Deliverable Proof – Reports resulting from the finalisation of a project task, work package, project stage, project as a whole - EIT-BP2018

Name of KIC project the report results from that contributed to/ resulted in the deliverable	E-Use - Europe wide Use of Sustainable energy from aquifers
Name of report	3.2.5 E-USE Final project results report
Summary/brief description of report	Final deliverable of E-USE(aq) project gives an overview of the barriers analysis and opportunities for ATES in Europe, the final evaluation and results of the pilots, including monitoring, optimisation and business cases, lessons learnt and an update of the climate impact
Date of report	31 December 2018

Supporting documents: Report attached

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Content

1. Identification of barriers and opportunities for ATES in Europe

Why is aquifer thermal energy storage (ATES) not widely applied in Europe, yet? The Climate-KIC project Europe-wide Use of Energy from aquifers - E-Use(aq) - identified three types of barriers: general barriers for all countries and specific barriers for countries with an immature and mature market. In the E-Use(aq) project it is also found that all barriers can be overcome and sometimes can even be turned around to opportunities.

General barriers and solutions for all countries:

1. Knowledge and skills are commonly divided between consulting, contracting and operation and maintenance companies. Especially, there is often an insufficient integration of underground system knowledge (like the wells) and the installation above ground (such as the heat pump). While this asks for different experts, users possess inadequate operational knowledge. E-Use(aq) showed that knowledge and skills can be integrated by good team work; see § 2.1. Continuing involvement of ATES providers during operation is important, especially for ignorant users.
2. Uncertainties originating from unfamiliarity with the underground and its characteristics. However, with proper subsurface site investigations and sufficient groundwater monitoring, adequate predictability is possible; see § 2.2.
3. Disappointing quality levels and limited robustness of the installation can be the consequence when unqualified companies design, install and/or operate ATES systems. Inadequate designs and insufficient operational management will then lead to unsatisfactory performance and a negative reputation. Within E-Use(aq) experienced Dutch partners cooperated with competent partners in other countries to show that ATES technology is not in its infancy anymore and that it can be a reliable source of sustainable energy; see § 2.3.

Barriers and solutions for countries with an immature market:

1. Because of lack of knowledge and experience, general public, property developers, building and utility companies as well as governments are unfamiliar with soil energy. E-Use(aq) improved knowledge and public awareness by events and publications; see § 2.1.
2. As a result of the unfamiliarity with the technology, there is a lack of adequate regulations. Instead of guidelines to hold on to, often long and uncertain permit procedures have to be faced. E-use(aq) assisted inexperienced authorities to facilitate ATES; see § 2.3.
3. People presume relatively large initial investments with uncertainty about the savings during operation. However, in the Netherlands a pay-back time of on average 7 years is realized; often significantly lower especially when also cooling capacity is needed, sometimes somewhat higher when mainly heat is required. Some of the pilots in the E-Use(aq) project realized lower pay-back times; see § 2.4. Increased efficiencies can be achieved by energy balance optimizations, see § 2.5 and § 2.6.

Barriers and solutions for countries with a developed market:

1. In dense urban settings ATES demand for subsurface space may exceed the available space in the local aquifer. Mutual interaction between systems is a potential thread to optimal and sustainable use of the aquifer. With the latest insights in planning of well locations and operation, mutual interaction does not have to have a negative effect, it can also work positively on energy output, when properly managed. See § 2.7.

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2. Interaction with polluted groundwater is likely in urban areas. Improper design and operation may lead to contaminant spreading and/or migration. But an integrated ATES-remediation approach with for instance optimization of redox conditions and increased temperatures enhancing biodegradation can accomplish groundwater remediation. See § 2.8.
3. A negative impact on groundwater quality is often feared. Such fear is not necessary (see § 2.6), but sustainable use and monitoring (see § 2.2) can be important to allow local authorities to issue a permit, together with energy balance as a permit prescription.

In the next chapter it is described in more detail how specific barriers were tackled in the project and how these can be turned into opportunities. The resulting expected climate impact is described in chapter 3.

2. Results from barrier analysis and pilot plants

2.1. Improving knowledge, quality and public awareness

In order to draw European attention to ATES, E-Use(aq) started pilots in several European countries, that show how to overcome barriers: two in the Netherlands, with a developed market, one in Belgium with a growing market, and three in the immature markets of Spain, Italy and Denmark. In the Netherlands a lot of knowledge and experience is already acquired. Also a legally enforced certification scheme is valid since 2014 for all companies working on ATES design, building and operation. By cooperation of Dutch and foreign partners in the realization of the pilots, knowledge and experience was successfully transferred. A wide range of ATES applications was included in the pilot selection: besides basically classical ATES with doublets of cold and warm wells, in the Netherlands (Delft), Belgium and Denmark, also a monowell system was demonstrated in the Netherlands (Utrecht) as well as a system with underground heat exchange in Spain, while in Italy a recirculation system (without actual storage) was installed. With public events and publications about the pilots and the overall projects, a wider public, with especially potential applicants, of the technology was informed, for instance municipalities in Belgium. Operations of all pilots are supposed to continue, so that permanent showcases stay available as central points for further proliferation of the technology.

2.2. Underground characterization and monitoring

In the Netherlands, nation-wide information about underground characteristics is readily available. However, this is information on a regional basis, which is not always detailed enough for applications of local groundwater use like ATES systems. For this, a detailed soil stratification investigation – when not available already for the local situation – is highly recommended, especially to avoid mixing of groundwater from different layers with varying geochemical characteristics, which can cause clogging problems. This was done for all pilots. In order to reduce costs, the boreholes for the soil stratification investigation can be combined with placement of necessary wells, either for groundwater extraction or infiltration or for monitoring.

For the pilot in Ham (Belgium) soil stratification was assessed carefully during placement of the wells. It turned out that the separating layer underneath the aquifer was located much deeper than expected. So, during the drilling it was decided to install much longer screens then originally designed. This increases the capacity of the system considerably. The additional drilling costs are in this case small compared to the advantage of higher groundwater flows and consequently more energy yield.

Compared to the Belgian pilot, the water bearing layers at the pilot sites in Nules (Spain) and Italy (Bologna) are very thin. So, well screens were positioned extremely carefully, based on a detailed soil stratification characterization. In Birkerød (Denmark) it was especially important to characterize the geochemical conditions, because of the partly unsaturated conditions of the aquifer, which was a challenge for both the ATES application and the remediation (see § 2.8).

Based on the soil data, model calculations provide the necessary information about energy yield and use of space. However, available data are usually not accurate enough to tackle soil heterogeneity. Depending on the scale of the heterogeneity and the coincidence of functions in the often crowded underground of cities, additional information can be gathered by high resolution temperature measurement, using fibre optics. This technology was demonstrated in the pilots in Delft and Utrecht (Netherlands) and Ham (Belgium).

2.3. Tackling legislative barriers

In the preceding project it appeared that in Germany influence outside premises is legally problematical. This was an important reason that a pilot was not realized in Germany. So, changes in German legislation seem to be inevitable for the proliferation of ATES.

However, in Spain a technical solution was applied to counteract a legal prohibition of infiltration. Since a return stream is considered to be waste water, also Spanish legislation makes application of ATES virtually impossible. The practical solution found involved the application of the Dynamic Closed Loop system (DCL®), a system that combines the advantages of a closed loop soil energy system and open ATES. Since groundwater stays underground, requirements that oppose ATES are circumvented. The municipality of Nules that was actively involved in the project is very enthusiastic about the results and is already initiating the installation of more comparable systems. Also other local authorities in the region that were informed (see § 2.1) are interested in the system and have made installation plans, in spite of the opposing legislation.

In Italy, consortium partners faced a lot of bureaucracy, because of doubts about aspects of the new technology at the departments of the Emilia-Romagna regional authorities. But by frequent contacts between consortium partners and regional officials during the preparation of the pilot – soil investigations and system design optimizations were executed by mutual agreement – a lot of information has been shared and consequently confidence was gained. At the event that was organised on site, public servants informed the project team that permission procedures for new systems can now be dealt with much faster.

In Belgium, legislative barriers hardly played a role, just as in the Netherlands, where standardized procedures haven been developed. However, for the Delft site temperature restrictions on infiltration water can become relevant in the future but usually they can be lifted for pilots. Regulations against contaminant migration are relevant for the Utrecht site, but the local authority, that is also responsible for groundwater contamination is involved in the pilot. In Denmark, the situation is comparable with the Utrecht site since the Capital Region of Denmark is involved in the project as initiator.

2.4. Analysis of business cases

In the Netherlands a typical pay-back time for ATES systems is about 7 years, although the differences can be big due to local conditions. When the main driver for installation is cooling capacity, lower pay-back times are possible. Comparable pay-back times seem attainable in other countries. In the Italian pilot, pay-back time is somewhat longer because of the necessary pioneering activities (soil investigations, design adaptations, difficult permit procedures) but with help of the already acquired information, new systems can be installed much cheaper in this region. The Spanish DCL® system is very cost-effective, with a pay-back time of only about 3 years. Also in Belgium such a short pay-back time was realized, but partly because the owner negotiated quite low prices for electricity. With a more common electricity prize level, pay-back time would be about 5 years. That is still quite low because of the very thick aquifer that made long well screens possible and consequently large groundwater flow volumes with high energy production. The pay-back time for the addition of Virtu® PVT panels (see § 2.5) is now with 8 years somewhat higher as the average pay-back time for the ATES system itself but is expected to go down when PVT production volumes increase. Additional costs for dealing with contaminants (see § 2.8) have to be compared with separate remediation costs. Calculations proved that the integration of ATES and bioremediation (ATES+) applied in Utrecht is significantly more inexpensive than all other remediation options. Compared to cleaning of the soil before start of ATES operation, the combination system is even about a factor 4 cheaper.

2.5. Energy balance optimization by integration with PV/T

For optimal functioning of ATES systems an equal need for heat and cold on an annual basis is necessary. Of course a precise balance is hard to obtain, even in Western and Central Europe, where the heating capacity needed in winter is roughly comparable to the cooling capacity needed in summer. In Northern Europe heating demand exceeds cooling demand and in Southern Europe, it is the other way round. In the Delft and Ham pilots therefore, energy balance optimization by a combination with cooled solar panels is demonstrated. This provides several additional advantages. With photovoltaic (PV) cells, as implemented in Ham, electricity needed for the water and heat pumps, is provided in a sustainable way. Preventing temperature increase of PV-cells due to solar radiation increases electricity production yield significantly. This can be done by cooling them (PV/T). The energy from the cooling-water is subsequently stored in the soil. Electricity used by heat pumps can be reduced when captured solar heat makes higher temperature heat storage possible. The solar panels are also suitable to harvest cold. The Delft pilot is used for the development of yet another combination: ATES and PV-cells integrated with solar heat collectors, Virtu®, in order to harvest and store more solar heat that conventional PV/T-cells. In the Delft case, the existing ATES system produced too much heat, while the cold stored was already depleted before the end of the cooling season. By enlarging soil energy application aboveground, encompassing another building with a large heating demand, and adding additional heat to the underground by Virtu, a much more robust system is created. Using the additional heat capacity enables the production of more cooling capacity, by creation of a larger cold water reservoir, so that a better energy balance is within reach.

2.6. Energy balance optimization by integration with district heating

ATES is attractive because it makes in a quite simple manner possible that surplus heat in summer seasons can be used in winter seasons, while surplus cold in winter season is used in summer, with minimal losses of energy. Also differences in supply and demand of thermal energy on smaller time scales can be met, for instance within 24 hours, when days are warm and nights are cold. But apart from temporal differences in supply and demand of heating and cooling, there are also spatial differences that could be overcome by a smart energy grid, e.g. when factories produce heat while nearby houses need heating. Such symbiotic cooperation's between providers and users of thermal energy can be incorporated quite easily when district heating systems are already operational. Of course this provides cooperation of several parties, but they will find each other when governments provide incentives to reduce CO_2 emissions, like a price on emitted CO_2. Such a smart grid is also compatible with ATES: heating and cooling demands at different places are met in the first place and only surpluses and shortages of thermal energy are counterbalanced by infiltration and extraction from the soil.

On a small scale the use of a heating grid is demonstrated in some pilots. In Ham, with intelligent computer programming, heating and cooling demands are first met between rooms as much as possible and only what is left is provided by or stored in the groundwater. In Bologna some rooms with computers always need cooling, which provides year round heat for other rooms, so only additional heat, or even more cold, is provided by the recirculation system. In Delft, the surplus heat, produced by an office building, that was until recently stored in the underground can now be used since a connection with a large experimental hall was made.

2.7. Dealing with mutual interaction between ATES systems

In areas with a lot of systems close to each other, interference between wells is imminent. When cold water enters warm well reservoirs, efficiency can drop considerably. Because of the inaccuracy of modelling outcomes, authorities often choose for certainty in avoiding interference when giving out permits. Consequently, a lot of underground space is not used.

But, when parties cooperate, possibly lead by a coordinating (municipal) agency, interference can also enhance efficiency by smart spatial planning, for instancing creating warm and cold lanes. To accomplish this, it is very important to have a good knowledge of the thermal plume around the wells, which differ in practice from model calculations. For this, high resolution temperature measurements can be helpful. Because of the cautious choices of authorities nowadays, a lot of additional underground space can be used, so that makes that these comparatively expensive fibre optic measurements become cost-effective in crowded areas.

In the pilots in Delft, Utrecht and Ham on a small scale the thermal plumes of the system wells were made visible. In the cases of Delft and Ham no interaction between the wells of the system was observed, but in the monowell system in Utrecht some of the warm water in the upper layer seems to enter the cold thermal plume below, which indicates negative interaction with a - small - drop in efficiency within the system. This demonstrates how monitoring of underground thermal plume development can contribute on a larger scale to multi-ATES system planning and operation.

2.8. ATES enables redevelopment of contaminated sites

Based on geochemical data from the extensive monitoring well network present in the Dutch city of Utrecht, it was concluded that the mere presence of numerous ATES systems did not lead to provable significant degradation of contaminants. Expected positive effects from mixing of reactants and heating of the groundwater by ATES could not be determined, most likely because of lack of optimal geo-biochemical conditions, e.g. suboptimal redox conditions, low organic matter concentrations and consequently small numbers of the proper micro-organisms. On the Utrecht pilot site, these micro-organisms were introduced into the soil, close to the ATES system according to the innovative ATES+ concept. Micro-organisms travelled through the ATES well screens without noticeable effect on system operations. A reactive zone was created in which degradations was enhanced considerably. Degradation continued for at least about a year, so repetitions of bacterial injections can be relatively limited and therefore it can be concluded that a cost-effective combination of ATES with groundwater remediation is possible. Lessons learned from the Utrecht pilot were immediately applied in the Danish pilot, with a more challenging contaminant situation and redox conditions far from optimal. For the necessary degradation process of reductive dechlorination, low redox conditions had to be enforced. Taking away oxygen also helps avoiding clogging problems in the ATES well screens by iron precipitation but at the same time forming of sulphur precipitates has to be avoided. Redox conditions were successfully optimized and now degradation progress is being monitored.

No negative effects of ATES system operations itself on quality groundwater in a relatively pristine aquifer was observed, as elaborately checked in the Belgian case.

3. Europe-wide Climate Impact from ATES

3.1. Future prospects for ATES market

The results of the pilot sites indicate that wider utilisation of ATES in Europe is possible, compared to results of the inventory that was made in the preceding E-Use(aq) Pathfinder project. Especially the success of the specific DCL® system implemented in Spain, will enlarge the ATES market because even thin aquifers have proven to be suitable for this type of ATES technology. Furthermore, energy balance optimization measures will facilitate ATES in cases with differences in heating and cooling demand. This is important in Southern and Northern Europe, where the climate causes varying demands, but just as well in the rest of Europe, dependant on the types of buildings. Besides the solutions tested in this project, other measures are possible, like combinations with use of energy from surface water. The market can, with proper site characterization and monitoring measures, also be enlarged by denser ATES well setting that are needed in crowded urban areas. Lastly it is shown that ATES can properly be applied in polluted areas since it facilitates remediation by a combination with enhanced degradation of soil and groundwater contaminants.

3.2. Climate Impact Assessment

E-USE(aq) shows, through the realization of 6 pilots in 5 different countries, how ATES systems can be implemented, thereby starting a flywheel-effect for the promotion and adoption of ATES systems throughout Europe. Once awareness has risen, the installation of 50,000 systems throughout Europe in the next decade, is deemed achievable by the consortium: for example on average 250 systems to be installed per year in 20 countries. With the CO_2 mitigation potential of 60 ton per system per year[1], these 50,000 ATES systems contribute to a total annual CO_2 emission reduction of 3 million tons CO_2 per year by 2030.

The conclusions derived from the Climate Impact Assessment performed by Quantis are: *The clear savings in terms of CO_2 emissions depend on the national electricity mix. If the general EU mix (here ecoinvent v3.3: 0.52 kg CO_2 eq./kWh) and the average from the three case studies is taken into account, the savings per system are 4'260 kg CO_2 eq./year. The scalability given by the project partner are for the pessimistic case 250 systems, 2'500 in the realistic case and 25'000 in the optimistic case. In the optimistic case a climate impact potential of 60 kt CO_2 eq. per year can be expected, while, in the pessimistic case a climate impact potential of 0.6 kt CO_2 eq. per year can be expected. In the realistic case a climate impact potential of 6 kt CO_2 eq. per year can be expected.*

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[1] The registrations of ATES systems and CO_2 emission reduction accounting of the Dutch Government indicate that the average greenhouse gas (GHG) emission reduction per ATES-system is between 45 and 80 ton CO_2/year in the Netherlands (Originally derived from CBS Warmte/koudeopslag per province in 2008; update tabel 6.2.2 Duurzame Energie in Nederland 2008 and http://www.olino.org/articles/2011/09/19/warmtepomp-vs-gasketel), strongly depending on size, type of building and climate. Taking into account experiences with systems in other countries, an average of 60 ton CO_2/year is supposed to be a representative GHG mitigation potential value per system.

3.3. Recommendations for next steps

It is recommended to continue operations of the pilot systems, since those have proven to be excellent showcases which can continue to be focal points of knowledge proliferation activities for ATES application, thus providing energy to the desired flywheel-effect. The local consortia built, will continue to operate the existing systems and are devoted to the accomplishment of installing many more. Updated results will be published regularly on their websites. Funding for elaborative monitoring (more than strictly necessary for the site owners) is important in order to be able to show the advantages of the systems to a broader public.

Important actions already set in motion include the presentation of the results of the E-Use(aq) project on these highly esteemed platforms:

- The Solutions Catalogue will be used as source for the realization of a poster to be presented in 2019 at the European Geosciences Union Conference (hosted in Vienna, Austria, from 7th to 12th February).
- and the European Geothermal Congress (hosted in The Hague, The Netherlands, from 11th to 14th June).
- On the Dutch national soil symposium Bodembreed, on 16 May 2019, the important innovation of ATES enhanced bioremediation of a solvent contaminated area – tested for the first time in history within the E-Use(aq) project in the field with a real ATES system – will be presented.
- On the European conference AquaConSoil, now in Antwerp (20 – 24 May 2019), following an earlier presentation of the Pathfinder results (in Copenhagen), and a (very successful) special session about the Demonstrator project (in Lyon), final results will be presented in a new special session focussing on the possibilities for ATES proliferation all over Europe.