Aquathermal Energy in Europe

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Foreword

In the three years of its existence, Netwerk Aquathermie (NAT) has worked hard on gaining practical experience, developing knowledge and sharing knowledge about aquathermal energy in the Netherlands. As an organisation, we have made great strides, but there is still a lot to be learned and done. A previous exploratory study within NAT revealed that aquathermal energy is a technology that is also used in other countries in Europe. Aquathermal projects in Belgium frequently made the news in recent years, and Scandinavia has long been known to be in the vanguard when it comes to renewable energy.

With a new phase of the Netwerk Aquathermie ahead of us and increasing interest in finding out what is happening in the field internationally, it seemed only logical to explore on a broader scale what is going on beyond our national borders. It is time to combine previous studies and graduation research, explore other projects and ask ourselves: what can we, as the Netherlands, learn from aquathermal projects in other European countries?

While the Netherlands has used natural gas as a source of heating for homes since the 1960s, other European countries might have made other choices. Reasons were the lack of fossil fuels in their own soil and the availability of other energy sources. As a result, the use of aquathermal energy as a source of heating in other countries is either popular or, conversely, unknown or rare.

This study does not pretend to be exhaustive. Limited by time and language as we were, this would have been practically impossible. Based on previous studies, information collected from the internet and input from the NAT network, we may assume that this report comprises a large part of the information currently available on aquathermal projects. But please let us know if you miss crucial information.

I would like to thank my colleagues from the NAT team and the people in Netwerk Aquathermie.

Rowan Benning
Netwerk Aquathermie Practice Connector

Content

Summary

Aquathermia is the term for heating and cooling buildings sustainably using heat and cold from water. This involves thermal energy from surface water (Dutch acronym TEO), wastewater (TEA) and drinking water (TED). The Netherlands is witnessing a rapidly growing increase in aquathermal energy. Projects are being explored throughout the country, and there are currently more than 85 ongoing projects. But what about other countries?

This inventory seeks to find out what is happening in the field of aquathermal energy in 12 countries in Europe. The countries were divided into two groups, depending on the extent to which a country is familiar with and has developed aquathermal energy. Every country has its own history and has made its own historic choices for energy systems in the built environment (natural gas, heat networks, electric), which determine new strategies for sustainable heat. This also impacts the extent to which countries are active in the field of aquathermia. Other factors that play a role are potential, landscape characteristics, structure of the energy market and laws and regulations.

Norway, Sweden and Finland are already successfully using aquathermal energy, although we have not found many projects. These countries have access to other sustainable resources than the Netherlands, such as hydropower and biomass. They use aquathermal energy for both heating and cooling. These systems often combine TEO and TEA, with seawater from the fjords also being a frequently used source. Challenges encountered (for example in Norway) include high investment costs in the development phase.

European countries where aquathermal energy is used relatively frequently are Germany, France, Switzerland and Monaco. Germany has a lot of experience with TEA, while TEO is still relatively new. France, on the other hand, has a lot of experience with TEO, particularly seawater. With many aquathermal projects, Switzerland is a front-runner, together with the Netherlands. Various guidelines have been drawn up regarding aquathermal energy, and the country is aware that there may be ecological effects. The Swiss Federal Institute of Aquatic Science and Technology (Eawag) has drawn up a map showing the locations of all projects in the country. The Principality of Monaco has been using heat from the sea for its buildings over 40 years.

Countries where aquathermal energy is used to a limited degree or is an emerging technology are Denmark, the United Kingdom, Belgium, Austria and Hungary. Because of the limited scale, it is difficult to take away any lessons from these countries. However, this does not mean that no knowledge is available and can be shared to fill knowledge gaps.

Based on the information found, the following five conclusions can be drawn:

1. In Europe, there are mainly TEA and TEO projects; TED is almost non-existent.
2. Heat supply is predominantly mid or high temperature.
3. Aquathermia is used as a single source or in combination with other sources.
4. The projects show that the Coefficient of Performance (COP) can certainly be higher than 3.
5. A heat and cold storage system (ATES) is not necessary for cooling with aquathermal energy.

It may be interesting for various subjects to carry out follow-up research at a European level, and to exchange knowledge about bottlenecks and possible solutions. This could contribute to the role that aquathermal energy can play in the energy transition in various countries.

Study set-up

The purpose of this study is to gain insight into the status of aquathermal energy in Europe compared to the Netherlands. The study question formulated is:

What is happening in Europe with respect to aquathermal energy
and what are relevant takeaways for the Netherlands?

It is assumed that this study may be useful for various parties. Market parties can use it to gain knowledge about opportunities for market expansion; source holders can use it as input for regulations; municipalities and governments can use it for governance purposes; and the NAT team can use it for input for NAT 2.0 and to determine where it stands.

Firstly, all existing studies and information about aquathermia in Europe were listed and collected. Next, desk research was performed to identify what other information was available. We also contacted various organisations inside and outside the NAT network for verification purposes. Together, this resulted in the present report.

What is Aquathermia?

Aquathermia is the term for heating and cooling buildings sustainably using heat and cold from water. This involves heating and cooling from surface water (Dutch acronym TEO), wastewater (TEA) and drinking water (TED). Aquathermal energy is one of the alternative forms of sustainable heating provided for in the Climate Agreement of the Netherlands.

Several considerations must be made when aquathermal energy is opted for. Of course, it starts with which of the three aquathermal variants is chosen and what the project looks like. Does it concern the supply of heat to a single building or are there several buildings that need to be connected to a heat network? And, of course, a heat pump is always required.
Apart from this, the following considerations must be made:

1) Buffer: having seasonal buffer yes or no.
2) Supply temperature. At which temperature will the energy be supplied: low temperature (LT), mid temperature (MT) or high temperature (HT)?
3) This obviously depends on the insulation value of the building or buildings to which the heat will be supplied. The better the insulation, the lower the heat demand and required supply temperature.
4) Back-up and peak load: will it be necessary to co-fire and if so, in what way?

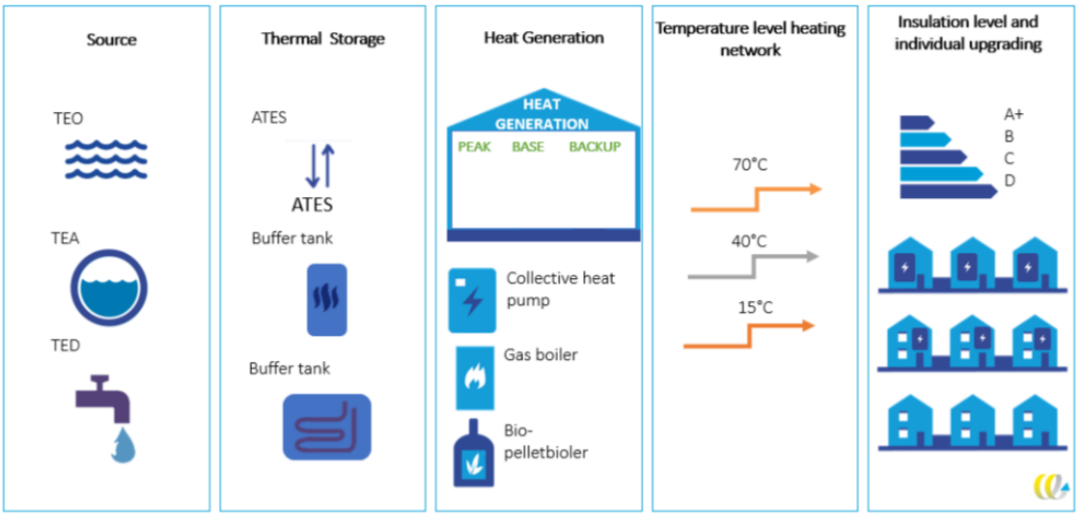


Image owner: CE Delft and Syntraal

<u>European insight</u>
Heat Roadmap Europe (HRE) is a series of studies into sustainable heating and cooling conducted from 2012 to 2019 that produced more than 50 reports and datasets. The project was financed by the European Commission. It focused on 14 EU Member States, including the Netherlands. The goal of the latest edition, Heat Roadmap Europe 4 (HRE4), was to develop low-carbon heating and cooling strategies. These roadmaps have been developed to redesign the sector by combining the knowledge of local waste heat conditions and potential savings with an energy system analysis (Heat Roadmap Europe, 2022).

One specific study by Aalborg University, based on HRE results, focuses on the potential of large-scale heat pumps in combination with a heat network. The study identifies seven sources for heat pumps; those offering the most potential and stable supply are aquathermal.

Type of Heat Source	Temperature	Stability/Security	Proximity to Urban Area
Sewage water	Δ	Δ	Δ
Ambient water	–	Δ	Δ
Industrial water heat	Δ	□	–
Geothermal water	Δ	Δ	□
Flue gas	Δ	–	–
District cooling	□	–	Δ
Solar heat storage	Δ	Δ	–

Based on an image from Aalborg University

Heat from sewage water is most reliable and locally available, which is why it is the most commonly used source for heat pumps in Europe, according to the study. Surface water follows as the second good source of energy; it is also a stable source, but not always locally available. The distance from the source to the urban area is sometimes too long (Neves & Vad Mathiesen, 2018).

Aquathermal Energy in the Netherlands

Netwerk Aquathermie

On 14 May 2019, 20 parties from government, water management, research and the commercial sector signed the Green Deal Aquathermia. For three years, they actively worked on achieving the Green Deal's goals:

- Bringing aquathermal energy to the attention of stakeholders.
- Developing and sharing knowledge about aquathermia.
- Assessing the value of aquathermia in practice.

All parties in the chain are needed to achieve the Green Deal objectives. These include source managers: water boards, Rijkswaterstaat and drinking water companies. But also parties that extract, store and transport heat, as well as users such as network operators, provinces, municipalities, research institutes and consultancy firms. During the term of this Green Deal (May 2019 - May 2022), the Network worked on knowledge development and knowledge sharing.

After finalising the Green Deal, Netwerk Aquathermie (NAT) will continue investigating how water as a source of energy can be used to heat homes and buildings. The aim is large-scale application of aquathermia to speed up the heat transition. The network encourages new initiatives, collects knowledge questions, puts together a research agenda and shares the collected knowledge. NAT works together with other programmes from the Dutch Climate Agreement.

In 2023, Netwerk Aquathermie will continue developing aquathermia, focusing on the creation of a level playing field, responsible use and standardisation of aquathermia. To support aquathermia in the long term and drive market development, we are seeking cooperation with Bodemenergie NL, the National Local Heat Transition Programme (NPLW) and the Netherlands Association for Sustainable Energy (NVDE).

Policy in the Netherlands

The Dutch government wants to reduce the Netherlands' greenhouse gas emissions by 49% by 2030, compared to 1990 levels, with a 95% reduction by 2050. These goals were laid down in the Climate Act on 28 May 2019 (Government of the Netherlands, 2023). This framework was developed using the collaborative Dutch Polder system. Over 100 stakeholders from across society contributed to developing the 2019 Climate Agreement, which contains emission reduction targets and measures in five sectors: electricity, industry, the built environment, mobility, and agriculture and the natural environment.

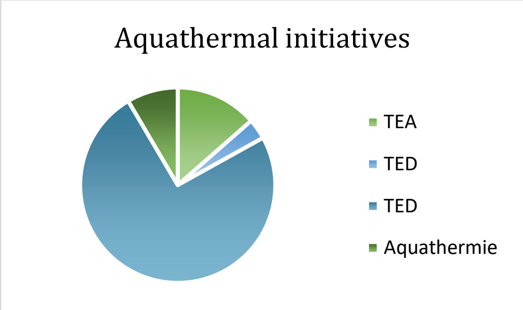
The Netherlands is facing energy security challenges. Natural gas is the largest source of domestic energy production and a key fuel for industry and for building heating. The Groningen gas field, located in the north-east of the Netherlands, is one of the largest gas fields in the world and was historically the main source of domestic gas production. Gas production activities in the Groningen field caused earthquakes, damaging over 10,000 buildings and resulting in strong public and political pressure to end gas production from Groningen as soon as possible. In response, the Dutch Cabinet issued decisions aimed at ending gas production from Groningen by mid-2022. Because of steady demand for natural gas and falling domestic gas supply, the Netherlands became a net gas importer for the first time in 2018.

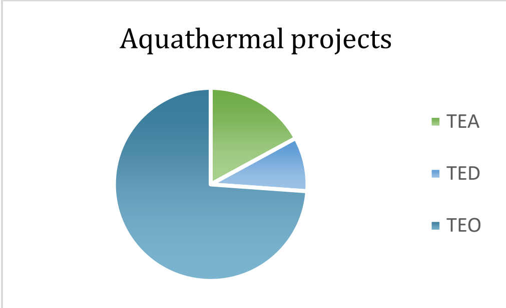
The government foresees that natural gas will be an important part of the energy system through at least 2030 and that low-carbon gases will play a critical role in transitioning to a carbon-neutral energy system, especially in the industry sector and other hard-to-decarbonise sectors.

To ensure reduced emissions from natural gas while maintaining energy security, the Netherlands is executing a broad policy agenda to reduce natural gas demand and accelerate the production and use of low-carbon gases (the Netherlands, 2020).

Aquathermal projects in the Netherlands

Netwerk Aquathermie knows about many different aquathermal projects and initiatives in the Netherlands. TEO is most popular in ongoing projects and new initiatives, followed by TEA. TED comes last.





* "Aquathermia" is used for projects where it is not yet known whether they are TEO, TEA or TED

Examples of Dutch aquathermal projects

Project name/location:	Thermo Bello, Culemborg
Active since	2009
Source:	TED
Supply:	Heating
Output:	Heating for 222 homes and 7 business premises
System:	Low-temperature warm water is supplied by means of an underground distribution network in the district. The homes and business premises receive hot water, and cooled water is returned to the heating station via a return pipe. In the heating station, the cooled water is re-heated using a heat pump and, if that is insufficient, one or two gas-fired industrial boilers. The temperature of the supplied water depends on the outside temperature. The maximum temperature of the water is approx. 50 °C. Water is only heated to this temperature in exceptional cases, so at outside temperatures of approx. -10 °C. The use of underfloor and wall heating and large heat-exchanging surfaces in general enable a low temperature of the water and thus an attractive generation efficiency of the heat pump. The warm water being too cold for tap water, all homes and businesses have made their own arrangements for this.
Governance:	Thermo Bello has been producing heat for a large part of the EVA Lanxmeer district since 2009. The private limited company (BV) is run by a director and one of the three founders. The shares of the BV are managed by the Coöperatieve Thermo Bello U.A. Members of this cooperative are residents in the district plus the EVA-Lanxmeer Residents' Association (BEL). Together, they own the company. The board of the cooperative consists of representatives of these two sections.
Other information	Thermo Bello charges customers standing charges and actual consumption, measured in gigajoules (GJ). The below rates are for 2022 and inclusive of VAT. - Standing charges for home connections (including the costs for the metering service) are €274.75 per home.

	- Standing charges for businesses depend on connection capacity, which differs per connection. - The consumption rate is 40.00 per GJ.

(Thermo Bello, 2023)

Project name/location:	De Veldkamp swimming pool
Active since	2018
Source:	TEA
Supply:	Heating
Output:	Savings of 230,000 m^3 gas
System:	CêlaVíta, which makes potato products on the outskirts of Wezep, discharges purified wastewater at a temperature of over 30 degrees into the sewer every day. Thermal energy is extracted from the sewage water by means of a heat exchanger. The extracted heat is heated to the desired temperature using a heat pump. Tauw Ambient Heat B.V. uses this heat for the gas-free heating of swimming pool De Veldkamp (600 metres away). This results in annual savings of 230,000 m^3 gas, which equates to a reduction of 410 tons of CO_2 emissions, or CO_2 emissions of 58 households.
Governance and other information	TAUW and Sport Fonds Nederland, the operator of the swimming pool, have jointly invested €350,000 in the project. The municipality of Oldebroek guarantees 50% of the total investment. The payback period of the investment is approximately 10 years.

(Potato heat for a swimming pool, 2023)

Project name/location:	Merwehoofd, Papendrecht
Active since	2004
Source:	TEO – Papendrechtse Geul
Supply:	Heating
Output:	Not known
System:	A heat network heats 401 homes by means of TEO. The apartment complex has a heat demand of 5,040 GJ per year. A central heat pump heats the water to the desired temperature. In summer, heat is stored in an ATES for use in winter.
Governance	Not known

(Merwehoofd Papendrecht, 2023)

For all projects known to NAT, click here. For all initiatives known to NAT, click here.

Aquathermia in Europe

Aquathermal energy has been around longer than we may think. One of the first aquathermal projects was in Zurich, Switzerland, in 1937. This concerned a heat pump using heat from the Limmat river to heat the parliament building (Zogg, 2008). Other older systems are found in Scandinavia, where the first heat pump has been using wastewater and seawater for cooling and heating a district network since 1984. The oldest project in the Netherlands dates back to the same period: Built in 1983, the Limburg provincial house was heated with water from the river Meuse (van Geffen, 2012). Unfortunately, the system did not function properly and was replaced by a gas boiler in 1985.

This section discusses several countries in Europe: what are their objectives for the energy transition, what does their current energy system look like, and what aquathermal energy projects do they have? We start in the North and work our way down to Southern Europe.

1. Norway

Norway's climate ambition is to emit 55% less greenhouse gases by 2030 compared to 1990 (DVN, 2021). Policy is based on the polluter pays principle. New gas connections have been banned since 2017, and heating buildings with natural gas has been banned since 2020. This is a small effort, as the country hardly has any gas infrastructure band used little natural gas anyway. Some of the Norwegian gas is used in the heavy industry, but most (87% in 2020) is exported (IEA, 2022). Norway has sufficient alternative renewable energy sources for its own energy consumption. The heat supply is electrified or has a heat network (mainly in cities). Heat networks are currently mainly supplied with heat from waste incineration and biomass (Heat Supplies, 2021). Aquathermal energy comprises a small part of the source strategy, and is mainly aimed at thermal energy from wastewater and seawater.

Examples of aquathermal projects in Norway

Project name/location:	Skøyen Varmesentral, Oslo
Active since	Not known
Source:	TEA as part of the energy mix (7.8%)
Supply:	Heating
Output:	Heating for 13,000 apartments with an average energy consumption of 10,000 kWh per year.
System:	A heat network with two large heat pumps for heating and hot water. The system uses 19 million litres of wastewater a year. 4 – 5 °C heat is extracted from the wastewater. The heat pumps heat the water to the desired high temperature (90 °C).
Governance:	Finnish company Fortum and the municipality of Oslo each own 50% of Fortum Oslo Varme.

(SØRENSEN, 2019)

Project name/location:	Forum Sandvika, Oslo suburb
Active since:	1989, retrofit in 1993
Source:	TEA
Supply:	Heating (56 °C) and cooling (18 °C)
Output:	52% of the energy demand (heating and cooling) is met with aquathermal energy
System	Two networks: one 10 km network for heat supply and one 4 km network for cooling. The average wastewater stream is 3,000 l/s. There are two heat pumps with a capacity of 6.5 MW for heating and 4.5 MW for cooling. Before

	the water enters the heat pumps, it is filtered in two steps: mechanically and with sedimentation. Peak management: heating station, with three oil burning vessels and conventional refrigeration.
Governance:	Energy supplier: Baerum Fjernvarme AS (part of Fortum Group)
Other information:	Installation company: Friotherm. Heating energy is also used to thaw pavements in winter.

(Friotherm, 2022)

Project name/location:	Drammen
Active since:	2011
Source:	TEO (seawater), fjord, 8 °C
Supply:	Heating
Output:	45 MW heat for 200 large buildings
System:	The fjord water is used to heat liquid ammonia at 4 bar until it boils and evaporates. The pressure is then increased to 50 bar, bringing the gas to 120 °C. This is used to heat the water in the system from 60 °C to 90 °C after which it is returned to the system. After heat transfer to the system water, the ammonia gas returns to a liquid form.
Governance:	Not known
Other information	The heat pump produces 3 kW thermal heat for every 1kW electricity. Installation company: Star Renewable Energy (Glasgow)

(Thorpe, this Norwegian city's district heating system uses cold water as source, 2015) (Anderson, 2015)

Project name/location:	Municipality of Eid
Active since:	2006
Source:	TEO (seawater)
Supply:	Heating and cooling
Output:	Heating and cooling for 90,000 m^2 of buildings
System:	Water from the sea is pumped to a heat exchange unit on shore. Here, the heat from seawater is transferred to a closed loop of freshwater. The heated freshwater is then pumped from the heat exchange unit to a heat centre containing heat pumps. From this heat centre, heated water is then distributed to customers. The energy stored in the warmed water is then transferred to end users via individual heat exchange units, and cold water is pumped back to the exchange unit.
Governance:	Not known
Other information	50 metre deep fjord, water temperature: 8 – 12 °C.

(Idso & Arethun, 2017)

Key takeaways from Norway

Fjords are considered a promising source. They are deep and the temperature of the water is relatively constant. Moreover, ebb and flow ensure natural renewal of the water. As a result, the ecological impact appears to be limited.

Projects in Norway are primarily aquathermal systems with heat pumps and an MT or HT heat network. The limited number of water-thermal energy production systems (WEPS) in Norway is due to high initial investment costs. In addition, there are insufficient sample projects with which to gain experience with maintenance costs and the technical performance of the system. There is also no central party responsible for coordinating all the project development (Idso and Arthun, 2017).

Annex 2 contains a list of other projects found during this study. It has been decided to only elaborate a few projects of the aquathermal variant in this chapter; readers can study the other projects themselves.

2. Sweden

Sweden's objective is to be climate-neutral by 2045, with a 70% reduction in CO_2 emissions compared to 2010 as an intermediate objective. At present, about 80% of Sweden's energy comes from nuclear energy and hydropower. The main sustainable sources are hydropower and biomass. The latter is used primarily for heating (Norström, 2020). Because other sources of renewable energy are available in Sweden, aquathermal energy is only used to a limited extent.

Examples of aquathermal projects in Sweden

Stockholm has both a heating and a cooling system that uses aquathermal energy. This is discussed in more detail below.

Project name/location:	Värtan Ropsten, Stockholm
Active since:	1984, retrofit in 2003
Source:	TEA and TEO (seawater) as part of the energy mix (26%)
Supply:	Heating
Output:	Capacity demand total network (cooling and heating): 100 GWh a year
System:	Total distribution system: 765 km. Specifically for Värtan Ropsten: seawater heat pumps (6x), total 180 MW.
Governance:	Energy company Forum is responsible for heating/cooling production and installed distribution systems.

(Värtan Ropsten, n.d.)

Project name/location:	Nimrod, Stockholm
Active since:	1995, retrofits in 2000 and 2001
Source:	TEO, the Baltic Sea
Supply:	Cooling
Output:	Capacity demand total network (cooling and heating): 100 GWh a year
System:	For the production of the refrigeration capacity required during summer, two compressors are operating in parallel, one with a 7 MW refrigeration capacity and one with 5 MW. At times with low cooling load, the capacity of both units is reduced to approx. 20% of full load, resulting in excellent part load values. During summer, heat is rejected to sea water flowing through the condensers.
Governance:	Energy company: Fortum, responsible for the production and distribution of heating and cooling.

(Nimrod, n.d.)

Project name/location:	Rya Värmepumpverk, Gothenburg
Active since:	1985
Source:	TEA, 12 °C (9 °C heat is extracted)
Supply:	Heating (75 °C and 85 °C), return temperature: 45 °C
Output:	Not known
System:	Heat network with 4 central heat pumps (total 160 MW). As the heat pumps are greatly flexible, they operate as peak loads.
Governance:	Not known
Other information:	COP of heat pumps: >3.

(Heat pumps using wastewater in Gothenburg, Sweden, 2022)

Key takeaways from Sweden
Despite the limited number of aquathermal projects and research reports in Sweden, the country shows that aquathermal energy can be used perfectly for heating AND cooling and that seawater can be a suitable source.

3. Finland

In Finland, renewable energy sources represent about 40% of energy end-consumption. The aim set in the National Energy and Climate Strategy up to 2030 is to increase the use of renewable energy so that its share in energy end-consumption rises to more than 50%. The most important forms of renewable energy used in Finland are bioenergy, hydropower, wind power and ground heat. Bioenergy is generated from biodegradable waste, side streams of agriculture and industrial production, and from municipal waste. (Renewable Energy in Finland, 2022)

Examples of aquathermal projects in Finland

Project name/location:	Katri Vala, Helsinki
Active since:	2006
Source:	TEA and TEO (seawater)
Supply:	Heating and cooling
Output:	Not known
System:	Katri Vala's five heat pumps simultaneously produce heat at 80 °C and cold water at 4 °C. The pumps are in direct connection with the seawater pump 600 metres away. In winter, heat is extracted from sewage water and cold from the sea. In summer, when the heat pumps are in free-cooling mode, heat is also produced in addition to cold. The heat surplus is discharged at sea. The 10,000 m^3 chilled water storage facilities are used to store energy at night for use during the next day at peak load hours.
Governance:	Helsinki Energy is responsible for the production, distribution and sale of heat.
Other information:	90% of buildings in Helsinki are connected to district heating. Helsinki operates kilometres of tunnels containing water, district heating and district cooling pipelines, electric cables up to 110 kV as well as electric and telecommunication cables for domestic purposes. The tunnels are big enough to accommodate a car.

(Helsinki Energy, 2022)

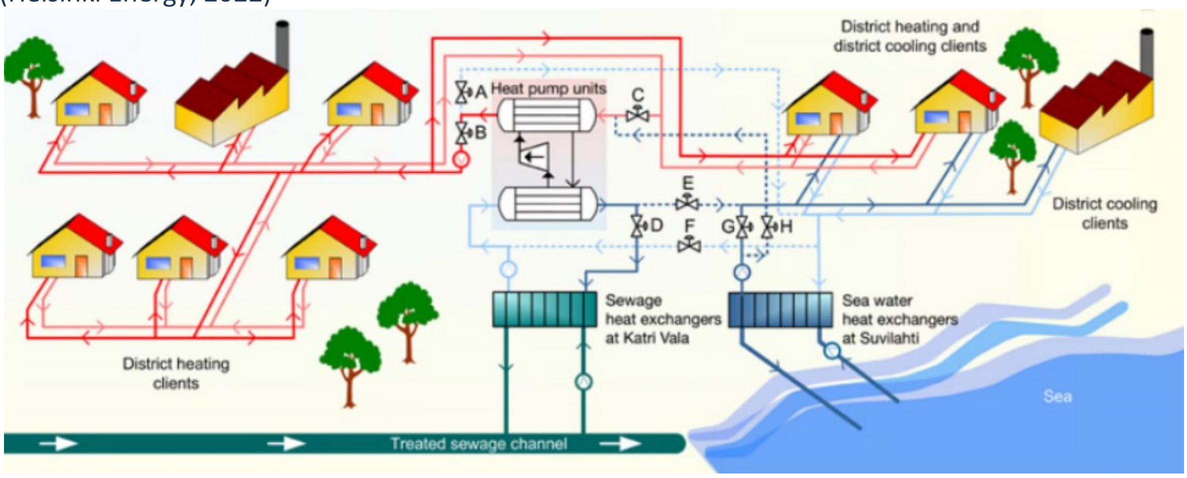


Image: Simplified diagram of Helsinki Energy network.
Image owner: Friotherm

Project name/location:	Suomenoja, Espoo
Active since:	2016: 2 heat pumps, 2021: 3rd heat pump added
Source:	TEA and TEO (seawater)
Supply:	Heating and cooling
Output:	340 GWh, annual heat for approx. 17,000 households
System:	Three heat pumps with a combined capacity of 60 MW, part of the Suomenoja CHP[1] plant. This is a power plant that supplies heat to a network of 800 km.
Governance:	Fortum, a state-owned energy company
Other information:	The water that remains after heat extraction for TEA is discharged into the sea via an 8 km long pipe.

(Suomenoja, 2022) (Fortum, 2022)

Project name/location:	Kakolanmäki, Turku
Active since:	2009: 1st heat pump, 2013: 2nd heat pump added
Source:	TEA
Supply:	Heating (85 °C) and cooling
Output:	Heating for 20,000 households a year, cooling 30 GWh a year
System:	Two 21 MW heat pumps, 15,000 m^3 water storage tank.
Governance:	Turku Energia Oy, which is responsible for the heat pumps, is owned by the city of Turku. The owners of the Kakolanmäki WWTP are the 14 municipalities and the city of Turku.
Other information:	TEA provides 8% of the heat for the district heating network. This equals 302 GWh a year.

(Turku Energia, 2022) (Turku, 2022)

Key takeaways from Finland

Aquathermal systems in Finland comprise storage, so that it is easier to respond at times when the supply is low (in the case of TEA) or for peak balancing. Storage is often underground, in man-made caves or tunnels. A combination of TEO and TEA works well in Finland, partly because aquathermal energy is used for both heating and cooling. In addition, the heat networks are very large, so that one source is not enough to meet the demand.

One of the main reasons for using cooling networks is the growing demand of business clusters wanting to outsource their utility services for their buildings. In addition, cooling networks are regarded as more environmentally friendly and cost effective compared to conventional technology with local small air conditioning units. (Helsinki Energy, 2022)

4. Germany

The “Energiewende” has been the defining feature of Germany's energy strategy for almost a decade. Yet despite good progress in terms of sustainable electricity, Germany is struggling to meet targets for sustainable transport and heating. In its energy transition so far, Germany has maintained a high degree of oil, natural gas and electricity supply security. Planned nuclear and coal phase-outs are set to increase the country's reliance on natural gas, making it increasingly important to continue efforts to diversify gas supply options, including through liquefied natural gas imports (Germany Energy Policy Review, 2020).

[1] CHP is short for ‘Combined Heat and Power’, the concurrent production of electricity and thermal energy.

Examples of aquathermal projects in Germany

Project name/location:	Singen
Active since:	2004
Source:	TEA
Supply:	Heating and cooling
Output:	240 MWh cooling and 660 MWh heat
System:	The wastewater energy is extracted with an 80 m. heat exchanger directly in the sewage pipelines. An electrically powered heat pump produces heating in winter and cooling in summer. The wastewater temperature is approximately 15 °C. The heat pump has a 200 kW cooling capacity and a 243 kW heating capacity.
Governance:	Not known
Other information:	The system's COP is 3.9.

(Petersen, 2018)

Project name/location:	Museum of Bavarian History, Regensburg
Active since:	2018
Source:	TEA
Supply:	Heating and cooling
Output:	Not known
System:	Two heat pumps with a 280 kW heating capacity and a 500 kW cooling capacity. Waste water is extracted at 70 l/s.
Governance:	The company Huber has supplied a heat exchanger and heat pumps.

(Huber, 2022)

Project name/location:	Grùne Au, Berlin
Active since:	2018
Source:	TEA
Supply:	Heating, 20% of demand
Output:	11,400 m^2 (113 homes)
System:	The system is a combination of a heat pump, combined heat and power system and a boiler. Annual heat demand is 750 MWh.
Governance:	Not known

(Wastewater heats residential complex in Berlin, 2019)

Key takeaways from Germany

In Germany, there is a lot of attention for and experience with TEA, which is why the number of projects shown above are only TEA. TEA is often used for both heating and cooling. This means that heat is extracted from the wastewater in winter and heat is extracted from the building in the summer and released to the wastewater.

The use of TEO is on the rise. Initiatives have been launched in cities such as Stuttgart, Mannheim, Berlin and Rosenheim. These projects are supported by the Living Lab for the Energy Transition under the title “Large-scale heat pumps in district heating networks – installation, operation, monitoring and system integration”. The German Federal Ministry for Economic Affairs and Climate Action has funded €21.3 million for this (Rhine Supplies Thermal Energy via New Large-Scale Heat Pump, 2022). The project in Mannheim is said to become the largest heat pump in Europe, measuring 18 metres in length and five metres in height. By extracting heat from the Rhine, it is expected to provide heat to 3,500 households and save around 10,000 tons of CO_2 emissions a year. A project worth following! Construction is scheduled for 2023.

5. Switzerland

Consisting mainly of nuclear and hydro generation, the energy system in Switzerland is one of the lowest in carbon intensity. However, following a referendum in 2017 that voted to phase out nuclear energy, Switzerland's energy sector is now undergoing a considerable transition. The challenge is to maintain the same low carbon generation and at the same time the high standards of supply security. In addition, Switzerland is committed to energy conservation. The new energy strategy will require opening the Swiss electricity market and full integration into the European electricity market to meet future energy needs. (Switzerland 2018 review, 2018)

Switzerland sees a lot of aquathermal potential in its deep lakes. The Swiss Federal Institute of Aquatic Science and Technology (Eawag) says that the potential of the large Swiss lakes is more than 60 MW (Jore, 2015). Eawag is also conducting research into TEA. For example, in 2009 the institute already published a study into the contamination of heat exchangers at 28 wastewater installations (Wanner, 2009).

Examples of aquathermal projects in Switzerland

Project name/location:	Tösswiese, Neftenbach
Active since:	< 2006
Source:	TEA
Supply:	Heating
Output:	Heating of 36 apartments and 12 houses
System:	4 – 5 °C heat is extracted from the wastewater. Heat pumps raise the temperature to 30 °C for heating and 68 – 70 °C for hot tap water.
Governance:	Collaboration between Stadtwerk Winterthur, the municipality of Neftenbach and HGW (housing association).

(Stadt Winterthur, 2006)

Project name/location:	Wintower, Winterthur
Active since:	Building dates from 1966, it is not known when the system was installed.
Source:	TEA
Supply:	Heating
Output:	480 kW for 22,000 m² office space
System:	Approximately 50 l/s of wastewater is removed from the sewer and pre-treated. Two submersible pumps transport the water to the two heat exchangers in the basement of the building. Heat transfer to the cooling medium takes place in the heat exchangers. The medium is heated and supplies the heat pump with the required energy. This provides about 600 kW for the heating system.
Governance:	The heating system was provided by the company Huber.
Other information:	The installation is also used for cooling in summer, extracting up to 600 kW of heat from the building. A maximum of 840 kW of heat is released to the wastewater in the sewer.

(Huber, 2022)

Project name/location:	GeniLac, Geneve
Active since:	2009
Source:	TEO, Lake Geneva
Supply:	Heating and cooling
Output:	Supply to 50 buildings

System:	Each building has its own heat pumps, which are connected to district heating. The heat from the lake is extracted at a depth of 45 metres. 6,000 m^3 water is recovered from the lake every hour.
Governance:	The project is operated by power company Services Industriels de Genève (SIG). They are working with the Federal Roads Office and Swissgrid (the national grid company) to facilitate the large-scale construction work and avoid continual traffic disruption during extension of the existing project.
Other information:	By 2018, the system had proved so effective that it has since been extended to Geneva city centre and seven municipalities. There is a move to connect over 350 buildings to the system by 2035. It is expected that 6x the amount of water will be pumped from the lake (36,000 m^3 per hour). TEA and geothermal energy are also being considered to make the network more sustainable.

(House of Switzerland, 2021)

Key takeaways from Switzerland

Switzerland has many examples of projects with both TEA and TEO (see also Annex 2). As in Scandinavia, the depth of the water source in the case of TEO seems to be positive for the operation and business case of the system. Various guidelines have been drawn up. The Federal Government's central platform Energieschweiz[2] has developed a guide for municipalities and builders especially for TEA (Heizen und Kühlen mit Abwasser). The Zürich subdistrict has guidelines for the planning, approval and implementation of wastewater energy systems (Heizen und Kühlen mit Abwasser, 2010).

The image below is an indication from 2019. The red dots indicate where thermal systems using lakes and rivers are in operation or have been planned. Drafted by Eawag, the image shows over 200 projects.

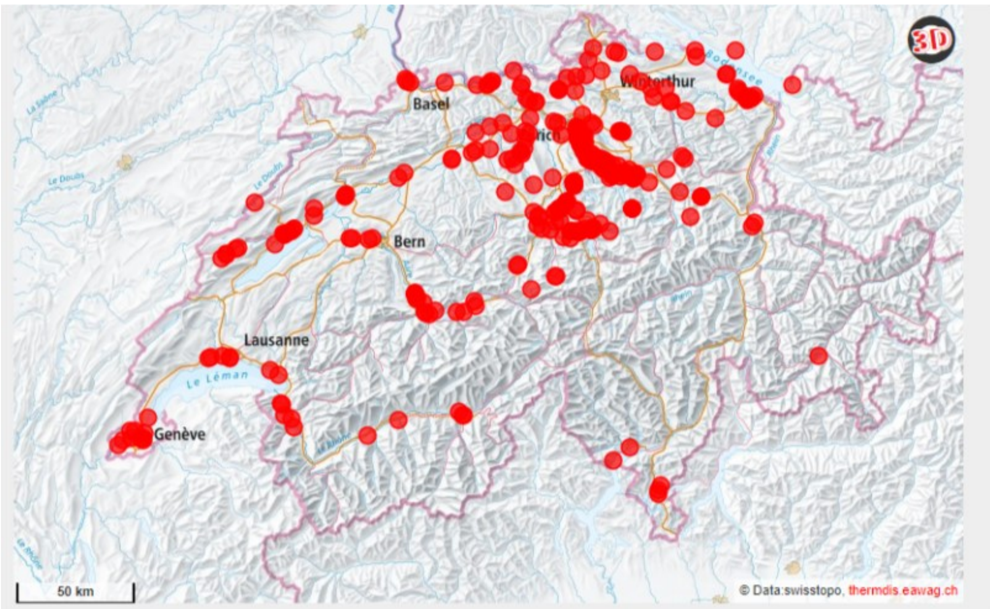


Image owner: eawag

[2] Objective: awareness, information, advice, training and further education, as well as quality assurance in the field of energy efficiency and renewable energies.

Ecology

Swiss federal regulations on protecting water resources say that "adding or extracting heat should not cause a variation in the temperature of water of more than 3 °C compared to what it is in its natural state". In waters with trout, it must not be more than 1.5 °C . At present, it is not possible to quantify the exact temperature variation that might trigger significant changes in the ecologies of lakes and rivers. The only thing that seems fairly certain is that an increase or decrease of 0.5 °C has no significant effect (Jore, 2015).

6. France

For many years, CO_2 emissions from energy generation in France were relatively low compared to similar countries, thanks to the large share of nuclear energy (71%) and hydropower (10%) (France, 2022). In 2021, France was not yet on track to meet its energy efficiency, renewable energy or emission reduction targets agreed in 2015. So, there is work to be done for France.

Examples of aquathermal projects in France

Project name/location:	Paris
Active since:	1991, fully sustainable since 2013
Source:	TEO, Seine
Supply:	Cooling
Output:	Cooling for 700 buildings, building surface area six million m^2
System:	There are at least seven refrigerated production locations and three cold storage locations. Cooling is produced in two ways: 1) air cooling towers; the water of the refrigerant circuit is in direct contact with the condensers. 2) open-circuit cooling system that pumps water from the River Seine. This system is equipped with intermediate heat exchangers that create a physical separation between the Seine water and the condensing circuit. A 140 km underground cooling network transported the cold (between 0.5 and 4 °C) to more than 500 customers.
Governance:	Climatespace (part of GDF Suez) develops and operates the cooling network on behalf of the city of Paris.
Other information:	With a new contract, Fraîcheur de Paris will be responsible for this project for the next 20 years and has plans to triple the length of the distribution network. This will entail 58 km of new distribution network, 20 new production plants and ten new storage facilities, to ultimately supply over 3,000 users with cooling. In 2010, the COP of the project was 3.8.

(Engie, 2022) (Climespace - City of Paris, 2011)

Because the system in Paris is under continuous development, it is difficult to identify the current status of the project. Another reason is that sources of information do not always state a date of publication, making it difficult to determine which is the most up to date. The above information can be seen as a minimum; the current project is certainly as large as this, but perhaps even (much) larger.

Project name/location:	Cherbourg
Active since:	2013
Source:	TEO (seawater)
Supply:	Heating
Output:	Heat for 1,300 homes
System:	Two heat pumps supply the heat network.
Governance:	System designed by EDF Optimal Solutions.

(EDF, 2015)

Key takeaways from France

France has the largest sustainable cooling system in Europe, which uses aquathermal energy as one of its sources. It is an inspiring example of how TEO can be used for cooling. Most aquathermal projects in France are TEO from seawater (thalassothermia). This shows that even without fjords, as in Scandinavia, seawater can be used for sustainable heating. France also has several TEA and TEO (freshwater) projects. There was not enough information to provide a proper representation and key takeaways in this section. An extensive list of the projects in France can be found in Annex 2.

Buildings in France that use TEO (seawater). Source: Ecoplage

7. Monaco

The smallest country in Europe has been using the Mediterranean Sea as a source of energy since 1963. The first system was installed at the Rainier swimming stadium, to heat water in the swimming pool. Today, there are more than 80 heat pumps, producing about 20% of Monaco's energy needs. The country aims to achieve carbon neutrality by 2050 (Monaconow, 2022). There will be a ban on the use of fuel oil for heating and hot water from 2022. To support the energy transition for buildings that still operate on fuel oil, the government has decided to install two ocean thermal energy loops in the districts of La Condamine and Larvotto. These loops will provide the buildings concerned with heat pumps that will supply hot water, heat and air conditioning while consuming very little electricity (Ocean Thermal Energy, 2022).

Aquathermia as an emerging technology

There are several countries in Europe where aquathermal energy is still in the early stages of awareness and development. This section examines some of these European countries in more detail, because lessons can be learned from them as well.

A. Denmark

Denmark's goal is to emit 70% fewer greenhouse gases by 2030 compared to 1990, while at least half of energy consumed must be renewable. Electricity generation in Denmark has changed fundamentally over the past two decades, with the country having switched from coal to wind energy and bioenergy. Supported by a flexible domestic power system, Denmark is widely recognised as a global leader in integrating variable renewable energy whilst maintaining a highly reliable and secure electrical power grid (IEA, 2017). Around two-thirds of the houses in Denmark are heated using a heat network. Currently, a lot of heat comes from waste incineration. In the future, Denmark aims at heat supplies for the heat networks that are even more sustainable.

Examples of aquathermal projects in Denmark

Project name/location:	Kalundborg
Active since:	2017
Source:	TEA
Supply:	Heating
Output:	Not known
System:	Heat pump capacity: 10 MW. 3,196 households are connected to the heat network. The heat pump supplies 10% of heat demand and is used for peak and back-up supply.
Governance:	Kalundborg Utility provides drinking water to 6,150 households in the city of Kalundborg, and is responsible for the district heating for around 5,050 households and the treatment of all wastewater in the municipality. It also owns the heat pump to extract excess heat from the wastewater.
Other information:	During the renovation of a power station (from coal to biomass), the heat pump provided 30% of the total heat demand. Investment costs: 7.25 million. Heat pump COP is 3.6 - 4.0.

(Celsius, 2020) (Niras, 2019)

Aquathermal initiatives in Denmark

Aquathermia is still an emerging technology in Denmark. We only found a few ongoing projects. There are, however, many different initiatives and pilot projects. A two-year test was carried out in Copenhagen in 2019 with 5 MW heat pumps using seawater and wastewater (State of Green, 2019). In Esbjerg, the largest seawater heat pump (50 MW) in the world will be installed with CO_2 as refrigerant. This choice was made to protect the vulnerable environment of the Wadden Sea (Fremtidens Fjernvarme, 2021).

There also are developments in TEA. This summer, Aalborg CSP signed a contract to connect a 2.5 MW ammonia heat pump to the district heating system of E.ON Denmark. This sustainable heat will be used in Frederikssund. The plan is to withdraw some 7 °C heat (pv magazine, 2022).

Key takeaways from Denmark
In Denmark, as in other Scandinavian countries, it is expected that the use of TEA will have a positive impact on the aquatic environment. TEA reduces the temperature of the water discharged into the sea, so that it is closer to the temperature of the water into which it is discharged (pv magazine, 2022).

Denmark already has many heat networks. This has an advantage for the aquathermal business case, as this cost item does not have to be included. As a result, having a minimum number of customers is less of a factor for feasibility of a project. All investments concern the size of the heat pump and the source of the heat (TEO; seawater or TEA). An average payback period of 6.5 years is expected (Foresight, 2019).

As for the governance of the heating companies in Denmark, they are owned by citizens or municipalities. Denmark has more than 340 heating companies, compared to five larger ones and a few smaller ones in the Netherlands (Huygen, Beurskens, Menkveld, & Hoogwerf, 2019).

B. United Kingdom

According to the International Energy Agency (2019), the UK has taken the lead in the transition to a low-carbon economy by taking ambitious climate action at international and national levels. One of the goals is a 57% CO_2 reduction by 2032 compared to 1990. The country's energy system has witnessed a rapid growth in the low-carbon energy share to over 50% of the electricity mix. In 2017, the energy mix looked like this: natural gas (41%), nuclear (21%), wind (15%, up from 3% in 2010), solar (3%), bioenergy and waste (11%), coal at 7% (vs. 29% in 2010) and hydropower (2%). The United Kingdom has committed to phase out all remaining coal-fired electricity generation by 2025 (IEA, 2019).

<u>United Kingdom</u>
In 2014, the Department of Energy & Climate Change (DECC) published a water-source-heat map. This "high-level water source heat map" shows 40 urban rivers in the UK with the greatest potential for using water source heat pumps for both heating and cooling. The map identifies areas of high heat demand along rivers with sufficient flow rates (Water Source Heat Map, 2022). The map was further detailed in 2015.

Examples of aquathermal projects in the United Kingdom

Project name/location:	Plas Newydd Country House and Gardens, Wales
Active since:	2014
Source:	TEO (seawater)
Supply:	Heating
Output:	Not known
System:	A tube is connected to the seawater and the heat exchanger. The heat is pumped by a 300 kW heat pump 30 metres up a rock wall to the 300-year-old country house.
Governance:	The project is owned by the National Trust.
Other information:	Installation costs: £600,000. COP is between 3 and 3.2.

(National Trust, 2022)

Project name/location:	Borders College, Galashiels, Scotland
Active since:	2015
Source:	TEA
Supply:	Heating
Output:	1.9 GWh a year, or 95% of heat demand
System:	Two heat pumps with a joint capacity of 800 kW.

Governance:	There is a 20-year contract between Borders College and SHARC Energy Systems. It is not clear what role Scottish Water, Scotland's water and sewerage service, plays in this project.
Other information:	Very first TEA project in the UK. The project's COP is 4.8.

(HPT TCP, 2022) (BBC, 2015)

Project name/location:	Kingston Heights, London, England
Active since:	2013
Source:	TEO, river Thames
Supply:	Heating and cooling
Output:	137 apartments and a 145-room hotel
System:	At two metres deep, the water has a constant temperature of 7 °C. There are two filters before the water reaches the heat exchanger. It is then taken 200 metres away to the heat pump, which raises the temperature to 45 °C degrees. The heat pump has a 2.3 MW capacity. The cooling capacity is unknown.
Governance:	Not known
Other information:	The maximum heat difference between the source and the water that flows back into the river is 3 °C. This has been agreed with the Environment Agency. Estimate CO_2 savings is 500 tons a year.

(Kingston Heights, 2020) (Thorpe, Smart Cities Dive, 2017)

Key takeaways from the United Kingdom

In the United Kingdom too, aquathermia is an emerging technology. There currently are only a few ongoing projects. Research has been and is being conducted into aquathermal energy by various universities and other organisations. For example, the Welsh Government has earmarked £450,000 for research into the possibilities of giving decommissioned coal mines a second life as a green source of energy to heat homes. The research seeks to identify the best locations for raising the water (Change Inc., 2022).

Another example is the Home Energy for Tomorrow (HE4T) project. This is a collaborative effort between London South Bank University and project leader ICAX Ltd. and is supported by Anglian Water and Thames Water, as part of their ongoing energy innovation work. The aim of the HE4T project is to explore heat recovery potential in the urban water cycle and use this information to promote this technology in the UK. It will look at how water systems (both potable water and wastewater) can be connected to the heat pump to boost efficiency - turning the water utilities into energy carriers. Currently an innovative heat pump is being developed & tested by ICAX Ltd. in the laboratory at LSBU. Thames Water and Anglian Water are collecting sewage temperature and flowrates data at various potential locations across London and the Midlands in order to better estimate the potential for wastewater heat recovery (HE4T project, 2022).

Aquathermal energy is considered a good opportunity to make the heat demand more sustainable and the UK is exploring the potential further, knowing that there are already various examples worldwide. The United Kingdom seems to be the only other country in Europe, apart from the Netherlands and Belgium, to have set its sights on TED.

C. Austria

Austria has the ambition to be climate neutral by 2040, 10 years ahead of the European Union's goal. Interim objectives are to phase out the use of oil and gas-fired heating systems by 2035, while new buildings may no longer be connected to natural gas from 2025 onwards. Hydropower is responsible for 60% of total electricity generation in 2018. The government plans to add another 5 TWh of hydropower, which will lead to the final target for 2030 of 27 TWh of electricity from hydropower

(Austria 2020, 2021). 26% of all apartment buildings are heated with district heating. This is also the largest heat source for commercial and government buildings. The heat comes from fossil fuels, biomass or waste incineration (Austria 2020, 2020).

Examples of aquathermal projects in Austria

Project name/location:	Amstetten
Active since:	2012
Source:	TEA
Supply:	Heating and cooling
Output:	230 kW of heat
System:	Heat is recovered from sewage water, which has a temperature between 10 and 15 °C. The heat pump has a rating of 228 kW and 186 kW of cooling capacity. To be used for heating, the temperature of the water is raised to 45 °C. Heat is distributed to the buildings via storage tanks and a low-temperature local heat network. The existing gas-fired boilers have been retained as a backup system to cope with exceptional peak demand (the heat pump system covers 99.9 %).
Governance:	The project was commissioned by Stadtwerke Amstetten, in collaboration with the WWTP.
Other information:	The investment is expected to pay off in around 12 years. The annual CO_2 reduction is estimated at 55 tons a year.

(Energy from sewage water, 2016) (Stadtwerke Amsetten, 2022)

Project name/location:	Straubing
Active since:	2010
Source:	TEA
Supply:	Heating and hot water
Output:	Heating for 102 apartments in 11 buildings
System:	Source temperature is 12°C C, supply temperature is 45 °C. There is a single, central heat pump with a capacity of 200 kW.
Governance:	Not known

(Ecotechnology, 2022)

Key takeaways from Austria

Unlike its neighbour Switzerland, there seem to be few aquathermal projects in Austria. Most of the projects found in this inventory are TEA. Because of the limited number of projects, there are no takeaways from Austria in terms of aquathermal energy.

D. Belgium

The Belgian National Energy and Climate Plan (NECP) sets 2030 targets for a 35% reduction of non-ETS GHG emissions versus 2005 levels. The EU-wide 2030 greenhouse gas emissions reduction target has been increased from 40% to 55%. Belgium's current objectives do not match this and should be increased.

Belgium is doing well in the field of sustainable electricity, with production having increased in 10 years due to solar panels and wind. By 2021, Belgium had the sixth-highest offshore wind capacity in the world and is planning for a major expansion. Belgium faces notable challenges as it continues to push for its energy transition, seeing as fossil fuels still account for a large part of its energy supply (IEA, 2022).

Examples of aquathermal projects in Belgium

During this inventory, we found one aquathermal project in Belgium: the renovation of the Brussels South water treatment plant. The associated administration office will be heated by TEA from March 2022 (HLN, 2022). Unfortunately, little information is available about this project.

Aquathermal initiatives in Belgium

Belgium has various studies and initiatives at various locations into the potential of aquathermal energy. An example is Flemish water purification company Aquafin. It is building a new office in Aartselaar for 400 employees, which will be heated and cooled with TEA via a connection to the sewer. A heat pump will upgrade the extracted heat to 34 °C to 40 °C, when there is a need for heating (GVA, 2022). Other examples are listed in Annex 2.

Key takeaways from Belgium

Aquathermia is still an emerging technology in Belgium. There are hardly any projects and a few enthusiastic initiatives. Our neighbour is closely monitoring the knowledge that is developed in the Netherlands and our approach.

E. Hungary

Hungary is one of the first countries in the world to put its carbon neutrality goal for 2050 into law. Other goals are to phase out coal by 2025 and a stronger focus on solar PV and nuclear power. Given its vulnerability and reliance on Russian gas, oil and nuclear fuel, the country's energy strategy prioritises energy efficiency, security of supply, and affordability. Being heavily reliant on fossil fuel imports, Hungary must diversify its renewable energy sources by drawing on the considerable potential of its wind and geothermal energy resources as well as extending the lifetime of existing reactors, where safety permits. (Hungary 2022, 2022).

Example of an aquathermal project in Hungary

Project name/location:	Military hospital, Budapest
Active since:	2014
Source:	TEA (10 – 20 °C)
Supply:	Heating and cooling
Output:	Heating and cooling for a 40,000 m^2 building
System:	A filtration unit cleanses the water before it is sent to the heat pump units. The heat pump system has a heating capacity of 3.8 MW and a cooling capacity of 3.3 MW. Heating and cooling is delivered to the building through air handling units. The heat is delivered at a low temperature of no more than 32 °C. Approximately 11,000 m^3 of sewage water pass the system every day.
Governance:	Heat pump supplier: Thermowatt
Other information	Estimated costs are EUR 2.5 million, with a COP between 6.5 and 7.1. The deltaT for heating is 32/22 °C and the deltaT for cooling is 6/12 °C.

(Sewage Budapest, 2020) (Chefdeville, 2022)

Key takeaways from Hungary

Hungary has several TEA projects (see Annex 2), which mainly supply heating and/or cooling to a single building. Because of the limited number of projects, there are no takeaways from Hungary in terms of aquathermal energy.

Conclusion

This inventory looked at 12 European countries in which aquathermal energy plays a role in making the demand for heating and cooling more sustainable. Mainly large projects were found, of well-known buildings or large heat networks. This is because, logically, more is published about these kinds of projects, making information easier to find online.

Going back to the research question: *What is happening in Europe in the field of aquathermal energy and what are relevant takeaways for the Netherlands?* it appears that plenty is happening in Europe in the field of aquathermal energy. There are many countries where projects have been realised and new initiatives are being started.

Based on the projects studied, several conclusions can be formulated:

- A lot of TEA and TEO, hardly any TED.

  The vast majority of projects are TEA, TEO or a combination of the two. TED is hardly used at all, with the exception of the Netherlands and the United Kingdom. The TEO projects not only have freshwater such as lakes and rivers as a source, but also seawater. This is something that is currently almost non-existent in the Netherlands.
- No heat supply at low temperatures.

  In the Netherlands, we mainly see opportunities for aquathermal energy in combination with low-temperature heat networks. This is not the case in other European countries, where heating is often upgraded to mid (±70 °C) and high temperatures (>80 °C).
- Aquathermia is used as a single source or in combination with other sources.

  Aquathermal energy is sometimes used as a single source for heat networks, but in several cases both TEO and TEA are used for heating and/or cooling buildings. We also found projects in which aquathermal energy was part of the energy mix of a network, for example in combination with geothermal energy. Combining heat sources increases the security of supply because a heat network is no longer dependent on a single source. A multi-source strategy helps to develop a robust heating system.
- COP higher than 3.

  Most aquathermal projects indicate that the COP is higher than 3, in some cases even higher than 4. Aquathermal energy is an efficient form of energy generation, even at high temperature regimes.
- ATES is not necessary for cooling with aquathermal energy.

  Aquathermal energy is already being used successfully in various places for cooling buildings. It turns out that the use of a thermal storage system is not necessary. Just like in the Netherlands, the subsoil in other European countries is not always suitable for ATES, but this does not show any restrictions for the possibilities of cooling buildings with aquathermal energy.

The inventory shows a varied picture of how aquathermal energy can be used in different environments. We can therefore learn a lot about other possibilities and variants for the application of aquathermal energy in the Netherlands. On the other hand, with knowledge of TED and low-temperature heat networks, the Netherlands can take a leading role in making the built environment more sustainable.

Follow-up

This inventory sketches a general picture of aquathermal energy in Europe and has yielded interesting insights for the Netherlands. The NAT office is of the opinion that these insights can also offer added value internationally. For that reason, this study report is translated into English. This will make it more widely accessible, so that it can be used for knowledge exchange with international organisations.

Together with the Dutch Association of Regional Water Authorities, we will explore through EurEau (European Federation of National Associations of Water Services) which ways of cooperation with European countries are possible. There are knowledge gaps on various topics that can be resolved at the European level. These include:

- Ecological effects: both the Netherlands and Switzerland recognise that there may be consequences for the ecology. Cooperation in this area could be conducive.
- Governance: Denmark is often cited as an example but has significantly differed from the Netherlands in terms of past choices. Let's look at other countries.
- Multi-source approach for heat networks: in Norway and Finland, aquathermal energy is often part of a mix of energy sources that supply heating and/or cooling to a heat network. This is not yet the case in the Netherlands. It would be interesting to explore this further, for example in terms of what it means for the business case.

If other parties have ideas as a result of this report or wish to join in the follow-up, please send an email to info@aquathermie.nl.

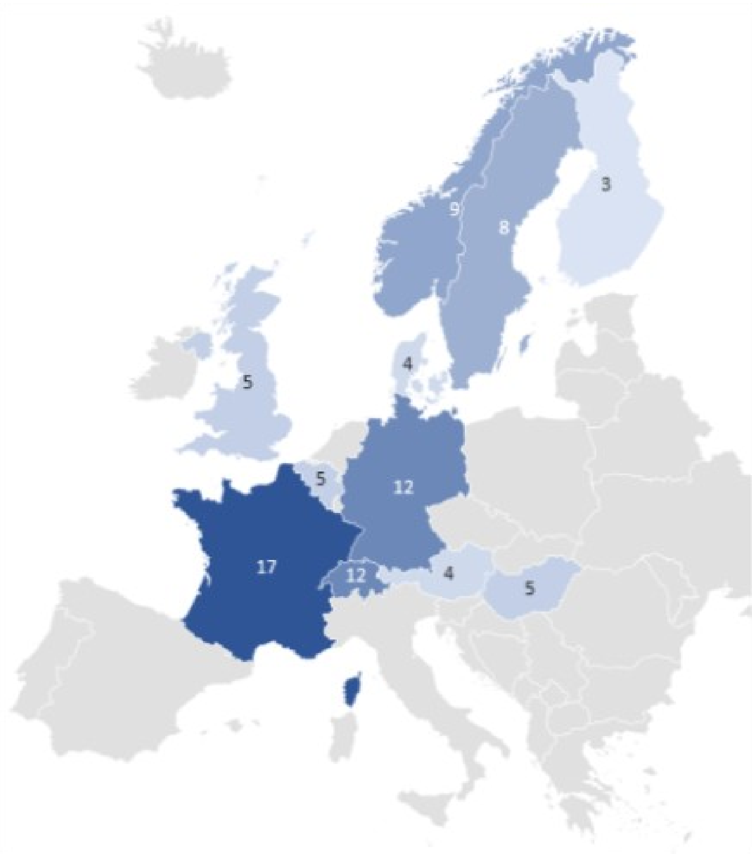
Annex 1: Overview of projects

The table below presents the aquathermal projects and initiatives found for each country during the inventory. The table is not an exhaustive overview of all aquathermal projects in a country. The actual number of projects is likely to be far higher than shown below.

Country	TEO	TEA	TEO-TEA combined	Initiatives	Total
Norway	5	3	1	*	9
Sweden	2	4	2	*	8
Finland	-	1	-	2	3
Germany	-	5	-	7	12
Switzerland	7	5	-	*	12
France**	17	-	-	-	17
Denmark	-	1	-	3	4
United Kingdom	2	2	-	1	5
Austria	-	3	-	1	4
Belgium	1	-	-	4	5
Hungary	-	4	-	1	5
Total	**34**	**28**	**3**	**19**	**84**

* For the countries with many projects, we did not look any further for initiatives in that country.
** It was unclear whether these are all realised projects or also initiatives

The data from the table are presented in the map below.



Annex 2: Other projects per country

Below are the projects per country that emerged during this study but are not elaborated in the report itself. Readers are invited to study these themselves.

Norway

- Projects:
    1. Oslo – Fornebu (TEO, seawater):
    2. Rolfsbukta (TEO), seawater
    3. Fredrikstad (TEA)
    4. Bodo NATO (TEO, seawater)

Sweden

- Projects
    1. Sala (TEO, seawater)
    2. Vilhelmina (TEA)
    3. Malmö (TEA)
    4. Helsingborg (TEA)

Finland

- Initiatives
    1. Salmisaari, Helsinki (TEO, seawater)
    2. Lahti (TEA)

Germany

- Pilots
    1. Hasteststraße, Hamburg (TEA), 2009 – 2010
    2. CELSIUS project: Mülheim, Nippes and Wahn (Cologne region) (TEA), 2012 – 2016
- Initiatives
    1. Hamburg (TEA)
    2. Mannheim, Stuttgart, Berlin and Rosenheim (TEO)
    3. Bremen (TEO)
    4. Berlin (TEA)
- Projects
    1. Lemgo (TEA)
    2. Witzenhausen (TEA)

Switzerland

- Projects
    1. Thermal spa Burgerbad at Leukerbad (TEO)
    2. Lausanne (TEO)
    3. Binningen (TEA)
    4. Münchenstein (TEA), residential home
    5. St. Gallen (TEA), office

  One website, multiple projects:

    6. Zurich (TEO), subdistrict parliament building
    7. St Moritz (TEO)
    8. Ticino (TEO), Swiss National Supercomputing Centre
    9. Horw (TEO)

Eawag has drafted a map showing thermal systems connected to rivers and lakes. This contains a number of TEO projects that are not mentioned above.

France

Due to the language barrier, it has not been possible to identify whether the projects below are ongoing projects or new initiatives.

1. Tours (TEA)
2. Paris (TEO)
3. Lake Annecy (TEO)

- One website, multiple projects/initiatives
  4. Briarritz (TEO, seawater)
  5. Brest (TEO, seawater)
  6. Boulange-sur-Mer (TEO, seawater)
  7. Marseille (TEO seawater), Smartseille district
  8. La Seyne-sur-Mer (TEO, seawater)
  9. La Grande-Motte (TEO, seawater)
- One website, multiple projects/initiatives:
  10. Roquebrune-Cap-Martin (TEA)
  11. Marseille (TEA), swimming pool
- One website, multiple projects/initiatives:
  12. Sète (TEO, seawater)
  13. Leucate (TEO, seawater)
  14. Dieppe (TEO, seawater)
  15. Ajaccio (TEO, seawater)
  16. Dunkirk (TEO, seawater)
  17. La Rochelle (TEO, seawater)
  18. Lorient (TEO, seawater)

Denmark

- Initiatives
  1. Aarhus (TEO, seawater)

United Kingdom

- Initiatives
  1. Kingston upon Thames, England (TEA)
- Project
  1. Campbelltown, Scotland (TEA)

Austria

- Pilot
  1. Vienna (TEA)
- Initiatives
  1. Bregenz (TEO), swimming pool and events hall
- Projects
  1. Weiz-Giesenhof (TEA)

Belgium

- Initiatives
  1. Anzegem (TED)

2. Mechelen-Noord industrial estate (TEA)
3. Ranst (TEO)

Hungary

- Initiatives
  1. Budapest (TEO)
- Projects

  One website, multiple projects/:
  1. MOM Culture centre (TEA)
  2. Budapest sewage work (TEA)
  3. University of Szeged (TEA)

Annex 3 Abbreviations

- ATES: Aquifer thermal energy storage
- COP: Coefficient of Performance
- HRE: Heat Roadmap Europe
- LT: low temperature
- MT: mid temperature
- HT: high temperature
- NAT: Netwerk Aquathermie
- TEA: thermal energy from sewage water
- TED: thermal energy from drinking water
- TEO: thermal energy from surface water: freshwater as well as salt water
- WEPS: water-thermal energy production systems

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