HEATING AND COOLING
EUROPEAN BUILDINGS WITH LAKES?

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Lake-source thermal district networks can save energy and emission for heating and cooling buildings. However, where and to what degree such systems could be an effective solution is unclear. We simulated that covering 17% of the cooling demand and 7% of the combined heating and cooling demand near European lakes is economically feasible and does not cause severe lake water temperature alterations in most cases.

Climate change is increasing the global demand for cooling, and novel approaches must be pursued to sustainably satisfy this need. Lakes are one underexplored source to assist in the efficient supply of both heating and cooling. In Europe, lakes commonly have a deep-water temperature that is considerably lower than the ambient air in summer, while being slightly higher during winter. The temperature difference between ambient air and the deep lake layer (hypolimnion) can be used to provide free (direct) cooling in summer, as well as to increase the efficiency of heat pumps when heating is required.

Lake-source district systems

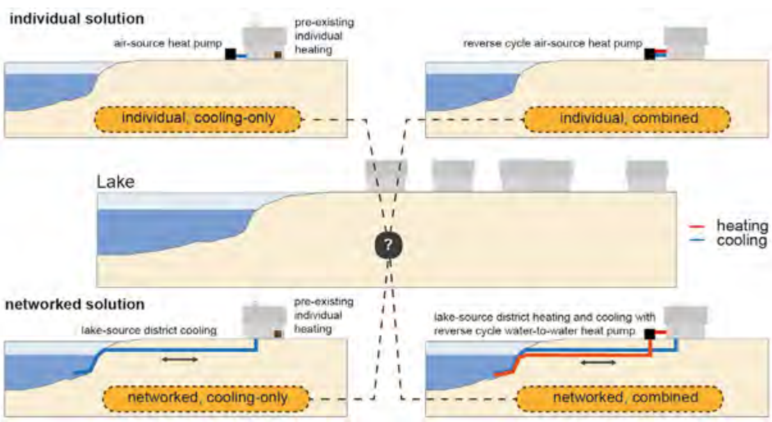
A district near a lake could be served by an energy system that can be configured in four ways: buildings can be individually cooled by an air-source chiller or heated and cooled by a reverse-cycle heat pump, in a decentralized way. Alternatively, networked solutions can exploit lake water either for cooling (cooling-only) or both heating and cooling (combined). These system configurations are shown in Figure 1. Lake-source heating or cooling is in principle applicable to any building type. However, more energy-efficient building constructions are more suited compared to less efficient buildings, as they require a lower heating supply temperature (we assumed 40°C) and their cooling-to-heating demand fraction is higher, making better use of the additional efficiency that lake-source systems can provide.

It is challenging to establish the exact conditions under which a lake-source centralized system (*i.e.* district network system) can outperform a decentralized system. Important variables that influence the economic viability of either system are the lifetime of the system, its capital and operational cost, and other exogenous variables, such as the electricity price, costs associated with CO_2 emissions, and interest rates. From an ecological point of view, implementing lake-source district systems affects the lake temperature. For this reason, the thermal response of the water bodies was modelled with and without heat injection and extraction from heating and cooling operations. Economic constraints, the availability of large lakes, and the availability and spatial distribution of building energy demand near lakes were also considered. Also, when deciding on the potential implementation, it is essential to relate operational savings to the required capital costs.

A techno-economic and ecologic modelling approach

We combined several methodological steps to identify, design and evaluate the techno-economic feasibility of thermal districts for each European country. In a recent study (Eggimann *et al.* 2023), geospatial analysis, graph-based network modelling, techno-economic accounting and thermal lake modelling were combined to estimate the efficiency of lake-source district systems and to evaluate the impact on lake water temperature. We combined lake data from the HydroLAKES database and OpenStreetMap to obtain geometric lake and building data. Climate data (weather files) were sourced from MeteoNorm. We used a validated lake model, Simstrat, to calibrate our simplified thermal lake model (for more detail on our methodological approach, we refer to Eggimann *et al.* 2023). Our approach allows us to carry out a realistic estimation of the potential of using lakes to heat and cool buildings at a larger geographical scale. The average daily building (thermal) energy demand was estimated using the spatial data combined with an energy signature calculation outlined in Eggimann *et al.* (2022) for Switzerland and extrapolated to other European countries using construction properties reported • • •

▲ **FIG. 1:** Four technological system configurations of how buildings situated close to a water body can be cooled and/or heated.



in TABULA (episcope.eu). Only lakes with a minimum size of 400 hectares (or 0.028 km^3 of water volume) and buildings within 1.5 km of lakeshores were considered (nearly 2'000 lakes). The energy demand for heating and cooling near the considered lakes is shown in Figure 2.

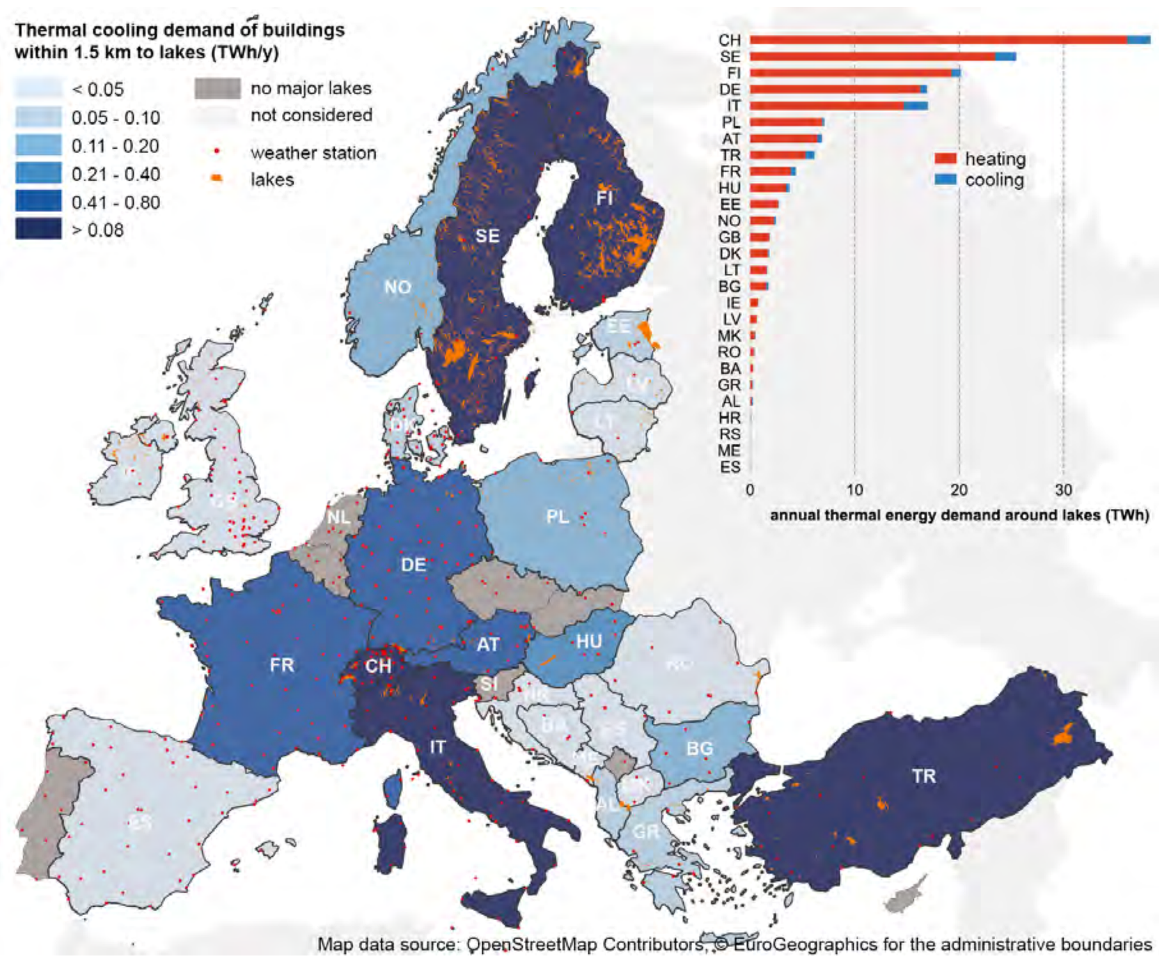
Country-specific potential of lake-source heating and cooling

For every European country, we simulated how much of the building demand can be covered by an economically viable lake-source system. Figure 3 shows results for the base scenario in Eggimann *et al.* (2023) assuming current climatic conditions. The total thermal energy demand of buildings around European lakes was estimated as ~11 TWh for cooling and ~150 TWh for heating. From these demands, the annual techno-economic potential was simulated to be 1.9 TWh for cooling-only systems, and 11.3 TWh for combined systems. The corresponding electricity savings were estimated to be 0.36 TWh in the cooling-only case and 0.78 TWh for the combined one.

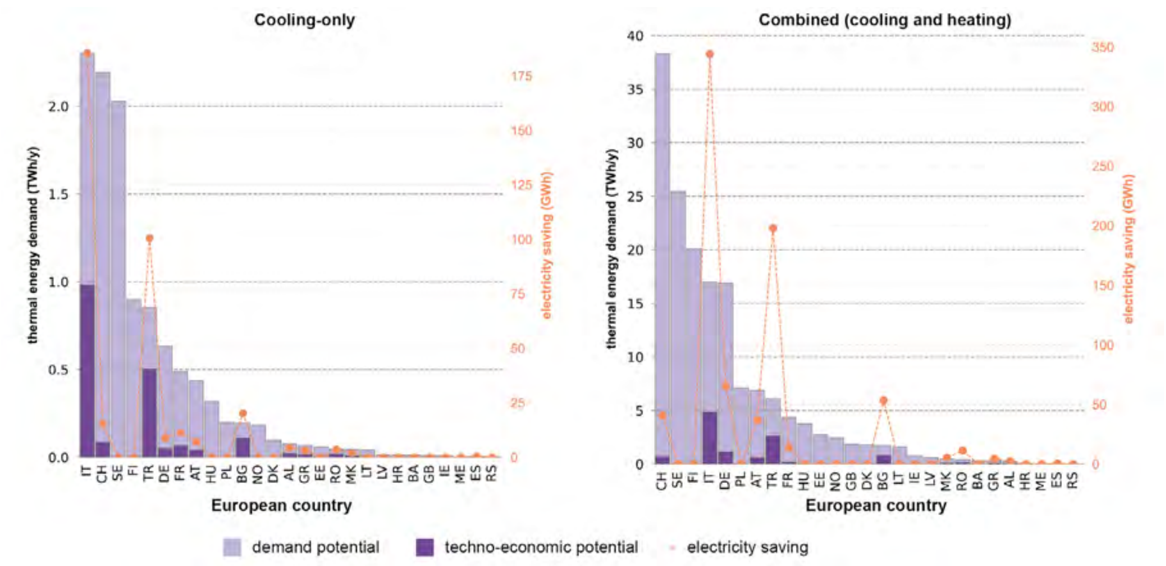
The distribution of our identified techno-economic potential is heterogeneous. When including technical and economic constraints in the analysis, lake-source systems show significant benefits only in a few countries, such as Italy, Turkey, Bulgaria, Switzerland, France and Germany. When the combined case is considered, a much larger heating and cooling demand potential was observed. Switzerland was found to have the highest energy demand to be potentially covered, with nearly 40 TWh per year, but due to techno-economic factors, only a relatively small portion of the demand can be feasibly covered by lake-source systems. Countries where electricity is expensive compared to capital costs are found to be more suitable for a profitable development of this infrastructure to exploit lakes (*e.g.* Italy, Germany and Turkey). Lake-source district systems were therefore found to be less viable in countries that, despite a large demand potential to be covered, had a lower relative electricity price (*e.g.* Switzerland). Another problem that might reduce the techno-economic potential of these systems is the availability of lakes that do not freeze over longer periods of time, such as in Sweden and Finland, which were deemed unsuitable in our study. Finally, our lake thermal model simulations showed that in most cases, the maximum temperature increase would be less than 0.5°C if all techno-economically feasible systems were implemented.

Lessons learnt

We have provided a first combined exploration of technological, ecological and economic dimensions to evaluate the potential of using lakes as a source for district heating and cooling systems at the European



▼ **FIG. 2:** Overview of the total annual thermal energy demand of buildings around European lakes. Original image source: Eggimann *et al.* (2023).



▾ **FIG. 3:** The simulated techno-economic potential for lake heating and cooling in Europe. The annual demand potential and the techno-economic potential are shown for using lakes for cooling-only (left) and combined heating and cooling (right). Values are shown for the base scenario from Eggimann et al. (2023) assuming a scenario with an interest rate of 4% and electricity prices twice as high as in the year 2021.

scale. Lake-source thermal networks are constrained foremost by the availability of lakes. However, also the spatial distribution of energy demand determines how much energy or emissions can be saved. The thermal energy demand of buildings near lakes considerably exceeds the techno-economically feasible potential. An estimated 17% of the cooling demand near European lakes can be covered by viable cooling-only lake-source systems. For combined systems, the viable demand is estimated at 7% of the total available combined heating and cooling demand. Annual electricity savings of 0.4 TWh (cooling-only) and 0.8 TWh (combined) is simulated for Europe. These electricity savings can be converted into CO_2 savings by assuming current CO_2 emission intensity of electricity, resulting in yearly CO_2 savings of 128 and 270 kt respectively.

The expansion of district thermal networks is a common strategy in many European countries to improve the efficiency of delivering heating and cooling to buildings. Based on our study, we find that integrating lakes can increase the attractiveness of such systems, particularly in Italy, Germany, Switzerland and Turkey. Even if the economic performance of these district systems is comparable to the one of individually heated and cooled buildings via heat pumps, the implementation of lake-source district heating would still lead to energy and CO_2 emissions savings due to the availability of free-cooling and a more efficient heat pump operation in winter. These savings add to the benefits of replacing current fossil fuel-based systems (*e.g.* oil or gas boilers) with heat pumps.

In our simulations, climate change was shown to increase the techno-economical potential of lake-source district systems of both types (combined and cooling-only). Future studies could consider additional interesting potential water bodies as viable energy sources, such as coastal waters, aquifers or rivers. The potential of using the sea for cooling and heating in countries with cities close to the seashore remains to be explored. However, last year's heat waves also revealed that heat injection in rivers is ecologically challenging and could lead to problems such as curtailment of power generation. ■

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