

**KEM Research review, evaluation and interpretation (max. 4 pages + annex)**

**TITLE *Infrasound generation and observation***

**KEM Quality review**

*Description of the scientific quality of the results (team, research method, research results, quality of the products, ...), if needed external review result (project evaluation text website)*

KEM-31 investigates the origin and impact of low frequency noises (LFN, sometimes called infrasound) related to mining activities, such as the production, transport and storage of gas, geothermal activities, or salt mining. It also addresses monitoring technologies and future trends of this issue in the Netherlands, providing some recommendations to address it.

LFN represents a nuisance to the effected population, in extreme cases it can have a negative impact on health. In the Netherlands, LFN-related complaints are rising, but so far, the phenomenon has not been systematically evaluated and standards are lacking. KEM-31 is a first and significant step to close this knowledge gap and exemplarily in addressing in high quality and impactful way a KEM research question of relevance to multiple stakeholders. LFN are a challenging topic, not only because measurements are sparse and LFN can travel long-distances, but even more so because the research must be multi-disciplinary and consider not only technological but also medical aspects as well as social and contextual factors.

The results of KEM-31 are summarised in a final report comprising about 100 pages. The report is technical in nature (as it should be) but understandable in most parts to non-experts. It is well written, clear, well referenced and overall well-illustrated, although some figures could be improved. The authors were successful in introducing the relevant topics, making the report a useful and understandable reference document for a wide audience. The report is well structured: It clearly outlines the scope of the research question, the methodology used and results of the study. The report describes well the state of the art based on a broad literature review and ends with well-balanced conclusions and recommendations. The split in three areas of analysis, observational techniques, the analysis of LFN generation at the source and potential impacts on health, is a sensible work breakdown structure. A public summary statement will help to bring this topic to the public.

The team of KEM-31 is composed of recognised experts in the topic, bringing together the interdisciplinary expertise needed to adequately address the question. KNMI and RIVM are the Dutch agencies most closely related to LFN, and the collaboration with M+P raadgevende ingenieurs B.V. enriched the team. Overall, the quality of the results and reports is fully satisfactory and in lie with KEM expectation.

**KEM Evaluation of the results**

*Evaluation whether the research questions are addressed adequately (questions answered, precision and uncertainties on outcomes, potential consequences on current practice addressed, ...) (project evaluation text website)*

The report first introduces in chapter 2 in understandable way the concepts of LFN and methods to measure and characterise it. This is clearly needed, since for example the atmosphere plays an important role in LFN transmission. In the reviewers' opinion, slightly more detail with respect to measurements techniques and sensors would have been useful, as would have been more comparison with the monitoring networks in other countries, but the chapter introduces all relevant background information needed for non-expert readers.

The second section of the report (Chapter 3) addresses exhaustively the various sources of LFN, and the mechanism how LFN are generated. This inventory is useful and in-line with the research question posed by KEM, especially considering that little comprehensive literature is available. The discussion on the noise effect of induced earthquakes establishes that while such noises do exist, they are infrequent, short-lived, and not a major source of nuisance. Noise reduction measures are only very briefly and purely qualitatively mentioned, a somewhat extended treatment outlining options and related costs would have added to the description. The inventory of sources of LFN would be even more useful if the sources could be ranked in relevance in the Dutch context, possibly even regionalised, or linked to medical effect and observations. For example, an atlas of the primary sources of LFN in the Netherlands in a given region could be developed. However, given the lack of observational data, complex propagation path, and challenging of associating LFN with source regions or individual sources, such a ranking and regionalisation is clearly beyond the scope of the study.

Chapter 4 on human perception of LFN, its health effects and societal response is a well-balanced introduction and analysis of the impact of LFN on people and communities. Based on empirical data and expert opinion, the chapter establishes the scale of the problem in the Netherlands, but also outlines the key challenges when assessing health effects, such as the role of co-determinants. Here again a more extended treatment of the state of the art also outside of the Netherlands would have been helpful, also with respect to existing normative frameworks.

The extensive final conclusions and recommendations section of the report is useful, since it lists in a comprehensive way the key findings and points at future research needs. Lacking in these recommendations is ranking to identify the most urgent and/or most cost-effective measures. The results overall are large, not specifically innovative or original research, and they cannot be readily published. However, they are fit for purpose and fully in line with the original KEM task. The report represents

in essence a good review article, written for a mixed audience, and it usefully rationalises the discussions on LFN, and to suggest future needs.

#### **KEM interpretation of the outcome**

*The interpretation of the results (consequences on methods/data to be used in practice, on risk instrument modules, on inspection procedures and operator procedures, ...) (project evaluation text website)*

The report on LFN should be made available openly, and it can serve as a useful and impactful reference document on the state of the art in understanding LFN in the Netherlands. The report is valuable for a range of stakeholders: Municipalities faced with LFN concerns, operators planning future activities or responding to complaints, concerned citizens and media, and last but not least also regulators. The report in that sense is also an example of a successful KEM-funded project that contributes to an informed dialogue on mining related effects.

The report gives important recommendations for 'good practise' monitoring approaches and instrumentation to be used (and not to be used). These can help to define more standardised and higher quality approaches to establishing LFN impact, and at identifying the potential sources of LFN. More harmonised approaches to measuring LFN, as well as more high-quality measurements overall, are needed to better define the scale of the problem and to identify useful mitigation measures.

The final discussion and conclusion sections are valuable outcomes of the report, because they identify knowledge gaps and future research need related to LFN. The obvious statement is that indeed more research in this domain would be desirable, especially at the interface of LFN and their potential health effects. The report adds a long list of suggestions for specific follow up actions. This is useful, albeit also challenging, because these suggestions vary greatly in importance, in costs, in timescale, in approaches and in actors that need to engage. The report outlines clearly that the topic may warrant follow up actions, but given the complexity of LFN, it is not obvious how potential follow up actions would look like, who should carry them out, what they may cost and who should fund them.

It is more relevant to conduct campaign style measurements using arrays to define the LFN 'landscape', to install more (low cost) sensor and build up a national network, to compile a list of detailed case studies, to work on better regulatory frameworks, or to work on the effect of LFN on individual and communities (to name a few of the suggestions). And which one of these actions should be part of the mandate of responsible agencies, which ones can be fundamental research projects or which one be potential follow-up KEM projects? An additional complexity comes from the fact that LFN is not solely a topic related to gas and geothermal mining activities but can be generated by many industrial activities (e.g., chemical sites, wind turbines) or nature effects, so ideally future activities would try to find synergies between different needs.

To define the next steps and possible follow up projects, it might be most useful to 1) publish this report and bring it to the attentions of stakeholders throughout Netherlands. 2) Invite interested stakeholders from federal/local offices, academia, industry, public, etc. to a dedicated workshop on LFN and its effects on people that discusses and prioritizes future R&D needs; 3) Translate these needs into project ideas that can be discussed, for example, with SODM/EZK/KEM. The next role of KEM could be to finance such a workshop.

#### **Closure text for the website**

*A summary in simple terms of the goal, the outcome and impact on mining policies or toolboxes of the research project (project evaluation text website)*

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LFN represents a nuisance to the affected population, in extreme cases it can have a negative impact on health. In the Netherlands, LFN-related complaints are rising, but so far, the phenomenon has not been systematically evaluated and standards are lacking. LFN are a challenging topic, not only because measurements are sparse and LFN can travel long-distances, but even more so because the research must be multi-disciplinary and consider not only technological but also medical aspects as well as social and contextual factors. The KEM-31 project is executed by recognised experts in the topic of KNMI, RIVM and M+P raadgevende ingenieurs, bringing together the interdisciplinary expertise needed to adequately address the question.

The results of KEM-31 are summarised in a final report comprising about 100 pages. The report is technical in nature (as it should be) but understandable in most parts to non-experts. It is well written, clear, well referenced and overall well-illustrated, although some figures could be improved. The report describes well the state of the art based on a broad literature review and ends with well-balanced conclusions and recommendations. The split in three areas of analysis, observational techniques, the analysis of LFN generation at the source and potential impacts on health, is a sensible work breakdown structure.

The report first introduces (Chapter 2) in understandable way the concepts of LFN and methods to measure and characterise it. Chapter 3 addresses the report exhaustively the various sources of LFN, and the mechanism how LFN are generated and chapter 4 on human perception of LFN, its health effects and societal response is a well-balanced introduction and analysis of the impact of LFN on people and communities. The extensive final conclusions and recommendations section, only missing a cost benefit-based prioritisation, of the report is useful, since it lists in a comprehensive way the key findings and points at future research needs. The report provides for important recommendations for 'good practise' monitoring approaches and

instrumentation to be used (and not to be used). These can help to define more standardised and higher quality approaches to establishing LFN impact, and at identifying the potential sources of LFN. More harmonised approaches to measuring LFN, as well as more high-quality measurements overall, are needed to better define the scale of the problem and to identify useful mitigation measures.

The authors were successful in introducing the relevant topics, making the report a useful and understandable reference document for a wide audience. The report is well structured: It clearly outlines the scope of the research question, the methodology used and results of the study. Overall, the quality of the results and reports is fully satisfactory and in line with KEM expectation. The report represents in essence a good review article, written for a mixed audience, and it usefully rationalises the discussions on LFN, and to suggest future needs. A public summary statement will help to bring this topic to the public.

The report on LFN can serve as a useful and impactful reference document on the state of the art in understanding LFN in the Netherlands. The report is valuable for a range of stakeholders: Municipalities faced with LFN concerns, operators planning future activities or responding to complaints, concerned citizens and media, and last but not least also regulators and the public. To define the next steps and possible follow up projects, it might be most useful to 1) publish this report and bring it to the attention of stakeholders throughout Netherlands. 2) Invite interested stakeholders from federal/local offices, academia, industry, public, etc. to a dedicated workshop on LFN and its effects on people that discusses and prioritizes future R&D needs; 3) Translate these needs into project ideas that can be discussed, for example, with SODM/EZK/KEM.