Overview of ground source heat extraction in Norway

2023

Total capacity and yearly developments

to

European Geothermal Energy Council (EGEC)

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Abstract

Due to the lack of an updated national database keeping track of extracted of ground source heat, its contribution to the national energy system relies on estimates. Two methods have been used. The NGU Granada database combined with an in-house database maintained by Midttømme and Ramstad, the number and depth of single wells and multiple ground source heat pump systems is provided. From data, the national thermal power and energy is estimated. Moreover, the national heat pump association (NOVAP) keep track of the heat pump sales.

In total, more than 50 MW of thermal power providing more than 160 GWh heat each year was added to the national system in 2023. When summarizing from 1980s till today, it is estimated that the ground source wells contribute with a peak capacity of more than 620 MW and around 2 TWh/year thermal energy. When estimating the total ground source heat using the numbers from the heat pump association, a power of 728 MW estimated to produce a yearly heat of 2.55 TWh.

The real numbers might be larger as both databases are sensitive to systematic under-reporting. Moreover, the estimates are highly sensitive to assumptions of heat extraction per meter well and the yearly capacity factor (i.e. hours/year of full capacity).

Overview of data sources

There is no national, complete oversight of the amount of ground source thermal energy that that has been maintained over time by the government. This is related to the lack of regulative measures for the extraction of heat. The heat from the ground is free of charge, it has never been taxed and thus been overlooked as an asset. Therefore, there has never been any governmental incentive to keep track and develop a national oversight. Moreover, since the wells are invisible (for others) and has practically zero areal footprint it is not being considered in areal planning.

This does not mean that the information is been overlooked by all. In this report we combine data from three individual data sources and combine them to provide a “best guess” of the national oversight. In the following we will go through the output data from each of the three data sources, before they are combined into the best guess. Then, in the last part of the report some recently developed multi-well cases are presented.

Background to understand the value created from the ground source heat

We will however display some large-scale systems examples here with a brief economic analysis. Typically, when large-scale systems are pr systems are reported it is the output capacity of the heating and cooling system (i.e. capacity of the heat pumps) that is given. In these cases, it is important to remark that the energy output of the system is a sum of the electrical energy required to run the heat pumps and circulation pumps etc. plus the heat extracted from the wells, i.e. the ground source thermal energy:

$$E_{out} = E_{el} + E_{gr} \qquad \text{Eqn. 1}$$

Even though the data often exists within the management system for each ground source heat system, the temperature difference between the water out of and into the well (ΔT, in Kelvin) and the mass flow rate (Q_m, in kg/hour), nor heat capacity of the fluid (C_v), is seldomly shared publicly. The heat extracted from the ground ($E_{gr} = C_v \Delta T Q t$), at any given hour ($t$), rely on calculations from the output energy of the heat pump system. Thus, the value created for the owner by the extracted ground source heat might be overlooked.

In some cases, however, the system performance factor is given, or coefficient of performance (C_{OP}) defined from the ratio of the thermal energy output divided by the electrical energy needed to run the operation is given via:

$$E_{out} = C_{OP} E_{el} \qquad \text{Eqn. 2}$$

By combining the two equations $C_{OP} E_{el} = E_{el} + E_{gr}$ we obtain $E_{el} = E_{gr}/(C_{OP} - 1)$, so when inserted into Eqn. 1 yields:

$$E_o = E_{gr}\left(1 + \frac{1}{C_{OP} - 1}\right) \qquad \text{Eqn. 3}$$

As such, if the C_{OP} is assumed (or given), one may calculate how much thermal energy that might be extracted from the ground source wells (E_{gr}) from given capacity via:

$$E_{gr} = E_o \frac{C_{OP} - 1}{C_{OP}} \qquad \text{Eqn. 4}$$

This equation is used in the presentation of the following three/four examples of recently deployed ground source heat system in Norway.

This is to emphasize on the value of the ground source heat gained from the multi-well systems, one is therefore required to subtract the electrical energy needed to operate the system, as done with the equation above.

The Granada wellbore database

The Geological Survey of Norway (named Norges Geologiske Undersøkelser, NGU) maintains a national database of drillholes drilled for water supply and ground source heat termed “Granada” (https://geo.ngu.no/kart/granada_mobil/). Here, each well is registered with location, depth, date, media, thickness of loose soil, yearly, and the drill-hole operator is given. The whole Granada database consists of 58 594 well entries till the end of 2023. In total 11 746 km drilled length is reported.

In Table 1, the summary of the deployment of ground source geothermal wells in 2023 when split between large multiple well systems, single houses, cabin/holiday house, farms, tourist industry and unknown category. In all 4222 wells were drilled with a total length of 1021 km.

A histogram over the depths of single household and multiple wells system are displayed in Figure 1 showing that the larger multiple wells systems are typically deeper than the individual single household systems. The trend over time display that the average GS heat well are getting progressively deeper Figure 2.

The total number of wells drilled each month is displayed in Figure 3, displaying a typical range of 3-500 wells being drilled each month. A rather un-usual pattern is seen in November and December 2023, where the number of wells plumbed almost by a factor 2. This trend is continuing into January and February 2024. From personal communication with the two main drilling companies in Norway, this pattern is an accurate description of the current day situation.

Given the oversight from NGU, the total overview revealed 60 individual companies drilling ground source heat wells in 2023. The biggest providers were Båsum Boring AS and Rototec AS, followed by SørNorsk Boring. All 60 providers are arranged from largest to smallest capacity (kilometers drilled) in Figure 4.

Table 1. Output from the Granada data base on number of wells and total drilled lengths during 2023 for larger multiple well systems, single houses, cabins, farms, tourist industry and Unknown category. The average depth is reported.

	Total Length, km	Number of wells, #	Avg depth, m
Larger, multiple well systems	697.2	2626	265.5
Single houses	272.1	1323	205.7
Cabin / Holiday house	24.9	141	176.4
Farms	13.8	67	205.6
Tourist industry	7.7	38	202.4
Unknown category	5.5	27	204.7
Sum	1021.2	4222	241.9

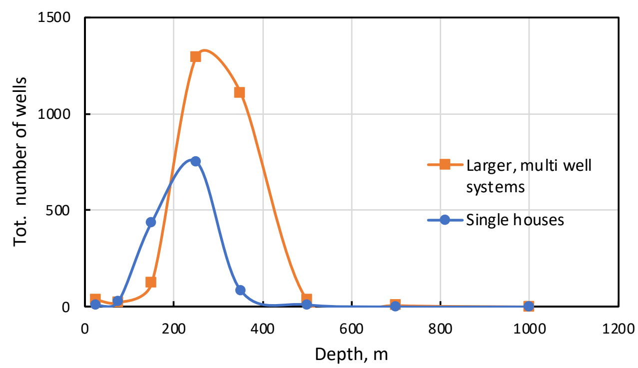

Figure 1. Histogram over the number of wells in different sized boxes: 0-50 m, 50-100m, 100-200m, 200-300m, 300-400 m, 400-600 m (46 wells), 600-800 m (7 wells) and more than 800 m deep wells. The larger multiple well systems are typically deeper than the single house wells.

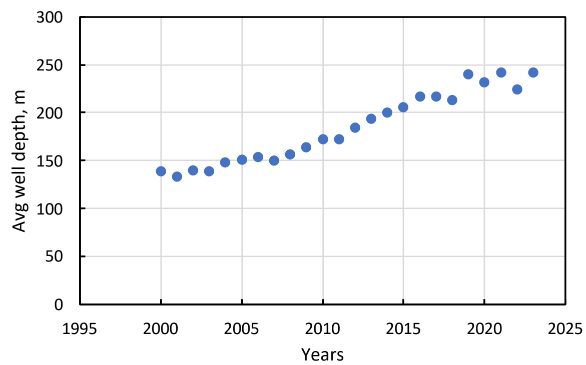

Figure 2. Average reported depth of ground source heat wells in the Granada database.

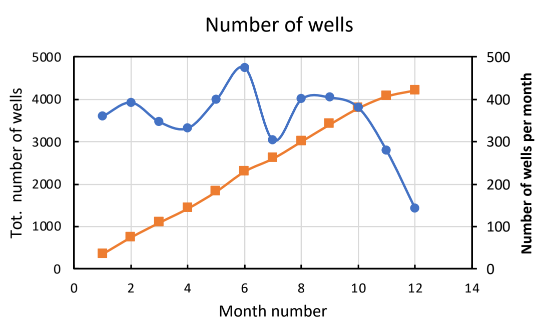

Figure 3. Number of wells reported each month during 2023.

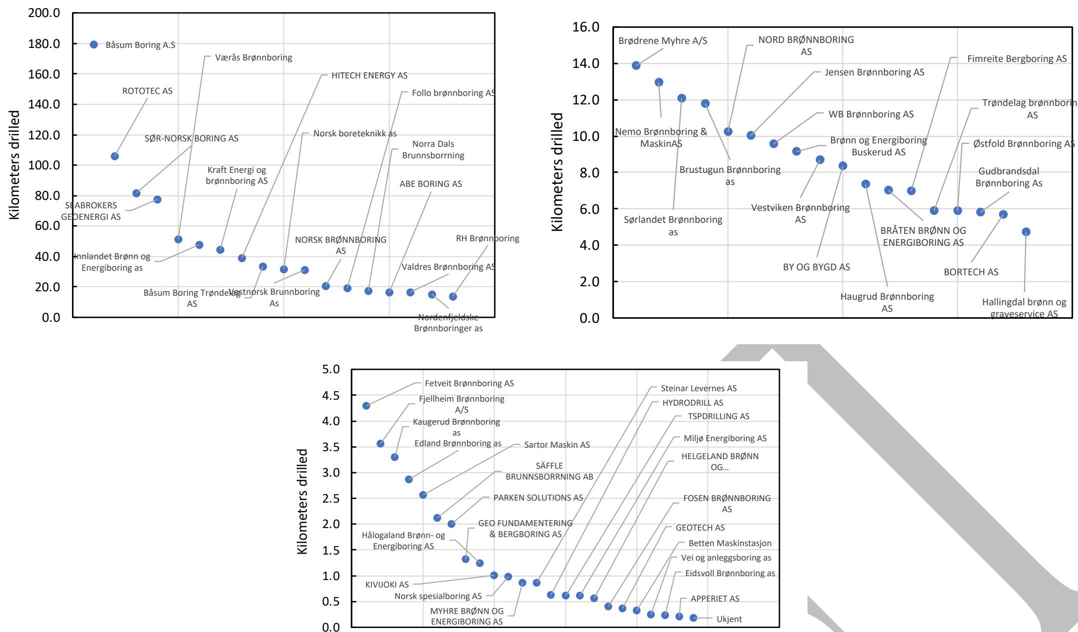

Figure 4. Oversight of the national actors drilling geothermal ground source wells in Norway during 2023 from the national NGU database.

In-house overview of multiple well GSHP systems

Kirsti Midttømme (NORCE) and Randi Kalskin Ramstad (Asplan Viak), have for several years kept track of *large* multiple well ground source heat pump (GSHP) systems in Norway. This oversight has been shared with NGU in 2014 and an earlier version till 2013 is publicly available[1]. Until today, the Midttømme-Ramstad database has 23 321 wells in 2042 GSHP systems. In 2023, 9 large-scale systems were reported with 106 wells with an average depth of 265.4 m with a total yearly length of 28.05 km.

There are double-counted systems/wells in the Midttømme-Ramstad and NGU database. Thus, to obtain a national estimate of ground source thermal power and yearly energy production from the drilled wells a detailed analysis to avoid double counting is required.

On removing double-counted wells in the database

Until recently (?), it has been voluntary to report geothermal ground source wells to the NGU database. Thus, when comparing the Midttømme-Ramstad (M-R) database to the NGU database, it becomes clear that the public database is incomplete. A rough go-through of all elements in the M-R database indicate that 60.8% of the wells were present in the Granada database in 2023. In 2017, however, approx. 70% of the wells were found in both databases, while in 2010, 2001 and all years from 1983-2000, 38.4%, 10.4% and 0.1% of the systems in the M-R were found in the Granada database. The fraction each year that has been assumed in between the counted years (shown as circles) is shown in Figure 5. Care must be taken when using the time-dependent fraction of the M-R database to be added to the Granada database, as much more work is needed to provide a more accurate estimate of the double-counted elements. This is, however, far out of reach for this report.

[1] https://www.ngu.no/upload/Georessurser/Grunnvarme/Grunnvarmeanlegg_092014.pdf

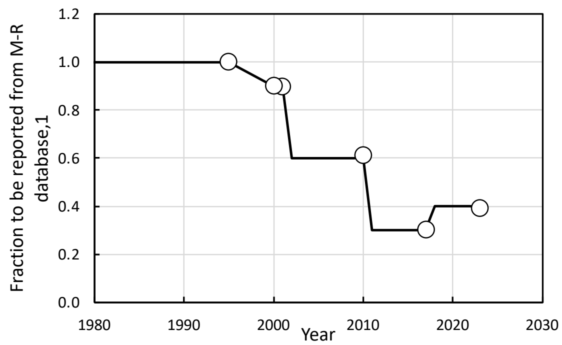

Figure 5. Fraction to be reported to the total overview from the Midttømme-Ramstad database. A rough assessment of double-counted elements have been obtained in the years shown as circles.

Figure 6 display the yearly number and total drilled length from the M-R database for large multiple well GSHPs systems from 1980s through to 2023. Here, the dashed lines represent the values in the report, while the solid line represent the adjusted amounts by multiplying with the fraction in Figure 5. The grey lines represent the number of wells, and black lines the total drilled length.

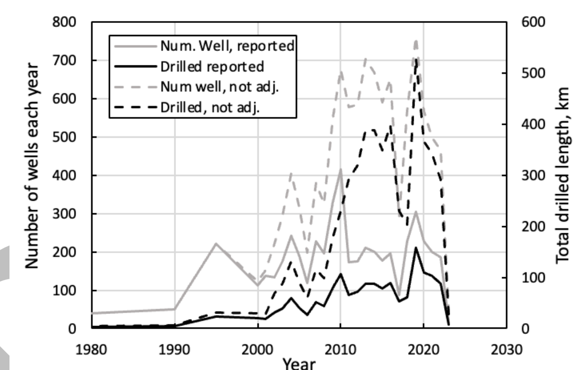

Figure 6. Yearly output from the Midttømme-Ramstad database and the reported value downscaled with the values in Figure 5.

From the data above, 11 kms drilled was added to the Granada database during 2023, thus adding 0.6 MW heat power and an additional heat energy per year of 2.1 GWh/y to the building sector.

Estimating power and yearly energy extraction from the ground – using the M-R database

A truly valuable component of the Midttømme-Ramstad is that the power is reported for 48 the GSHP systems, and in 21 cases out of these also the yearly thermal energy is provided. For each case the number of wells and total drilled length has also been given enabling an estimate of the yearly capacity factor (i.e., number of hours in a year of full operation) and extracted heat per meter well. The heat pump output originate from both the input electric energy (dissipated to heat) and the heat from the ground. When the output HP capacity is multiplied by $1 - 1/C_{OP}$, where the coefficient of performance (C_{OP}) is assumed to be 4.5 (on average) the heat from the ground can be calculated. It is important to emphasize this, because this heat is an addition to the national energy system.

The average ground source power from each well as function of average depth is shown in Figure 7. Here, the data is shown for different number of wells in each system. For each group of number of wells the slope is given to estimate the extracted heat power per meter. As may be seen, there is a tendency that by increasing number of wells the extracted power increase. An average of 52 W/m is provided (Table 2). For the 21 cases where also yearly total energy is provided, the capacity factor (in unit: h/year) can be estimated from the ratio of the reported energy (MWh/year) divided by the power (MW).

This data is proven useful when estimating the total power from total depth and number of wells. As such, a value of 55 W/m is used for larger parks, and a value of 30 W/m is used for single house systems.

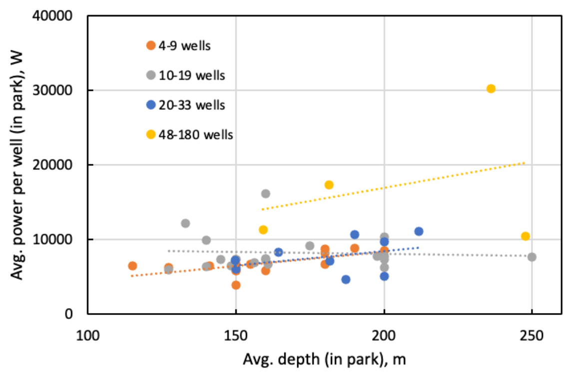

Figure 7. Average heat power from the well plotted for different well park sizes. From the slope between average park depth and provided power, the power per meter can be determined as shown in Table 2.

Table 2. Cases reported where power and yearly energy output of the heat pump is provided in the database. The heat supply from the ground is estimated from an assumed coefficient of performance of 4.5. Data is divided into down for system sizes with given number of wells system.

Number of wells	Cases reported with power	Power per meter, W/m	Cases reported with yearly energy	Yearly capacity factor, h/y
4-9 wells	16	37.0	2	2923
10-19 wells	19	-4.6	11	3504
20-33 wells	9	38.9	7	3895
48-180 wells	4	70.2	1	2613
Total:	**48**	**52.1**	**21**	**3536**

Estimating the total thermal extraction from the drilled ground source heat wells – Combining the Midttømme-Ramstad and Granada database

The adjusted output from Midttømme-Ramstad from 1980s till 2023 in Figure 6 was added to the yearly output from the Granada database. Figure 8 display the total number of ground source heat wells, while Figure 9 display the number of wells in multiple well systems and single-well systems. The yearly and cumulated fraction of number of wells as part of multiple-well GSHP systems is shown in Figure 10 displaying a steadily increasing trend since early 2000s.

When multiplying the drilled length of single and multiple wells each year in Figure 11 with 35 W/m and 55 W/m, respectively, the power developed each year and the cumulative contribution to the national energy system is shown in Figure 12. Multiplying with a capacity factor of 2500 and 3500 hours/year for single and multiple well systems the yearly thermal energy contribution to the national energy system is shown in Figure 13. Here, the national contribution for the single and multiple well GSHP systems are singled out, while the total contribution to the national thermal ground source power and total energy is provided in Figure 14 and Figure 15, respectively.

In 2023, 49 MW power is added to the system providing in all 161 GWh/y conflict free, firm, carbon neutral energy (Table 3). In all, at the end of 2023 it is estimated that a total thermal power extracted from ground source wells at a peak capacity of 617 MW (available the coldest day) supplying 1.94 TWh of heat each year. This heat enable de-carbonization and the direct use of electricity that may serve better purposes in our national system.

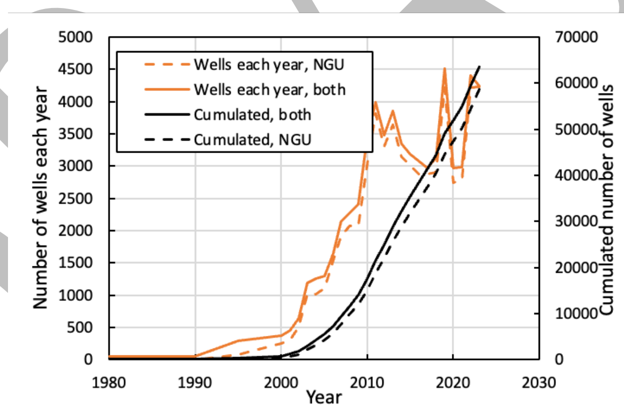

Figure 8. Number each year and total cumulated number of ground source wells from the NGU database and the adjusted output from the M-R database.

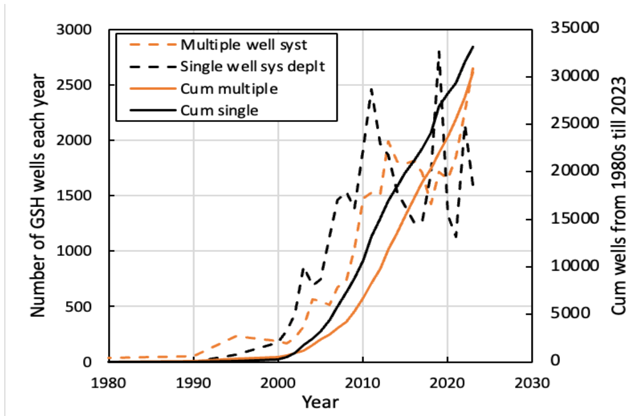

Figure 9. Number of wells in large multiple well-systems and single well systems. Fraction of wells in large multiple well systems each year (dashed) and cumulated (solid). The fraction of wells in large-multiple wells system is steadily increasing.

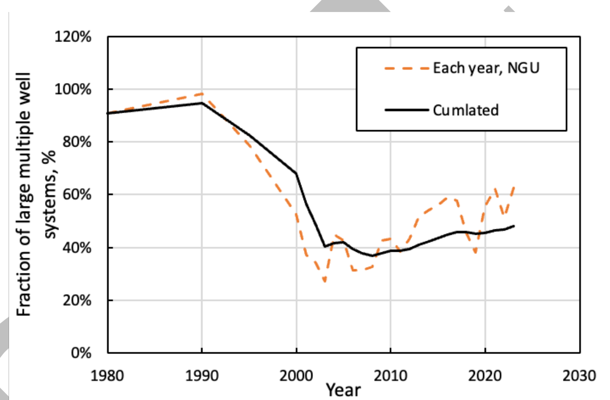

Figure 10. The fraction of wells in large multiple systems deployed each year and the total cumulative fraction.

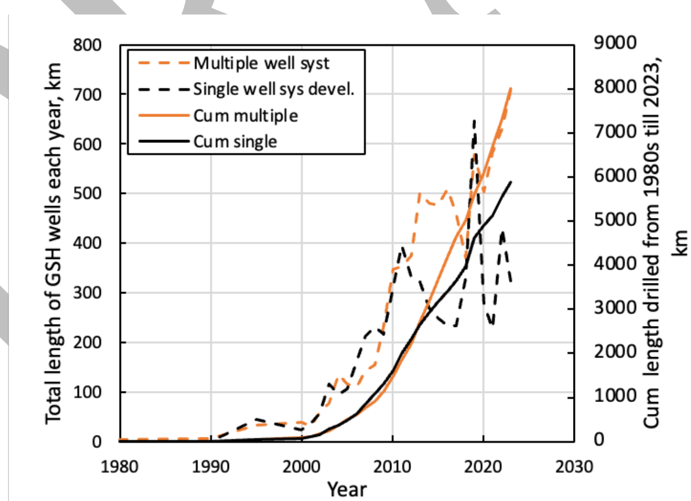

Figure 11. Total length drilled in single-well and multiple well systems each year and total since 1980s.

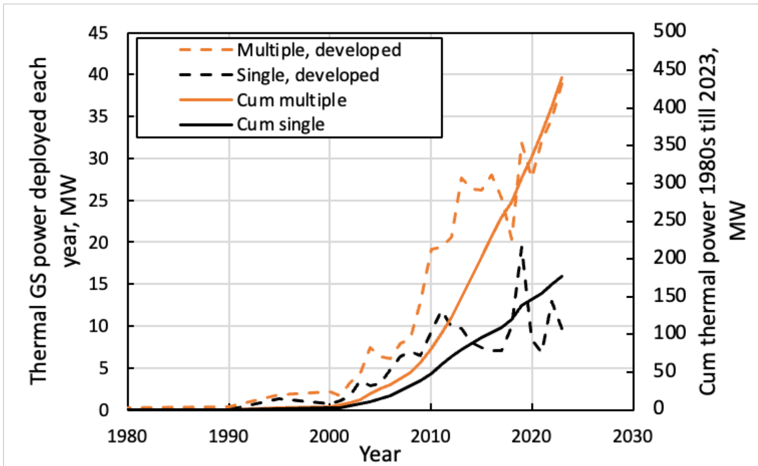

Figure 12. Thermal power developed each year for single and multiple well systems. The total cumulated thermal power displayed with solid line.

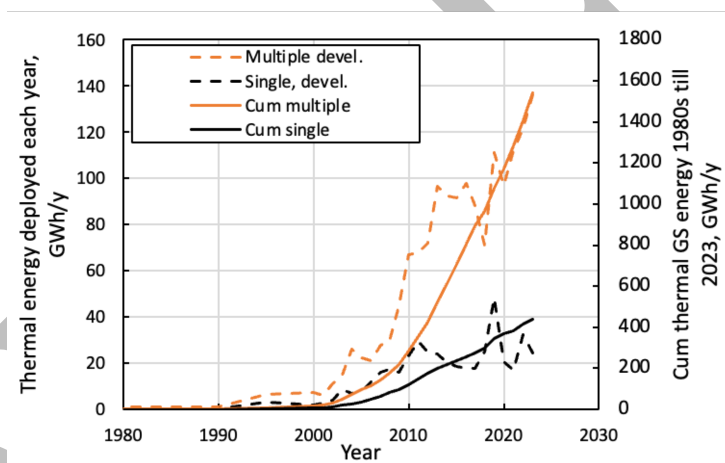

Figure 13. Ground source thermal energy in single and multiple well systems each year and total since 1980s.

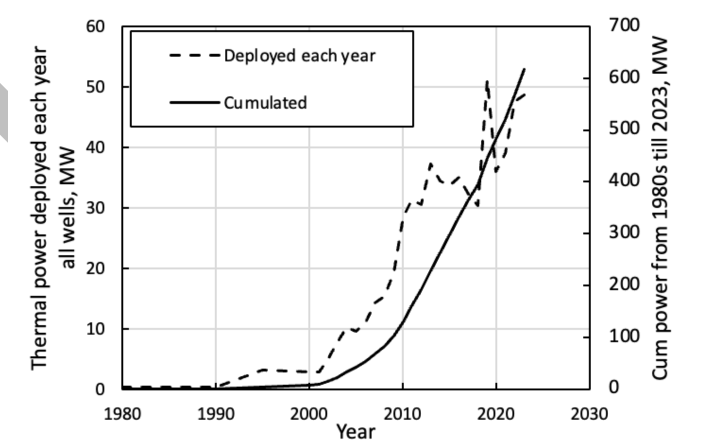

Figure 14. Total ground source thermal power for all wells each year and total since 1980s.

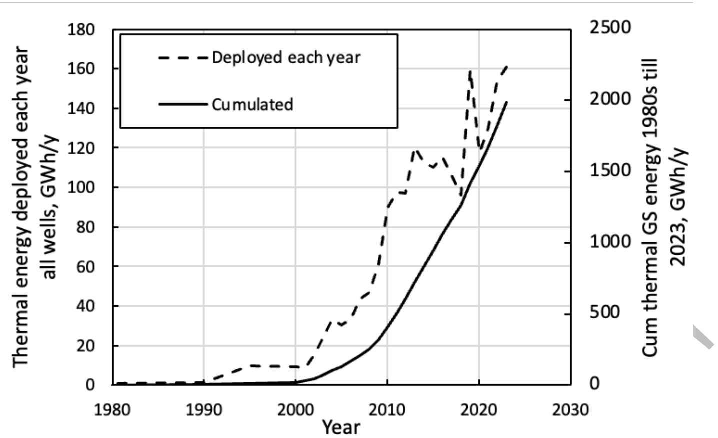

Figure 15. Ground source thermal energy each year added to the system each year (dashed) and cumulated total amounts since 1980s (solid line).

Table 3. Summary of the ground source thermal power and yearly energy extracted from ground source thermal wells in Norway from the Granada database and the non-double counted fraction of the Midttømme-Ramstad database.

	Developed 2023						1980s - 2023	
	Total Length, km	Number of wells, #	Well efficiency, W/m	Capacity factor, h/year	Power, MW	Thermal energy, GWh/year	Cumulated power, MW	Cumulated energy, GWh/year
Larger, multiple well systems	708.2	2642	65	3500	46.03	161.1	520.8	1822.8
Single well systems	324.0	1596	30	2500	9.72	24.3	176.3	440.7
Sum	**1032.2**	**4238**			**55.8**	**185.4**	**697.1**	**2263.5**

Output from national heat pump sales database

Norsk Varmepumpeforening (NOVAP) have been tracing the annual heat pump sales since 1987. In this context, only the fluid-fluid heat pumps are relevant, even though these systems may also be used to extract heat from the sea. In all 4700 fluid-water heat pumps were sold during 2023 (orange circles in Figure 16). It might be assumed that ≈90% (???) of the heat fluid-fluid heat pump sales were used in ground source heat pump systems, equating to 4230 units (dashed line). Moreover, the average lifetime of a heat pump is 19-21 (?) years (varying greatly). To first order one may thus subtract the average number of heat pumps sold in 2002-2004 (i.e., 1871 units) shown in blue. Thus, it might be estimated that 2450 new ground source heat pump units were added to the national energy system in 2023, i.e., a fraction 52-1% of the 4700 water-fluid heat pumps that were sold.

This number might be compared to the 4238 wells that were drilled during 2023 in 1596 single and 2642 multiple well units reported in the NGU and Midttømme-Ramstad data bases. In multiple-well systems, a single heat pumps serve multiple wells.

When summing up the ground source heat pumps excluding the replacement heat pumps, around 49 600 GSHPs are operative in Norway.

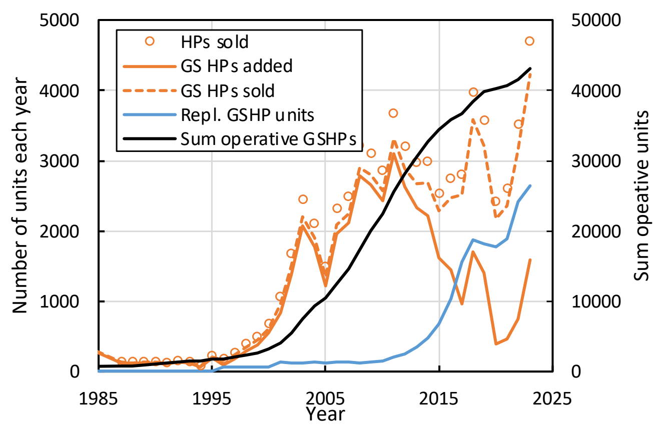

Figure 16. Water-fluid heat pumps sold from 1987 till 2023 (circles). The ground source (GS) heat pumps is assumed to be 90% of the total number of units (dashed). Subtracting the replacement pumps (i.e., 15-17-year-old units in blue) the number of units added to the national energy system are displayed by the solid orange line. Sum of all added units in black solid line equating to approx. 49 600 units.

In the NOVAP database the heat added to the building is reported. This heat originates from the electricity needed to run the system and the heat added from the ground. To estimate the heat extracted from the ground Eqn. 4 was used. Assuming a COP of 4.5 the fraction of heat from the ground is 0.78. Table 4 provides an overview of heat pumps of various capacity enabling an estimate of the number of new heat pumps added to the national system, the added power and added yearly thermal energy one may extract from the ground. Assumptions for the calculation were shown in Table 5.

An average power and yearly energy of 14.7 kW 51 MWh is estimated from all units developed in 2023. Assuming the same average power and thermal energy from the ground source heat pump systems holds for all years, the total ground source thermal power and energy may be estimate from the 49 600 units that are estimated to be operative today as shown in Figure 17 and Figure 18, respectively.

In 2023, a total ground source thermal power of **728 MW** producing a yearly amount of **2.55 TWh** of conflict free, carbon neutral, renewable and firm energy available also at the coldest, darkest hour extracted from GSHP systems.

The estimates are sensitive to assumptions as described in the text.

Table 4. Water-fluid heat pump (WF-HP) capacity range and number of units sold of the different types. The middle HP thermal power and thus, the thermal power extracted from the ground is estimated from assumptions in Table 5. Thus the ground source thermal power and energy added to the national energy system is estimated to be 36 MW and 126 GWh for 2023.

WF HP capacity, kW	WF-HPs units sold	WF-GSHP units added	Avg HP thermal power, kW	Avg. Thermal power from ground, kW	GS thermal power added, MW	GS thermal energy added, GWh
>10	2028	1057	5	3.9	4.11	14.39
10-20	2122	1106	15	11.7	12.91	45.18
21-50	256	133	35	27.2	3.63	12.72
51-100	213	111	75	58.3	6.48	22.67
101-500	78	41	250	194.4	7.91	27.68
501-1000	3	2	750	583.3	0.91	3.19
> 1000	0	0	1675	1302.8	0.00	0.00
Sum	4700	2450			35.95	125.82
Average GS power per unit:			14.7	kW/unit		
Avg. yearly GS energy per unit:			51	MWh/unit		

Table 5. Assumptions used in the calculation of thermal power and thermal ground source energy in Table 4.

Avg. vapacity factor GSHPs	3500	hours/year
COP (avg)	4.5	
Ground source frac	0.778	
Fraction of new 2023	52.14%	

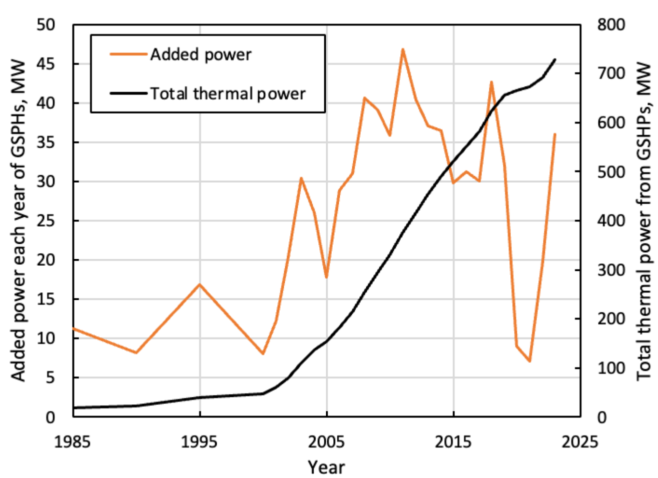

Figure 17. Added power each year (orange) and the cumulated sum of all components since 1987 till 2023 of the ground source heat i.e., the electrical energy is subtracted from the heat added to buildings.

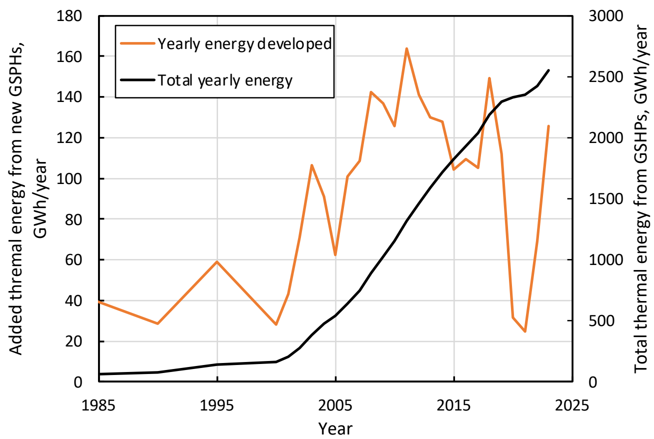

Figure 18. Yearly ground source thermal energy developed each year in orange, and the cumulated sum since 1987 assuming a fixed average capacity for each well.

Summary

There is no national fully updated database that keep track of the contribution of the extraction of ground source heat. Thus, it is continuously being overlooked in the public debate. Two methods have been used to estimate the total contribution. When counting the number of ground source heat wells it the total contribution to the national thermal power and energy is provided. This is done by combinging two databases. In total, 49 MW providing 161 GWh/year was added to the national system in 2023. When summarizing from 1980s till today, it is estimated that the ground source wells contribute with a peak capacity of 617 MW and 1.94 TWh/year. The estimates are highly sensitive to assumptions of heat extraction per meter well and the yearly capacity factor (i.e. hours/year of full capacity).

This estimate is combined with heat pump sales history from 1983 till today and the sales of various size heat pumps in 2023. When assuming a coefficient of performance, the contribution from the ground source heat is estimated. In 2023, it is estimated that a total ground source heat power of 36 MW supplying 126 GWh of yearly thermal energy is added to the system. When integrating up from 1983

The estimated numbers heavily rely on the assumptions used. A detailed database, allowing to add up the national contribution rather than estimating from the presented top-down analyses. Having a better oversight is required to develop policies that could facilitate the development of conflict free energy. Its contribution to the national system is crucial, as this carbon neutral energy source is available at demand – thus reducing the buildout demand for the society to meet its overall decarbonization goals.

Examples of large-scale multi-well ground source heat pump systems in Norway

Due to the scale-free behavior, it makes energic and economic sense to deploy also single well systems to harvest ground source heat for private single households. Although, the good examples are often large multi-well systems. Here, the value for the owner is evaluated in a series of examples (7th April version only 1 example – more to come!).

Value for the owner

The value created by the ground source heat pump systems for the owner are two-fold: It reduces the reliance of alternative energy for heating and cooling during peak-demand. As such, it reduces the financial risks of extreme prices, and moreover, it provides energy for free over the year – thus reducing the demand for buying energy (either molecules or electrical). To estimate relation between the yearly energy production, and the power of the system, the yearly capacity factor (f_{cap}, unit: hours/year) provides a useful concept. This is defined as the ratio between the yearly thermal energy output of the system (E_{out}, unit: kWh/year), and the peak power (P_p, unit: kW) of heat-pump system,

$$E_{out} = f_{cap} P_p \quad \text{Eqn. 5}$$

This, factor is reported when both the power and energy output is provided. In other cases, it relies on estimates from similar systems. Typically, the number differs for the heating and cooling demand – dictated by the local climate, the building, the geological thermal coefficients, and of-course the system design and operational management.

The alternative cost of other energy sources that could serve the heating and cooling demand varies significantly during the day, and between seasons and years. A precise estimate of the value of such a system for the operator is given by the integral of 1-hour interval increments (or 15 minute) where the extracted heat times and alternative cost are provided. If this data is unknown, then the value created for the operator might be estimated on yearly averages are used combined with likely price scenarios. The latter option is used here.

Value for the user – do not overlook the value for the society

The reduced use of electrical energy for heating and cooling purposes is freeing out energy for the society, making it much easier for the society to meet its decarbonization and climate reduction goals *and* enabling industry and job growth. The value is two-fold, as a reduced overall electrical energy use over a normal year is key to capacity planning, but more importantly, it reduces the build-out demand of the electrical transfer and power production capacity. The scale of the electrical energy system is designed to meet peak demand. In the competition of area, and all associated sabotage and natural risks, and material use – this is particularly valuable for all.

Estimating economic value for the operator

In its simplest form, the value created by the owner of ground source heat systems is given by an overview of the expenses:

a) up-front CAPEX (CAPital EXpensens),

b) the yearly operative expenses (OPEX) to overlook, run and maintain the system, and
c) an assessment of reoccurring re-investments to replace larger components (e.g., heat pumps with an average life-time expectancy of 17 years (REF?)).

The value created by the system is the heat extracted from the ground that reduces the alternative cost of energy. In that case Eqn. (4) is used if only the energy output from the GSHP-system to the building is given. To estimate the revenue from this, rely on the alternative cost of thermal energy, either that being the electricity cost for the consumer (including VAT and other taxes) or being the gas price. In the following two scenarios have been used, namely a price of 0.05 Euro/kWh and 0.1 Euro/kWh as yearly average – knowing that the price is often much higher (especially in Norway) when the demand for heat is the largest.

The internal rate of return (IRR) is a useful concept when evaluating how to spend money within a company (or family). Typically, in cases where IRR exceed the weighted average costs of capital plus a risk premium (WACC+), an investment is profitable. The estimate of IRR rely on the net cash flow (N_{CF}) is calculated from the sum of all expenses and revenues each year.

An alternative way to estimate the value of an investment, is to estimate the discounted net cash flow in year (t), D_{NCF}(t) for each year from a given interest rate (r), the following equation is used:

$$D_{NCF}(t) = \frac{N_{CF}(t)}{(1-r)^t} \qquad \text{Eqn. 6}$$

In Excel, the expenses and revenues are shown each year, together with net cash flow and discounted net cash flows are provided. An interest rate of 5% is used here. By summing up DNCF till year t one may determine the time it takes to regain the investment capital, i.e., the time for return of capital.

All these concepts are used to understand the reported value of each case for the operator from the assumed input factors in Table 6used in all the examples below. Here, the CAPEX/OPEX factor, and a re-occurring CAPEX investment factor of 0.07 (i.e., 1/14th of the initial investment) occurring at an average heat pump lifetime of 15 year is used. All these assumptions are subject to change, and they will affect the overall economy lifetime. The discount rate is assumed to be constant of 5% through to 2056 (32 years) and a risk premium of 1% is used. Such a low value of risk premium is used because of the maturity of the system. Moreover, when wells are drilled in crystalline rocks, the wells are extremely mechanically stable so its sensitivity to natural risks is low. The risks to sabotage is near zero, because of the low conflict potential of the energy solution compared to other energy options.

Table 6. Assumptions used to evaluate the economical contribution of the examples evaluated in this report.

Input parameters:		
Energy price, scenario 1	0.1	Euro/kWh
Energy price, scenario 2	0.05	Euro/kWh
CAPEX/OPEX factor	50	1/50
Re-occurring CAPEX reinv.	0.07	1/14
Avg heat pump lifetime	15	yr
Discount rate	5%	
Risk premium	1%	

Arsenalet Industry park – Kongsberg Defense and Aerospace

The newly developed 177 well ground source heat pump system developed at Arsenalet industry park, Kongsberg Norway. The ground source heat wells were drilled down to an average 300 m depth. In total 53 100 m wells were drilled, at a system cost of around 30 MNOK. The work was done over 3.5 months. The energy provided by the ground source heat pump system serves both cooling and heating purposes – where cooling is performed by dumping heat from the summer into the ground. The general and specific input data for the analysis is shown in Table 6 and Table 7 respectively. The reported values are displayed in green.

Table 7. Input data for the analysis of the Arsenalet industry park.

Coefficient of performance, heat (assumed)	4.5	
Ground source factor, heating	0.78	
Coefficient of performance, cooling (assumed)	10	
Ground source factor, cooling	0.90	
Peak power of the system		
Heat	1.7	MW_h
Cooling	3.2	MW_c
Heat from ground	1.3	MW_h_g
Heat to ground (cooling)	2.9	MW_c_g
Yearly energy		
Heat to the building	2100	MWh_h/year
Heat to the ground (i.e. Building cooling)	4600	MWh_c/year
Total thermal energy to building (per design)	6700	MWh_th/year
Yearly thermal energy with the ground via wells		
Heat extracted from ground	1633	MWh_h_g/year
Heat fed to the ground (cooling)	3578	MWh_c_g/year
Total thermal energy exchange with the ground	5211	MWh_th_g/year
Estimates of yearly capacity factor		
Heating	1235	h/year
Cooling	1438	h/year

Based on the assumptions avbove the complete economic analysis can be estimated as shown in Table 8. Based on the discounted cash flow analysis the invested up-front capital is regained after 6 or 19 years, dependent upon the price scenarios for alternative energy that otherwise had to be procured. The internal rate of return (IRR) is either 22% or 7.5%, dependent upon the two price scenarios. The key output economic analysis is shown in Table 9 and Figure 19.

Table 8. CAPEX, OPEX, revenue in price scenario 1 and 2, and net cash flow and discounted NCFs as function of time. Re-occurring capex after 17 years.

Year	CAPEX	OPEX	Rev, scen 1	Rev. Scen 2	NCF, scen 1	NCF, scen. 2	Sum NCF, scen. 1	Sum NCF, scen 2	Thermal energy	Disc. NCF, scen. 1	Disc. NCF, scen. 2	Sum DNCF, scen. 1	Sum DNCF, scen. 2

	Meuro	Meuro/y	Meuro/y	Meuro/y	Meuro/y	Meuro/y	M Euro	M Euro	MWh/y	M Euro/y	M Euro/y	M Euro	M Euro
2023	€ (2.59)	€ (0.05)	€ 0.52	€ 0.26	€ (2.12)	€ (2.38)	€ (2.12)	€ (2.33)	5211	€ (2.12)	€ (2.38)	€ (2.12)	€ (2.38)
2023	€ -	€ (0.05)	€ 0.52	€ 0.26	€ 0.47	€ 0.21	€ (1.65)	€ (2.07)	5211	€ 0.45	€ 0.20	€ (1.67)	€ (2.18)
2024	€ -	€ (0.05)	€ 0.52	€ 0.26	€ 0.47	€ 0.21	€ (1.18)	€ (1.80)	5211	€ 0.43	€ 0.19	€ (1.24)	€ (1.99)
2025	€ -	€ (0.05)	€ 0.52	€ 0.26	€ 0.47	€ 0.21	€ (0.71)	€ (1.54)	5211	€ 0.41	€ 0.18	€ (0.84)	€ (1.81)
2026	€ -	€ (0.05)	€ 0.52	€ 0.26	€ 0.47	€ 0.21	€ (0.24)	€ (1.28)	5211	€ 0.39	€ 0.17	€ (0.45)	€ (1.64)
2027	€ -	€ (0.05)	€ 0.52	€ 0.26	€ 0.47	€ 0.21	€ 0.23	€ (1.02)	5211	€ 0.37	€ 0.16	€ (0.08)	€ (1.47)
2028	€ -	€ (0.05)	€ 0.52	€ 0.26	€ 0.47	€ 0.21	€ 0.70	€ (0.76)	5211	€ 0.35	€ 0.16	€ 0.27	€ (1.32)
2029	€ -	€ (0.05)	€ 0.52	€ 0.26	€ 0.47	€ 0.21	€ 1.17	€ (0.50)	5211	€ 0.33	€ 0.15	€ 0.60	€ (1.17)
2030	€ -	€ (0.05)	€ 0.52	€ 0.26	€ 0.47	€ 0.21	€ 1.64	€ (0.24)	5211	€ 0.32	€ 0.14	€ 0.92	€ (1.03)
2031	€ -	€ (0.05)	€ 0.52	€ 0.26	€ 0.47	€ 0.21	€ 2.11	€ 0.02	5211	€ 0.30	€ 0.13	€ 1.22	€ (0.89)
2032	€ -	€ (0.05)	€ 0.52	€ 0.26	€ 0.47	€ 0.21	€ 2.58	€ 0.28	5211	€ 0.29	€ 0.13	€ 1.51	€ (0.76)
2033	€ -	€ (0.05)	€ 0.52	€ 0.26	€ 0.47	€ 0.21	€ 3.05	€ 0.54	5211	€ 0.27	€ 0.12	€ 1.78	€ (0.64)
2034	€ -	€ (0.05)	€ 0.52	€ 0.26	€ 0.47	€ 0.21	€ 3.52	€ 0.80	5211	€ 0.26	€ 0.12	€ 2.04	€ (0.53)
2035	€ -	€ (0.05)	€ 0.52	€ 0.26	€ 0.47	€ 0.21	€ 3.99	€ 1.06	5211	€ 0.25	€ 0.11	€ 2.29	€ (0.42)
2036	€ -	€ (0.05)	€ 0.52	€ 0.26	€ 0.47	€ 0.21	€ 4.45	€ 1.32	5211	€ 0.24	€ 0.11	€ 2.53	€ (0.31)
2037	€ (0.17)	€ (0.05)	€ 0.52	€ 0.26	€ 0.30	€ 0.04	€ 4.75	€ 1.41	5211	€ 0.14	€ 0.02	€ 2.67	€ (0.29)
2038	€ -	€ (0.05)	€ 0.52	€ 0.26	€ 0.47	€ 0.21	€ 5.22	€ 1.67	5211	€ 0.22	€ 0.10	€ 2.89	€ (0.20)
2039	€ -	€ (0.05)	€ 0.52	€ 0.26	€ 0.47	€ 0.21	€ 5.69	€ 1.93	5211	€ 0.20	€ 0.09	€ 3.09	€ (0.11)
2040	€ -	€ (0.05)	€ 0.52	€ 0.26	€ 0.47	€ 0.21	€ 6.16	€ 2.19	5211	€ 0.20	€ 0.09	€ 3.29	€ (0.02)
2041	€ -	€ (0.05)	€ 0.52	€ 0.26	€ 0.47	€ 0.21	€ 6.63	€ 2.45	5211	€ 0.19	€ 0.08	€ 3.47	€ 0.06
2042	€ -	€ (0.05)	€ 0.52	€ 0.26	€ 0.47	€ 0.21	€ 7.10	€ 2.71	5211	€ 0.18	€ 0.08	€ 3.65	€ 0.14
2043	€ -	€ (0.05)	€ 0.52	€ 0.26	€ 0.47	€ 0.21	€ 7.57	€ 2.97	5211	€ 0.17	€ 0.07	€ 3.82	€ 0.22
2044	€ -	€ (0.05)	€ 0.52	€ 0.26	€ 0.47	€ 0.21	€ 8.04	€ 3.23	5211	€ 0.16	€ 0.07	€ 3.98	€ 0.29
2045	€ -	€ (0.05)	€ 0.52	€ 0.26	€ 0.47	€ 0.21	€ 8.51	€ 3.49	5211	€ 0.15	€ 0.07	€ 4.13	€ 0.36
2046	€ -	€ (0.05)	€ 0.52	€ 0.26	€ 0.47	€ 0.21	€ 8.98	€ 3.76	5211	€ 0.15	€ 0.06	€ 4.28	€ 0.42
2047	€ -	€ (0.05)	€ 0.52	€ 0.26	€ 0.47	€ 0.21	€ 9.45	€ 4.02	5211	€ 0.14	€ 0.06	€ 4.42	€ 0.48
2048	€ -	€ (0.05)	€ 0.52	€ 0.26	€ 0.47	€ 0.21	€ 9.91	€ 4.28	5211	€ 0.13	€ 0.06	€ 4.55	€ 0.54
2049	€ -	€ (0.05)	€ 0.52	€ 0.26	€ 0.47	€ 0.21	€ 10.38	€ 4.54	5211	€ 0.13	€ 0.06	€ 4.67	€ 0.60
2050	€ -	€ (0.05)	€ 0.52	€ 0.26	€ 0.47	€ 0.21	€ 10.85	€ 4.80	5211	€ 0.12	€ 0.05	€ 4.79	€ 0.65
2051	€ -	€ (0.05)	€ 0.52	€ 0.26	€ 0.47	€ 0.21	€ 11.32	€ 5.06	5211	€ 0.11	€ 0.05	€ 4.91	€ 0.70

2052	€ (0.17)	€ (0.05)	€ 0.52	€ 0.26	€ 0.30	€ 0.04	€ 11.62	€ 5.15	5211	€ 0.07	€ 0.01	€ 4.98	€ 0.71
2053	€ -	€ (0.05)	€ 0.52	€ 0.26	€ 0.47	€ 0.21	€ 12.09	€ 5.41	5211	€ 0.10	€ 0.05	€ 5.08	€ 0.76
2054	€ -	€ (0.05)	€ 0.52	€ 0.26	€ 0.47	€ 0.21	€ 12.56	€ 5.67	5211	€ 0.10	€ 0.04	€ 5.18	€ 0.80
2055	€ -	€ (0.05)	€ 0.52	€ 0.26	€ 0.47	€ 0.21	€ 13.03	€ 5.93	5211	€ 0.09	€ 0.04	€ 5.27	€ 0.84
2056	€ -	€ (0.05)	€ 0.52	€ 0.26	€ 0.47	€ 0.21	€ 13.50	€ 6.19	5211	€ 0.09	€ 0.04	€ 5.36	€ 0.88

Table 9. Key output of capital analysis of the project.

Output	IRR	Return of cash, yrs
Price scenario 1	22.01%	6
Price scenario 2	7.53%	19
WACC+ (5+1%)	5.00%	
Risk premium	1%	

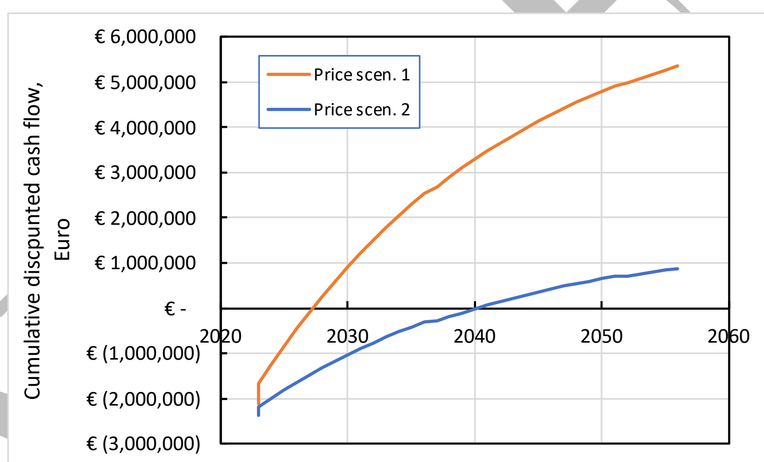

Figure 19. Cumulative discounted cash flow for an internal rate of 5% (i.e., average cost of capital). The down-payment time of invested capital is either 6 or 19 years dependent upon the alternative cost of energy (price scenario 1 of 0.1 Euro/kWh and scenario 2 is 0.05 Euro/kWh).