Kloosterman, F. (2019) *Mapping liquefaction based on CPT data for induced seismicity in Groningen, Earthquake Geotechnical Engineering for Protection and Development of Environment and Constructions*, CRC Press, Pages 8. ISBN: 9780429031274

KEM-15

Cacace, M., Hofmann, H. Shapiro, S.A. (2021) *Projecting seismicity induced by complex alterations of underground stresses with applications to geothermal systems*, Sci Rep 11, 23560, DOI: 10.1038/s41598-021-02857-0

Mathur, B., Hofmann, H., Cacace, M., Hutka, G., Zang, A. (2022) *Thermo-hydro-mechanical simulation of cooling-induced fault reactivation in Dutch geothermal reservoirs* (in preparation)

Gergő Andra, Hutká, Máuro Cacace, Hannes Hőfmánn1,2, Arno Zang (2022) *Seismicity catalogues from Coulomb failure stress models related to cold water-injection in geothermal wells in the Netherlands* (in preparation)

Gergő András Hutka, Mauro Cacace, Hannes Hofmann, Arno Zang, Lei Wang , Yinlin Ji (2022) *Numerical investigation of the effect of fluid pressurization rate on laboratory-scale injection-induced fault slip* (in preparation)

KEM-16

TNO (2022) The PySub Subsidence Model Framework: Technical Reference, TNO: TNO2022_R11962

KEM-17

Baumann, T., Kaus, B., Popov, A., and Urai, J. (2020) *The 3D stress state within typical salt structures,* EGU General Assembly 2020, Online, EGU2020-15513. DOI: 10.2516/yeast/2020068

Bérest, P., Brouard, B., Karimi-Jafari, M., & Réveillère, A. (2020). *Maximum admissible pressure in salt caverns used for brine production and hydrocarbon storage*. *Oil & Gas Science and Technology-Revue d'IFP Energies. nouvelles*, *75*, 76. HAL Id: hall-02981415

KEM-19

Moghadam A., Peters E. , Nelskamp S. (submitted 2022) *Gas leakage from abandoned wells: A case study for the Groningen field inthe Netherlands*. International Journal of Greenhouse Gas Control 126 (2023) 103906.

KEM-34 (2 out of many)

Mario Martinelli, Cihan Cengiz, Antonis Mavritsakis, Mandy Korf (2022) Seismic fragility functions for embankments on liquefiable soils affected by induced seismicity (in preparation)

E Ruigrok, A Rodriguez-Marek, B Edwards, P Kruiver, B Dost, J Bommer (2022) Derivation of a near-surface damping model for the Groningen gas field *Geophysical Journal International*, Volume 230, Issue 2, August 2022, Pages 776-795, DOI: 10.1093/gji/ggac069

KEM-35

TNO (2022) Status of the TNO Model Chain Groningen per October 1, 2022 and recommendations for the public Seismic Hazard and Risk Analysis TNO: TNO2022_R11961

Kraaijpoel D, Martins JE, Osinga S, Vogelaar B, and Breunese (2022) J. Statistical analysis of static and dynamic predictors for seismic b-value variations in the Groningen gas field. Netherlands Journal of Geosciences, Volume 101, e18. https://doi.org/ 10.1017/njg.2022.15

Annex EH Current composition KEM panel and KEM- subpanel

KEM expert panel

President	
Prof Frank Baaijens	https://www.tue.nl/en/research/researchers/frank-baaijens/ Chairman KEM. Rector Magnificus Eindhoven.
Members	
Prof. Iunio Iervolino	http://wpage.unina.it/iuniervo/ Professor Naples, Stanford and Columbia. Expert on earthquake damage and risks
Prof Stefan	Wiemerhttp://www.seismo.ethz.ch/en/about-us/all-employees/stefan-wiemer/ Head Swiss Seismological Service, professor ETH. Expert induced seismicity
Prof Robert Zimmerman	https://www.imperial.ac.uk/people/r.w.zimmerman Professor of rock mechanics Imperial College London. Editor in Chief International Journal of Rock Mechanics and author textbook Fundamentals of Rock Mechanics.
Prof Majid Hassanizadeh	http://www.geo.uu.nl/hydrogeology/majid/cvmajid.html / Professor U t r e c h t University. Expert in fluid flow in porous media.
Prof. Inga Berre	https://www.uib.no/en/persons/Inga.Berre Professor University of Bergen. Expert in Modelling coupled processes in the subsurface.
Secretary	
Ipo Ritsema	https://www.linkedin.com/in/ipo-ritsema-4502481a/

KEM coordinator EZK	
Karin van Thienen-Visser	https://www.linkedin.com/in/karin-van-thienen-visser-52624b17/
KEM coordinator SSM	
Barend van Engelenburg	https://nl.linkedin.com/in/barend-van-engelenburg-89b1658
Contact NCG	
Herman van Os	https://www.linkedin.com/in/vanosherman/?originalSubdomain=nl (terminated in 2021)

KEM subpanel

Prof Stefan	Wiemerhttp://www.seismo.ethz.ch/en/about-us/all-employees/stefan-wiemer/ Head Swiss Seismological Service, professor ETH. Expert induced seismicity
Prof. Iunio Iervolino	http://wpage.unina.it/iuniervo/ Professor Naples, Stanford and Columbia. Expert on earthquake damage and risks
Prof. Fabrice Cotton	https://www.gfz-potsdam.de/staff/fabrice-cotton/ Professor of Seismology< Geoscience group at Potsdam University, Topic Director Geo-Hazards at GfZ
Prof. Femke Vossepoel	https://www.tudelft.nl/citg/over-faculteit/afdelingen/geoscience-engineering/sections/reservoir-engineering/staff/academic-staff/dr-ir-fc-femke-vossepoel/ Associate Professor in Geophysical data assimilation at Delft University
Prof. Pierre-Yves Bard	https://www.linkedin.com/in/pierre-yves-bard-b8847717/?originalSubdomain=fr Professor of Seismic risks at Grenoble University, Researcher at ISTere/IFFSTAR, Grenoble
Secretary	
Ipo Ritsema	https://www.linkedin.com/in/ipo-ritsema-4502481a/

Appendix F Terms, abbreviations and definitions

	Ground movementsThis includes seismic ground movements or vibrations and slow ground subsidence or rise under.
Soil	subsidenceSoil subsidence is the sinking of the earth's surface. For this are various causes. The process is slow and therefore distinguishes soil vibrations.
Dashboard	Simple presentation of strategic objectives. In this context, the knowledge level and availability of public tools for threat and risk analysis of my effects
DeepNL	NWO scientific research programme on the behaviour of the deep subsurface, influenced by human activities
	EZKMinistry of Economic Affairs and Climate
Induced	earthquakeAn earthquake caused by human activity such as the producing gas from deeper underground
FCM	Fragility and Consequence Model, which - given calculated ground movements (PGA, PGV) - calculates safety risks based on building vulnerability. Version 7 is currently in use.
GMM	Ground Motion Model, model used to calculate the (probabilities of) ground motions that may occur during 48 an earthquake of a given magnitude occurring at a given location. The Groningen GMM was d e v e l o p e d in several steps. The first simple model GMM version 0 (V0) was created in early 2013 for the 2013 Extraction Plan. In the years that followed, the model b e c a m e progressively more sophisticated. The current model has version number 6. NAM is currently working on the development of version 7
HRA model	Computer model used to calculate the seismic threat and seismic risk in Groningen
	IMGInstitute for Mining Damage Groningen
KEM	Mining Effects Knowledge Programme, research programme to develop an independent knowledge position commissioned by the Minister for Economic Affairs on the advice of the Dutch Safety Board (OVV). The aim is to increase understanding of possible threats and risks of mining activities in the Netherlands
KEM Panel	Panel of independent scientific experts overseeing the quality, relevance, completeness, appropriateness and independence of the KEM
KEM	subpanelKEM subpanel threat and risk analysis model developments, targeted On the (through the KEM expert panel) advice on development of the public SDRA
KNGMG	Royal Dutch Geological and Mining Society
	KNMIKoninklijk Nederlands Meteorologisch Instituut
	NACNetherlands Earth Science Congress
	NAMNederlandse Aardolie Maatschappij
	NCRNational coordinator Groningen
	NiBNational information facility Soil subsidence
	NPRNational Practice Guideline. A computational assessment according to the NPR indicates whether a building is strong enough to withstand earthquake loads. The NPR offers clients,

	provide structural engineers and contractors with (technical) guidance for new construction and preventive reinforcement of existing buildings
	PEGA
	PEGAParliamentary Inquiry into Groningen Natural Gas Extraction
PGA	Peak Ground Acceleration: the highest ground acceleration that occurs at a given location during an earthquake
PGV	Peak Ground Velocity: the highest speed at which the ground moves at a given location
Seismic ground motion	The vibration of the ground as a result of an
earthquake Seismic ground	speedThe speed at which the ground vibrates as a result
of an	
	earthquake
Seismic ground	accelerationThe change in the speed at which the ground vibrates due to an earthquake
Shake maps	Maps showing the contours of the occurred maximum ground acceleration (the PGA), maximum ground velocity or maximum pseudo spectral acceleration (PSA) for a given earthquake
SSM	State Supervision of Mines (supervisor of oil and gas production in the Netherlands, among other things)
	SDRASeismic threat and risk analysis
	SHRASeismic Hazard and Risk Analysis
State-of-the-art	Highest level of development according to the current state of
the art Tcbb	Technical committee on soil movements
TCMG	Temporary Committee on Mining Damage (merged into the Groningen Mining Damage Institute from 1 July 2020)
TNNetherlands	Organisation for Applied Scientific Research
Validation research	Checking a value or method to demonstrate show that a device, system or instrument is capable of producing intended results with a high degree of certainty