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Key Performance Indicators

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1 Introduction

The Support Unit of the Geothermal Implementation Working Group started to monitor the execution of the Geothermal Implementation Plan (DG IP) since 2020 about its targets on cost reduction. The first step was to define Key Performance Indicators to monitor the learning curve on cost of geothermal technologies. Reference plants and assets were then defined with the first list of key performance indicators.

Now the forum to support ETIP-Geothermal and IWG-Geothermal has a mandate to update Key Performance Indicators to cover all geothermal technologies, not only deep geothermal. The new process started when the project Geotherm-For was launched in 2022.

The forum is presenting in this report a new set of complementary Key Performance Indicators (KPIs) to support new policy and regulations from the EU green deal. On top of looking at cost reporting, it is now including references to made in Europe manufacturing.
From the first KPI's to monitor the targets of the SET Plan IWG, specifically those related to cost reductions and improved efficiency of geothermal energy utilization, in addition now it looks at the requirements from the Net Zero Industry act (NZIA) about 'made in Europe' manufacturing.

The monitoring process has been influenced by two key elements from 2022 to 2025:

1) The adoption of the Net Zero Industrial Act (NZIA) with requirement of manufacturing components made in Europe in 2024, and the delegated act in 2025
2) The updated assumptions for the EU reference scenario on energy with energy cost in 2024

The Support Unit proposed these KPIs to a wide range of geothermal stakeholders during public online consultation, followed by validation workshop of these KPIs.

This 2025 version is the new report on the KPIs, which is also reported on an annual basis. The Support Unit describes reference plants and assets, which are based on a European average profile for a range of plants, its components and size, and the corresponding costs. Data have been collected from the literature, reports of public authorities and interviews of market actors.

2 Overview about trends and methodology

2.1 Methodology

2.1.1 Targets

The strategic cost targets for deep geothermal energy set in 2018 were:
1. Increase reservoir performance resulting in power demand of reservoir pumps to below 10% of gross energy generation and in sustainable yield predicted for at least 30 years by 2030;
2. Improve the overall conversion efficiency, including bottoming cycle, of geothermal installations at different thermodynamic conditions by 10% in 2030 and 20% in 2050;
3. Reduce production costs of geothermal energy (including from unconventional resources, EGS, and/or from hybrid solutions which couple geothermal with other renewable energy sources) below 10 €ct/kWhe for electricity and 5 €ct/kWhth for heat by 2025;
4. Reduce the exploration costs by 25% in 2025, and by 50% in 2050 compared to 2015;
5. Reduce the unit cost of drilling (€/MWh) by 15% in 2020, 30% in 2030 and by 50% in 2050 compared to 2015;
6. Demonstrate the technical and economic feasibility of responding to commands from a grid operator, at any time, to increase or decrease output ramp up and down from 60% - 110% of nominal power.

2.1.2 Monitoring baseline

In common with other Implementation Working Groups of the SET-Plan Actions, the IWG on geothermal decided to update the Implementation Plan by the SET Plan Steering Committee, in December 2023.

In order to develop metrics for the strategic targets, the first aim was to identify cost structures of reference plants in typical European settings that cover the exploration phase, the construction phase such as capital expenditures associated with drilling of wells and constructing a power plant and operating expenditures. As cost structures and economic metrics strongly depend on the weighted average cost of capital (or discount rate), the Support Unit has assumed a uniform discount rate as described below in the section ‘System boundaries & clarifications’.

Updated are based on costs reported in news and publications, and during validation workshops by market actors.

2.1.3 The new requirements for NZIA and EU energy modelling

1) In May 2025, the EC adopted the EU Delegated Act on ‘Primarily Used Components’ and Implementing Act on ‘Main Specific Components’ for the Implementation of the Net-Zero Industry:

Two political benchmarks: Commission & Member States shall support net-zero manufacturing projects to ensure the reduction of strategic dependencies by reaching a manufacturing capacity of:
• at least 40% of EU annual deployment needs for the corresponding technologies necessary to achieve the Union’s 2030 climate and energy targets;
• an increased Union’s share for the corresponding technologies in view to reach 15% of world production by 2040, based on the monitoring in the Act.

The geothermal main specific components listed in NZIA act are:

- Heat exchangers resistant to geothermal corrosive operating conditions
- Submersible pumps resistant to geothermal corrosive operating conditions
- Brine re-injection pumps

2) In 2024, the EC reviewed the Technology assumptions in the context of the EU Reference 2025 Scenario for Energy:

The technical assumptions present costs of geothermal technologies, based on a series of parameters:

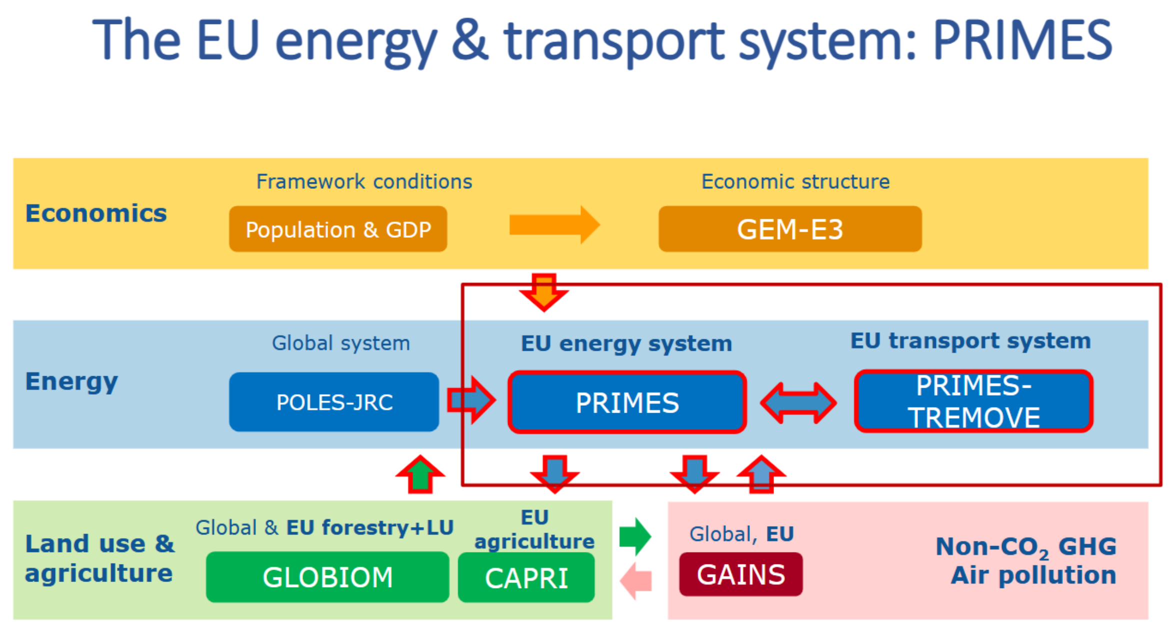

Figure 1: The EU energy & transport system: PRIMES (EC)

The techno-economic assumptions used in the PRIMES modelling suite are organized by sector, mainly as follows:
1. Energy: includes data for the buildings sector (equipment & renovation), industrial sectors, electricity and heat generation, storage technologies and alternative fuels
2. Transport: includes data for the transport technologies and alternative fuel infrastructure
3. Biomass supply: includes data for conversion technologies to produce liquid, gaseous, and solid fuels from biomass

Previous technology cost assumptions used in the modelling were publicly disclosed:
◦ Technology assumptions used in the EU Reference Scenario 2020
◦ Technology assumptions used in the Climate Target Plan 2040 Impact Assessment

2.2 Trends about costs of geothermal technologies

Since the first assessment in 2019, several factors influenced the costs of geothermal technologies. Firstly, Techno-economic characteristics improve due to:
• Learning-by-research (LBR): R&D investments leading to basic technology improvement and innovation, assumed exogenously,

• Learning-by-doing (LBD): improvement of costs and efficiencies due to accumulated experience in the production and installation of a specific technology, depending on the volume of new installations and the scale of their industrial production.

Secondly, several Innovations lead to cost reduction. Current innovation trends that are impacting the next generation of projects include:

(a) **Increasing the plant capacity** through a process of diversification and multi-purpose applications. By generating electricity or heat, or with Combined geothermal Heat and Power (CHP) systems, these plants are spreading for their capacity to maximise the output from geothermal resources. Another trend includes the extraction of minerals, like lithium and potassium, from geothermal brines that generate additional revenue for geothermal projects. At the same time, we need to bear in mind that subsurface conditions influence whether such dual use is economically viable or desirable. Heat-only production at locations with a significant heat demand and moderate temperatures in the subsurface can be the most economic choice, e.g. in the Paris basin.

(b) **Adapting the depth** to reach more accessible reservoirs, taking advantage of increased efficiency of production at lower temperatures.

(c) **Adopting the right number of wells** to balance resource extraction and sustainability. New drilling design with sub-horizontal wells allow for greater contact with the geothermal reservoir therefore improving efficiency by increasing the surface areas through which heat can be extracted. In some European countries where geothermal energy was produced by extraction-only. Finally, the adoption of three or more wells rotating in use contribute as well to the extension of the lifespan of the resource.

(d) **Expanding Greenfields**, moving from the vicinity of known areas and expanding the geothermal asset with new exploration techniques.

(e) **Adopting de-risking approaches** by developing several projects in a same area, so called project portfolio approach.

3 Key Performance Indicators 2025

3.1 Reference plants

In the first costs reporting in 2019, reference plants were used as a KPI to address the challenges set by the Implementation Plan's target to "Reduce production costs of geothermal energy to below 10 €ct/kWhe for electricity and 5 €ct/kWhth for heat by 2025". The reference plants considered only for deep geothermal, serve as benchmarks, representing typical configurations and performance metrics informing the industry on cost reductions and efficiency improvements.

The choice of reference plants was defined to specifically address the challenges defined in the Implementation Plan's target to "Reduce production costs of geothermal energy (including from unconventional resources, EGS, and/or from hybrid solutions which couple geothermal with other renewable energy sources) to below 10 €ct/kWh$_e$ for electricity and 5 €ct/kWh$_{th}$ for heat by 2025". From 2023, the IWG on geothermal covers also shallow geothermal to geothermal HP systems.

3.1.1 Type of plants

Originally, six plants were considered: three for power production including one on EGS, and three plants for heat supply including one combined heat & power system:

- 20 MW$_e$ high temperature plant (Flash turbine)
- 10 MW$_e$ medium temperature plant (Binary turbine)
- 5 MW$_e$ electric EGS plant (or thermal EGS plant with a capacity of 25 MW$_{th}$)
- 10 MW$_{th}$ heating plant
- 10 MW$_{th}$ heating plant assisted with large heat pumps
- 5 MW$_e$ and 20 MW$_{th}$ CHP plant

Seeing the market development from 2019 (starting date) to 2024, the added value of monitoring cost developments for the different plants sizes has been limited. There is a need to consider a small-scale system with a geothermal heat pump to reflect the current scope of IWG and ETIP. Therefore, this report is focusing on the follow 4 reference:

- **20 MW$_e$ high temperature plant (Flash turbine)**
- **10 MW$_e$ medium temperature plant (Binary turbine)**
- **20 MW$_{th}$ heating plant**
- **50 kW$_{th}$ heating and cooling system assisted with heat pumps**

3.1.2 Sources of data

For each plant category, the reference plant has been taken from the costs of plants in operation. The source is often from a basket of plants in a developed area, for example:

- 20 MW$_e$ high temperature plant (Flash turbine): Tuscany, Italy
- 10 MW$_e$ medium temperature plant (Binary turbine): Bavaria, Germany
- 20 MW$_{th}$ heating plant assisted with large heat pumps: France, Netherlands
- 50 kWth heating and cooling system assisted with heat pumps: France, Netherlands and Germany

The costs of geothermal plants depend notably upon economies of scale. The levelized cost of electricity decreases with an increase in installed plant capacity. In general, economies of scale allow both unit capital cost (in euros per kW installed) and unit operating and maintenance cost (in euros per kWh produced) to decline with increased installed capacity.

3.1.3 System boundaries & clarifications

We do not consider the impact of energy storage or other system services that geothermal plants may provide, as there are insufficient examples and reported costs to give a sufficiently detailed picture. Storage of electricity produced by geothermal power plants can be used for several purposes. Geothermal supplies a base load power, and when there is peak wind, or peak solar, geothermal power plants can have a flexible generation to ramp up and down its generation of electricity. Underground thermal energy storage associated to deep geothermal plants are still at a stage of development, with some demonstrations across Europe already.

Our reference plants have the following system boundaries:

- From project investigation, exploration and development until production,
- We do not consider the transportation/transmission and distribution costs and benefits e.g. electricity distribution and DH infrastructure. End of life is also not yet included.

Lifetime of geothermal plants for ground source Heat Pump, powerplant and heat only plant exceeds 50 years. The expected lifetime of wells is more than 50 years.

The weighted average cost of capital or the discount rate is fixed at 5%, for a period of 20 years. Wells or plants may not be fully depreciated but for our purposes, the residual value in the cash flow tail is of secondary importance.

3.1.3.1 Heat plant

For a geothermal district heat plant, we assume that a plant will supply heat to a district heating network, to nearby greenhouses and agricultural businesses, or process heat to nearby industrial customers. Our reference plant is a geothermal doublet system accessing a reservoir at a depth between 2500 m and a production temperature of around 80 °C. Operational hours range from 3800 to 6000 hours annually.

For the geothermal HP system, we consider a large building of about 10 dwellings, requiring a capacity of 50 kWth for heating and cooling. It consists in a closed loop geothermal system, with 8 wells at 120 m deep, assisted with an heat pump.

3.1.3.2 Power plant

For the power plant, the reference plant of 10 MWe medium temperature plant (Binary turbine), has at least three wells to a depth at 4000 m and a reservoir temperature in excess of 150 °C. Operational hours range from 6000-8000 annually.

For the 20 MWe high temperature plant (Flash turbine), at least four wells are drilled at 2500 m to find 250°C.

3.1.3.3 Cost structure

Exploration and adaptation of a given technology to an unexplored geological context presenting a higher degree of risk than in commonly known and well-understood areas, and possibly the rising ambient air temperature, are a new concern and cost drivers for geothermal projects. Geothermal energy projects require substantial up-front investments and from the investor's point of view long time horizons before a venture becomes profitable. Furthermore, drilling and exploration may take several years, and 3 to 6 years can pass between exploration and first production, with the cumulative cash-flow becoming positive after quite a number of years after production has commenced.

Overall, unit costs for installed capacity for geothermal power generation per MW_e range between 4 and 7 million of euro (€ million) in Europe, and for heat generation about €1 and 2 million per MW_{th}; costs for the distribution systems excluded. Unit capital cost are higher than for virtually all other renewable energy technologies and depend highly on the specific site and technology chosen. These investment costs for geothermal plants are balanced by its base load factor with high number of annual operating hours, so the capability to supply renewable heat in winter, also in times of 'dunkelflaute'.
Capital costs depend strongly on the:

- Number of geothermal wells required;
- Depth of the reservoir, and hence drilling;
- Geological conditions;
- Location and access to drilling site(s) and size of the plant.

3.1.4 Update 2025

Geothermal technology for electricity

- **20 MW_e high temperature plant (Flash turbine)**

Geothermal high temperature plant 20 MWe (Flash turbine):
The current estimate is 3800 EUR/kW, so a cost increase of 12% from the scenario 2020 (3383 EUR/kW) due to inflation price for equipments and services.
In 2030, We estimate 2980/kW EUR for 2030, but RD&I would allow reduce cost to 2000 EUR/kW in 2040 and 1800 EUR/kW in 2050.

- **10 MW_e medium temperature plant (Binary turbine)**

The current estimation is 4000 EUR/kW, so a cost increase of 29% from the scenario 2020 (3131 EUR/kW) indeed both inflation price for equipments and services and new generation of technologies can have such costs today but not on an average.
In 2030, we estimate also 3500 EUR/kW for 2030, but RD&I would allow further cost reduction to 2500 EUR/kW in 2040 and 2250 EUR/kW in 2050.

On top of the overnight Investment Costs in a greenfield site, variable non fuel cost must be counted. Assumptions for 2025 are 0.13 EUR/MWh for Geothermal high temperature plant and 0.11 EUR/MWh for Geothermal medium temperature plant, but RD&I can improve systems to lower these costs for 2030-2050.

Regarding fixed Operation and Maintenance costs, annually, Geothermal high temperature plant has 2% of O&M costs. Geothermal medium temperature has 4% O&M costs.
But RD&I and better efficiency would reduce it to 2% from 2030 onwards for all geothermal technologies. It would mean:

- Geothermal high temperature plants have 60 EUR/kW of fixed O&M in 2020, but 59.6 EUR/kW in 2030, 40 EUR/kW in 2040 and 36 EUR/kW in 2050.
- Geothermal medium temperature plants have 143 EUR/kW of fixed O&M in 2020, but 70 EUR/kW in 2030, 50 EUR/kW in 2040 and 45 EUR/kW in 2050.

Geothermal technology for heating:

- **20 MW_{th} heating plant**

KPIs in **district heating systems** (e.g., 20MWth geothermal heating plant in Paris, France) focus on energy delivery consistency and cost per delivered MWth, ranging from €1–2 million.

The current assumption for the overnight Investment Costs in a greenfield site for a traditional **geothermal DH system** of 20 MWth, we assume an average investment cost of 30 million euro in total so 1500 EUR/kW.

In 2030, We assume a reduction to 1400 EUR/kW for 2030, but RD&I would allow reduce cost to 1000 EUR/kW in 2040 and 800 EUR/kW in 2050.

- **50 kW_{th} heating and cooling system assisted with heat pumps**

Geothermal heat pump for domestic residential, the current assumption on Purchasing cost is of 1500 EUR/kW (so for a typical 12 kWth HP, a cost of 18000 EUR), so a cost reduction of +10% from the scenario 2020 : https://energy.ec.europa.eu/data-and-analysis/energy-modelling/eu-reference-scenario-2020_en (1695 EUR/kW).
In 2030, assumptions report a cost from 1287 EUR/kW to 1997 EUR/kW maximum.
With R&I, it is today hard to assume ultimate costs but the minimum basis between 950 and 1,600 EUR/kW. For the maximum, one can assume a cost lower than the 2025 number of 1,500 EUR/KW. On average, ultimately the costs would be around 1,250 EUR/kW.

Geothermal heat pump for commercial buildings (water or brine/water), the current estimated purchasing cost is 1130 EUR/kW, so a cost reduction of 5% from the reference in 2020 (1190 EUR/kW) reference: https://energy.ec.europa.eu/data-and-analysis/energy-modelling/eu-reference-scenario-2020_en .
With an already 2025 average of 1130 EUR/kW, one can consider in 2030 the average being below the current cost. Assuming the same 5% cost reduction in a 5 years period would lead to an average cost in 2030 of 1070 EUR/kW.
Ultimate assumptions for the years 2050 are between 675 and 1021 EUR/kW. With R&I, it is today hard to assume ultimate costs but the average should be closer to 900 EUR/kW.

For the geothermal heat pump water (w/w), the average cost in 2030 is the same or is lower than the current data of 726 EUR/kW. In the ultimate assumption it should be then even lower, close to minimum purchasing costs in 2030: 668 EUR/kW.

3.2 Reference assets

3.2.1 First list 2020

The reference assets are used to assess progress against the targets of the implementation plan of the SET-Plan's action on geothermal energy, which is one of a number of technologies that have been identified in two Actions whose purpose it is to position Europe as "No. 1 in Renewables". Those actions are (1) to sustain technological leadership by developing highly performant renewable technologies and their integration in the EU's energy system and (2) to reduce the cost of key technologies. The original SET Plan 'Deep Geothermal Implementation Plan' (2018) had 8 research and innovation activities as well as 2 activities on non-technical barriers and enablers that serve to address the targets of the declaration of intent. The research and innovation activities are expected to yield concrete steps in the field of:

1. Artificial lift technologies (such as pumps in production wells) that will result in an increase reservoir performance by lowering the power demand for plant operations to below 10% of gross energy generation by 2030;

2. Development in turbine technologies are expected to improve the overall energy conversion efficiency, including efficiency gains in the bottoming cycle of geothermal installations at different thermodynamic conditions by 10% in 2030 and 20% in 2050;

3. The development of exploration tools that will reduce the unit finding cost (€ per potential capacity of a geothermal reservoir) by 25% in 2025, and by 50% in 2050 compared to 2015. The reduction in unit finding cost not only covers methods and tools that deliver improved reservoir definition prior to drilling but an increase of the probability of success for exploration wells;

4. Advances in drilling technologies are expected to reduce the unit cost (€/MWh) of a well's thermal output by 15% in 2020, 30% in 2030 and by 50% in 2050 compared to 2015;

5. Advances in geothermal power flexibility will enable geothermal plant operators to develop additional revenue streams resulting from the grid operator's need to improve reliability and stability, specifically geothermal power plant operators may demonstrate the feasibility of fast output ramp-up and -down between 60% - 110% of nominal power.

3.2.2 Update 2025

From the defined reference assets in 2019 from ETIP and IWG on geothermal, a new focus is brought on the list for the Net Zero Industry Act, NZIA, that has been adopted May 27, 2024. The list of main specific components for net-zero technologies - specifically used for geothermal technology or for a limited set of technologies was adopted in a EC Delegated act on primarily used components under the Net-Zero Industry Act in May 2025:

	Sub-categories of net-zero technologies	Final products	Primarily used components
Heat pump and geothermal energy technologies	Heat pump technologies	Heat pumps	• Heat pumps • Four-way valves • Scroll compressors / heat pump rotary compressors
	Geothermal energy technologies	• Geothermal power plants • Geothermal direct use systems	• Heat exchangers resistant to geothermal corrosive operating conditions • Submersible pumps resistant to geothermal corrosive operating conditions • Brine re-injection pumps
Energy system-related energy efficiency technologies	Energy system-related energy efficiency technologies	• Organic Rankine cycle (ORC) power systems	• ORC turbines
	Heat and cold grid technologies	• Heating and cooling distribution system pipework	• Pipe fitters and couplers

Figure 2: list of geothermal technologies in the EC Delegated act on primarily used components under the Net-Zero Industry Act

For each 3 reference assets, here the situation in terms of manufacturing:

- Heat exchangers resistant to geothermal corrosive operating conditions

Heat exchangers are a very important part of the vast majority of geothermal installations[1]. With the heat exchangers, the heat from the subsurface is transferred to a secondary loop, often a district heating loop, but it can be any other heat distribution or ORC working fluid loop. The geothermal fluid

[1] Thermal baths and Icelandic domestic hot water are notable potential exceptions.

often has a high mineral content and is corrosive. After extraction of useful heat, the geothermal fluid is normally re-injected into the subsurface, maintaining subsurface conditions as constant as possible.

Heat Exchangers (Shell & Tube, Plate & Frame, Air Cooled) are also used in other sectors for different applications (Chemical, Petrochemical, Oil & Gas, HVACR, Food & Beverage, Pulp & Paper, Power Generation). Europe has always been a strong market for heat exchangers and, globally, this market has been a leader for heat exchangers. This region has notably the presence of most of the global leaders in heat exchanger manufacturing. The demand is boosted mainly due to the increased replacement demand for the heat exchangers. Issue concerns the material used for these components which are based on titanium, material not produced in Europe. China leads the global titanium mineral production, with its mine output of ilmenite reaching approximately 3.1 million metric tons of titanium dioxide content in 2023. This figure nearly doubled the production of Mozambique, the world's second-largest titanium producer.
Alfa Laval AB (Sweden), Danfoss & Sondex Holdings A/S (Denmark), Kelvion Holdings Gmbh (Germany), SPX Corporation (U.S.), Xylem Inc. (U.S.), Gunter AG & Co. KG (Germany), Hamon & Cie International SA (Belgium), Modine Manufacturing Company (U.S.) and SWEP International AB (Denmark) are the other most active players in the heat exchanger market. A special case is Inovaterm, a Turkish manufacturer with sites also in Croatia which is a manufacturing and construction company that builds geothermal power plant projects from planning and design to engineering, procurement, and construction, together with commissioning and handover. The company manufactured heat exchangers and other equipment for the Turkish and the global (Dominica etc.) markets. Newcomers to the European geothermal market are large manufacturers coming from India and Japan, or very specialised SMEs in Europe (FUNKE) able to answer project specific challenges of corrosion and scaling with steel, titanium and titanium-base alloys.

- Submersible pumps resistant to geothermal corrosive operating conditions and Brine re-injection pumps

Production and reinjection pumps installed in deep geothermal plants for power plants and District heating plants are manufactured by companies such as SLB, Baker Hughes, ITT/Goulds, Canadian ESP, Flowserve, Halliburton, Weatherford International, Borets Company and LLC. These companies have been identified as the top players in the global electrical submersible pumps market and for the supply of these equipments to the geothermal sector. Many of these companies are also global manufacturers of other equipments for geothermal like valves, monitoring and control systems associated to the lifting mechanisms. Downhole pumps are used in geothermal wells to increase the flow of brine and increase or maintain the flow rate. Such equipment is particularly important for geothermal heating and cooling projects which are usually not based on geothermal steam resources, and where artesian flow alone often does not suffice to guarantee the economics of the project.
Typical ESPs have a lifetime of around 4-5 years, with costs comprised between EUR 180,000 and EUR 300,000, not including operational costs up to EUR 100,000 per year (excluding electricity to run the pump).

On top of these three assets selected by the EC for its delegated act on NZIA regulations, a monitoring will be done in next years about other equipments associated to geothermal technologies, mentioned in the 2025 delegated act of NZIA:

1) Heat pumps:

- Heat pumps
- Four-way valves

- Scroll compressors / heat pump rotary compressors

2) Organic Rankine cycle (ORC) power systems:
- ORC turbines

3) Heating and cooling distribution system pipework:
- Pipe fitters and couplers

Potential new components will also be monitored:
1) Drilling rigs and components
2) Casing and tubing
3) Wellheads and valves
4) Low-voltage and high-voltage drives
5) Co-products for mineral extraction from geothermal brines
6) Exploration tools: Seismic vibrators etc.

4 New parameters with technical Assumptions for EU modelling

To improve costs assessment, further parameters can be considered. From the Technical Assumptions for EU modelling on geothermal technologies, more parameters could be added to reinforce the understanding of the cost of geothermal plants. They will not have an impact on the competitiveness of geothermal plants, a contrary it will reinforce competitiveness of geothermal technologies.

Geothermal is a versatile, clean and secure energy source. Geothermal technologies supply heating, cooling and hot water to domestic use, for both residential and commercial buildings. Heat and cold can be distributed with heat pumps and district heating.

Geothermal generates electricity around the clock, with high enthalpy (<200°C) and medium enthalpy (100-200 °C) resources.

Geothermal provides also thermal storage and co-production of minerals.

All these geothermal technologies should be reported as geothermal in the EU reference scenario.

Based on the technical assumptions from PRIMES, here below, some new indicators must be set:

Power & Heat

Overnight Investment Costs in a greenfield site, excluding financial costs during construction time				**Fixed Operation and Maintenance costs, annually**				**Variable non fuel cost**				**Electrical Efficiency (net) in optimal load operation**				**Self Consumption of electricity**				**Technical lifetime**
EUR/kW				**EUR/kW**				**EUR/MWh**				**ratio**				**%**				**Years**
2020	**2030**	**2040**	**2050**	**2020**	**2030**	**2040**	**2050**	**2020**	**2030**	**2040**	**2050**	**2020**	**2030**	**2040**	**2050**	**2020**	**2030**	**2040**	**2050**	

Figure 3: Technical Assumptions on Power & Heat for EU modelling – PRMES (EC)

The use of these PRIMES indicators above discuss to monitor cost developments in geothermal *power* production. However, it is important to note that this plant concerns power production, or power + heat production; and not heat-only from large geothermal plant for DH or Industry. This means that a significant part of the geothermal reality is not seen by PRIMES. The same holds true for underground thermal energy storage.

GEOTHERM FORA recommends to work on reference plants for PRIMES for these two technologies in the coming years. Reference data for the co-production of minerals from geothermal brines seems to be more difficult and less urgent to develop. As yet, this is very case-specific and the production of heat or power will follow the reference cost structure of that part of the co-production project.

Domestic geothermal HP

	Purchasing cost							**Efficiency**						
	Current	**2030**			**Ultimate**			**Current**	**2030**			**Ultimate**		
Technology		**From**		**To**	**From**		**To**		**From**		**To**	**From**		**To**
	in EUR/appliance							**kWh/appliance**						

Figure 4: Technical Assumptions on Domestic geothermal HP for EU modelling – PRMES (EC)

4.1 Heat pump water (w/w) and Heat pump ground efficiency (PRIMES reference)

- Heat pump ground plants have on average 1 point more efficiency than Heat pump air to air: in the current assumption for the residential sector, if reporting 3.89 efficiency for heat pump air to air in South countries, a value of 4.89 must be reported for Heat pump ground.
- This 1-point difference in efficiency must be reported for all current and future assumptions 2030 and ultimate.

- Heat pump (ground) water (w/w) have on average 1 point more efficiency than Heat pump ground: in the current assumption for the residential sector, if reporting 4.89 efficiency for heat pump ground, a value of 5.89 must be reported for Heat pump water (w/w).
  This 1-point difference in efficiency must be reported for all current and future assumptions 2030 and ultimate.

- The same efficiency gain (1-point) must be done for commercial buildings.

- But for the HP ground technology, the geothermal sector assumes a current EU average efficiency for the residential and commercial building sector, with an SCOP of 4.5., in 2030 the average efficiency would be 5.5 and 6.5 ultimately in an EU average. It means 1-point efficiency gain per period, following the current trend in efficiency gain for Heat Pump ground. For the HP water (w/w), the current efficiency is 5.5, and in 2030 it will be on average 6.5 and ultimately 7.5.

4.2 Electrical Efficiency (net) in optimal load operation

- Geothermal heat only plant for District Heating is a renewable energy technology with an efficiency of 100%, not from the data given by the EU modeling of 10% (https://energy.ec.europa.eu/data-and-analysis/energy-modelling_en). In the case of DH geothermal, there are no losses as for all RES without combustion, the efficiency is 1.00.

District Heating geothermal systems use more and more heat pump, so in these cases, the efficiency is increasing to more than 300%.

4.3 Technical lifetime for geothermal

• Lifetime of geothermal plants for Heat Pump (ground), powerplant and heat only plant exceeds 50 years, so not 25, 30 or 35 years as reported in the assumptions. We have a database of plants in operation to show this.

4.4 Overnight Investment Costs

In a greenfield site, excluding financial costs during construction time, for a Geothermal Heat only plant are lower than the drafted assumptions:

• The current assumption drafted for the overnight Investment Costs in a greenfield site is 1820 EUR/kW. Today for a traditional geothermal DH system of 20 MWth, we assume an average investment cost of 30 million euro in total so 1500 EUR/kW.

• In 2030, assumptions report a cost from 1722 EUR, for 2040 it is 1701 EUR and 1680 EUR for 2050. These assumptions are high.
We assume also 1400 EUR for 2030, but RD&I would allow reduce cost to 1000 EUR in 2040 and 800 EUR in 2050.

4.5 Suggestions for improvement

Assumptions for geothermal Power and Heat plants

Assumptions for geothermal power plants

- the number of hours of operation per year for each powerplant must be reported as it influences costs for variable non fuel cost in EUR/MWh.
- this will allow to also report the load factor of each technology. It is important for geothermal being a base load technology with a capacity factor higher than 80%. This directly influences the costs of each technology but also the system costs: infrastructure grids, storage capacity…
- for geothermal power plants, the distinction of high and medium enthalpy must be reported in PRIMES model, in as technological trends and a new generation of technologies influences these plants.
- For 2030, 2040 and 2050 recent publications from ETIPs and the IEA special report on geothermal energy presents these assumptions 2030-2050.

Assumptions for geothermal heat only plants

- heat grid infrastructure length and costs have to be considered as for electricity grid infrastructures.
- in the PRIMES model sheet for domestic uses, for residential and commercial buildings the district heating must be better defined to report correctly costs and efficiency.

Assumptions for heat pump ground-source and heat pump ground and surface water (w/w)

- **Lifetime:** there is no reference to the lifetime of these technologies. This must be added as they influence the Levelized Cost of Heating technologies. HP ground and ground water technologies have today a lifetime higher than 50 years

- **Purchasing costs:**

  - materials can be more expensive due to recent inflation.
  - But R&I reduce cost especially for drilling phase.
  - market development increases competition and it reduces costs.

- **Efficiency:**

  - HP ground have an higher efficiency gain from 0.5 to 1.0 better than to all HP air to air and air to water.
  - HP ground for commercial buildings have an higher efficiency than for residential.
  - R&I allows to improve this efficiency.
  - To calculate this efficiency, it is better to consider the Seasonal performance factor (SPF) and not the Coefficient of Performance (COP).
  - As HP ground supply heating, cooling and domestic hot water, the efficiency must report the combined efficiency of these three supplies.
  - Geothermal can provide free cooling (efficiency higher than 20)

- **Capacity**: To report the purchasing cost, the capacity sets for each technology must be better detailed. HP ground has a capacity of 12-25 kWth for residential and HP ground and water have a capacity of 25 kW to 1 MW for commercial buildings. This capacity aims to supply heating, cooling and domestic hot water with one single technology.

- **Operating hours**: to report the efficiency, the hours of operation per year must be taken into account for all production of heating, cooling and hot water.

- **Combined systems**: to report the efficiency and the costs on a fair basis, the systems supplying heating, cooling and hot water in a single technology such as HP ground and water should see their costs and efficiency combined. The same combination must be done for the other technologies providing heating, cooling and hot water in a single technology or with multi-technologies.

- **Temperature levels**: The supplying heating temperature, cooling temperature and domestic hot water temperature must be set and harmonized for all domestic residential and services technologies

e.g. supplying heating at T = 35°C and active cooling at T = 7°C, and DHW, during operating hours ideally calculated by the model for various European regions.

Free cooling: heat pump ground and heat pump water can provide free-cooling supplying cooling at T = 18°C, in western Europe climate conditions.

- **HP water (w/w)**:. HP Groundwater has the best efficiency of all HP.

- **Climatic zones**: south countries, middle south countries, middle north countries and north countries: within a Europe, there are several air temperature zones. Unit cost of heating and cooling depend on purchasing cost, efficiency, operating hours and equipment lifetime. Climate change effects on operating hours of heating and cooling must be taken into account. The "Heat urban island" impact has to be considered.

EXAMPLE ON EFFICIENCY AND ELECTRICAL CONSUMPTION

The comparison between air HP and geothermal HP on efficiency and electrical consumption can be detailed with the following example.

In Spain, following the EC publication on 1st of January 2013 establishing guidelines on how Member States are to estimate the values of Qusable and SPF for the different heat pumps technologies and applications, IDEA has detailed these guidelines for Spain taking into consideration differences in climatic conditions within the country. They propose a weighting factor (FP) about the climatic conditions and a correction factor (FC) taking into consideration the temperature levels of distribution and for the test conditions of the COP. When comparing an air source system in climate zone A (FP = 0.60) with a geothermal system, assuming the same climate region (FP = 1.13), a system with a distribution temperature of 50 °C (FC= 0.68) and a technology that offers the same basic COP, we would

Geothermal system: SPF1 = COP * 1.13 * 0.68
Air HP system: SPF2 = COP * 0.60 * 0.68
ΔSPF = SPF1 – SPF2 = COP * 0.68 * (1.13 – 0.60) = COP * 0.68 * ΔFP

Under these assumptions (same climate, distribution temperature and underlying technology of HP components), the difference in SPFs is given by the difference in the weighting factors, thus:

$$\Delta SPF = COP * FC * \Delta FP$$

The difference in electrical consumption (see above) for the same amount of heat Q is given by:

$$\Delta E/Q = \Delta SPF = COP * FC * \Delta FP$$

The relative (percentage) reduction in energy consumption is given simply by

$$\Delta E/E * 100$$

finally we get:

$$\Delta E/E * 100 = Q/E \ \ \Delta SPF * 100 = 1/SPF * COP * FC * \Delta FP * 100 = COP*FC /(COP*FC*FP) * \Delta FP*100 = \Delta FP/FP * 100$$

The relative variation in the weighting factors gives us the relative variation in energy consumptions, for the case study above the result is:

ΔFP/FP * 100 = (1.13 – 0.60)/1.13 * 100 = 47%

Meaning that having two systems in the same climate region, with a similar distribution temperature and with a HP that offers the same basic COP, the air HP systems would consume approx. 50% more electricity than a geothermal HP system.

have:

- **self-production: services provided by geothermal** such as seasonal thermal storage in the underground must be reported in the PRIMES mode.

5 Conclusions

In the initiative from the SET Plan IWG on geothermal to design a learning curve for all geothermal technologies, the setting of key performance indicators is crucial. Regular updates are required.

In this review 2024-2025 the scope has bene enlarged to not focus only on LCoE, but also including other costs. It has also set new KPI regarding made in Europe manufacturing as required by the NZIA.

From this new state, the learning curve will continue to be produced monitoring costs reduction and a first state of art on European manufacturing will be produced from year 2026.

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