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Technical and Economic Feasibility Analysis for Geothermal Cooling in Türkiye

Carried out under the bilateral energy partnership on behalf of the German Federal Ministry for Economic Affairs and Climate Action

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On behalf of the German Federal Ministry for Economic Affairs and Climate Action (BMWK), the Deutsche Energie-Agentur (dena) – the German Energy Agency – works with numerous political and business actors in both countries in the areas of activity of renewable energy, energy efficiency, energy infrastructure, and the linking of sectors, thereby contributing to a structured exchange and transfer of knowledge.

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Content

1 Introduction

This feasibility analysis was compiled as part of the German-Turkish Energy Partnership, which was founded by the governments of both countries in 2012. The working groups of the German-Turkish Energy Partnership pursue the goal of contributing to the modernisation and enhancement of the value chain of the Turkish energy sector through an intensive exchange of ideas. Achieving the Turkish government's energy goals entails tapping deeper into the significant potential of renewable energy, exploiting the considerable potential for energy efficiency in all consumption sectors, as well as shaping energy infrastructure and integrating renewable energy sources into the energy market.

The aim of this feasibility study is a technical and economic analysis of the potential of geothermal cooling in Türkiye.

1.1 Background

Geothermal technology for heating and cooling in Türkiye with renewable energy has already been considered in a number of studies (Baba and Chandrasekharam, 2022; Mertoglu, Simsek and Basarir, 2021), dossiers (Buchin and Wilkens, 2020) and reports (IRENA, IEA and REN21, 2020; IRENA and IGA, 2023), whilst the Turkish government has announced a National Cooling Action Plan, covering sustainable and natural cooling technologies (Republic of Türkiye, 2023).

In general, there is great potential for the use of various renewable energy sources for heating and cooling in Türkiye. Different technologies are available for this purpose, which are already being used successfully in Germany. The particular challenge for cooling in Türkiye is to replace the predominantly electricity-operated cooling systems with alternatives that utilise renewable energy. Although accurate data on energy consumption for cooling in Türkiye is not available, studies show that energy demand for cooling homes, public facilities and workplaces across the region has been on the rise since the turn of the millennium (Scoccimarro et al., 2023). This feasibility study shows the available and usable potential of geothermal energy as primary energy for generating cooling in Türkiye. For this purpose, the following two utilisation concepts are considered:

1. Construction of a new geothermal plant with cooling generation and comparison with conventional technologies.

2. Retrofitting an existing geothermal plant for cooling generation as well as the continued use of existing distribution networks.

In point 2, a practical approach is taken, via which an existing electricity-powered cooling plant can be conceptually replaced by a geothermal-powered plant through a judicious combination of technologies.

1.2 Energy policy considerations and reliability of the electricity supply

In Türkiye, generating renewable electricity from geothermal energy goes back to the 1970s, but only makes up about 3% of the country’s electricity generation (IRENA, 2023). Beyond electricity, geothermal energy used for heating is also an established practice. Among the 15% of renewables in the total final energy consumption mix, geothermal is the largest with a share of 45%, followed by hydropower (23%) and bioenergy (14%) (IEA, 2021a; IRENA, 2023).

Due to its geographical location, the potential for the use of renewable geothermal energy is considered to be very high. The technical potential for heat generation from geothermal energy is specified in literature at 31,500 MW_{th} (276 TWh), and the installed electrical capacity reached 1,691.4 MW_e by 2023, with most of the sources located in the west (Cariaga, 2023; Mertoglu, Simsek and Basarir, 2021).

Türkiye's final energy consumption has almost doubled since 2000, driven by rapid economic and population growth (IEA, 2021a, 2023b). Imported fossil fuels dominate the energy supply but thanks to significant efforts in renewable electricity, this trend was reversed, with a renewable energy share of 15% in 2020 (IRENA, 2023).

According to data from the International Energy Agency (IEA), approximately 9% of global demand for electricity is used for air conditioning. Even including future efficiency improvements, a jump from 2,020 TWh in 2016 to 6,200 TWh in 2050 is projected for residential and non-residential buildings worldwide (IEA, 2018, 2023a).

The percentage of final energy demand for electricity used for air conditioning may increase to anywhere from 10% to almost 16% depending on the region (IEA, 2018). These trends pose challenges for the electricity supply in Türkiye on multiple levels.

The increase in renewable power sources, such as wind and photovoltaics, poses great challenges to power grids due to fluctuating capacities. In addition, air conditioning in Türkiye already leads to peak consumption during summer, while electricity demand is the lowest in February. However, the grids, some of which are in need of renovation, are designed for centralised, controllable electricity production in the east of the country and distribution of the energy to the west (Ergur, 2023; Smith *et al.*, 2022).

New concepts are needed to relieve the strain on the electricity grid and absorb load peaks. Deep geothermal energy, a renewable energy source, can help with this issue (IRENA and IGA, 2023).

The Turkish government is increasingly approving areas for geothermal projects and encouraging companies to invest in geothermal plants (IEA, 2021a). In 2020, Türkiye was among the top five geothermal countries worldwide in terms of heating and cooling using geothermal energy (IRENA and IGA, 2023). Aside from the ongoing growth of geothermal projects for electricity generation, which is also forecast for the coming years, the continued proliferation of projects for the supply of geothermal district heating, especially in the Aegean region, is also expected. In addition to the implementation of new geothermal projects, increasing the efficiency of existing plants is gaining in importance.

1.3 Use of deep geothermal energy for electricity generation in Türkiye

Between 2012 and 2022, the total amount of electricity produced grew by 36% to 326 TWh, whilst the share of low-carbon sources also increased significantly from 27% to 42%. Still, coal (34%) and gas (23%) make up the majority, followed by hydro (21%), wind (11%) solar (5%) and geothermal power (3%). About 5% of the electricity was exported (Electricity Maps, 2023; Ritchie, Roser and Rosade, 2022).

Another cornerstone of the country's economic growth is to be its entry into the nuclear energy sector. Currently, four reactors with a total capacity of 4,800 MWe are under construction in the south (Akkuyu) of the country, with a planned staged completion between 2023 and 2026. Two further large projects with a comparable capacity are planned for plants in the north (Sinop) and northwest (Igneada). For practical implementation, Türkiye is seeking expertise and financing from abroad (World Nuclear Association, 2023).

Türkiye’s natural gas and oil needs are highly dependent on imports, whereas domestic coal production meets nearly half of coal demand. The Turkish government's goal is to reduce import costs by promoting renewable energy and reducing overall energy consumption via energy efficiency measures (IEA, 2021a).

Using deep geothermal energy for energy provision is one step towards achieving this goal. It holds great potential for growth in Türkiye and is continuously increasing in importance. Currently, the focus is primarily on electricity generation using geothermal energy. Cascading use, electricity – heating – cooling, has only been implemented in isolated cases so far.

By the end of 2020, 62 geothermal plants were already in operation (Mertoglu, Simsek and Basarir, 2021). By 2022, the installed electrical capacity was projected to be 1,691.4 MW_e (Cariaga, 2023). The estimated electricity generation potential from geothermal sources in Türkiye is around 2,000 MW_e with the highest share in Western Anatolia (MENR, 2023). Due to the positive trend in the use of geothermal energy for electricity generation, expanding it by adding a coupled heating supply is increasingly becoming the focus (IEA, 2021a).

2 Thermal cooling

Cooling can be achieved via a compression cooling process that runs on electricity or via a sorption cooling process that runs on heat. Using renewable energy sources to supply heat is an environmentally sound alternative to fossil fuels. In this section, the possibilities of thermal cooling are presented and explained, with steam jet cooling system being a special case, as it requires steam to run.

2.1 How thermal cooling works

In general, cooling is achieved by extracting heat from the room/building in the case of air conditioning, or from the process in the case of process cooling. For heating, heat is supplied instead.

Depending on the process, a distinction is made between compression and sorption cooling processes. Vapour-compression cooling systems require electricity to run, while sorption cooling systems require heat.

Sorption cooling systems are operated using heat. For this purpose, the sorption cooling system is integrated hydraulically into a heating water network, which can be supplied by a local power-generating plant or via a district heating system. At present, this heat is still mainly generated by burning fossil fuels. In a cooling circuit, the refrigerant is liquefied, during which it releases heat and is subsequently allowed to evaporate at a lower pressure for cooling, thereby extracting heat from the room. To dissipate the waste heat, an auxiliary cooling circuit is required, which releases this heat into the environment. Dry re-cooling plants, wet cooling towers or hybrid designs can be used for this.

Cooling for air-conditioning or a process cooling supply can be decentralised and carried out directly at the beneficiary’s location. This requires a connection to a heat supply, which can also be used for heating in winter. Alternatively, it is possible to set up a cold-water network with centralised cooling. This has the advantage of a more efficient operation of the cooling systems and offers the option of redundancy. One disadvantage is that an additional cooling network is required, which cannot be used for heating in winter.

For the generation of heat, renewable energy sources can be used instead of burning fossil fuels. For Türkiye, the use of deep geothermal energy is an interesting prospect, as it holds great potential, as described above.

This feasibility study shows the possibility of using geothermal energy as a renewable heat source to drive cooling systems. The use of available geothermal energy has a number of advantages over the use of fossil fuels. In principle, the heat distributed to the buildings could come from fossil energy, but this would contradict the climate, energy saving and import independence goals.

This study aims to provide an overview of locations in Türkiye with the corresponding potential for using geothermal energy for thermal cooling. A distinction is drawn between expansion in connection with existing geothermal production plants, including the possibility of cascading use, and the construction of new plants along with the development of new regions. Areas with temperatures below 100°C are also of interest, with existing geothermal plants, as well as regions where geothermal energy is not yet being exploited but which hold the corresponding potential.

2.2 Systems and processes for cooling using heat

Generally, it can be said that in order to cool an object, it is always necessary to remove heat energy from the location to be cooled. For this, work must be done. Or, seen from an energy context, primary energy needs to be expended.

Conventional systems used for large-scale cooling are usually vapour-compression cooling systems (VCCS) that require electricity or gas as energy in order to run (primary energy).

If these are to be replaced by systems that run on heat, the following options exist for large-scale cooling:

1. Adsorption cooling systems
2. Absorption cooling systems (ACSs)
3. Steam jet cooling systems (alternative process)

If renewable heat sources are used, they must be available locally and it must be possible to meet and supply the energy demand (heat requirement) locally.

In the following, the three aforementioned processes will be explained briefly. A detailed technical presentation will not be provided as part of this report.

Regarding 1: An adsorption cooling system is a sorption c**Fehler! Linkreferenz ungültig.** that operates using a solid sorbent. It consists of two working chambers filled with sorbents, a condenser and an evaporator. For example, the sorbent can be silica gel and refrigerant water. The process is discontinuous and closed. Because of the discontinuous mode of operation, an adsorption cooling system can also be used as a cold storage unit.

Adsorption cooling units with a nominal capacity of several 100 kW can currently be deployed. They require less maintenance compared to vapour-compression cooling systems (Krystallas, 2017).

Despite the advantage of a lower temperature of the heat used to run the system, the output usually limits its applications, as a cooling capacity in the megawatt range is not possible. This could only be achieved by connecting multiple adsorption cooling units. This requires individual planning and concept development for the respective location and application in order to estimate the costs (e.g. space requirements) and utility (cooling capacity) from a financial standpoint.

Regarding 2: Absorption cooling systems can be built in any size, just like vapour-compression cooling systems. Figure 1 shows the working process of an absorption cooling system (ACS). Compared to a vapour-compression cooling system, there are fewer moving parts, but heat at a higher temperature is required to drive the system (usually > 80°C, e.g. district heating or geothermal energy). The process of converting the heat supplied at a higher temperature into work makes it possible to replace the mechanical compression process in the ACS.

An important difference is the coefficient of performance of both systems. In the sample case study (Section 4.5), the replacement of a vapour-compression cooling system with a cooling capacity of 4.6 $\mathrm{MW_c}$ is examined. For such a cooling system, a coefficient of performance (COP) of 4 to 5 can be assumed. A comparable single-effect ACS has a COP of 0.7 for generating a cooling capacity of 4.6 $\mathrm{MW_c}$. If the heat for supplying the absorption cooling system has temperatures significantly higher than 100°C, a double-effect ACS should be considered for the most efficient energy transformation, as its coefficient of performance is 1.3.

Whether the production temperature of a specific site is sufficient for the use of a double-effect ACS or whether the heat transfer will need take place at a lower temperature level depends, among other things, on the on-site conditions, which will need to be examined in each individual case.

It should be noted that there are sometimes significant differences between the dimensions of vapour-compression and absorption cooling systems due to their design. The latter are often significantly larger. This must be taken into account when replacing them in an energy hub.

An absorption system is economically viable when sufficient (waste) heat is available at a cost-effective price.

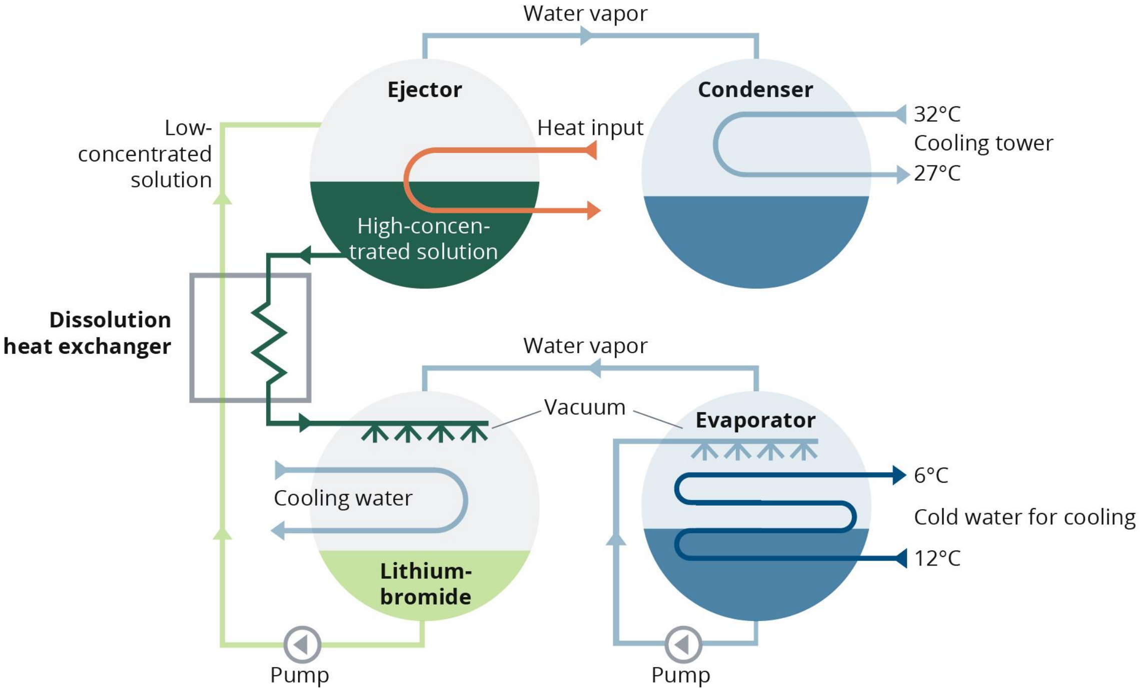

Figure 1: Schematic representation of an absorption cooling system. Source: BHKW Infozentrum GbR

Regarding 3: Steam jet cooling systems may present a further alternative. This type of cooling is also available with higher capacities, e.g. with multi-effect systems.

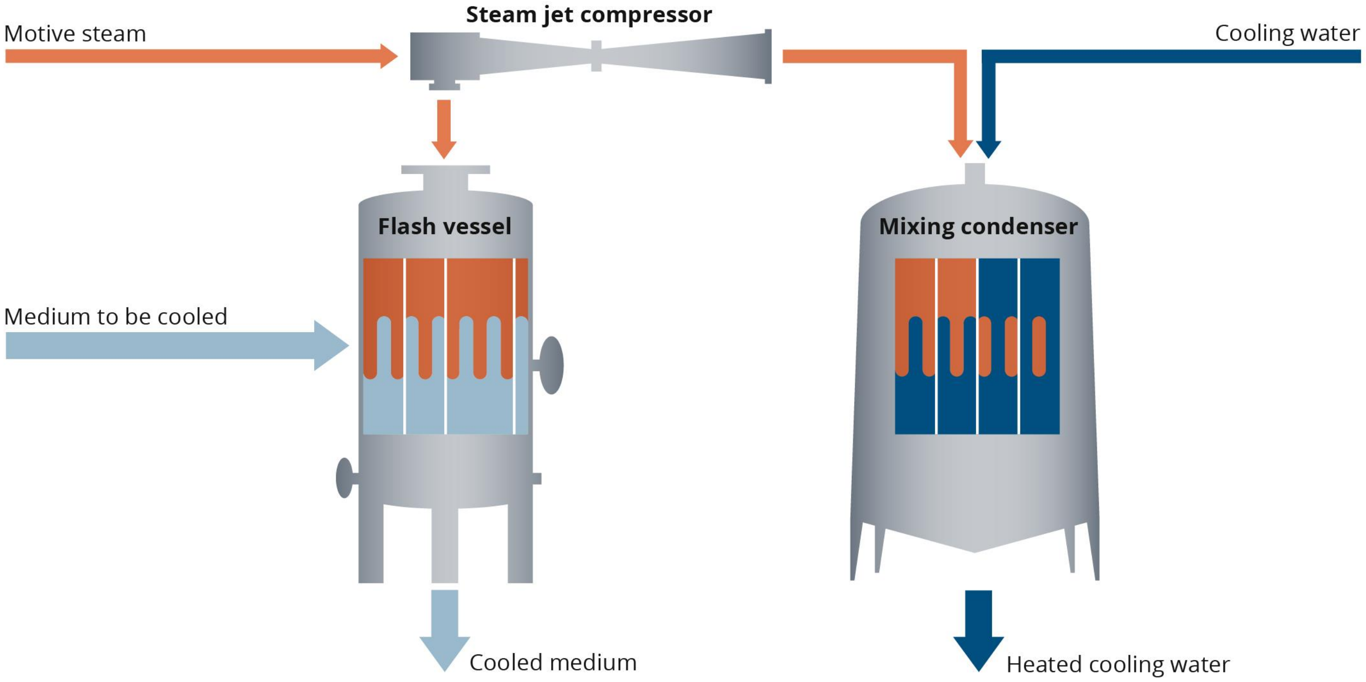

Figure 2: Diagram of steam jet cooling system with mixing condenser. Source: Own illustration, dena, 2025.

In a steam jet cooling system, water is used as the refrigerant. Steam needs to be generated as the thermal energy source.

Steam jet cooling systems use the principle of flash evaporation (see Figure 2). The liquid (water) to be cooled is passed through a flash evaporator. The pressure in this evaporator is below the vapour pressure of the liquid. As a result of the expansion, part of the liquid evaporates (flash vapour), and in this way the heat of evaporation is removed from the heat content of the liquid. This causes the liquid to cool down to boiling temperature at the respective evaporator pressure (vacuum). The flash vapour obtained is extracted by a steam jet vacuum pump, compressed and condensed in a downstream condenser. The pressure level of the condenser is determined by the temperature of the cooling water used in it. The condensate produced needs to be cooled in a cooling tower.

The advantages are similar to those of the ACS. There are practically no rotating or moving parts, it is environmentally friendly as no special refrigerant is necessary (water is used as the refrigerant), and only a small amount of electrical energy is needed to pump the cold and cooling water.

Because steam is needed to drive the system, and this steam would first have to be produced, the use of a steam jet cooling system is only possible at locations with correspondingly high production temperatures. If exhaust steam is available, the steam jet cooling system is an alternative worth considering (Schwarz, 2013).

Steam jet cooling systems can only be used for cooling applications above 0°C due to the freezing point of water.

3 Cooling with geothermal energy

The use of geothermal energy for energy provision has so far focused exclusively on the provision of geothermal heat for the generation of electricity. In many regions, the supply of heat from geothermal energy has been done in combination with balneological uses. Currently, only one instance is known in Türkiye where geothermal energy is used for air conditioning.

3.1 Possible uses of geothermal energy

The use of geothermal energy for energy provision along with its advantages and disadvantages have been described many times in the past and can generally also be implemented in Türkiye. **Figure 3** shows the possibilities of using geothermal energy sources.

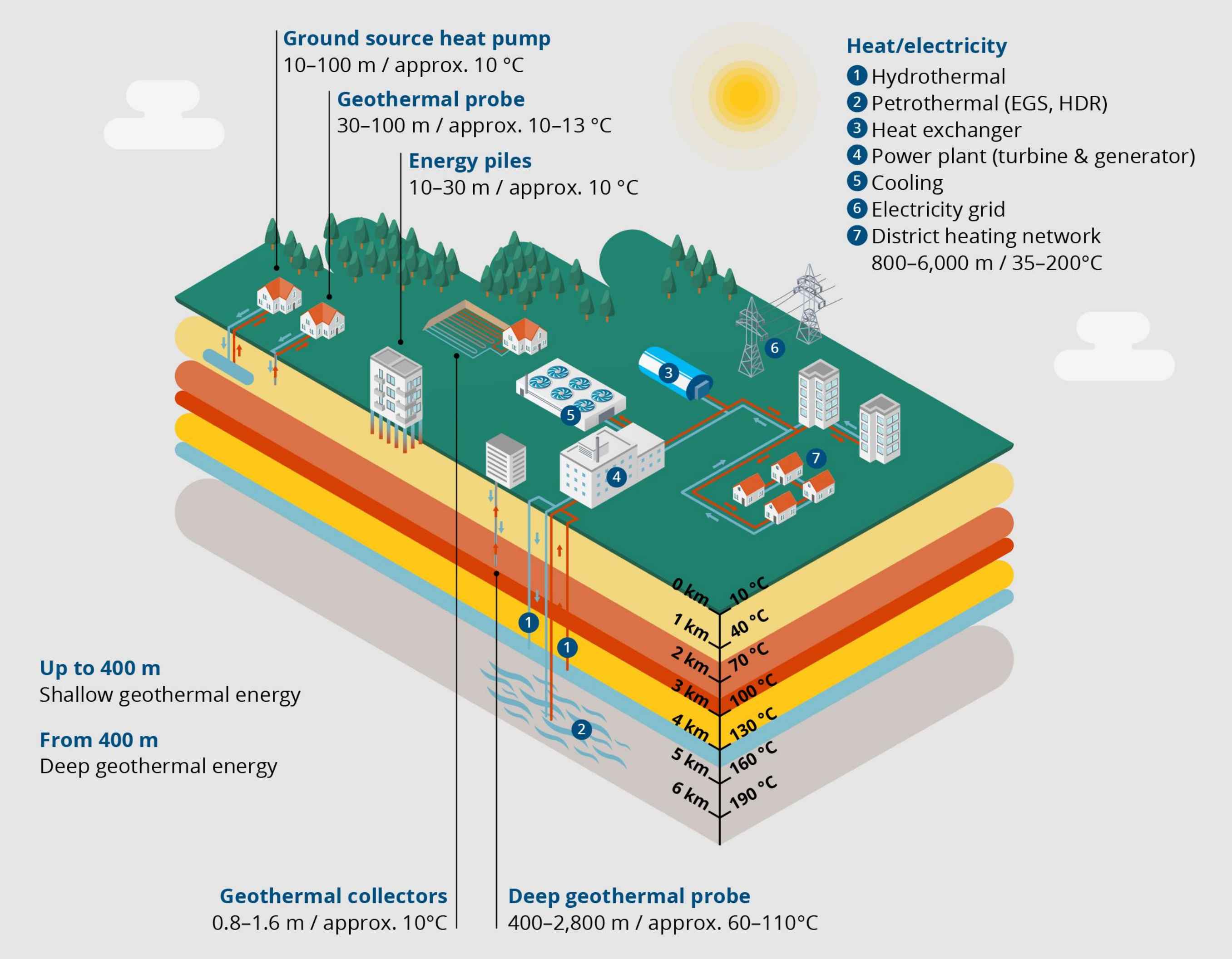

Figure 3: Usage of geothermal energy sources. Source: Own illustration, dena, 2025.

The geothermal gradient is a measure of geothermal utilisation potential. It involves a change in temperature depending on the location. It describes the increase in temperature with increasing depth. The average geothermal gradient is 3°C/100 m. Locally, the gradients can deviate greatly from this average value. In volcanic areas, there is often no upper limit. A defined surface temperature is assumed, which is relatively constant at a depth of 2 m but can vary greatly from region to region.

In Türkiye, an average of 20°C is taken as the defined surface temperature. This means that with a geothermal gradient of 3°C per 100 m, a temperature of 20°C + 30°C = 50°C prevails at 1,000 m.

Due to the highly favourable geothermal conditions, there are reservoirs in Türkiye where temperatures of 170°C exist at a depth of just 600 m. This means that the geothermal gradient is 25°C per 100 m, starting from a surface temperature of 20°C. This shows that the geological conditions for the use of deep geothermal energy in Türkiye are highly advantageous.

Originating from Germany, the terms ‘shallow’ and ‘deep’ geothermal energy are often used in Türkiye, which are not entirely correct. In Germany, the notional limit is a depth of 400 metres. This is no longer applicable in reservoirs, such as those exemplified above with a gradient of 25°C, as a temperature of 95°C already exists at this depth. In comparison, temperatures in Germany at a depth of 400 m range between 27 and 39°C, depending on the region and gradient.

For this reason, the following simplified characterisation is used for the geothermal reservoirs in Türkiye:

	Temperature	Classification	Utilisation
1	< 100°C	Low enthalpy range	only heat utilisation
2	100 – 230°C	Medium enthalpy range	generation of electricity with ORC and heat utilisation
3	230 – 300°C	High enthalpy range	direct generation of electricity and heat utilisation
4	< 300°C	Steam reservoirs*	direct generation of electricity and heat utilisation

*Special case: steam reservoirs can occur in isolation starting at 240°C in various regions worldwide.

Table 1: Geothermal reservoirs in Türkiye

This means that in case (1), only heat and cooling can be supplied. For all other cases, depending on the sales potential and region, usage as a trigeneration plant/combined cooling, heat, and power plant can be implemented according to the energy balancing assessment.

In order to take full advantage of geothermal heat, cascading use is possible depending on the production temperature and regional final energy demand. Especially with high temperatures, it makes sense from an energy standpoint to first generate electricity from the geothermal energy and then use the residual heat in a cascading system to supply heating and cooling (see **Figure 4**: Cascading use).

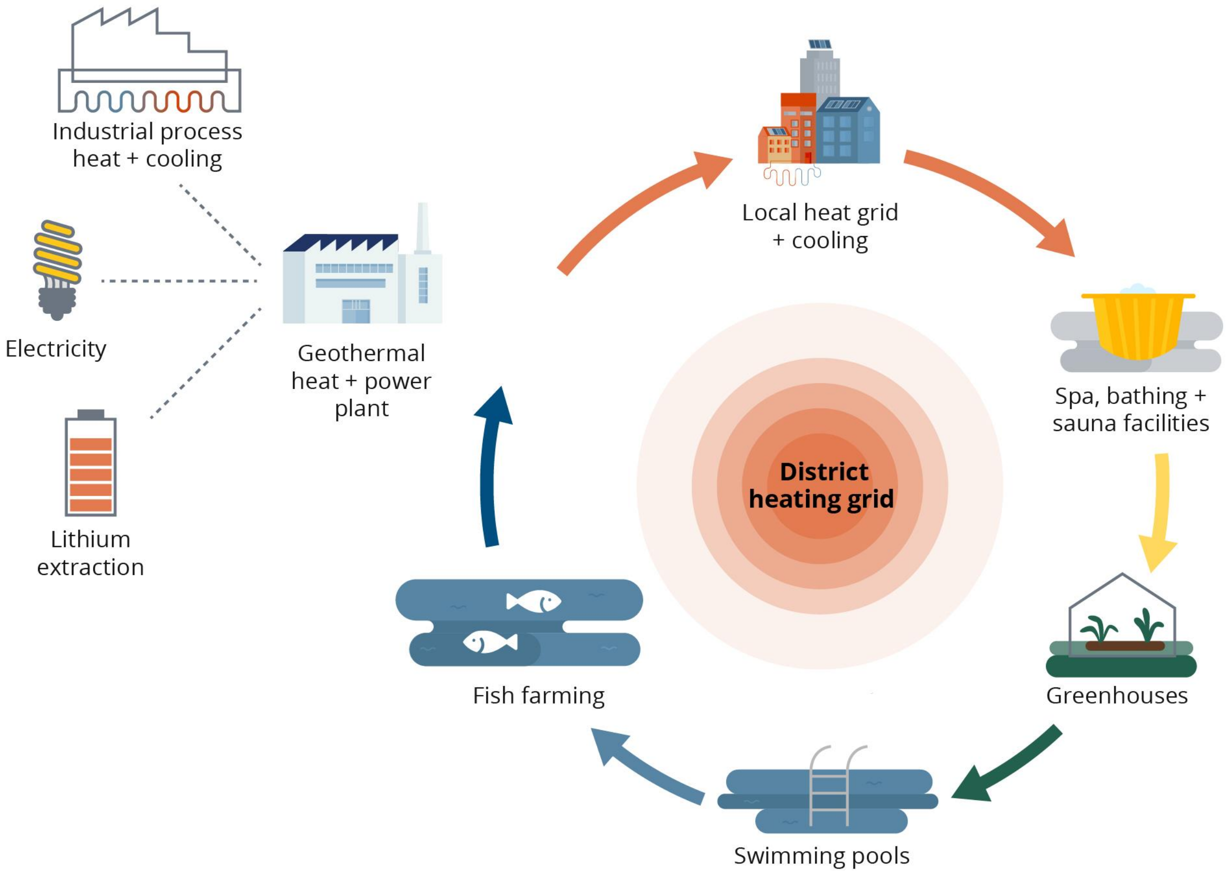

Figure 4: Cascading use. Source: Own illustration, dena, 2025.

3.2 Geothermal utilisation potential in Türkiye

The Turkish government's goal is to reduce the import costs of fossil fuels by promoting the development of renewable energy sources, while reducing consumption via energy efficiency measures. Using deep geothermal energy for energy provision is one step towards achieving this goal. It holds great potential for growth in Türkiye and is continuously increasing in significance. If the existing geothermal potential is utilised, Türkiye could serve the heat and cooling demand of approximately 15% of its building stock, conservatively estimated.

Türkiye is located in the Alpine-Himalayan orogenic belt at a site of high tectonic activity and enjoys high geothermal potential thanks to favourable geological conditions. The first geothermal research projects and investigations were initiated by the MTA (Turkish General Directorate of Mineral Research and Exploration) in the 1960s. Over the last five years, important geothermal goals have been achieved. For example, approximately 450 geothermal fields have been identified by the MTA.

From a geological perspective, Türkiye is rich in geothermal energy resources. There are around 1,000 geothermal sources distributed throughout the country. The geothermal capacity is split up into geothermal fields, of which 78% are located in Western Anatolia, 9% in Central Anatolia, 7% in the Marmara region, 5% in Eastern Anatolia and 1% in the other regions. A total of 90% of the geothermal resources are low and medium enthalpy geothermal areas suitable for direct applications (heating, thermal tourism, production of minerals, etc.). Only 10% can be used for indirect applications such as electricity generation. Geothermal energy is currently used for electricity generation, the heating of greenhouses and residential buildings, thermal and health tourism, industrial mineral extraction and drying (Mertoglu, Simsek and Basarir, 2021).

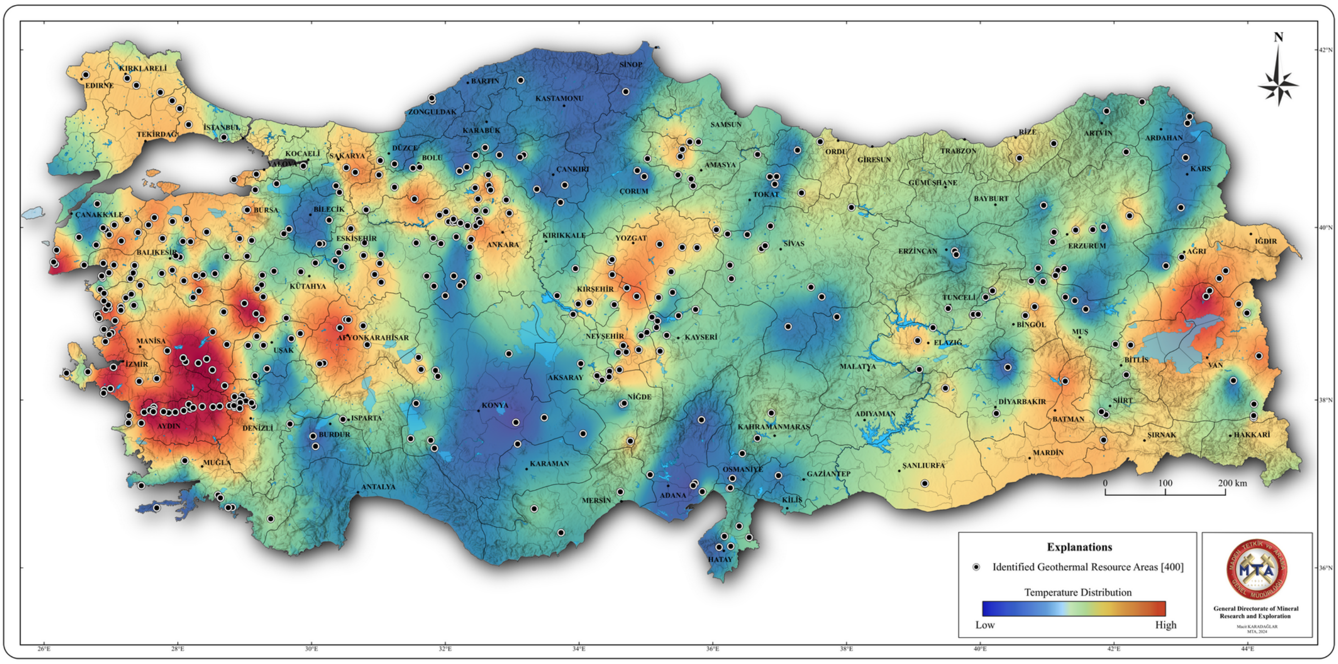

Figure 5: Geothermal fields in Türkiye. Source: General Directorate of Mineral Exploration and Research Türkiye

In the extraction of geothermal energy, a distinction is made between petrothermal and hydrothermal systems. In Türkiye, only hydrothermal systems exist to date. The first sites for petrothermal use are currently being sought.

In terms of energy usage, geothermal energy can be used as thermal energy in the form of primary energy for electricity generation and as residual heat or, at lower geothermal temperatures, directly for supplying heat. The electricity is fed exclusively into the regional electricity grid and remunerated according to the current feed-in requirements. Due to these innovations, heat extraction (with subsequent generation of cooling) has currently become more lucrative compared to electricity production. The thermal energy (residual heat from electricity production or direct utilisation) is used to supply heat or serves as the energy to drive thermal cooling processes. In the future, the latter is expected to expand the potential uses of geothermal energy by contributing more greatly to the production of cooling energy and thus to air-conditioning in buildings and, if possible, to process cooling. The first geothermal cooling application was realised in 2018 in Balçova/Izmir by Izmir Jeotermal Inc. (Mertoglu, Simsek and Basarir, 2021).

Use of the thermal water itself currently exists only in the balneological sector. Many application examples already exist for this. In the future, demineralisation of the thermal water may open up additional possibilities for its use, allowing further business areas to be established.

Figure 6: Geothermal plants in Türkiye and the respective production temperature. Source: Mertoglu, O., Simsek, S. and Basarir, N. (2021)

3.3 Renewable heating and cooling in Türkiye

A large portion of energy consumption in Türkiye results from the provision of heating and cooling for buildings. Heating is provided mainly via oil- or natural gas-fired plants or by district heating, which also runs on fossil fuels.

Building cooling is provided mainly via centralised or decentralised electrically operated cooling systems. Large consumers, such as hotels, schools and hospitals, often have their own CHP plants to provide heat and electricity, as well as separate electricity-powered systems for cooling. Due to the separation of the systems, a large percentage of the thermal energy generated goes unused, especially in the summer months.

In other areas, such as large-scale power plants or the use of deep geothermal energy, the residual heat after electricity generation is only occasionally used to supply district heating to households. The supplies of heat and cooling are currently still two largely separate areas and markets in Türkiye.

In principle, geothermal heating and cooling in geothermally active areas is interesting and suitable for a grid-based supply of dense settlement structures. For heating residential buildings and commercial facilities such as hotels, swimming pools and greenhouses, the usable geothermal potential is currently estimated at 31,500 MW_{th} (Canbaz *et al.*, 2020).

3.4 Evaluation of various geothermal cooling technologies

3.4.1 Adsorption cooling systems

Adsorption cooling systems can be operated starting at a feed temperature of > 60°C and are available with a capacity of up to 100 kW. Due to these parameters, they are particularly suitable as a decentralised supply for apartment blocks, supermarkets or other smaller buildings. However, compared to the other cooling technologies presented, adsorption has a low COP of only about 0.4. Above all, their use should first be assessed in areas where district heating networks are already in place, because their particular process technology means they cannot be used to only provide cooling, but also as cold storage.

Because adsorption systems are able to provide cooling at low feed temperatures, it is possible to connect them to existing district heating networks, and thus use the heat which is not used for heating purposes in summer for cooling. Due to the low cooling capacity, the use of adsorption systems in central cooling plants must be considered on a case-by-case basis. For a higher cooling capacity, multiple adsorption cooling systems can be connected together. However, this results in a larger space requirement and coordinated operation of the individual units.

3.4.2 Absorption cooling systems

Absorption cooling systems (ACSs) can be designed and used as single-effect (COP of 0.7) or double-effect (COP of 1.3) units. Their output range is between 0.02 MW_c and up to 5 MW_c. This makes them suitable for supplying cooling to industry, housing estates, hospitals and other large-scale consumers.

- Single-effect ACSs can be used from a temperature > 85°C. In principle, they are suitable for use at all locations shown in **Figure 5**.
- From temperatures > 130°C, double-effect ACSs can be used due to the higher COP. This is the case at 26 locations as shown in **Figure 6**. Thanks to its better COP, the double-effect cooling system requires less heat energy to drive it, which also optimises its use in terms of cascade utilisation.

Compared to adsorption systems, ACSs can only be connected to existing district heating networks if the supply temperatures are raised in summer.

Since a temperature of at least 85°C is required for cooling, this means that the supply temperature in the district heating network will need to be approximately 95°C in summer due to the losses, and not 70 to 75°C as is usually the case.

In addition to decentralised installation at the customer's site, it is also possible for the cooling system to be installed at the location of the geothermal plant and for it to convert the geothermal heat into cooling energy there. The cold is then distributed to the consumers via a ‘cooling network’.

If the cooling system is located at the consumer's site, the heat for driving the system must be transported at a high temperature level via a piping system from the geothermal site to the location where the cooling is generated.

Both variants have advantages and disadvantages, as there are efficiency losses due to the ambient temperature and user behaviour, which must be considered depending on the location.

At particularly high temperatures or high flow rates, due to the upper capacity limit of the available ACSs (maximum cooling capacity of 5 MW_c), multiple cooling units can be connected in series to fully convert the available heat into cooling.

3.4.3 Steam jet cooling systems

A steam jet cooling system is a thermal cooling system that is driven by steam energy. The COP of the process is 0.5 based on a cold-water temperature of 8°C/16°C in the cold-water circuit and a cooling water temperature of 29°C in the re-cooling system, as well as a saturated steam pressure of 3.6 bar (absolute) of the motive steam jet. Due to the low COP, its application is only prudent from an energy standpoint if a sufficient quantity of steam is available.

It is particularly suitable for use in geothermal power plants in Türkiye. The reservoirs in the medium and high enthalpy regions often supply geothermal steam in addition to thermal water. This is ideal for use as motive steam to drive a steam jet cooling system. By utilising this partly unused steam, which is extracted together with the thermal water, cooling can also be generated in the geothermal power plants at the same time as electricity generation, which can be used for air conditioning and other applications.

Since the conditions on the Turkish market are ideal for this technology, this alternative should always be considered for a geothermal power plant.

3.4.4 Evaluation of geothermally fed cooling plants

Geothermally fed cooling plants can be used in a variety of ways. The basis is that geothermal use is already available or planned and the consumer for the cooling is in the immediate vicinity or the heat extracted from the geothermal plant is fed into a corresponding heating network.

Decision criteria include:

a) Required cooling capacity and coolant temperatures for e.g.:

- Air-conditioning in residential, office and commercial areas
- Process cooling for machines and units
- Cooling of server rooms, IT equipment and switchgear
- Cold storage and warehouses

b) Supply reliability with redundancy and load demand

c) Possibility of coupling different units (For example, it should be determined whether coupling with a vapour-compression cooling system is possible for peak load coverage and redundancy).

d) The heat available as a medium for driving the system at the time of selection with corresponding parameters (see **Figure 7**).

e) Centralised or decentralised generation of cooling (The decision to supply cooling in conjunction with a heat network or to set up a central cooling plant with a cooling network depends on the location and demand).

In addition to the cooling capacity of the various engineering options for the process, the temperature of the medium that will be used to drive the system is a determining factor. **Figure 7** shows the temperature ranges within which the various systems can be used.

The steam jet cooling system occupies a special position in this context, as steam with an appropriate level of purity is needed to drive it. It is possible to use existing geothermal steam to drive the system or, at correspondingly high-temperature thermal waters, to generate steam using the hot geothermal fluid, which feeds the steam jet nozzle in a secondary circuit. This should always be examined as an alternative to steam generation from combustion.

At present, there are no real-world cases where a geothermally driven steam jet cooling system has been implemented. A test system is currently in the works.

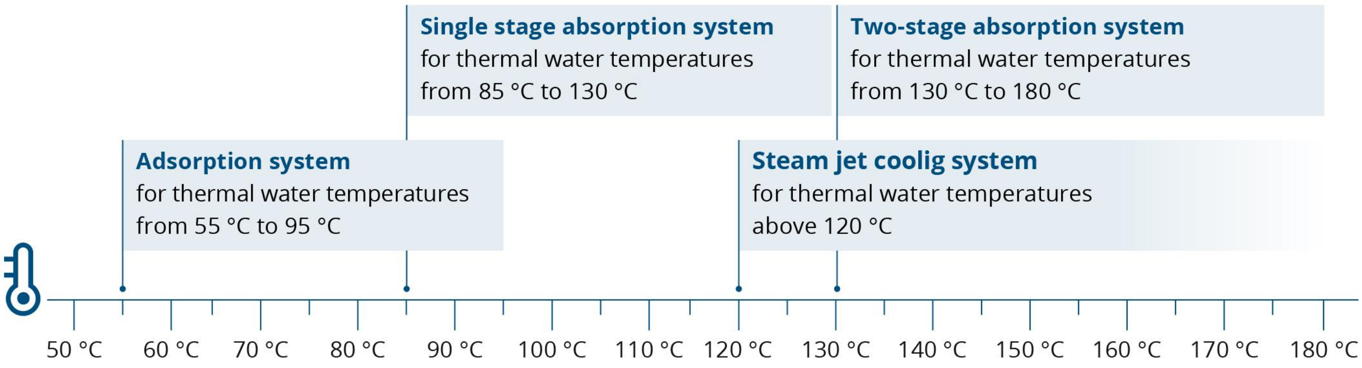

Figure 7: Temperature ranges for different system types. Source: Own illustration, dena , 2025.

4 Cooling potential in Türkiye

The objective of this feasibility study was to investigate how Türkiye's geothermal potential can be used for thermal cooling. For this purpose, process engineering solutions and economic relationships were presented. One possibility is to expand geothermal electricity generation to also include the generation of cooling. In this case, the geothermal energy harvested is not only used to generate electricity – heat is also extracted from it. This heat can in turn be used to supply heat, but also as energy to drive systems for cooling. In principle, it is possible to operate electricity and cooling generation systems in parallel or in series (one after the other).

In addition, the geothermal utilisation potential for the supply of heat and cooling in lower enthalpy regions is to be estimated.

4.1 Analysis of cooling demand in Türkiye

Most buildings in Türkiye are cooled using split systems. These split systems run on electricity. The condenser for these systems is located outside the building and is often attached to the building wall. It is connected to the evaporator or the ventilation unit inside the building via pipes. The refrigerant is transported through these pipes. Worldwide (and also in Türkiye), this form of building cooling is by far the most common for residential buildings. Demand for split systems quadrupled on a global scale between the 1990s and 2016, and the trend is increasing (IEA, 2018). Demand for cooling tripled over the same period. The share of commercial buildings increased from 6 to 11.5% (see **Figure 8**).

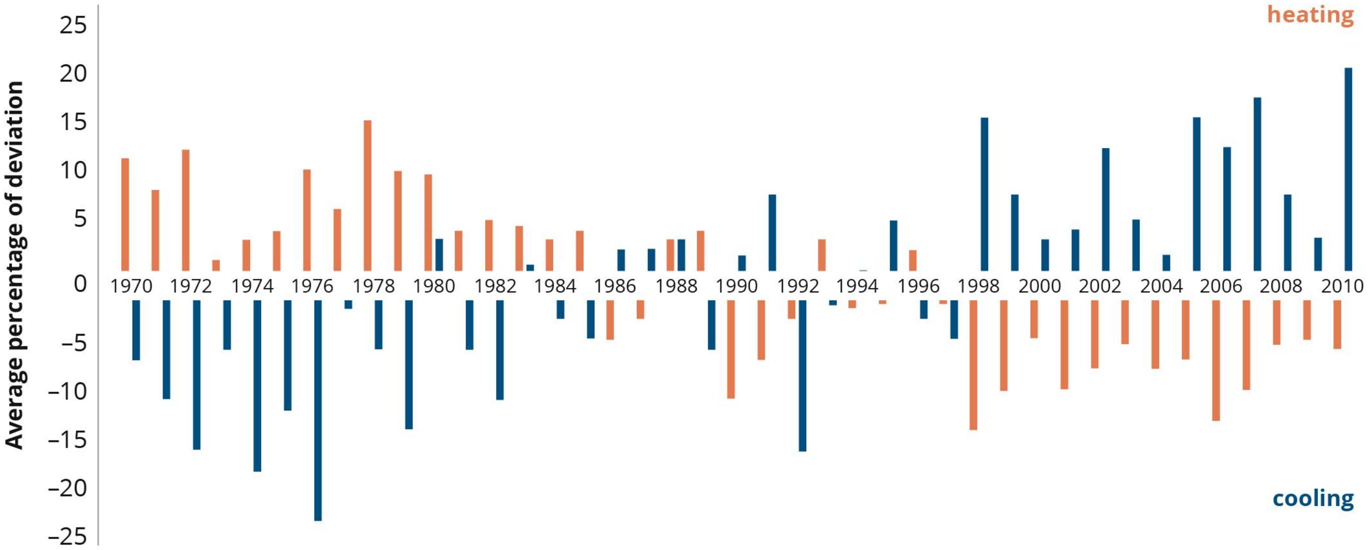

Figure 8: Increase in cooling demand and reduction in heating demand. Source: Climate Central

Figure 8 shows that air conditioning is expected to grow in importance. The requirements for the supply of cooling have changed significantly in recent years. These include the climate crisis, an increased need for comfort, data centres or mechanisation, changes in building architecture, legal requirements, an increased security of supply, etc. The following trend can be observed worldwide: demand for cooling is increasing, while demand for heating is decreasing due to energy-saving measures.

4.2 Basic principles for the use of geothermal cooling systems

Conventionally, the required heating energy is generated using gas-fired boilers and hot water heaters for heating and hot water supply. Split systems are used for air-conditioning, and for higher cooling requirements, e.g. for process cooling, the cold is generated via vapour-compression cooling systems.

Heat is mainly required in winter for building heating and hot water. In summer, heating needs are limited to hot water production and a small number of consumers for specific applications.

Cooling is required mainly in summer. This is not only due to the higher outdoor temperatures and heat from the sun, but also due to dehumidification in air conditioning systems. There is year-round demand for the re-cooling of server rooms, cooling and dehumidification of indoor spaces for specific applications and, if necessary, to balance out solar heat input in these spaces. Depending on the technical building configuration (TGA), the cooling requirements in buildings may fluctuate greatly. Fluctuations in cooling are due to weather conditions and the usage behaviour of the relevant users.

For geothermal cooling, as with the supply of heat, the heat must also be extracted. It is possible to generate the cooling locally, directly at the customer's location, or to do so centrally. In the latter case, a cooling network is required. As a rule, heating and cooling networks must always be operated separately due to thermodynamic principles, and coupling is not possible. For example, heating networks are operated in the temperature range between 45 and 95°C and cooling networks in the temperature range between 6 and 12°C.

For the design of the heat extraction from a geothermal plant and the necessary transport line to the cooling consumer, a detailed assessment of cooling demand over the course of a year is necessary. Since the heat required to drive the system can be described as primary energy, the provision of primary energy as a function of cooling demand (and the resulting heat demand) is of great importance.

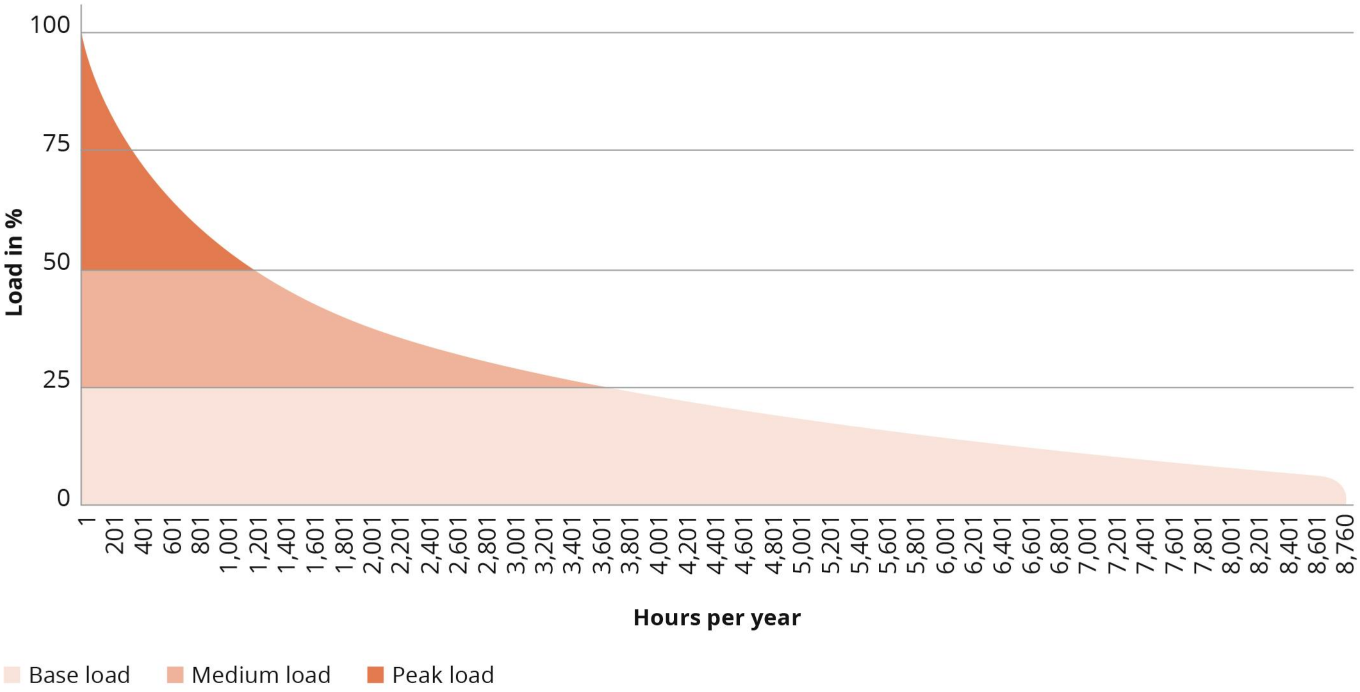

Figure 9: Load duration curve. Source: Own illustration, dena, 2025.

Figure 9 shows an ‘ordered load duration curve’, which represents the main cooling requirements over the course of a year. This shows, for example, how much cooling capacity is required for how many hours each year.

The corresponding demand and change over time must be determined specifically for each location. In the case of new installations, this can be done using the planning documents; in the case of existing ones, it can be done using the available energy and supply data.

In the case of existing installations, depending on the system, measuring systems already exist that can be used. If the available measured values are insufficient, a measurement campaign is necessary to determine cooling capacity and annual consumption. The following applies: the more advanced the implementation of measuring systems in existing installations, the greater the accuracy of the data collected. Particularly in older installations, the available measuring points are only rudimentary. In such cases, an interpolation of the momentary situation with a subsequent plausibility check is necessary. If necessary, assumptions for cooling demand may need to be made using the supply data, i.e. the total purchase of natural gas and electricity.

4.3 Concepts for using geothermal energy to generate electricity and to provide heating and cooling

Two different examples are examined here for the economic assessment of a geothermal cooling system.

Example A: There is an operational geothermal power plant at the site, with a production well, an ORC plant for electricity generation and an injection well. A heat extraction system for the supply of heat and cooling generation is not yet in place. The necessary investments to generate cooling include the conversion of the thermal water system with the integration of a heat exchanger, the implementation of a suitable absorption cooling system and the construction of the infrastructure needed to transport the heat or (depending on the concept) the cold to the consumer.

Example B: There is no geothermal plant at the site, and no wells have been drilled yet. The site under consideration is located in an area which (according to **Figure 5**) has usable geothermal potential. The necessary investments consist of the drilling of the geothermal wells, the construction of the geothermal plant including heat extraction, the implementation of a suitable absorption cooling system and the infrastructure needed to transport the heat or cold to the consumer. Whether electricity generation is possible depends on the geothermal parameters and heating/cooling demand and will need to be decided on a case-by-case basis.

In principle, it is possible to operate geothermal plants as trigeneration plants/combined cooling, heat and power plants. Depending on the customer's needs and the application, there are electricity-first and heat-first variants. This means that priority is given to either electricity generation or the supply of heat/cooling. On the primary side, the thermal water system can be set up in such a way that electricity generation comes before heat extraction (series arrangement), or both are located alongside each other (parallel arrangement). There are industrial process engineering solutions for both variants, whereby the application depends on both the geothermal parameters and the heating/cooling requirements.

Both options are presented below as examples, whereby the idealised assessments refer to the conventional use case that both electricity generation and heat extraction take place at the location of the wells.

In Figure 14 the electricity-first variant with a series arrangement is shown. In this case, electricity generation takes priority, and the provision of heat as primary energy for cooling is secondary. The prerequisite for heat extraction is the supply temperature for the cooling system. For efficient cooling with a single-effect absorption system, a temperature of at least 85°C is necessary at the inlet of the cooling system. If the temperature at the inlet is higher, this improves the efficiency of the cooling.

The supply of primary energy and thus the adjustments to match the cooling requirements take place via the freshwater quantity in the secondary circuit and not via the temperature in the primary circuit (thermal water system).

It should be noted that a limiting factor for the use of geothermal energy for energy provision in Türkiye is also the injection temperature. Scale deposits occur when the temperature falls below a hydrochemically determined limit temperature. The limit temperature depends on the gas content as well as the material composition of the thermal water and is thus reservoir- and site-dependent. For example, in some geothermal regions located in the west of the country, this limit temperature is between 70 and 90°C, depending on the location.

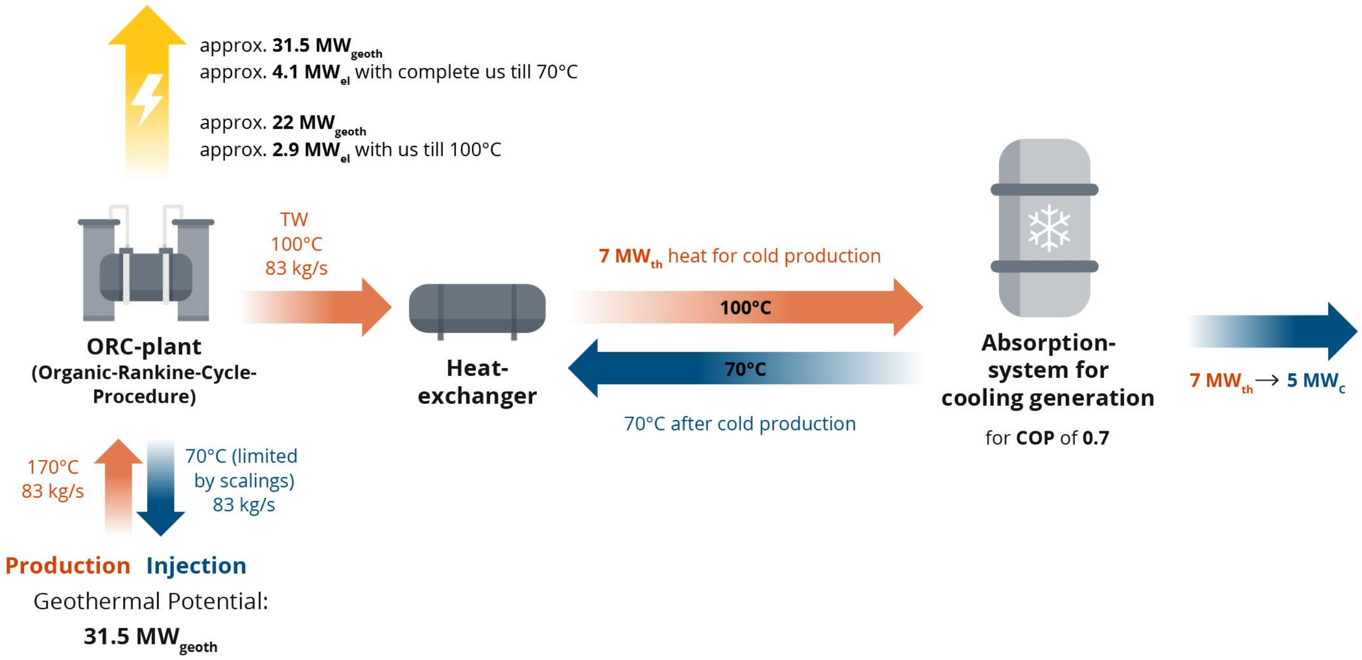

Figure 10: Electricity-first variant. Source: Own illustration, dena, 2025.

In the example shown, an available mass flow of thermal water of 83 kg/s, a specific heat capacity of thermal water of 3.8 kJ/kg*K (mean value of thermal waters) and a maximum possible temperature of 100°C at the example site are assumed. This results in 31.5 MWth of usable geothermal heat. Based on experience from various geothermal projects, the net efficiency for electricity generation is assumed to be 13%. This means that with a geothermal output of 31.5 MWth, an electrical output of 4.1 MWel is produced within the design range.

	Unit	Well
Production temperature	°C	170
Injection temperature		
Max.	°C	90
Min.	°C	70
Delivery quantity	kg/s	83
Geothermal energy	MWth	31.5
Electricity (net = 13%)	MWel	4.1

Table 2: Sample geothermal parameters

For example, in order to generate 5 MW_c, a single-effect ACS with a COP of 0.7 requires a heat input of around 7 MW_{th}. This heat needs to be extracted from the thermal water and conveyed to the site of the ACS. The 7 MW_{th} results from the flow rate and the temperature difference of the industrial water that transports the heat from the geothermal plant to the ACS. This example only considers energy-related aspects and does not provide a detailed design. For the effective operation of a single-effect ACS and considering the limit temperature for precipitation, the temperature for heat extraction from the geothermal plant is assumed to be 100°C. Taking into account the losses in the heat exchanger as well as the transmission losses in the pipelines, the inlet temperature in the ACS is still 95°C. To transport the 7 MW_{th} to the ACS, a flow rate of about 65 l/s is required for a temperature difference of 25°C (95 - 70°C).

This in turn means that less energy is available for electricity generation. Due to the necessity to reach freshwater temperatures of 100°C, a temperature spread from 170 to 70°C is no longer possible for electricity generation; instead, we only have a range from 170 to 100°C. This reduces the usable geothermal energy for electricity generation to 22 MW_{geoth} and the electrical power that can be generated to approximately 2.9 MW_{el}.

In **Figure 11**: Heat-first variant, the heat-first variant (or in our case, 'cold-first' variant) with a series arrangement is shown. Priority is given to covering cooling requirements, after which electricity is generated from the residual heat. This would also be possible as a parallel arrangement by dividing up the quantity of thermal water and routing it in parallel to electricity generation and heat extraction, depending on heating needs.

The idealised example in **Figure 11**: Heat-first variant assumes a maximum cooling requirement of 5 MW_c. If a single-effect ACS with a COP of 0.7 is used, a heat input of about 7 MW_{th} would be required. From an energy standpoint, about 24.5 MW_{geoth} remains for electricity generation. Thus, with a net efficiency of 13%, an electrical output of around 3.2 MW_{el} can be generated at the design point. Due to the high supply temperature, a flow rate of about 20 l/s would be necessary in this example. At these high temperatures of 170°C, a double-effect ACS could also be used, which has a COP of 1.3.

This would mean that only 3.85 MW_{th} of thermal power would be needed to generate 5 MW_c of cooling. This would have the advantage that 27.65 MW_{geoth} would be available for electricity generation instead of 24.5 MW_{geoth}. The variant to be used would have to be determined from a process engineering, business management (double-effect ACSs are more expensive than single-effect ones), and a producer or customer perspective. The information provided merely aims to showcase the various possibilities.

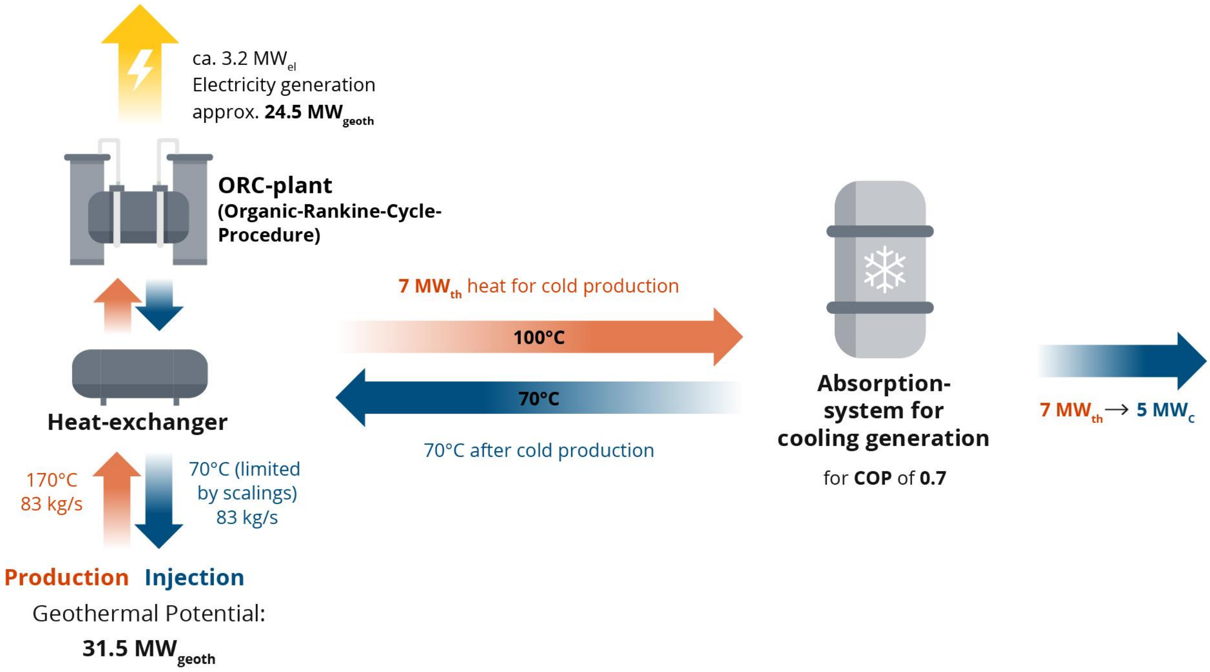

Figure 11: Heat-first variant. Source: Own illustration, dena, 2025.

In the case of geothermal cooling, the temperature and flow rate of thermal and industrial water depend on the regional and seasonal cooling demand and can only be determined as part of the concrete design or planning after the exploration results are available. The examples detailed in **Figure 10** and **Figure 11** are based on idealised energy calculations.

Basically, the generation of electricity and cooling are coupled to each other. If cooling demand is lower, more electricity can be produced and vice versa. This means that for the design of the power-generating plant, the electricity generation bandwidth must be determined as a function of cooling demand. The power-generating plant should not be designed too large, so that it runs at the optimal operating point and not at partial load; on the other hand, if it is designed too small, opportunities for the maximum exploitation of geothermal energy would be wasted.

For this, individual, site-specific considerations are necessary, taking into account the investments and operating costs. It should also be noted that the amount of electrical energy actually generated over the entire year will be higher, as the heat for driving the cooling unit varies depending on the demand for cooling, which in turn depends on the time of day and season as well as other climatic conditions.

This means that when demand for cooling is lower, more geothermal energy is available for electricity generation.

From an investment standpoint, and considering the operating costs, it should be examined whether the heating network should be designed in an energy-efficient fashion, so that it supplies heat to a central cooling system when needed, which then generates cold and feeds it into the cooling network. In periods with increased heating demand, little or no cooling is needed, and the heat extracted from the geothermal energy can also be supplied to heat consumers via the existing heating network. The combined usage of geothermal energy for cooling and direct use for heating optimises the necessary investments and running costs for the supply of heat. Due to the constant, even utilisation of the heat network, the power-generating plant can also operate constantly at the design point and is thus more efficient. Specific costs are reduced, and CO_2 emissions are lowered.

4.4 Comparison of geothermal cooling using geothermally generated electricity versus cooling with geothermal heat

The following theoretical analysis compares cooling with geothermally generated electricity versus cooling generated using geothermal heat. At the start of the study, the existing 61 geothermal power plants in Türkiye had a total capacity of 1,576 MW_e. Assuming a standard gross efficiency for geothermal electricity generation of 17%, this requires a geothermal potential of around 9,270 MW_{th}. A net efficiency of 13% is assumed for the electrical power fed into the grid, since internal consumption needs to be deducted in this case. This means that around 1,200 MW_e is available for cooling using geothermal electricity. This figure is used to draw comparisons in the following paragraphs.

Due to the process technology employed, electricity generation by a geothermally operated ORC power plant is possible from a thermal water temperature of approx. 85-90°C or higher. For economically viable power generation to take place, production temperatures of at least 120°C must be available. At these temperatures, cooling is also possible with a double-effect ACS. Just like electricity generation, cooling also has a lower efficiency limit of approximately 70-80 °C, after which the efficiency is significantly below the assumed 13%. The usable temperature levels are therefore comparable for both technologies.

In order to demonstrate the economic efficiency of the direct use of geothermal heat for cooling, the cooling capacity that can be generated via direct use by means of an ACS is compared to the cooling capacity that can be generated by a vapour-compression system that runs on electricity.

The coefficient of performance (COP) is a ratio of heating or cooling energy generated by one unit of input energy. A COP of 1 describes the case in which the input energy equals the output energy. Usually the COP exceeds 1, meaning that the output energy is higher than the input.

A COP of 4 is assumed for cooling by an electrically operated compression system. Because the energy is transmitted via high-voltage lines, the location of the cooling system is independent of the location of the geothermal wells. Energy losses due to line resistance are neglected. Compression systems with a COP of 4 would thus be able to generate a total cooling capacity of 4,800 MW_c from the available geothermally generated electrical output of 1,200 MW_e.

The generation of cooling via the direct conversion of geothermal heat into cold is more strongly linked to the location of the geothermal wells. The transfer of heat or cold is economically feasible over a distance of several kilometres. The heat losses that occur in the process are neglected in this analysis.

A single-effect ACS has a COP of 0.7. With the high thermal water temperatures in Türkiye, which are used for electricity generation, the use of a double-effect ACS is also possible. A COP of 1.3 is assumed for this. By directly using the geothermal heat for cooling, a cooling capacity of 6,490 MW_c would be possible for the single-effect system and 12,050 MW_c for the double-effect system. Compared to the vapour-compression system, this corresponds to about 1.3 times the cooling capacity for the single-effect ACS and about 2.5 times the cooling capacity for the double-effect ACS.

	Absorption cooling system	Vapour-compression cooling system
Available primary energy	9,270 MW_{th}	1,200 MW_e
Achievable cooling capacity (single-effect)	6,490 MW_c	4,800 MW_c
Achievable cooling capacity (double-effect)	12,050 MW_c	

Table 3: Comparison of absorption and vapour-compression cooling systems

This comparison clearly illustrates the benefits of direct conversion of geothermal heat into cooling using an ACS. If electricity is first generated from geothermal heat, this provides greater flexibility for further use, e.g. for cooling (independent of location, as distribution takes place via the electricity grid).

Direct production of cooling using geothermal energy by means of an ACS requires more effort and incurs more expenses for heat extraction and its integration into the geothermal plant as well as the pipe system. On the other hand, a greater cooling capacity is possible (see **Table 3**).

Cooling using geothermal electricity is less favourable from an energy-efficiency standpoint, since heat is first used to generate electricity, which in turn is used for cooling. This conversion process is no longer necessary if geothermal heat is used directly for cooling.

4.5 Possible geothermal cooling potential in Türkiye

The following theoretical assessment shows the possible cooling capacity that can be generated using the currently known geothermal potential in Türkiye. In general, this can substitute fossil-generated electricity used for cooling and reduce carbon emissions.

Based on the current estimated usable geothermal potential of 31,500 MW_{th} (Canbaz *et al.*, 2020), around 22,000 MW_c of geothermal cooling could be generated using a single-effect ACS with a COP of 0.7. If this cooling were to be produced using electricity-driven cooling systems based on a COP of 4, an electrical input of around 5,500 MW_e would be required.

If we exclude the 3,828 MW_{th} already utilised by the plants in operation, we still achieve a cooling potential of over 19,000 MW_c, which can replace an electrical input of 4,850 MW_e.

This amount of electrical power would no longer need to be produced, and CO_2 would be saved if fossil fuels were used to generate it.

4.6 Economic viability of geothermal cooling in the case of an existing plant and an example site

In the following scenario, an existing plant is examined that already feeds electricity into the grid. The plant is redesigned in such a way that it can supply a fictitious building complex with the representative cooling requirement via an ACS. For the aspect of economic efficiency, it is assumed that the example location already has a cooling supply that uses a vapour-compression system, which is operated using electricity. Here too, only an energy-related analysis is performed, since variation and optimisation of the parameters can only be carried out when actually drawing up the design, and when regional and entrepreneurial circumstances are known.

It is assumed that an energy hub is available at the example location which distributes the heating, cooling and electricity. From there, the primary energy (heat) arriving from the geothermal plant can either be distributed directly for use and/or converted into the required form of energy (cooling). If vapour-compression cooling systems are already installed in this case, they can be replaced by systems powered by geothermal heat.

Due to the spatial separation between the energy hub and the buildings to be supplied at the location, a heating and cooling network exists on site. The different network temperatures and temperature differences between the feed and return flow in the cooling network compared to the heating network must be taken into account. Both are separate. A common grid is not possible because of the different temperatures and temperature differences between the feed and return flow. This places different demands on the energy supply and the operation of the systems than if the supply of heating and cooling in the buildings to be supplied were decentralised.

When converting to a geothermal heating supply and geothermal cooling, an overall control system and the network hydraulics must be considered. If necessary, adjustments may have to be made when converting the cooling systems or expanding the supply network, e.g. to the pumps, so as not to worsen the network hydraulics as a result. One advantage of this idealised centralised energy supply is that the cooling capacity generated can always be adapted to demand, which enables a more effective utilisation of the individual units. The overall supply is optimised and equipped with an appropriate redundancy.

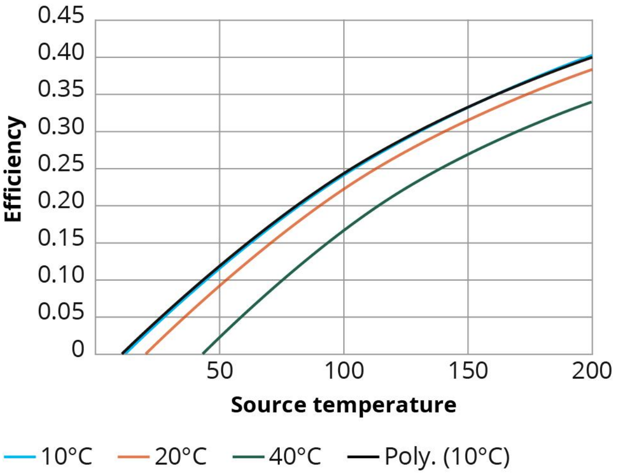

Figure 12: Carnot efficiency as a function of the source and outdoor temperature. Source: Own illustration, dena, 2025.

The available geothermal energy results from the product of the mass flow of thermal water, the temperature difference between the production and injection sides, and the specific heat capacity of the fluid. The maximum amount of electrical power that can be generated from this is limited physically by the Carnot efficiency (see **Figure 12**). The amount of electrical power that can actually be generated is further reduced due to various factors (ambient temperature, internal friction of the mechanical components, etc.).

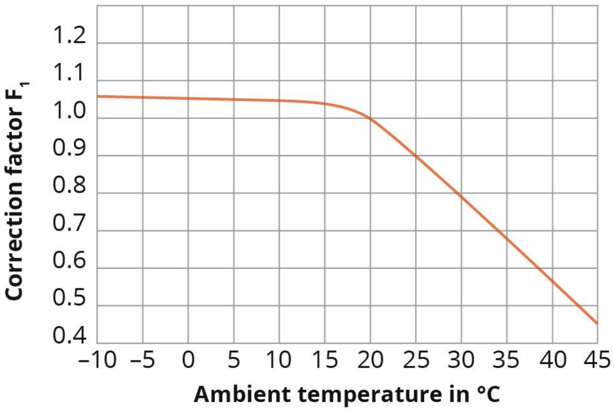

Figure 13: Relationship between efficiency and outdoor temperature. Source: Own illustration, dena, 2025.

At the example site, there is already a geothermal power plant with the production parameters as shown in **Table 2**. When adding a cooling system to the geothermal plant, it is assumed that the reduction in profits from the production of electricity due to the reduced heat supply will need to be compensated for via the sale of heat and/or cooling. Thus, a cooling price is determined that compensates for the losses in electricity generation. This serves as the basis for further analysis.

The net efficiency of an ORC power plant at the design point is about 13% at a delivery temperature of 170°C and an average ambient temperature of 18 to 20°C, as is often stated for power plants in western Türkiye. As can be seen from **Figure 13**, the efficiency decreases with increasingly higher outdoor and thus an increased re-cooling temperature. When estimating the operating hours for a vapour-compression cooling system, outdoor temperatures of more than 22°C are assumed. As a first approximation, a reduction of approximately 25% in the amount of electricity generated can be assumed here.

For geothermal cooling, on the other hand, a supply temperature of only approximately 100°C is required on the thermal water side. If the efficiency of the ORC power plant is considered along with this data in conjunction with the presentation of the Carnot efficiency, the result is a significantly lower efficiency of approximately 4% net in the summer months.

The COP of a single-effect ACS is generally 0.7 and cannot be increased by much. If a double-effect ACS is used, the higher drive temperatures can be used more effectively to provide cooling. Machines of this type are driven with temperatures of 130 to 190°C, which reduces the heat requirement by approximately 50%. Since the COP almost doubles at the same time, correspondingly less energy is required to drive the system. For the double-effect ACS, a COP of 1.3 was assumed.

For the economic analysis, further assumptions must be made regarding cooling demand and energy costs at the example location. Representative energy costs are shown in **Table 4**.

Energy costs*			In Euro**	
NG	0.844	TL/kWh	0.022	€/kWh
Electricity	2.51	TL/kWh	0.066	€/kWh
Water	43.92	TL/m^3	1.158	€/m^3

*As of Sept. 2024, Source: Epias.com.tr, Enerya.com.tr 04.09.24 **Exchange rate as of Sept 2024: 37.9 TL/€

Table 4: Comparison of absorption and vapour-compression cooling systems

The following three assumptions are made for cooling demand at the example location:

1. There is no cooling demand during the winter period.
2. The cooling period is from 1st May to the end of September.
3. The overall COP of the existing electricity-operated cooling system is assumed to be 4.

4.6.1 Cooling price of the preinstalled vapour-compression cooling system

The cooling capacity of the preinstalled vapour-compression cooling system at the example site is 4650 kW_c. To produce this amount of cold, it consumes 1.512kW_{el} of power (170 kW_e for cooling towers, 179 kW_e for pumps and 1163 kW_e for the chiller itself) and $41m^3$ of water per hour. It has a COP of 4. This means that every kW_e the chiller consumes produces 4 kW_c. The average cooling demand at the example site is 12 GWh_c. The average cooling price with the given system is 3.17 ct/kWh_c

4.6.2 Heating costs for supplying single- or double-effect ACS

To produce this amount of cooling with a single-effect ACS (COP = 0.7), 17.14 GWh_{th} of heat is required, whereas with a double-effect ACS (COP = 1.3) only 9.23 GWh_{th} would be required.

As shown in **Table 2**, the usable heat output from geothermal potential is approximately 31,500 kW_{th}. Hence, with a production period of 8,000 hours per year, 252,000,000 kWh_{th} of heat could be extracted.

If the ORC power-generating plant and heat supply are connected in parallel, the heat costs are calculated according to **Table 5, Table 6** and **Table 7.**

Three possibilities of heat extraction for cooling generation are compared.

1. The heat extraction takes place at a source temperature of 170°C and a single-effect ACS is used (see **Table 5: Heat price, single-effect absorption cooling system at 170°**C)
2. The heat extraction is carried out at a reduced temperature, which is adapted to the requirements of the single-effect ACS (see **Table 6**)
3. The heat extraction takes place at a source temperature of 170°C and a double-effect ACS is used (see **Table 7**)

The calculation of the **heat price** is carried out under the assumption that the geothermal heat to be provided for cooling is no longer available for the electricity generation process. This loss is to be compensated for via the sale of cooling.

The price of heat extraction for the subsequent cooling generation is based exactly on the amount that the power plant operator loses (=remuneration rate), which would otherwise be fed into the plant to generate electricity. This remuneration at the time of the analysis is 3.34 TL/kWh_{e}. This could also increase by 0.48 TL/kWh_{e} if the components for power generation are manufactured at a corresponding level of vertical integration inside Türkiye. However, this was not taken into account for the following considerations and can be investigated in a further study.

Calculation of heat price – single-effect absorption cooling system at 170°C	
Cooling demand	12,000,000 kWh
COP of single-effect absorption cooling system	0,7
Heat for cooling – single-effect	17,140,000 kWh
Efficiency of ORC electricity generation	13%
Qty. of electricity that can be generated	2,228,200 kWh
Reduction due to high outdoor temperature	−25%
Qty. of electricity that can be generated	1,671,150 kWh
Remuneration according to feed-in tariff in TL	3.34 TL/kWh
TL to EUR exchange rate	37.9 TL/€
Remuneration in EUR	€0.088/kWh
Loss due to heat transport	€147,449.95
Heat price in EUR	**0.860 ct/kWh**

Table 5: Heat price, single-effect absorption cooling system at 170°C

Calculation of heat price – single-effect absorption cooling system at 100°C	
Cooling demand	12,000,000 kWh
COP of single-effect absorption cooling system	0.7
Heat for cooling – single-effect	17,140,000 kWh
Efficiency of ORC electricity generation	4%
Qty. of electricity that can be generated	685.600 kWh
Remuneration according to feed-in tariff in TL	3.34 TL/kWh
TL to EUR exchange rate	37.9 TL/€
Remuneration in EUR	€0.088/kWh
Loss due to heat transport	€60,482.20
Heat price in EUR	**0.353 ct/kWh**

Table 6: Heat price, single-effect absorption cooling system at 100°C

Calculation of heat price – double-effect absorption cooling system at 170°C	
Cooling demand	12,000,000 kWh
COP of double-effect absorption cooling system	1.3
Heat for cooling – double-effect	9,230,769 kWh
Efficiency of ORC electricity generation	13%
Qty. of electricity that can be generated	1,200,000 kWh
Reduction due to high outdoor temperature	−25%
Qty. of electricity that can be generated	900.000 kWh
Remuneration according to feed-in tariff in TL	3.34 TL/kWh
TL to EUR exchange rate	37.9 TL/€
Remuneration in EUR	€0.088/kWh
Loss due to heat transport	€79,396.12
Heat price in EUR	**0.860 ct/kWh**

Table 7: Heat price, double-effect absorption cooling system at 170°C

In the case of heat extraction at 100°C (**Table 6**), an efficiency of only 4% is assumed. A comparable geothermal power plant with similar reservoir and brine conditions can reach an overall net efficiency of electrical power generation of 13% (annual average) if the heat is extracted at 170°C.

According to the Carnot process (see **Figure 12**), the efficiency of the ORC process is linked to the production temperature of the geothermal well, which feeds the ORC process. The feed temperature in this case is only 100°C, which limits the maximum efficiency.

The efficiency is not only dependent on the production temperature of the geothermal well, but also on the ambient temperature (see **Figure 12** and **Figure 13**). This is because in the ORC process the media is cooled with air condensers which consume electricity. The higher the ambient temperature, the more air volume flow is necessary for cooling and the more electricity is consumed by the air condensers. This lowers the net efficiency of the whole system.

The low feed temperature of the ORC (100°C) and the high ambient temperatures during the cooling periods (usually in summer) lead to the low efficiency.

The most favourable heat price of the three variants is obtained by extracting the heat at 100°C using a single-effect ACS. In particular, this is possible if the power-generating plant and the cooling system are in the same location. If the locations are separate, it may be expedient to use a double-effect ACS.

Cooling price of single- and double-effect ACS at different source temperatures

In the event that the cooling is produced and sold by the geothermal company, the cooling prices are calculated according to the following three variants:

1. Use of a single-effect ACS with direct use of a source temperature of 170°C.
2. Use of a single-effect ACS with subsequent use of the residual heat from a power-generating plant of 100°C.
3. Use of a double-effect ACS with direct use of a source temperature of 170°C.

The following example calculations refer to the ACS of the model "World Energy 2ABH1300" with a cooling capacity of 4,571 kW, which is sufficient to replace the formerly installed 4,650-kW vapour compression system. The data sheet of the model can be accessed Online (World Energy, 2019).

Explanation: in the left column, the investment for the cooling system is taken into account, and in the right column it is not. Only the operational costs are shown.

Calculation of cooling price single effect absorption cooling system at 170°C		
	With investment	Without investment
Cooling capacity	4,571 kW	4,571 kW
COP	0.7	0.7
Heat for cooling – single-effect	6,530 kW	6,530 kW
Efficiency of heat exchanger and heat losses	95%	95%
Heat requirement for cooling	6,874 kW	6,874 kW
Heat price	€0.0086/kWh	€0.0086/kWh
Cost of geothermal heat per kWh of cooling	**€0.0123/kWh$_c$**	**€0.0123/kWh$_c$**
Cooling water requirement	33 m^3/h	33 m^3/h
Water costs	€1.158/m^3	€1.158/ m^3
Cost of cooling water per kWh of cooling	**€0.0084/kWh$_c$**	**€0.0084/kWh$_c$**
Electricity for cooling towers	140 kW	140 kW
Electricity for cooling water pumps	191 kW	191 kW
Electricity for absorption cooling system	9 kW	9 kW
Total electricity requirement	340 kW	340 kW
Electricity price	€0.066/kWh	€0.066/kWh
Electricity cost per kWh of cooling	**€0.0049/kWh$_c$**	**€0.0049/kWh$_c$**
Variable total costs per kWh of cooling	€0.026/kWh$_c$	€0.026/kWh$_c$
Depreciation of equipment over 10 years	€0.012/kWh$_c$	€0.000/kWh$_c$
Total costs per kWh of cooling	€0.038/kWh$_c$	€0.026/kWh$_c$
	3.8 ct/kWh$_c$	2.6 ct/kWh$_c$

Table 8: Cooling price, single-effect absorption cooling system at 170°C

Calculation of cooling price single effect absorption cooling system at 100°C		
	With investment	Without investment
Cooling capacity	4,571 kW	4,571 kW
COP	0.7	0.7
Heat for cooling – single-effect	6,530 kW	6,530 kW
Efficiency of heat exchanger and heat losses	95%	95%
Heat requirement for cooling	6,874 kW	6,874 kW
Heat price	€0.004/kWh	€0.004/kWh
Cost of geothermal heat per kWh of cooling	**€0.0050/kWh$_c$**	**€0.0050/kWh$_c$**
Cooling water requirement	33 m^3/h	33 m^3/h
Water costs	€1.158/m^3	€1.158/m^3
Cost of cooling water per kWh of cooling	**€0.0084/kWh$_c$**	**€0.0084/kWh$_c$**
Electricity for cooling towers	140 kW	140 kW
Electricity for cooling water pumps	191 kW	191 kW
Electricity for absorption cooling system	9 kW	9 kW
Total electricity requirement	340 kW	340 kW
Electricity price	€0.066/kWh	€0.066/kWh
Electricity cost per kWh of cooling	**€0.0049/kWh$_c$**	**€0.0049/kWh$_c$**
Variable total costs per kWh of cooling	€0.018/kWhc	€0.018/kWhc
Depreciation of equipment over 10 years	€0.012/kWh$_c$	€0.000/kWh$_c$
Total costs per kWh of cooling	€0.031/kWh$_c$	€0.018/kWh$_c$
	3.1 ct/kWh$_c$	1.8 ct/kWh$_c$

Table 9: Cooling price, single-effect absorption cooling system at 100°C

Calculation of cooling price double effect absorption cooling system at 170°C		
	With investment	Without investment
Cooling capacity	4,571 kW	4,571 kW
COP	1.3	1.3
Heat for cooling – single-effect	3,516 kW	3,516 kW
Efficiency of heat exchanger and heat losses	95%	95%
Heat requirement for cooling	3,701 kW	3,701 kW
Heat price	€0.0086/kWh	€0.0086/kWh
Cost of geothermal heat per kWh of cooling	**€0.0070/kWh$_c$**	**€0.0070/kWh$_c$**
Cooling water requirement	18 m^3/h	18 m^3/h
Water costs	€1.158/m^3	€1.158/m^3
Cost of cooling water per kWh of cooling	**€0.0046/kWh$_c$**	**€0.0046/kWh$_c$**
Electricity for cooling towers	75 kW	75 kW
Electricity for cooling water pumps	90 kW	90 kW
Electricity for absorption cooling system	9 kW	9 kW
Total electricity requirement	174 kW	174 kW
Electricity price	€0.066/kWh	€0.066/kWh
Electricity cost per kWh of cooling	**€0.0025/kWh$_c$**	**€0.0025/kWh$_c$**
Variable total costs per kWh of cooling	€0.014/kWh$_c$	€0.014/kWh$_c$
Depreciation of equipment over 10 years	€0.017/kWh$_c$	€0.000/kWh$_c$
Total costs per kWh of cooling	€0.031/kWh$_c$	€0.014/kWh$_c$
	3.1 ct/kWh$_c$	**1.4 ct/kWh$_c$**

Table 10: Calculation of cooling price, double-effect absorption cooling system at 170°C

Results of the comparison:

If heat is extracted in an existing geothermal power plant process, which is then no longer available for electricity generation, this results in the lowest **heat price** of 0.35 ct/kWh$_{th}$ for heat extraction at a temperature of 100°C. This is due to the fact that the ORC process only achieves an efficiency of approximately 4% at this low supply temperature, which means that the feed-in deficit that needs to be compensated is small. Since this heat can only be converted using a single-effect ACS, this results in a **cooling price** of 1.8 ct/kWh$_c$ (excluding investment in the cooling system) or 3.1 ct/kWh$_c$ (including investment in the cooling system).

Compared to the vapour-compression cooling system with a price of 3.2 ct/kWh$_c$ (without investment; see **chapter 4.6.1**), the use of geothermal energy to provide cooling via a single-effect ACS is more economical at a price of 1.8 ct/kWh$_c$ (without investment).

If the heat is extracted at a higher temperature of 170°C, a larger feed-in deficit in electricity generation will need to be compensated for. This results in a higher **heat price** for this scenario of 0.86 ct/kWh$_{th}$. The **cooling price** in this case, using a double-effect ACS, is only 1.4 ct/kWh$_c$ (without investment) or 3.1 ct/kWh$_c$ (with investment). The reasons for this are the better COP and the lower electricity and cooling water requirement of the double-effect ACS compared to the single-effect ACS.

Compared to the vapour-compression cooling system with a price of 3.2 ct/kWh$_c$ (without investment), the use of geothermal energy to provide cooling via a double-effect ACS is more economical at a price of 1.4 ct/kWh$_c$ (without investment).

4.7 Grid-independent operation and operation that is beneficial to the grid

4.7.1 Structure of the electricity and heating market

The Turkish **electricity market** has been liberalised to a large extent. The transmission grid is operated by the state-owned company TEIAS. It has a monopoly position. During the liberalisation of the energy market, the transfer of the regional electricity grids to private companies was completed. The distribution or sale of electricity to consumers is carried out via 21 regional, private companies (AHK Türkiye, 2021).

As independent producers, private companies can sell their electricity from renewable-power-generating plants to a state-owned or private supplier. Grid access itself is regulated by the regulatory authority for the energy market.

The Turkish **heating market** is still dominated by natural gas. Coal, biomass and geothermal energy are currently only used as secondary sources for heat generation. Around 48% of Turkish households use a central boiler serving one dwelling, and 11% use central heating for multiple housings. The share of decentralised heating stoves is 35%. More than 6% of households use electrical heating (TUIK, 2022).

After fossil-powered heating systems, Türkiye has a sizeable number of solar heating installations on rooftops, totalling almost 18 gigawatt hours of installed capacity, predominantly in medium- and lower-income households in the south-eastern part of the country (IEA, 2021a). In industry, the demand is covered by natural gas, electricity or heat pumps. The use of stoves for space heating is particularly widespread in South Anatolia, and decentralised heating systems are predominant in Ankara, Istanbul and Eskişehir. In regions of Türkiye with a warmer climate (west and south coast), air conditioners are also used as a heating alternative. In the Aegean region, geothermal plants are already being used for the supply of heat.

District heating obtained exclusively from geothermal energy is used in a total of 18 towns in 11 different provinces in residential and public buildings (Parlaktuna, Çelem and Parlaktuna, 2021). In rural areas, heating with traditional biomass such as wood and fertiliser is common. 17.5 million households are heated using natural gas (Ergur, 2022). They are supplied by 69 licensed natural gas suppliers.

4.7.2 Supporting regional electricity grids, ensuring grid stability through geothermal cooling

In Türkiye, electricity demand for air conditioning accounts for a significant amount of the total consumption and is expected to rise. This trend poses challenges for the electricity supply in the country on multiple levels. In particular, the capacities of regional distribution grids and transformer stations need to be revised in line with regional demand development trends.

Particularly in the southern regions, regional grid failures may occur due to high demand during the summer months. The background to this is that the currently installed centralised and decentralised cooling systems for large-scale consumers such as hotels, shopping centres, clinics, office buildings, universities, etc. predominantly use electricity as their primary energy. Therefore, there is an additional load on the regional electricity grid. It may also cause facilities to install natural gas or oil-based auxiliary energy production units as a backup system.

New concepts are needed to relieve the strain on the electricity grid and absorb load peaks. Geothermal energy, a renewable energy source, can provide a solution to this issue. Heat-operated cooling units relieve the strain in the electricity grid. Geothermal cooling can therefore assume a key position, especially in regions with highly favourable geothermal conditions.

4.7.3 Increasing availability by ensuring grid stability

A reliable electricity supply is only possible with a stable energy infrastructure and the complex interplay of power plants, transformers, storage systems and lines.

The basis of energy infrastructure is the electricity grid, which is subdivided into multiple voltage levels. The transmission grid transports the quantities of electricity from the producer to the distribution grids in the regions. There, the electricity is stepped down to a lower voltage in order to supply industry or households. The distribution system operators supply local electricity consumers, such as individual households, at the low- and medium-voltage levels, or larger consumers, such as energy-intensive companies, via medium-voltage grids.

It is important that grid security continues to be guaranteed in a grid during projected maximum transmission and supply tasks even if a component, such as a transformer or a circuit, fails or is switched off. In this case, this means that there must not be any inadmissible supply interruptions or a worsening of the disruption. The voltage must remain within the permissible limits, and the remaining equipment must not be overloaded.

The growth in decentralised power-generation units feeding into the grid places new demands on the distribution grids. Previously, electricity flowed from a central power plant to many thousands of consumers. Now, there are a large number of decentralised electricity producers. This means that the electricity grid must now intelligently link the producers and the consumers in order to flexibly coordinate generation and consumption.

The use of geothermal energy has an advantage here. Compared to decentralised plants, whose output is often dependent on the wind and sun, geothermal power-generating plants play a unique role. They can generate electricity independently of climatic and seasonal fluctuations and feed it into the grid in a decentralised fashion.

This means that electricity grids are facing continuously growing challenges. The expansion of renewable energy brings fluctuations in electricity generation and loads on the grids that have to be managed by the grid operators. It must be examined to what extent new lines at the extra-high voltage level will be able to bridge the distances between generation centres and consumption centres in the future.

With the decentralised integration of renewable power-generating plants, the additional capacity requirements of the electricity grid must take three further developments into account:

- Due to weather-related fluctuations, electricity generation in supra-regional and regional grids will become **increasingly irregular**, which will have an impact on grid stability.
- Electricity generation is becoming more **diverse and decentralised**, and more and more small power-generation plants utilising renewable energy sources need to be connected to the grid.
- The integration of decentralised renewable power-generating plants will result in much more complex electricity flows. Electricity will no longer flow in just one direction on its journey from the transmission grids via the distribution grids to the consumer.

If the proportion of renewable energy in electricity generation grows significantly faster than the expansion of the grid, corresponding measures will be necessary. Temporary transmission bottlenecks must be prevented. We speak of a ‘grid bottleneck’ when electricity cannot reach the consumer due to insufficient transmission capacity. In order to avoid these bottlenecks or, if necessary, to eliminate them, various measures can be taken while the grid is in operation. Two such measures are feed-in management and redispatch management. Both procedures are used to bridge temporary bottlenecks.

Feed-in management: protecting the grid from overloads

If, due to the aforementioned fluctuations in the electricity to be fed into the grid, the currently available grid capacity becomes insufficient to transport the total amount of electricity generated, grid operators can employ feed-in management to avoid grid bottlenecks and ensure the security of supply.

In these situations, grid operators feed less energy into the grid from electricity generated from renewable energy, which is actually the preferred source. In concrete terms, renewable power-generating plants, for example, are then temporarily throttled or even switched off. As a rule, grid operators should only use feed-in management as a last resort to avoid bottlenecks. This procedure is not comparable to peak shaving, which is already included in the grid planning.

Redispatch: balancing power flows in different directions

Redispatch is a measure used to control the flow of electricity. The strain on certain parts of the electricity grid is relieved through physical laws. With redispatch, the power plant output is deliberately reduced on one side of the line and deliberately increased on the other side. This reduces the total current flowing through the line. The necessary agreements for this are made between the respective grid operators and the responsible power plant operators.

Geothermal cooling: replacing electricity-powered cooling systems

In geothermal cooling, only heat from geothermal sources is used as energy to provide cooling. This means that no additional electricity is required by the consumer and thus no overloading of the electricity grid occurs. The electricity demand for the geothermal plant increases only insignificantly as a result of the extraction of heat and the use of an ACS.

In terms of electricity demand, a good estimate can be provided for the operation of a geothermal plant. For the production of electricity, only the surplus is fed into the grid, and in the case of direct use, demand behaviour is even more favourable with the use of a cooling system, since in summer, the main consumer – the production pump – does not have to be throttled. There is a relatively even consumption pattern with direct geothermal use for supplying cooling.

5 Ecological and economic potential in Türkiye

Currently, approximately 360,000 MW of district heating can be provided using geothermal energy in Türkiye. If this district heating were to be used entirely for cooling in the summer, an estimated 24 Tt of CO_2 could be saved annually compared with cooling via the usual electricity-driven vapour-compression systems.

5.1 Carbon footprint of conventional cooling methods

In 2016, almost 10% of the electricity generated worldwide was used for cooling (IEA, 2018). For Türkiye, exact numbers are not available. Nevertheless, looking at the level of warming in recent years and the rising number of cooling degree days (CDD), drawing conclusions from the worldwide average can be considered a conservative approach (IEA, 2021b).

Taking the world average electricity consumption for cooling as an example for Türkiye, 29,770 GWh of electricity was used for cooling purposes in 2022 (IEA, 2023b). The carbon intensity in the electricity mix is 430g/kWh (Electricity Maps, 2023). As a rough estimation, this results in CO_2 emissions of 12,8 million t in 2020 for cooling.

5.2 CO_2 savings potential through the use of geothermal energy to supply cooling

There are different ways to estimate the CO_2 savings potential of geothermal cooling systems. The entire geothermal potential of Türkiye can be used regardless of location, possible cooling infrastructure or necessary drilling depth and without a more detailed analysis of the cooling systems that can be used. However, this would inevitably include those cooling supply projects that would be economically non-viable compared to other cooling methods due to their remoteness from larger consumer structures or higher drilling costs.

For sites that are already supplied with geothermal heat in the form of district heating, a much more precise statement can be made concerning the CO_2 savings potential with regard to an economically viable implementation. These sites are mostly located in the west of the country near large built-up areas. However, there are also sites in the east and in the interior of the country with geothermal district heating systems (see **Table 10**).

Since the technical feasibility of these locations has been proven in the form of a plant that has already been realised, and the consumer structures for district heating are in place, the CO_2 savings potential is illustrated on the basis of these practical examples.

At sites with a production temperature below 80°C, none of the previously described technical applications can be realised.

At sites with a production temperature between 80 and 130°C, the integration of a single-effect ACS is feasible. For sites with multiple wells that have both higher and lower production temperatures, an average value of 105°C was assumed. For the sites listed herein, this results in a geothermal potential of 358 MW_{th} (assuming a maximum cooling of 60°C). With this, approximately 250 MW_c could be generated using single-effect absorption cooling systems with an average COP of 0.7.

City	District	Production [m³/h]	Production [l/s]	Temperature [°C]	delta T (up to 60°C)	Residences	Geothermal potential [kW]
Afyon	Central District (Afjet)	1,500	416.67	95	35	30,000	55,416.67
Afyon	Sandıklı (Sanjet)	1,440	400.00	80	20	18,000	30,400.00
Ağrı	Diyadin	180	50.00	78–85	18–25	2,000	3,800.00
Ankara	Kızılcahamam	63	17.50	75	15	3,000	997.50
Balıkesir	Gönen	–	–	60–70	0–10	2,500	–
Balıkesir	Edremit	1,440	400.00	58	–	7,500	–
Balıkesir	Bigadiç	54	15.00	98	38	3,000	2,166.00
Bursa	Central District	1,080	300.00	88	28	5,400	31,920.00
Denizli	Sarayköy	260	72.22	145	85	5,000	23,327.78
Izmir	Balçova-Narlidere	2,020	561.11	90–144	30–84	50,500	115,140.00
Izmir	Bergama	180	50.00	65	5	850	950.00
Izmir	Dikili	200	55.56	80	20	2,500	4,222.22
Izmir	Çeşme	49	13.61	57	–	–	–
Kırşehir	–	983	273.06	55	–	1,800	–
Kütahya	Simav	828	230.00	130–150	70–90	15,000	69,920.00
Manisa	Salihli	540	150.00	88	28	12,000	15,960.00
Nevşehir	Kozaklı	–	–	94	34	3,500	–
Yozgat	Sarıkaya	180	50.00	57	–	2,000	–
Yozgat	Yerköy	648	180.00	65	5	1,000	3,420.00

Table 11: Cooling price, double-effect absorption cooling system at 170°

Conventional systems use electricity to provide cooling. For relatively new split systems, a COP of 3.9 can be applied (Mitsubishi Electric, 2017). If a geothermal energy source is used for the production of 250 MW_c, a capacity of approximately 64 MW_e and, assuming 8,000 operating hours per year, approximately 512 MWh_l of electricity generation can be saved. This corresponds (with the current energy mix in Türkiye) to annual CO_2 savings of about 180,000 t of CO_2 if the current infrastructure is used.

To meet the entire cooling demand of the country using geothermal energy, a cooling demand of 116,103 GWh_c (assuming a current figure of 29,770 GWh for cooling and an average COP of 3.9) would **require a cooling capacity of 14.5 GW_c** (assuming 8,000 operating hours per year and an average COP of 1).

As described in section 1.3, the geothermal potential in Türkiye is 31.5 GW_{th}, which results in an electricity generation potential of about 3 GW_e.

Based on the operating conditions for the ACSs, we assume that a double-effect ACS can be used in cases where electricity generation is also feasible.

From the electricity generation potential, the preceding usable geothermal energy source has a potential of 17.6 GW_{th}, assuming a gross efficiency of 17%.

If this geothermal energy were to be converted into cooling by means of a double-effect ACS, it would cover a demand of 22.9 GW_c. This corresponds to 1.6 times Türkiye's cooling consumption in 2018.

This rough calculation completely neglects location-related parameters such as drilling depths, necessary pipeline lengths and the resulting economic considerations. However, it gives an indication of the magnitude of the potential for geothermal cooling in Türkiye, which is currently almost completely untapped.

6 Acceptance of geothermal energy and possible conflicts of use

The extended application of geothermal energy not only for electricity generation, but also for the supply of heat and generation of cooling could once again improve the acceptance of geothermal energy use. The local communities adjacent to the geothermal power plants and their residents could participate directly in geothermal energy by being supplied with heat from the geothermal power plant. In addition, this heat can be used to generate cooling, which can be used for air conditioning in residential and commercial premises and also commercially for cooling in cold stores.

6.1 Stakeholders in the use of geothermal energy

Geothermal electricity generation has experienced massive expansion over the past decade. Türkiye ranks 4th in the world in terms of installed geothermal capacity. Renewable energy accounts for approximately 17% of electricity generation (excluding hydroelectric power). Geothermal energy accounts for almost one fifth of this. In Aydin and Gediz graben, in particular, geothermal electricity is generated by power plants built in the last 15 years, each with capacities ranging between 15 and 150 MW_e.

These regions are particularly characterised by their agriculture. In Aydin, for example, around 1.5 million fig trees, 15 million olive trees and 1 million orange trees are cultivated, and 110,000 t of figs, 110,000 t of olives and 45,000 t of grapes are harvested each year. There is almost no agricultural product that does not grow in these regions. In part, the agriculture already uses the waste heat from the geothermal power plants in its greenhouses. This is an energy policy advantage.

Power plants in the region are built by private companies. Engineering comes from local and foreign companies. Türkiye's geothermal energy experience has emerged as a private-sector-driven development. With its growing experience in the sector, the private sector overcame reservations focused on project performance targets in the first phase projects, and efficient business development processes were achieved. On the other hand, the geothermal energy sector has mostly focused on electricity. Although this situation has changed rapidly recently, it is clear that there are different business models, new stakeholders and new responsibilities awaiting the geothermal energy sector in the field of geothermal heating and cooling.

In the initial phase of geothermal energy use, most of the fields (concessions) were acquired by purchasing from the state-run Turkish Directorate of Mineral Research and Exploration (MTA). Subsequently, the private sector was actively involved in field development. Although there is detailed geological and geothermal data for the fields provided by the MTA, more detailed studies are being carried out for wells and power plants in line with private sector practices.

As long as the design and engineering, construction and operation of the geothermal power plants are carried out properly, emissions will be under control and thermal water will be re-injected without exposure to the environment. Apart from general geothermal energy development risks such as the reservoir drying out and becoming unstable in the medium-term, unwanted emissions and unpleasant odours may occur in some cases. Although remaining isolated, such incidents can lead to unrest and emotional reactions among residents of local communities located near geothermal power plants and surrounding farmers and can greatly affect the image of geothermal electricity generation. Insufficient awareness and scepticism may arise among the public against the use of geothermal energy. Such individual examples may cause reactions to the implementation of new projects in these regions. Therefore, during the development phase of geothermal energy projects, it becomes even more important to properly promote geothermal energy and the opportunities it offers to the region and where possible to implement projects that directly interact with the inhabitants of the region, such as heating and cooling.

6.2 Marketing concept for CO_2 equivalence

The use of geothermal energy for cooling can strengthen cooperation between the operators of geothermal power plants and the residents of neighbouring local communities as well as local farmers, since there is direct contact through the supply of heating and cooling. The residents and farmers are direct beneficiaries of a primary energy on site. The approach of a regional energy supply and its use can be fulfilled directly and re-establish the acceptance of geothermal energy. What is important in this context are initial examples and reference projects for its use which show how energy for cooling can be generated in an environmentally friendly way and how both the consumption of fossil fuels and CO_2 emissions can be reduced.

Once the first projects have been successfully realised, references and real-world examples will be available, which on the one hand will sustain public support, while also serving as practical examples for many other regions for corresponding cooling projects.

7 Summary and subsequent steps

The use of geothermal energy in Türkiye is mainly focused on electricity generation and the supplying of heat. Supplying geothermal cooling or geothermal trigeneration is not yet a focus for geothermal companies, although cooling demand for buildings and facilities is increasing steadily worldwide.

This feasibility study shows the possibilities of using geothermal energy for cooling and gives an overview for replacing the current electricity-powered cooling systems.

7.1 Basic principles

The starting point for the feasibility analysis was dena's dossier on heating and cooling in Türkiye, published in July 2020, entitled ‘Technology overview: renewable heating and cooling’. Under point 6 of this dossier, the technology for geothermal cooling was presented, and it was explained that there is great potential for the use of various renewable energy sources for heating and cooling in Türkiye. Different technologies are available for this purpose, which are already being used successfully in Germany. The particular challenge for cooling in Türkiye is to replace the predominantly electricity-operated cooling systems with alternatives that utilise renewable energy. Approximately 10 - 16% of Türkiye’s total electricity consumption is used for cooling.

This feasibility study shows the available and usable potential of geothermal energy as primary energy for the generation of cooling in Türkiye. For this purpose, the following two options are considered:

1. Possible geothermal potential for the construction of new geothermal plants with cooling generation and comparison with conventional technologies.

2. Example option of retrofitting an existing geothermal plant for cooling generation as well as the continued use of existing distribution networks.

In point 2, a practical approach is pursued by conceptually comparing the use of an electricity-operated cooling system with a geothermally operated system through a judicious combination of technologies. For this purpose, sample calculations are presented from the point of view of the geothermal power plant operator. These show that the loss in electricity generation when heat is extracted for cooling can be compensated for – even after taking into account the applicable regional cooling price.

7.2 Technical summary

In Türkiye, the energy demand for cooling buildings, equipment, food and for dehumidification is also increasing significantly. This is influenced by the climate crisis and by increasing mechanisation. On the other hand, there is a decreasing need for heating, also influenced by the climate crisis, but also by energy-efficiency and building renovation measures.

Currently, cooling in Türkiye is mainly supplied using electricity-driven split systems and, in case of greater cooling needs, by vapour-compression cooling systems. ACSs driven using heat or geothermal heat are not yet common. Since ACSs require heat to operate, their application is especially interesting when renewable energy sources are used.

In particular, the use of geothermal energy, which holds great potential in Türkiye, represents a good basis for primary energy. The basis for the supply of heat and cooling using geothermal energy is achieving a balance between the geothermal conditions and the local cooling demand. Both need to be reconciled and balanced since, unlike electricity generation, the extraction of geothermal energy is coupled to the energetic utilisation demand and thus an interaction exists, as with any heating and cooling supply.

A distinction is made between the two main variants of a geothermal trigeneration/combined cooling, heat and power system:

1. Electricity-first geothermal plant – in this case, electricity generation takes priority, and the heating/cooling supply is downstream.

2. Heat/cold-first geothermal plant – in this case, the supply of heat/cooling takes priority, and the electricity generation is downstream.

These two applications are to be seen as basic variants, since an intermediate solution is usually realised in series or parallel operation for technical and economic reasons.

There are various technical solutions for cooling generation. At present, electricity-powered systems are the main ones used in Türkiye. If geothermal energy is to be used, plants that require heat as energy to drive the systems are necessary. Section 2.2 describes these systems and recommends the use of ACSs. An absorption system is to be used when sufficient (waste) heat is available at a cost-effective price. Theoretically, this is the case for every geothermal power plant site but should be considered and calculated individually based on the circumstances and site.

A vapour-compression cooling system has the advantage that, in addition to lower waste heat, it can react to rapid load changes in cooling demand. This makes it highly suitable for peak and medium load supply and as a redundancy system. The geothermally operated ACS can cover the base load of a cooling supply. It experiences less wear and tear and thus has a longer service life.

The decision whether to use a centralised cooling system with a cooling network or a decentralised one at the user's site must be made on a case-by-case basis. In general, the heat required to drive the system must always be extracted from the geothermal system and transported to the cooling system. For this purpose and when considering whether to use a centralised or decentralised cooling supply, a holistic approach is always necessary, as many influencing factors must be taken into account. These include the demand for cooling (output and annual demand), the availability and reliability of the energy to drive the system (electricity or heat), permit requirements depending on local and regional circumstances, and the general technical feasibility.

7.3 Results

The results presented symbolise ideal conditions and are based exclusively on energy-related considerations. Variation and optimisation of the parameters can only be carried out when actually drawing up the design and when regional and entrepreneurial circumstances are known. At present, each geothermal project is still individual in nature in terms of location and geothermal energy. This is especially true when expanding the use of geothermal energy for energy provision if, in addition to electricity generation, useful and final energy (heating and cooling) is to be provided.

This feasibility analysis uses idealised examples to demonstrate the possibility of geothermal cooling and the resulting carbon savings. Conventional systems use electricity as the energy to provide cooling. For relatively new split systems, a COP of 3.9 can be applied (Mitsubishi Electric, 2017). If a geothermal energy source is used for the production of 250 MW_c, a capacity of approximately 64 MW_e and, assuming 8,000 operating hours per year, **approximately 512 GWh_e of electricity generation can be saved**. This corresponds (with the current energy mix in Türkiye) to **annual CO_2 savings of about 180,000 t of CO_2** if the current infrastructure is used.

Furthermore, it was examined whether it makes sense to replace the amount of electricity from Türkiye's energy mix required for the electricity-based cooling supply with geothermally generated electricity, or whether it is cheaper to supply this cooling directly using geothermal heat.

In order to demonstrate the economic efficiency of the direct use of geothermal heat for cooling, the cooling capacity that can be generated via direct use by means of an ACS was compared to the cooling capacity that can be generated by a vapour-compression system that runs on electricity. Compression systems with a COP of 4 would be able to generate a total cooling capacity of 4,800 MW_c from the available geothermally generated electrical output of 1,200 MW_{el}.

Comparing this with the use of an ACS, the following result is obtained.

A single-effect ACS has a COP of 0.7. With the high thermal water temperatures in Türkiye, which are used for electricity generation, the use of a double-effect ACS is also possible. A COP of 1.3 is assumed for this. By directly using the geothermal heat for cooling, a cooling capacity of 6,490 MW_c would be possible for the single-effect system and 12,050 MW_c for the double-effect system. Compared to the cooling capacity of 4,800 MW_c produced by a vapour-compression cooling system, the single-effect ACS produces around 1.3 times the cooling capacity and the double-effect ACS 2.5 times the cooling capacity.

Furthermore, an example was used to investigate how the loss in electricity production could be compensated for by extracting heat for cooling.

Results of the comparison:

If heat is extracted in an existing geothermal power plant process, which means it is no longer available for electricity generation, the heat must be sold at a minimum **heat price** of 0.35 ct/kWh_{th} to compensate for the loss in the case of heat extraction at a temperature of 100°C. Since this heat can only be converted using a single-effect ACS, this results in a **cooling price** of 1.8 ct/kWh_c (excluding investment in the cooling system) or 3.1 ct/kWh_c (including investment in the cooling system).

Compared to the vapour-compression cooling system with a price of 3.2 ct/kWh_c (without investment), the use of geothermal energy to provide cooling via a single-effect ACS is more economical at a price of 1.8 ct/kWh_c (without investment).

If the heat is extracted at a higher temperature of 170°C, the use of a double-effect ACS is possible. This results in a higher **heat price** of 0.9 ct/kWh$_{th}$. The **cooling price** alone is only 1.4 ct/kWh$_c$ (without investment) or 3.1 ct/kWh$_c$ (with investment). The reasons for this are the better COP of 1.3 for the double-effect ACS and the lower electricity and cooling water requirement.

Compared to the vapour-compression cooling system with a price of 3.2 ct/kWh$_c$ (without investment), the use of geothermal energy to provide cooling via a double-effect ACS is more economical at a price of 1.4 ct/kWh$_c$ (without investment).

The results of the economic feasibility analysis are presented in **Table 5: Heat price, single-effect absorption cooling system at 170°C**, **Table 6** and **Table 7** for the heat price and in **Table 8** and **Table 9** for the cooling price. **The cooling price shows that geothermal cooling is cost-effective**. Even taking into account the necessary investments, the cooling price of the double-effect ACS is still lower than that of the vapour-compression cooling system.

The feasibility analysis thus shows that the **use of geothermal energy for cooling is economically feasible**. However, this does not exclude individual, site-related and entrepreneurial considerations before an investment decision is made.

In addition, the following coupling should be explained.

If the demand for heating energy and the demand for cooling energy are compared, it becomes apparent that both processes complement each other. During the heating period, little or no cooling energy is needed for air conditioning, but heating energy is needed for space heating and providing hot water. In summer, only cooling is needed for air conditioning, and heating is only needed for providing hot water and selected applications. If the cooling and heating supply are coupled, the expenditure for heat extraction from geothermal energy can be used not only for cooling, but also for the supply of heat, both in terms of energy provision and cost-effectively. **Geothermal heat-cooling coupling is to be recommended.**

7.4 Possible next steps/recommendations

Geothermal cooling is an economically attractive option for providing cooling in an environmentally friendly and direct fashion. The technical possibilities are available, which is why the development of a reference project is recommended. Reference projects provide a good basis for market entry and are strongly advocated from both an energy and environmental perspective.

Various configurations are possible for the investment and operation of such a plant:

A geothermal power plant operator makes the investment and is responsible for operating the plant. They supply heat as power to drive the cooling plant, which is located at the consumer's site. It is necessary to develop mechanisms for concluding an energy purchase agreement for heat with this operator for a period of up to 15 years.

An existing geothermal district heating supply is expanded to include geothermal cooling and, depending on the location and utilisation profile, generation of cooling is set up centrally with a cooling network or externally at the consumer’s location. This means additional revenue is possible in summer.

If the available investment funds are low, the following contracting model can be used:

Contracting example 1: the geothermal power plant operator invests and also builds the cooling plant at the consumer’s location or at the geothermal plant and supplies heat as well as cooling to the consumer under a contracting agreement.

Contracting example 2: a separate contractor invests, buys the heat from the geothermal power plant operator, and delivers it to the consumer or completely handles the heating and cooling supply for the customers.

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9 Glossary

Term	Definition
Absorption and adsorption cooling systems	Sorption cooling systems are heat-driven cooling systems that utilise the evaporation process of a refrigerant as well as its temperature-dependent solubility to generate cold.
Shaft sinking	Drilling a vertical geothermal well.
Combined heat and power plant	Combined heat and power plants use the principle of cogeneration to generate electrical energy and heat. They are preferably operated at the location of heat consumption or at the location of the usable waste heat.
Vapour pressure	Vapour pressure is the pressure of the vapour in a closed system in the presence of the respective liquid phase when in a state of equilibrium.
District heating	District heating refers to thermal energy stored in a medium (e.g. water) that is transported through pipelines to the place to be supplied with heat (e.g. residential buildings, hospitals, etc.).
Geothermal gradient	The geothermal gradient is the change in temperature as depth increases. It is usually expressed in °C/100 m.
Geothermal power plant	A geothermal power plant generates electricity via a working fluid circuit that is separate from the thermal water system, which drives a generator via a turbine. Because the enthalpy of the thermal water is usually low, an organic compound is chosen as the working fluid.
Geothermal potential	Geothermal potential refers to the amount of heat stored in the thermal water, which limits the maximum amount of usable energy.
Hydrothermal system	In a geothermal energy context, a hydrothermal system refers to the use of an underground, natural water conduit. Due to the high pressures that exist in the layers deep within the earth, the thermal water can reach high temperatures, which in turn can be further utilised in the form of heat or electricity.
Vapour-compression cooling system	Vapour-compression cooling systems are cooling systems that utilise the evaporation process of a refrigerant to generate cold, whereby the refrigerant vapour undergoes a mechanical compression process.
Petrothermal system	In petrothermal systems, geothermal energy is extracted independently of water-bearing underground layers. For this purpose, water is pumped through the fissured underground layers, which act as a heat exchanger. The heated water is then pumped back to the surface, where energy is extracted from it.
Reservoir	Naturally occurring underground water-bearing layers are referred to as reservoirs.
Electricity generation potential	In this report, the electricity generation potential refers to the maximum amount of electrical power that can be generated by geothermal energy in a particular area, given the current state of technology.
Deep geothermal energy	Deep geothermal energy refers to the use of geothermal energy starting from a depth of 400 m and includes both hydrothermal and petrothermal systems.
Thermal water	In this report, thermal water refers to the underground water extracted via deep geothermal processes, which is heated by the prevailing pressures.

Term	Definition
Heat of evaporation	The heat of evaporation is the amount of heat required to convert a certain amount of a certain liquid to a gaseous state.

10 Abbreviations

AHK	Delegation of German Industry and Commerce Türkiye
Gt1	Geothermal Well 1
Gt2	Geothermal Well 2
ACS	Absorption Cooling System
BAFA	Federal Office for Economic Affairs and Export Control
CHP	Combined heat and power plant
BMWi	Federal Ministry for Economic Affairs and Energy
BWP	Bundesverband Wärmepumpe e.V.
COP	Coefficient of Performance
dena	German Energy Agency
EEG	Renewable Energy Sources Act
EEWärmeG	Renewable Energy Heat Act
PFC	Perfluorocarbon (fully halogenated hydrocarbon)
Fm	Full cubic metre of wood (without gaps)
FQCP	Field Quality Control Plan
gec-co GmbH	gec-co Global Engineering & Consulting-Company GmbH
HFC	Hydrofluorocarbon (partially halogenated hydrocarbon)
IEA	International Energy Agency
SPF	Seasonal performance factor
KfW	Credit Institute for Reconstruction (German state-owned investment and development bank)
VCCS	Vapour-compression cooling system
CCHP	Trigeneration plant/combined cooling, heat, and power plant
MAP	Market Incentive Programme (Germany)
MTA	Turkish General Directorate of Mineral Research and Exploration
ORC	Organic Rankine Cycle
PV	Photovoltaics
SSAC	Sorption-supported air conditioning
TGA	Building Services/Equipment (Technische Gebäudeausrüstung)
HP	Heat pump

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