Anna van Buerenplein 1
2595 DA Den Haag
P.O. Box 96800
2509 JE The Hague
The Netherlands

www.tno.nl

T +31 88 866 00 00

TNO report

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Large-Scale Energy Storage in Salt Caverns and Depleted Gas Fields - Public summary on project and outcomes

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Author(s)	Remco Groenenberg
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Contents

1 Preface

This public report summarizes the main outcome of the research project “Large-Scale Energy Storage in Salt Caverns and Depleted Gas Fields”, abbreviated as LSES. The project, which was given subsidy by RVO, had two main goals:

1. Improve insights into the role that large-scale subsurface energy storage options can play in providing flexibility to the current and future transitioning energy system;
2. Address techno-economic challenges, identify societal and regulatory barriers to deployment, and assess risks associated with selected large-scale subsurface energy storage technologies, in particular Compressed Air Energy Storage (CAES) and Underground Hydrogen Storage (UHS).

The research was carried out by TNO in close collaboration with project partners EBN, Gasunie, Gasterra, NAM and Nouryon. Activities were divided over 4 work packages that ran in parallel:

1. Analysis of the role of large-scale storage in the future energy system: what will be the demand for large-scale storage, when in time will it arise, and where geographically in our energy system will it be needed?
2. Techno-economic modelling (performance, cost, economics) of large-scale energy storage systems, focusing in CAES and UHS in salt caverns, and UHS in depleted gasfields - analogous to UGS (Underground natural Gas Storage).
3. Assessment of the current policy and regulatory frameworks and how they limit or support the deployment of large-scale energy storage, and stakeholder perception regarding energy storage.
4. Risk identification and screening for the selected large-scale subsurface energy storage technologies.

The results of the activities performed in these four work packages are detailed in four separate public reports. These four reports are complemented with a public synthesis paper that summarizes the main project findings.

1.1 Project details

Subsidy reference: TGEO118002

Project name: Large-Scale Energy Storage in Salt Caverns and Depleted Gas Fields

Project period: April 16, 2019 until August 30, 2020

Project participants: TNO (executive organization), EBN, Gasunie, Gasterra, NAM and Nouryon

Het project is uitgevoerd met subsidie van het Ministerie van Economische Zaken en Klimaat, Nationale regelingen EZ-subsidies, Topsector Energie uitgevoerd door Rijksdienst voor Ondernemend Nederland.

1.2 Project summary

Future outlooks agree that a portfolio of flexibility options needs to be deployed in the energy system to enable the integration of large-scale intermittent renewable energy sources. As part of the solution space, large-scale energy storage underground can provide flexible bulk power management services for electricity, gas and heat commodities, and offers essential services to society in the form of strategic energy reserves and balancing solutions for unavoidable seasonal variations. It is also a key enabler for the Power-to-Gas value chain, i.e., the large-scale conversion of renewable electricity into versatile energy carriers (e.g. hydrogen) that can be efficiently transported and stored for longer periods of time. Today, many of these services are provided by the storage of natural gas, which is already safely stored in large quantities (about 14 billion m^3, or 140TWh) in salt caverns and depleted gas fields in the Dutch subsurface, and that of many other countries in Europe, to balance supply and demand on a daily basis and secure supply during cold winters. However, as the role of natural gas will decrease in the Dutch energy system the need grows for the large-scale storage of energy in a different form.

In this project, we identified the opportunities (technical, market) and challenges (technical, economic, market, societal, and regulatory) for implementation of two such alternative forms of energy storage underground: Compressed Air Energy Storage (CAES) in salt caverns and Underground Hydrogen Storage (UHS) in salt caverns and depleted gas fields. A diverse set of research activities was executed in four work packages of which the results will be summarized below.

In work package 1 the potential role of large-scale storage in the future energy system was explored with the use of two energy system optimization models and for two reference years: 2030 and 2050. Both models are optimization models, i.e., they minimise the social cost of the power (COMPETES, a European electricity market model) or energy (OPERA, a national integrated energy system model of the Netherlands) system while satisfying demand and emission requirements.

For 2030, the reference scenario is based on the targets and policy measures of the Climate Agreement (CA) of June 2019 and designated briefly as CA2030. The modelling results indicate that relatively limited electricity storage (1-2 TWh) is foreseen for the year 2030. Furthermore, the annual volume of hydrogen stored in the models is in the range of 66 GWh (OPERA) to about 900 GWh, and depends strongly on a) reaching the Climate Accord ambitions to install up 3-4 GW electrolysis capacity and b) the uptake of this additional hydrogen by demand sectors (and their demand profiles).

For 2050, the reference scenario is based on the National Management (NM) scenario, developed recently by Berenschot and Kalavasta (2020). The modelling results show that in 2050 flexibility requirements for electricity are dominantly provided by cross-border trade and storage in electric vehicles. In both models electricity storage is dominated by batteries of electric vehicles (EVs), with total annual storage volumes of all EV batteries that are fairly similar (30-33 TWh). In the model outcomes, other technologies besides EV batteries, such as CAES, hardly play any role in electricity storage. Apart from specific modelling characteristics and limitations, the major reason for this finding is that alternative flexibility options in the model have a better techno-economic performance to meet the flexibility needs of the Dutch power system. Note, however, that the current study focusses on the flexibility needs due to the variability of the residual power load – notably VRE supply – and did not consider other stability and flexibility needs of the power system.

The modelling results do show a clear, significant role for UHS though, notably in terms of annual volume of H_2 stored (17-22 TWh). This type of energy storage, however, is not typical seasonal storage – such as the current storage of natural gas. An indicator for this are the annual full cycle equivalents (FCEs) of UHS, defined as the number of times the storage is filled and emptied, ranging from 6 (OPERA) to 14 (COMPETES). Consequently, the required size (physical storage capacity) of this storage medium is much smaller (1.5-2.9 TWh; 2-3% of total H_2 demand, requiring 10-20 salt caverns) than the total annual volume stored (17-22 TWh; 20-30% of total H_2 demand).

A limitation of both models is that they optimise over a single year only and not over a time horizon. Moreover, as the models aim for minimal cost, they do not allow for any redundancy in the system to cover for events that jeopardize the security of supply (e.g. exceptional weather conditions, supply disruption, etc.) and to meet other policy-strategic considerations (e.g. strategic reserves, energy independence, etc.). With reference to exceptional weather conditions, it must be noted that in the current study, the model analysis focussed solely on the flexibility (storage) needs during a typical ('normal') weather year and do not consider these needs during more extreme weather years, e.g. with a Dunkelflaute (a prolonged period of very cold and calm weather in winter).

In work package 2 the technology concepts, deployment status, and technical performance of CAES and UHS were assessed, and several open questions regarding the techno-economic feasibility of these technologies were addressed.
CAES is an electricity storage technology. At charge, electrical energy is stored in mechanical form by compressing air, and stored in (commonly) salt caverns. At discharge, electricity is regenerated by using the compressed air to drive a turbo-expander/turbine. There are two main technology concepts, which mainly differ in how they deal with the temperature change of the air during compression and expansion: diabatic CAES (D-CAES), without storage of compression heat, and advanced adiabatic CAES (AA-CAES), in which the heat generated during compression is stored for re-use during expansion.

Worldwide, two CAES plants have been commercially operational for many years, one in Germany (Huntorf, 321MW power capacity, 2.5GWh storage capacity, up to 8 hours discharge) and one in the US (McIntosh, 110MW power capacity, 2.6GWh storage capacity, up to 24 hours discharge), both of which are based on the relatively mature D-CAES concept (TRL 7-8). Round-trip efficiencies of up to 60% are deemed feasible for D-CAES with efficient utilization of waste heat (produced while combusting the secondary fuel to heat up the expanding air) during the generation process. AA-CAES is not a mature technology (TRL 5), mainly because efficient thermal storage of heat at the very high temperatures involved (up to 580°C) is challenging and costly.

CAES systems are classified by two performance parameters: their generation capacity at full load (power output in MW), and the duration (in hours) over which this power can be delivered. By multiplying one with the other, the electricity production capacity (in MWh) is obtained. Typically, the power range of CAES systems is between 100-500MW, and the duration over which this power can be delivered ranges from hours to a day, i.e., they operate on intra-daily to daily cycles. Geomechanical numerical simulations that were done in this project show that the pressure and temperature effects of this fast-cyclic injection and withdrawal of air do not jeopardize cavern stability and integrity.CAES systems are designed to be competitive in delivering a suite of flexibility services that are valued by utility companies, owners of generation assets, and grid operators. They can generate revenue from two main groups of services: arbitrage, i.e., providing electricity traders a means to earn money by levering the hourly price differences on electricity markets; and ancillary services, such as frequency regulation, reserve power, black start, load following, and synchronous inertia, that are procured by grid operators and asset owners of generation assets to manage grid stability.

While the technical potential for developing CAES in salt caverns in the Dutch subsurface is deemed high (about 0.58TWh in ca. 321 to be developed salt caverns onshore according to TNO and EBN), the market readiness can be improved e.g. by developing innovative business cases and market structure evolution. Next to this, the further roll-out of variable renewable energy technologies, such as wind and solar in the Netherlands and surrounding countries, is expected to increase the need for flexibility services that CAES can offer. An exploratory economic analysis that was done in this project indicates that a price arbitrage-only business case for D-CAES may not be viable**.** An important limitation in the analysis is the assumption of full-load only operation mode, which leads to economically suboptimal simulated asset operation. CAES is however well-suited to operate at lower power, and can do so with minimal efficiency loss at power outputs down to 15% of rated power. Furthermore, the exploratory analysis does not include additional (complementary) revenue streams (e.g. from ancillary services such as grid balancing, redispatch, black start, etc.), and excludes a multi-year stochastic analysis of the variability of renewables feed-in and its influence on electricity prices. Hence the total revenue is probably underestimated significantly.

In recent years, several demonstration and (commercial) development projects have been conducted and/or are ongoing (in the Netherlands, Denmark, UK, and US) which indicates a strong renewed interest in CAES, probably sparked by the increasing need for flexibility services to integrate the growing share of variable renewables (wind, solar).

Analogous to natural gas, hydrogen can be stored underground (UHS), in compressed gaseous form, in salt caverns and potentially also in depleted gasfields, in which tens of millions (cavern) to (potentially) billions of m^3 (depleted gas field) of hydrogen can be stored. According to TNO and EBN, about 14.5 billion m^3 (43.3 TWh_t) hydrogen storage capacity could potentially be created in to be developed salt caverns in the Dutch subsurface onshore, while in depleted gas fields 93 billion m^3 (997 PJ; 277 TWht) could be created onshore, and 60 billion m^3 offshore (644 PJ; 179 TWht). A technical performance analysis of the Grijpskerk, Norg and Alkmaar UGS facilities as if they would be used for storing hydrogen, and a comparison to their current performance for natural gas, reveals that the lower density (8-10 times) and viscosity of hydrogen relative to methane results in 2.4 to 2.7 times higher withdrawal rates for hydrogen. These high rates partly compensate for the lower energy content (3-4 times lower) of hydrogen, resulting in an energy throughput of 0.7 to 0.8 times that of methane.

Worldwide, four storage facilities for pure hydrogen in salt caverns are already operational, and practical experience with these sites has shown that hydrogen can be safely stored in this way for long periods of time. Important challenges remain to be addressed though, in particular in relation to the integrity and durability of wellbore materials and interfaces, because injection and withdrawal are expected to occur much more frequently and cyclically, and at higher volumetric rates than is currently the case.

Hydrogen can also potentially be stored in depleted gas fields. Recent demonstration projects in Argentina and Austria with injection of up to 10% of hydrogen in a mix with natural gas into a depleted gas field have shown that hydrogen can be safely stored without adverse effects to installations and the environment. However, not all hydrogen was recoverable due to diffusion, dissolution (into formation water), and conversion to methane. No sites exist however where pure hydrogen is stored, and there are open questions regarding the influence of geo- and biochemical reactions of hydrogen with rocks, fluids and micro-organisms in depleted gas reservoirs and the potential (technical, environmental, economic) risks associated with these reactions, in particular the formation of hazardous and/or corrosive fluids, and the degradation of injection and/or withdrawal performance, that may negatively impact feasibility.

Indeed, the results of a literature review and geochemical modeling study done in this project show that geochemical processes that could be of concern for hydrogen storage in the Netherlands include a) reduction of iron minerals (pyrite) forming H_2S;b) reduction of hematite to magnetite, sequestering H_2 and producing H_2O; and c) reduction reactions and H_2S formation change the fluid composition and pH, possibly resulting in precipitation and dissolution of secondary minerals (changing the pore space). In particular, pyrite reduction as a result of H_2 storage may occur, leading to H_2S formation in the gas phase, which may affect safety, materials selection, facility design and economics. However, because kinetic effects were not taken into account in the modelling, these results reflect a worst case scenario. Also, the presence of H_2S scavenging minerals such as siderite may again “absorb” the H_2S, a reaction that was not extensively studied in this project. To accurately assess the risk of H_2S formation in hydrogen storage reservoirs it is of the utmost importance to improve the predictive power of the geochemical models, which will require incorporation of kinetic rates at high temperatures and high H_2 partial pressures (obtained with laboratory experiments), as well as H_2S scavenging reactions and transport in the reservoir. Furthermore, a biochemical modelling study indicates that bacterial sulphate reduction and methanogenesis may both pose a risk for underground hydrogen storage, which is also reported in literature. In the simulations, the extent of sulphate reduction modelled leads to significant levels of H_2S. How likely these amounts of H_2S are to develop will require further experimental and numerical modelling research.

An exploratory analysis of the economics of a flexible hydrogen production asset with storage in a salt cavern vs. continuous hydrogen production indicates that the lower electricity costs in the business case for the flexible production asset, due to reaped benefits from being able to “overproduce” (and store) hydrogen at low electricity prices, appears insufficient to compensate for the extra investments in a larger electrolyser, the storage and the related equipment, and the higher operational costs. Especially an increase in the amount of hours with low electricity prices (due to a larger installed capacity of solar and offshore wind) and further developments in electrolyser technology favour the business case of flexible hydrogen production and storage, and provide perspective on a viable business case. Additional revenue streams (to selling hydrogen) can be generated by including alternative benefits of storage in the business model that were outside the scope of this study. Examples are earnings from offering flexibility services to the electricity system with the up- and down- regulating capacities of the electrolysers, and remunerations for offering security of supply of hydrogen to market players and society.

In work package 3 the permit procedure for large-scale subsurface energy storage projects and their societal embedding were studied. One of the key results from both the literature study and the interviews with the various operators is the importance of involving the local community well before, during and after the decision-making process. At the start of a project, the societal playing field (stakeholder analysis, cultural and historical background, community dynamics) must be taken into account, based on which the level of participation and the participation strategy can be determined. Although the Environmental Act will include, for storage projects, new requirements for participation at an early stage (the exploration phase), in addition to the decision-making phase, the new requirements, too, have little substance and leave a great deal of room for further interpretation. Consequently, the level of participation must not be determined from legal frameworks, but from the societal playing field, and in relation to the overall project strategy. Involving stakeholder is important in all the phases, from the early preparations till the realization.

Furthermore, the study identified a need for supporting energy policy at the national as well as the regional and local level. An important policy instrument for large-scale subsurface energy storage is the Vision on Subsurface Planning (In Dutch: *Nationale Structuurvisie Ondergrond* - STRONG), in which subsurface energy storage in depleted gas fields and salt caverns is anchored. Subsequently, it is important that energy storage is also sufficiently embedded in provincial/regional and municipal/local policy related to the ambitions on sustainability and the energy transition. If types of energy storage such as CAES and UHS are given a role in local energy policies and environmental plans, it will give the local community and stakeholders the opportunity to submit their views and discuss the role of this type of storage in their immediate environment.

Finally, the study found that there is a lack of experience among project developers, the competent authority and their advisors with the development and decision-making process for large-scale subsurface energy storage projects, which results in lengthy (pre-) development phases due to the complexity of these projects, the long duration of the permit process to get all required permits, and the interaction with the local community. More experience would help to set up a more effective decision-making process. Building on a solid knowledge base, getting routines in the permit procedures as well as providing clarity on the different roles of all bodies that are involved in evaluating and granting the permits are essential elements in speeding up the decision-making process. The Minister of Economic Affairs and Climate has a decisive role in the duration and the quality of both the licensing procedure and the participation process. At the same time, the fact that the Minister has to combine different roles and responsibilities (policy maker, coordinating body and competent authority) in different stages of project development is very challenging and previous research shows that it could cause distrust in the fairness of the decision making process. The new coordination regulation that applies to large-scale subsurface energy storage projects is intended to strengthen the governing role of the Minister of Economic Affairs and Climate and provides tools to do so.

In work package 4 the potential risks associated with UHS and CAES in salt caverns, and UHS in depleted gas fields (porous reservoirs) were inventoried, and possible mitigation measures were explored. Risks were inventoried by conducting a literature review, and supplemented with expert knowledge. All risks were included in a risk inventory that categorizes the risks into their relevant project phase, system component, reservoir storage type and TEECOPS (technical, economic, environmental, commercial, organisational, political and societal) category. In total, 159 risks were derived from 40 references, of which about half (75) pertain to operating the storage facility. The purpose of the risk inventory is to serve as a starting point and checklist to identify and manage risks in development projects, and to provide guidance on potential mitigation measures to reduce the risks.

In order to improve our understanding of the significance of the risks associated with underground hydrogen storage (UHS), a selection of six key risk themes associated with storage of hydrogen was made: material integrity/durability, leakage of hydrogen, blow-out, diffusion and dissolution, loss and/or contamination of hydrogen, and ground motion (subsidence, induced seismicity). A qualitative non site-specific comparison was made for these risk themes between UHS and underground storage of natural gas (UGS, with methane as a proxy for natural gas), primarily based on differences in gas properties. Overall aim of this comparison was to leverage the experience from UGS to provide useful information to better understand and reduce risks and consequences, increase control and inform stakeholders. Although in general, UGS and UHS have a similar risk profile, there are also differences that were highlighted in this study:

- Hydrogen has a much wider flammability range and a much lower ignition energy compared to methane, and is therefore more prone to ignite when released. On ignition methane radiates heat and creates a flame that is clearly visibly. Ignited hydrogen on the other hand radiates little (infrared) heat (IR), but emits substantial UV (ultraviolet) radiation. The lack of IR gives little sensation of heat, but the exposure to a hydrogen flame will still cause severe burns because of the UV radiation. Because a burning hydrogen flame is also not easily detectable (contrary to methane), it increases the risks associated with hydrogen when it ignites to form a flame. Detection sensors validated for hydrogen should be used to detect possible hydrogen releases.
- In case of leakage of hydrogen or methane in confined spaces, where undetected leakages can lead to large-volume accumulations, or in case of a catastrophic event (e.g. a blow-out) that leads to an uncontrolled large-volume release, there is an elevated risk of explosion for both hydrogen and methane when ignited.
- In the absence of confinement and congestion though, no overpressures are generated, and the consequence of ignition of both hydrogen and methane is limited to a jet fire. However, the hydrogen flame is expected to be narrower and reach higher, which together with the lower energy content of hydrogen likely reduces the effect of heat radiation.
- Hydrogen has the ability to react with rocks and reservoir fluids and may interact with microbes in the reservoir. This might affect reservoir performance (e.g. by pore clogging due to precipitation of minerals or rapid bacterial growth in the near-wellbore region) and/or could result in loss of hydrogen and/or contamination of

the production stream due to the formation of H_2S, a toxic, corrosive gas that degrades wellbore materials and poses a threat to human health when released to the atmosphere.

Although the risks associated with UHS are generally known, further research (laboratory experiments, numerical modelling, material testing, pilot-scale field tests) is required in particular on a) the long-term durability of rocks and (well) materials (steel alloys, cement, elastomers, etc.) when subjected to hydrogen under an alternating pressure regime that causes mechanical and thermal stresses, and b) interactions of hydrogen with rocks, fluids and microbes in reservoirs and their effects on reservoir performance, quality and retrievability of the stored hydrogen, and integrity and durability of materials subjected to products of such interactions (e.g. H_2S).

1.3 Project execution:

The project's research has been carried out by TNO in close collaboration with the five industrial project partners. Apart from regular updates on the status of the project via e-mail, this collaboration is reflected in a total of 7 meetings and which concerned the following ones: a kick-off, progress, mid-term and "final results" meeting, and which were completed with two dedicated workshops. The last meeting that took place replaced the foreseen public event (not possible to organize due to COVID-19) on the outcome of the project and which concerned an online Q&A meeting with the entire consortium and during which a reflection took place on the project and its outcomes.

For work package 3 the Erasmus University, via it its incubator GovernEUR[1], was involved and actively contributed to the study on the subject of societal embedding of large-scale subsurface energy storage. Furthermore, Utrecht University became involved to inventorize and describe several legal aspects seen either as barriers or as support for implementation of large-scale subsurface energy storage. The contributions from these two 3rd parties have become available via the final report of work package 3 (and its appendices) and were found to be required to have sufficient quality generated on these subjects as this could not be sufficiently guaranteed out of TNO as appropriate staff turned out to be not sufficiently available to contribute. The involvement of the 3rd parties is also reflected in the final cost statement as here, contrary to the original project budget, some 3rd party costs are present. It is also worth to mention that during the course of the project for work package 3 it was agreed with the project consortium to not work and deliver an argument map (on societal arguments in favor and against large-scale subsurface energy storage), as it was felt that this was premature, and would not specifically have an added value to the other outcomes of this work package.
The project suffered from a somewhat later start, and some delay in the work consequently, due to some legal issues and pending signatures on the participation agreement for the project. Hence, a change of the project end date to end of August 2020 was requested and confirmed by RVO.

[1] https://governeur.nl/

1.4 Contribution of project to goals of the subsidy program

Enabling the implementation of large-scale energy storage can be a multi-faceted win for industry, government and society. This project identified technical, economic, societal & regulatory challenges and risks for CAES in salt caverns, hydrogen storage in salt caverns and hydrogen storage in depleted gas fields, and the options and opportunities for further work on such challenges and for mitigations of such risks. For the energy sector the introduction of more intermittent renewable energy sources poses challenges. To have technologies at sufficient TRL and markets in place within the required timescales, the removal of technical and non-technical barriers requires action on the short term. The outcomes of this project may be used to shape the industry technology and investments roadmaps. Furthermore, the outcomes of the project may be a source for the Dutch governmental bodies to develop policies for the progression towards commercial implementation of large-scale energy storage. As large-scale subsurface energy storage can play a pivotal role in allowing integration of higher shares of intermittent renewable energy sources in the Dutch energy system, its efficient, cost-effective implementation will be important in the transition towards a robust, reliable and affordable climate-neutral energy system.

In this project, improved insights were obtained into the role that large-scale subsurface energy storage technologies can play in providing flexibility to the current and future transitioning energy system. Furthermore, specific risks and challenges were addressed with respect to integration into the energy system, productivity and operational aspects, and societal, legal and regulatory embedding.

For the knowledge position of the Netherlands this project was the first to assess the need for large-scale storage options in detail along with a first of a kind multi-disciplinary approach to study the technology gaps, economics, market, societal, risks and regulatory challenges for large-scale subsurface storage technologies. It has highlighted the most important development lines needed to bring the technologies a step closer to demonstration and market implementation.

1.5 Spin-off

During 2020, and on basis of the ongoing work in this project, a project proposal has been submitted to a Dutch funding scheme for research on the geo- and biochemical reactions and effects of hydrogen in depleted gas fields and salt caverns. Several of the industrial parties in this project have confirmed to take part in this new proposed project and for which the confirmation of the requested Dutch public funding is pending.

Further spin-off might be expected during 2021.

1.6 Dissemination and open Publications on project

The four final reports and the synthesis paper will be made public in January 2021 via the following TNO webpage[2] and which publication will be given attention via

[2] https://www.tno.nl/nl/aandachtsgebieden/energietransitie/roadmaps/een-betrouwbaar-betaalbaar-en-rechtvaardig-energiesysteem/robuustheid-en-flexibiliteit-van-het-energiesysteem/onderzoek-naar-grootschalige-ondergrondse-energieopslag/

diverse media channels (e.g. LinkedIn post, Twitter, announcement in Energeia, etc.).

Furthermore, from the context of the research performed in this project, the following publications are worth mentioning:

- "*Maatschappelijke en Juridische Inbedding van Ondergrondse Energieopslag*", with authors from TNO, Erasmus University and Utrecht University, submitted for publication in *Rooilijn* magazine (https://www.rooilijn.nl) early 2021.
- Juez-Larré, J., Goncalvez-Machado, C, and Groenenberg, R. Performance assessment of underground gas storage for potential hydrogen storage in the Netherlands. Extended abstract, 1st Geoscience & Engineering in Energy Transition Conference (GET), November 2020.
- At the end of 2020 a second study will be completed for the Ministry of Economic Affairs and Climate following a first study completed in 2018 on the technical potential for subsurface storage in the Netherlands[3]. This second study will be made public beginning of 2021 and has made use of the outcomes of our project.

1.7 Contact information

For further information on this project and the project outcomes, please contact TNO, Applied Geoscience research group, via secretariaat-aarde@tno.nl or by phone at +31 88 8664256.

[3] https://www.rijksoverheid.nl/documenten/rapporten/2018/11/20/ondergrondse-opslag-in-nederland---technische-verkenning