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From: Chairman KEM scientific expert panel Prof. F. P.T. Baaijens Date:
17 August 2023
Subject:Mining effects knowledge programme (KEM), Annual report 2022

His Excellency, Honourable Minister,

In 2016, the Minister of Economic Affairs took the initiative to set up and launch the Mining Effects Knowledge Programme. Budget has been made available at EZK and SSM for this purpose. The independent KEM scientific expert panel (KEM panel) was set up to test the research questions put forward, ensure scientifically sound and independent (international) implementation and interpret the research results in terms of quality and impact.

The KEM panel started on 31 May 2017 and has now been in operation for 6 years. This 5e annual report describes the results achieved up to December 2022. This is in light of the mission, strategic research framework and research agendas associated with the KEM. In accordance with the EZK Minister's room letter,
dd 24-06-2016, parliamentary paper 32849, no 80, this report focuses on the substantive progress of the research programme and knowledge assurance and exchange. This is not an annual financial report.
It also discusses the results of the 2022 KEM evaluation. This external evaluation concluded that KEM is largely effective and efficient. The annual report indicates how the shortcomings and recommendations will be addressed.

This letter also sets out a number of issues that the KEM panel chairman would like to discuss with you in a forthcoming progress meeting.

1. Results of the KEM research programme in 2022

The KEM programme is running as mandated. The quality of most of the projects is excellent in the opinion of the KEM panel and the impact is meaningful. The strategic objectives are being met. There has been a shift from research into seismicity Groningen to soil subsidence and leakage risks from 2020, and more attention is being paid to impacts of mining activities that are part of the energy transition. The
priorities indicated in the report "Towards a (national) research agenda and risk toolbox in the Netherlands" were leading in this regard.

Some specific outcomes and impacts of KEM studies delivered in 2022 are:

- The project investigating long-term pressure equalisation and fluid flow in and around gas fields in the northern Netherlands, its long-term soil movement effects (subsidence and seismicity) after Groningen gas field closure, will be completed in 2022. The results provide more clarity on location and nature of likely soil movements after cessation of production in Groningen and neighbouring gas fields. The study concludes that after cessation of extraction, the probability of soil subsidence and seismicity around the Groningen gas reservoir increases slightly but will be limited and above the Groningen gas reservoir mainly decreases. In this project, long-term fluid leakage or
  -migration effects considered. The probability and magnitude of gas leakage risks are considered small (KEM-19).
- The KEM-24 project that studies the effect of gas injection to influence reservoir pressure (stop or reverse pressure drop) on seismic risks will be completed by the end of 2022. Unfortunately, the project - partly due to the 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 SDRA Groningen tool developed by TNO (this new research will start in 2023 under project number 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 was 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. This has been shared with DeepNL.
- In 2021, the literature review, KEM-31, on the generation, propagation and potential effects of low-frequency noise (LFG) from mining installations was completed. This study showed that the assessment of LFG from mining installations involves a large number of variables and unknowns, which means that a simple assessment of LFG is not always possible. In addition, it follows from this literature review that much knowledge has not yet been centralised or harmonised, such as, for example, the general characterisation of the noise field, the most appropriate measurement standards, case studies of LFG near mining installations and the derivation of dose-effect relationships. SSM is considering a follow-up.
- 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 Groningen SDRA (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 of 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.
- 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 investigated and developed in KEM-43 in 2022 concern: (1) the calibration with more and better data, (2) alternative seismic source model (a.o. based on KEM-08 insights), the ground motion model (a.o. based on KEM-02, KEM-04 insights) suitable for risk analysis after cessation of production (3) GMMV7 ground motion model and consequence model (in line with KEM subpanel advice). 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.

The following research projects, which started in 2022 or earlier, continue through 2023:

- 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 looked at (the combination of) geomechanical and operational parameters, which 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 completed after which it will be published by SSM.
- The KEM-16 project focuses on the development and integration of public subsidence threat and risk analysis tools. One subproject concerns the quantification of subsidence from a combination of shallow causes and deep causes. A second subproject concerns subsidence for an area with multiple deeper causes (multiple gas extraction). The project is largely completed 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 and the likelihood of surface damage to buildings has been delayed and will be specified in 2023 (KEM-16b).
- A literature review on monitoring methods of underground CO_2 storage offshore (KEM-27). Many borehole and geophysical methods have been used and evaluated in various CO_2 storage projects worldwide. A technical review is conducted on best practices for monitoring CO_2 injection and, in addition, new techniques are evaluated. The results should help sharpen the monitoring guidelines for CO_2 storage in the Netherlands.

- A study and risk analysis of underground hydrogen (H_2) storage in conglomerates of salt caverns (KEM-28). 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.
- KEM-34, a contribution to a large EU project, focuses on being able to quantify the vulnerability of various infrastructures to earthquakes, which can cause damage. The project also focuses on accelerating risk communication with national or regional safety teams. KEM-34 focuses on the case of Groningen, targeted rapid threat information (KNMI) and risk information on dykes, bridges, locks and infrastructural works.
- 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 following research questions were considered by the KEM panel in 2022 and approved for addition to the KEM work stock:
- The influence of controlled brine bleed-off on the stability of caverns and cavern clusters (KEM-45).
- 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).
- 3D modelling of subsidence with heterogeneous geological substrates and comparison with existing 1D/2D subsidence tools to determine at which heterogeneity existing modelling is inadequate (KEM-47).
- 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).

These projects are very likely to be tendered in 2023 and will continue into 2024-2025.

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.

In 2022, the KEM panel, together with the scientific research programme DeepNL, argued in a widely supported memorandum for a national coordinated research strategy for the responsible use of the Dutch subsurface for the energy strategy. The proposed research strategy includes long-term independent scientific (NWO), applied research (including KEM and GTIs) and monitoring (including KNMI) as well as the development of public DRA tools. The KEM panel is pleased that the Parliamentary Inquiry into Groninger Earthquakes now makes the same recommendation and that the Ministry of Economic Affairs and Climate has pledged to work on it (Measure 49).

2. Results of KEM knowledge assurance and exchange

The KEM panel advised in 2018 that knowledge assurance can best be shaped by the deployment of public tools for the analysis and representations of mining threats and risks. These tools (or toolbox) can be developed and implemented with initial funding through KEM, and maintained with additional funding from the Ministry of Economic Affairs or SSM. In 2020, this advice from the KEM panel resulted in the development and launch of TNO's public seismic threat and risk analysis tool for gas extraction in Groningen (= the public SDRA). In 2020, the KEM subpanel was established to advise on plans for the further development of this public SDRA. The public SDRA was again used by EZK in 2022 to underpin the operational strategy of the Groningen gas field for the 2022- 2023 gas year. In December 2022, the KEM subpanel issued advice to SSM for the 2023 gas year regarding the TNO

Status and model version report. Advice on TNO model developments report (2021) to EZK is scheduled for February 2023.

The KEM panel recommends that all seismic risk tools under development, largely outside KEM, be based on a common methodology. This harmonisation increases quality, simplicity, avoids duplication and makes communication clearer. The interpretation of the development of public tools for other mining effects needs further attention.

The KEM website (kemprogramma.nl) has existed since October 2018 and aims to share KEM research results and evaluations. The website had about 2450 visitors in 2022, who viewed more than 28,000 pages (40% more than in 2022), mainly the KEM project pages. These pages show the research question, reports and evaluations, as well as the potential impact of research. EZK and SodM interpret the results (found on the nlog.nl and SodM websites).

Communication with the research field in the Netherlands (including involvement with DeepNL research) is going well, including through the colloquium series set up jointly with DeepNL in which research results from both programmes are presented and discussed. Contacting stakeholders in different mining regions about the results of conducted research and raising new research questions is not the primary task of the KEM panel, but of the Ministry of Economic Affairs (e.g. KEM-48) and SSM. The KEM subpanel did suggest some topics that could be picked up in KEM.

3. KEM panel and KEM subpanel activities

The KEM panel was supplemented by Prof M Gerritsen after the departure of Prof I Berre from the University of Bergen. The entire panel met four times (twice online and twice physically) in 2022, discussing new research questions and project progress and discussing and finalising results and evaluations of projects.

As of 2022, the KEM subpanel has issued two opinions regarding TNO's public SDRA model Groningen to SSM and EZK, respectively.

4. KEM evaluation: conclusions, recommendations and improvement actions

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 the management of mining risks 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. This led to a decision by SSM and EZK in late 2022 to continue KEM for at least 5 years (2023-2027). See Parliamentary letter on Mining Knowledge Programme, dated 20-12-2022, reference PDGGO-DTDO / 22556192. The evaluation also identified shortcomings and made recommendations. These concern:

- Tightening the mission, as set out in late 2022 in room letter (Parliamentary paper 32849, no. 213): (1) Conduct independent applied research to increase understanding of the potential impacts and uncertainties of mining activities, (2) Synthesise 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 trust 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.

Actions for this were agreed by the end of 2022 and will be developed and implemented in 2023.

Conclusions KEM annual report 2022 and outlook activities in 2023

Through 2022, KEM has given a solid impetus with impact to public knowledge development on mining risks and engaging renowned international research groups. KEM ran well in 2022 and is expected to do so in the coming year, the first of the next period.
In 2023, results are expected from several KEM projects still ongoing at the end of 2022, such as research questions related to seismic risks in geothermal energy, validation of GMMV7 using 3D wave modelling and vulnerability of infrastructures, such as dykes and bridges, in stronger quakes (European project). In addition, the two pilots on subsidence will be completed resulting in publicly available subsidence tools. In 2023, the results of the research into hydrogen storage in salt caverns and the monitoring of CO_2 storage offshore will also be delivered. In addition, five new projects, partly prompted by citizens' requests, will be launched.

The positive KEM evaluation led to the continuation of KEM with a plan to address a number of identified shortcomings and recommendations.

Topics for the KEM progress interview

I propose to organise a progress meeting with You soon to explain this 5^{e} annual report of the KEM panel, specifically exchanging views on the following issues:

1. Comment on the status of KEM through 2022 and look ahead to the ongoing KEM research programme 2023-2027.
2. Agree KEM strategy 2023-2027, explain status of improvement actions following KEM review in 2022 and discuss steering dashboard to be used.
3. Discussion operational areas for improvement:
    a. appointment policy and staffing of the KEM scientific expert panel,
    b. lagging spending on KEM in 2023 at both SSM and EZK, both with different causes,
    c. Harmonisation other seismic HRA instruments.
4. Expectations towards KEM (and DeepNL) regarding the design of a national research strategy for responsible use of the Dutch Subsoil in the context of the energy transition by strengthening independent research at NWO, KEM and JTIs (Cabinet response Measure 49 to PEGA recommendation 9).

I will ask the secretary of the KEM panel to schedule an appointment for this in consultation with the EZK and SSM representatives. Preference will be given to the end of September or first half of October, given the fourth agenda item.

I hope this has adequately and sufficiently informed you about the activities and results in the past year of Mining Impact Knowledge Programme.

Kind regards



Professor Frank Baaijens (chairman)

cc: Prof I. Iervolino, Prof S. Wiemer, Prof R. Zimmerman, Prof M. Hassanizadeh, Prof I. Berre, Drs I.L. Ritsema (secretary)

cc: Esther Pijs, Caroline van Dalen (Ministry of EZK) and Theodor Kockelkoren, Francine Kiewiet de Jonge - Lulofs (SSM)