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 Solutions catalogue
Summary/brief description of report	This report summarizes the E-USE(aq) project main achievements for the ATES-sector development as low carbon energy solution for heating and cooling of buildings. The report presents the concept and the main learning points from the E-USE(aq) project in order to promote the replication of ATES plants based on the developed solutions and acquired knowledge in E-USE(aq) pilots.
Date of report	25 November 2018

Supporting Documents: report attached

Climate-KIC is supported by the EIT, a body of the European Union

Summary

Introduction

The Solution Catalogue reads as a standalone document summarizing the E-USE(aq) project main achievements for the ATES-sector development. It presents the main learning points from the E-USE(aq) project in order to promote the replication of ATES plants based on the developed solutions and acquired knowledge in E-USE(aq) pilots.

Target audience of the catalogue are the following types of stakeholders, as identified via the Business Case analysis:

- Real estate owners;
- Public authorities;
- Policy makers;
- ESCO;
- Renewable energy plants installers;
- Multi-utility companies (as district heating networks managers).

The solutions catalogue will be used as a 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). The poster will be designed to be used also as a further communication and dissemination tool to be distributed by the project partners among the identified stakeholders via the following channels: i) digital version on project partner sites and on social media (i.e. LinkedIN, Twitter, …), ii) printed version (during project partners participation to conferences or events like EGU, EGC, AquaConsoil, …), iii) translated version to national events to which each partner may participate, iv) via national Climate-KIC and/or central Climate-KIC channels.

ATES concept

Aquifer Thermal Energy Storage (ATES) systems consist of an aquifer to store and recover thermal energy for buildings connected to it. An aquifer is a layer of permeable soil containing groundwater and covered at the top and bottom by impermeable layers. In winter, groundwater is pumped from the warm groundwater well to the buildings where a heat pump is used to extract the heat from the groundwater for a comfortable climate inside the building. The cooled groundwater is simultaneously injected in the cold well. In summer the flow direction is reversed: extracting the previously stored cold water from the cold well for cooling the building (directly or through a reversible heat pump, depending on cooled groundwater temperature) and again charging the warm well for winter.

This operation creates cold and warm water wells that increase energy efficiency of space heating and cooling. ATES suitability depends mainly on subsurface characteristics as it relates to the feasibility of storing heat in aquifers which is due to physical and geological properties. Moreover, the associated buildings need to have a heating and cooling demand. ATES systems are often applied for large buildings rather than single building or house, as utility buildings like hospitals, shopping malls and office buildings.

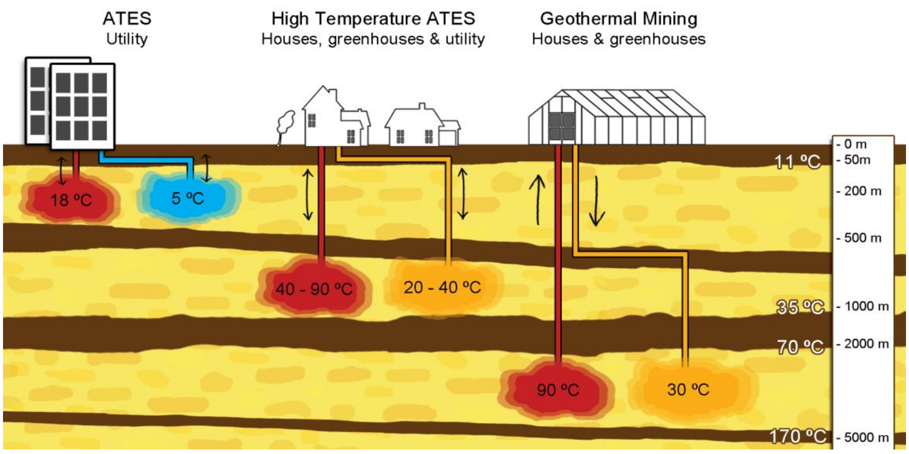

Figure 1 – Different types of ATES energy systems

ATES has a significant climate mitigation impact: based on the register of ATES systems and CO_2 emission reduction accounting of the Dutch government, the average GHG-emission reduction per ATES system in the Netherlands is between 45 and 80 tCO_2/year. Starting from this data, 0.3 tCO_2/year per m^2 is a representative GHG reduction potential indicator for ATES systems in Europe.

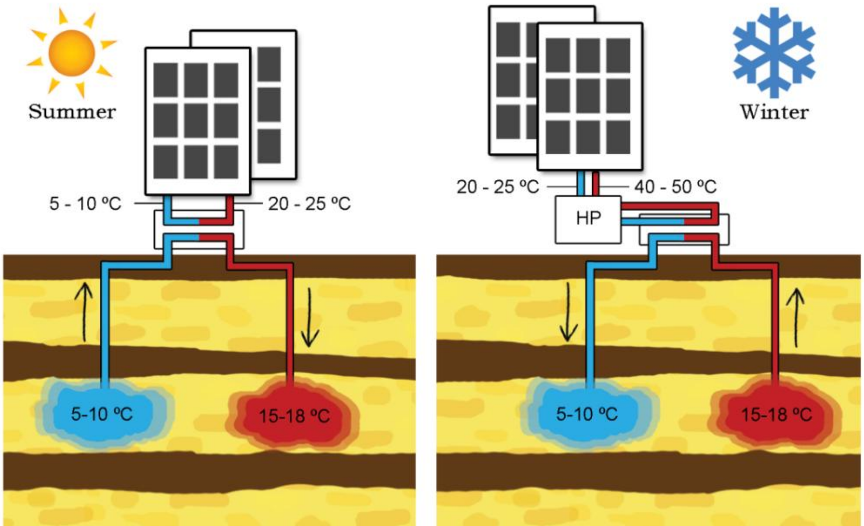

Figure 2 - Illustration of the basic working principle of a low-temperature seasonal ATES system. Left: in direct cooling mode while storing heat for winter. Right: vice-versa in heating mode supported by a heat pump while storing cooling capacity for summer.

ATES market: current developments

Market for ATES solutions varies considerably. ATES developments were mainly carried out in the Netherlands, while this technology is now also picked up in other countries, such as Belgium, Denmark, Germany, Sweden, the US. On the one hand, in the Netherlands ATES systems are a standard construction option and currently more than 2500 plants are installed. This results from a combination of positive factors including favourable subsurface properties, supportive policy initiatives and high commitment among market parties. Other European countries show great potential as well, based on the characterization of their subsurface. However, the current level of implementation outside the Netherlands stays behind at European and worldwide level (Fleuchaus P., 2018).

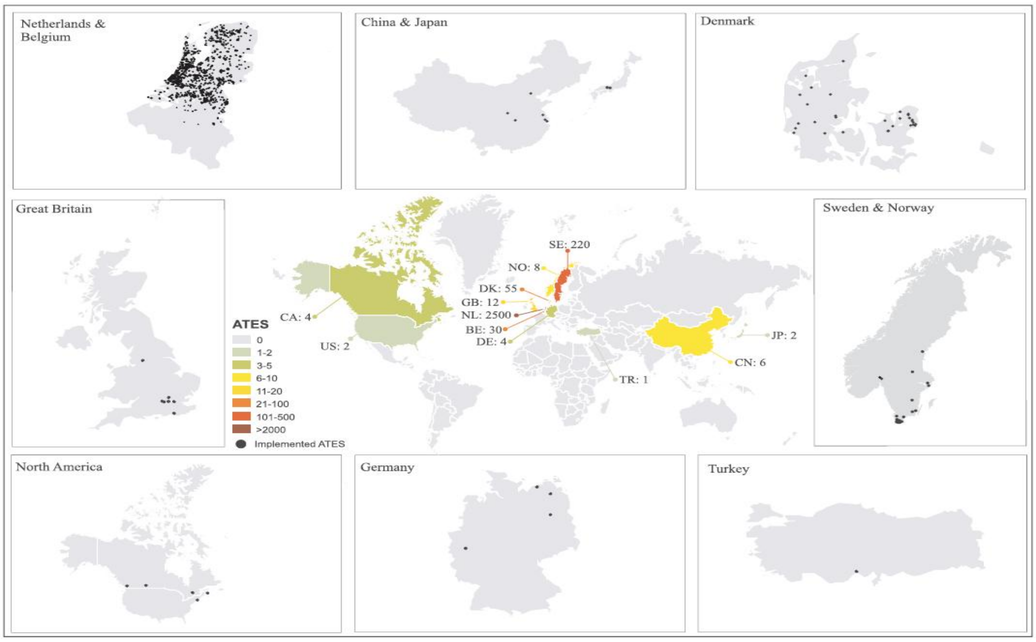

Figure 3 - Worldwide distribution of ATES systems (Fleucheus et al, 2018).

E-USE(aq) partners have analyzed the main barriers to ATES adoption in Spain, Italy, the Netherlands and Belgium, which, in general terms, can be grouped according to ATES market maturity:

1. General barriers: quality levels of ATES system, legislative barriers, separation of knowledge and skills in the supply chain for ATES implementation and realization, uncertainty about ATES impact on groundwater characteristics.
2. Mature markets barriers: interference between ATES systems, interference with polluted groundwater.
3. Novel markets barriers: awareness, lack of knowledge, large initial investments, unfamiliarity with the underground and its characteristics.

In 6 pilot plants distributed all over Europe, the E-USE(aq) project partners have tackled these barriers by testing a combination of innovative solutions.

Table 1. Innovative solutions tested in each pilot plant.

ATES market	**Main Barriers**	**Solutions**
Novel	Obstructing regulation	Dynamic Closed Loop probe Pilot site: Nules (ES)
	Familiarity, awareness and complexity of regulatory practices	ATES application in cold low temperature district heating Pilot site: Bologna (IT)

Mature	Mutual interaction amongst ATES systems	Energy optimization between different ATES buildings and integration with Virtu® PVT panels Pilot sites: Delft (NL), Ham (BE)
	Competition with other subsurface functions	Combined ATES with bioremediation Pilot sites: Utrecht (NL), Birkerod (DK)

E-USE(aq) solutions

Dynamic Closed Loop (DCL) probe

DCL probe is a hybrid solution between a closed loop and an open loop system, coupling the advantages of both. In fact, the groundwater is not extracted from the ground (as in an open loop system), but the heat exchange is increased if compared with closed loop system because the groundwater flows along the closed loop tube and heat exchanger. This system does not require an additional borehole for groundwater reinjection, since the water only flows between two different layers.

The standard system consists of a borehole and a probe with 25 kW heat exchange power, and a flow rate of 3-4 l/s. The solution is considered a closed loop system and therefore the authorization process in Spain can last only up to 3 weeks.

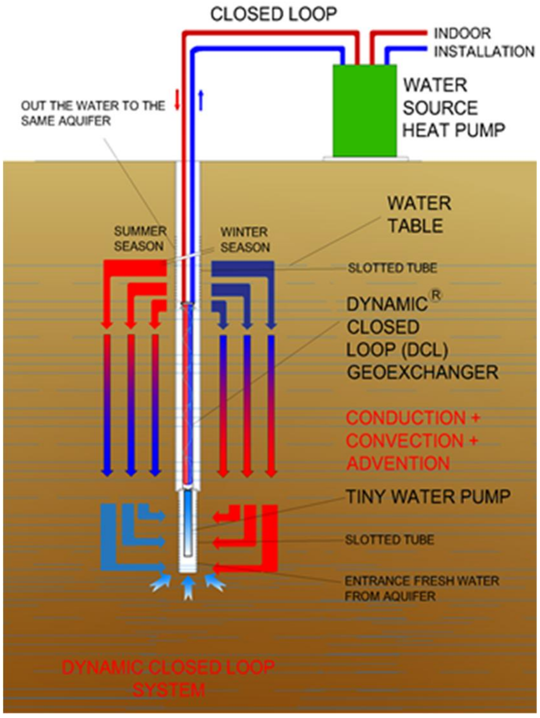

Figure 4 - Scheme of the DCL® system.

A geothermal heat pump system with four DCL probes has been installed in Nules (Spain) to maintain the water temperature of a swimming-pool at 28°C. The Spanish pilot plant is in operation since the end of 2016. The DCL probes working data have been registered on a weekly basis: in particular, the temperature and water depth variations in the groundwater have been monitored in three piezometers around the DCL probes and in a fourth piezometer placed at a certain distance from the DCL probes, in the thermal plume direction.

ATES application in cold low temperature district heating

ATES systems can be effectively integrated in buildings with different thermal demand. In Bologna, a small scale cold low temperature district heating (LTDH) system is tested. In general, a LTDH network has the ability i) to supply low temperature district heating to space heating and hot water preparation, ii) to distribute heat with low grid losses, iii) to recycle heat from low temperature sources, iv) to integrate thermal grids into a smart energy system, and v) to ensure suitable planning, cost, and motivation structures. In particular, by introducing some additional decentralized heat supply, a cold LTDH can be realized, which is a hybrid system that can use a lower supply temperature in the distribution network. This lower temperature is sometimes called an intermediate temperature, since it is lower than the actual customer temperature demand. The heat supply is then guaranteed by using local temperature boosters, such as boilers or heat pumps.

The Italian pilot plant in Bologna has 3 extraction and 3 injection wells able to cover a space heating peak demand of 146 kW and also a space cooling peak demand of 156 kW with an overall mean groundwater extraction rate of 3.5 l/s. Paramount information for a correct design of the system were the buildings energy audit and the knowledge of subsurface system properties by tracer tests, pumping tests and chemical-physical analysis. Depending on the season, the extracted groundwater is heated up or cooled down by a heat exchange through a secondary circuit, being the primary one the groundwater extraction-injection wells pipeline. The secondary circuit feeds the heat pumps/chillers, which are placed in two substations that are connected to the buildings served by the pilot plant. The peculiarity of the pilot plant is that some rooms need space cooling all over the year, and so they are fed with cold water by a dedicated chiller. A similar approach can be also used at a larger scale to integrate e.g. waste heat or waste cold streams.

Energy optimization between different ATES buildings and integration with Virtu® panels

There is a temporal mismatch between availability of solar heat and the demand for heat and seasonal storage can overcome this mismatch. ATES storage can also allow heating and cooling demands to be offset on an annual basis, through use of a warm and a cold well. However, in buildings and climates where heating demand is larger than cooling demand (e.g. Northern Europe), a supplementary source of heating is usually required to achieve this annual balance. Solar thermal collectors can sustainably provide the extra required heating capacity. In addition, this solar heat usually can be stored at higher temperatures compared to the temperature produced by space cooling from the cold well, thus further increasing the energy efficiency in heating mode. Hybrid PVT panels like Virtu® give an extra added value to ATES system since PVT panels produce simultaneously solar heat and power: so, the electrical power required to run the ATES system heat pump is also generated from a sustainable source, reducing the reliance on the power grid, and moving further towards a carbon neutral system.

Combining ATES with (bio)remediation

Most often ATES systems are located in urban areas, which are frequently affected by groundwater contamination. In particular, chlorinated solvents are often observed as contaminants in urban areas (see figure 4 for the situation in The Netherlands).

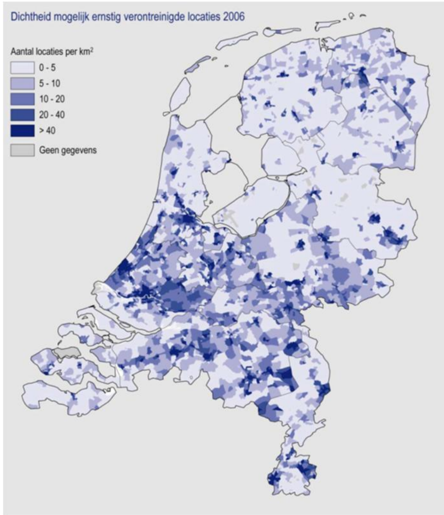

Figure 5 - Location of 400.000 serious contaminated sites in The Netherlands (MNP, 2007)

The combination of ATES and bioremediation of groundwater aims at the acceleration of biodegradation of contaminants like VOCl. Especially the elevated temperature of 17oC in the warm well plays an important role in the acceleration of biodegradation, as at higher temperatures microorganisms show higher microbial activities. Laboratory research showed that optimization of other parameters like i) right redox condition and ii) presence of bacteria that can perform reductive dechlorination are relevant boundary conditions to reach higher biodegradation rates. Therefore at laboratory scale the proof of principle was already demonstrated (Zhuobiao Ni et al. 2015).

The first ATES system in contaminated groundwater was constructed at Strijp S, Eindhoven , The Netherlands (Slenders et al. 2010). However, this system was a recirculation system in which the groundwater pumping regime was designed to avoid the groundwater to move away from the original position and no specific increase of the temperature of the groundwater was aimed at. In the Welgelegen pilot in Utrecht (The Netherlands) a monowell ATES systems functioned already for several years in a slightly contaminated groundwater. In 2017 this system was expanded with an injection well as well as some monitoring wells that aimed at the acceleration of the biodegradation. Since then the system is a real ATES & Bioremediation system. Inoculation of a specific *Dehalococcoides bacteria* (DHC) culture showed an optimization of redox condition and showed an increase of the dechlorination degree, indicating that the biodegradation was stimulated in this system.

The second ATES & Bioremediation system is located at the site Hammerbakken, near Copenhagen (Denmark). This site is known for its high concentration of VOCl by the Capital Region of Denmark. This authority is interested in the proof of concept at pilot scale of the combination ATES and Bioremediation. Therefore, in December 2017 the pilot was built based upon a recirculation system at relatively high temperature. After optimizing the redox condition in August 2018 the first dechlorination could be observed, which was followed by injection of a DHC culture in November 2018. This inoculation is expected to accelerate the biodegradation further and will be monitored in the coming months.

From E-USE pilots to Europe wide application: turning barriers to opportunities

Awareness 	ATES system is not very well known by the general public and consequently it is often missing in local policies for establishing sustainable energy mix. ATES system is overlooked because of the low visibility of the underground systems, which is actually an additional advantage given the lack of impact on urban landscapes. E-Use(aq) pilots have been presented at more than 20 different events and approached about 500 stakeholders, raising attention on the technology. Increasing the awareness around the demonstration sites is a key aspect for a successful market uptake.
Complexity of authorization procedures 	E-USE(aq) pilots show the opportunities related to ATES application which can be useful in reducing the uncertainty related to this type of plants from the point of view of the authorities. In the Italian pilot more information about the local geohydrology and geochemical conditions and experience with the application of ATES was acquired that can be used for other systems in the area. A trust relationship has been built with the authorities that can now facilitate also new projects.
Obstructing regulations 	The Spanish pilot is an example of a practical solution for a regulatory problem: in Spain it is not allowed to reinject extracted groundwater. In response to that, a system was developed that keeps the water underground (DCL® probe). Similar practical solutions can be developed elsewhere in cooperation with E-Use(aq) consortium.
Unfamiliarity with the underground 	Detailed knowledge of the subsurface as for aquifer characteristics as well as soil layering is crucial for proper ATES system design: system failure due to inadequate knowledge of the underground is still occurring even in mature markets like the Netherlands. It is very important that mixing of water from different water bearing layers with varying chemistry is avoided, since this can lead to precipitation and clogging of the system. Soil characterization, groundwater modelling and temperature distribution monitoring (after installation) are tools to overcome this barrier.
Presence of thin aquifers 	E-Use(aq) project preliminary results showed that ideal conditions for ATES operation (thik, low gradient, high permeability aquifers) are not ubiquitous in Europe. In Spain, E-USE(aq) partners developed a system that is applicable in thin water bearing layers (DCL® probe). Thanks to the fine results of the Spanish pilot, this system opens the door to a much wider application of the system, not only in Spain but also in many other European regions.
Impacts of ATES on groundwater quality	In agreement with previous results from the Netherlands, the pilots in Spain and Belgium showed that ATES operation does not lead to harmful (bio)chemical degeneration. With appropriate site specific design, additionally, when groundwater contamination is already present, it can be

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	remediated during ATES system operation. A successful combination of ATES and bioremedation is demonstrated in the Dutch pilot in Utrecht (bioremediation coupled to an existing ATES system) and the Danish pilot (ATES and bioremediation installed simultaneously).
Expertise availability	Running the pilots provided the necessary experience for the local consortia. For a steep learning curve, interested parties can cooperate with the E-Use(aq) project partners. In the project, Dutch specialists from Climate-KIC partners Deltares, TU Delft and WUR and associated partners Bioclear and IFTechnology supported project partners in Belgium, Spain, Italy and Denmark with their experience on ATES systems.
Integration of knowledge and skills	ATES systems require knowledge and skills that are divided among different players. The Belgian pilot showed how important it is that HVAC specialists communicate frequently with the ATES system specialists, in order to ensure optimal functioning of the ATES systems. In the project, the necessary integration of expertise was realized by establishing pilot project teams with frequent communications and meetings. This approach is a blueprint for the future realization of ATES systems.
Appropriate professional level of operators	The theme of qualified professionals has been tackled in the Netherlands with a specific training and certification programme, offered by 'Bodemenergie NL', a geothermal energy sector association. The certification is registered at national level by the organization that secures the quality level of the installation sector. In Europe, the GEOTrainnet is available to train professionals in the installation of shallow geothermal systems.
Balance between heating &cooling demand	Due to climate and/or to building utilization (offices tend to need more cooling, houses more heating), the energy demand for heating and cooling often do not match exactly. This can be managed by a combination with solar thermal collectors as shown in the Belgian pilot and the Dutch pilot in Delft. In Belgium, it is shown that solar panels can be used to store additional heat as well as cold. In Delft, additional heat is loaded in the aquifer, although originally the ATES system accumulated to much heat. By attaching a second building to the system, a more robust operation is possible with matching heat demand. When using the heat, also additional cold is provided, matching the original cooling deficit.
Compatibility with district heating	Low temperature district heating is an opportunity to integrate ATES in district heating networks, allowing to transfer surplus heat and cold at particular places towards locations where there is demand for it and to store excess heat or cold when abundant and retrieving it when needed. Both the Dutch pilot in Delft and the Italian pilot demonstrate the possibilities. In Delft, excess heat from an office building is used in a test facility building. The concept of the combination with district heating is discussed in more detail in the performance report of the Italian pilot.

Zero non-renewable requirements	ATES system can run on fully renewable sources: a self-sufficient system is possible by a combination with photovoltaic (PV) cells, which provide the necessary electricity for the heat pumps. When cooling these photovoltaic cells , as it has been done in the Belgian pilot and the Dutch pilot in Delft, electricity output is significantly more efficient and the generated heat can be stored. When this PVT system is used not only to increase the volumes with higher (and later lower) temperatures, but also to increase the temperature high enough (high temperature storage), no heat pump is needed anymore and consequently the electricity demand is lowered.
Interference between ATES systems	Short-cut flows, caused by water extraction and infiltration and ambient groundwater flow, can have considerable effects on thermal efficiency of the systems. When for instance water from a cold well of one system is migrating to the warm reservoir of another system, this effect will be negative. But when system application is coordinated and cold and warm wells are aligned properly, designed interference could improve the efficiency substantially, as is proven by partners WUR, TUD and Deltares.

In numbers: ATES benefits in E-USE(aq) pilots

ATES systems are cost effective

- In the Spanish pilot site **payback times** are as low as **3 years** making ATES system an economically feasible renewable energy solution. Thanks to the optimization performed in Nules E-USE(aq) pilot, it has been possible to **reduce installation costs** from for a single 100 kW system from 38.000€ to 27.600€ (-27%).
- Especially in combination with cooling, ATES systems generate **savings up to a factor 4** compared to conventional systems as shown in the pilot in Ham.

ATES systems are contributing to a low carbon energy system

- In Nules, the plant allowed saving 60% of yearly natural gas consumption.
- In Bologna, the plant will allow yearly savings of 36 tons/year of CO_2 emissions and yearly energy savings of 12 TOE.
- In Delft, the optimization with integrated PVT panels lead to saving 25 tons of CO_2.

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