

Deliverable report

CoSi modelling assumptions

Technical report

Deliverable ID and name

D1.18 CoSi modeling assumptions

Authors

Daniel Philippen, SPF-OST
Kevin Meili, SPF-OST
Michel Haller, SPF-OST
Kanchan Bohara, SPF-OST
Neha Dimri, SPF-OST

Date of publication

24/02/2026

Acknowledgement

This research published in this publication was carried out with the support of the Swiss Federal Office of Energy as part of the SWEET consortium CoSi.

© **SWEET-CoSi**

February 24, 2026

Cite as:

Philippen et al. (2026). CoSi modelling assumptions. SWEET-CoSi

Content

List of Abbreviations	4
Summary	5
1 Introduction	6
2 Investment costs	7
2.1 Methodology	7
2.1.1 Considered costs	7
2.1.2 Conversion of costs	7
2.1.3 Synthesis of Market data and Projections	8
2.2 Electricity production technologies	11
2.2.1 Rooftop PV	11
2.2.2 Wind turbine	13
2.2.3 Hydropower	14
2.2.4 Gas turbine	15
2.2.5 Geothermal	16
2.3 Heat production technologies	18
2.3.1 Air-Source Heat Pump (ASHP)	18
2.3.2 Ground-Source Heat Pump (GSHP)	20
2.3.3 Wood Boilers	22
2.3.4 Gas Boiler	24
2.3.5 Oil Boiler	24
2.3.6 Solar Thermal	25
2.3.7 District Heating	27
2.4 Combined heat and power (CHP) production technologies	29
2.5 Batteries	30
2.6 Hydrogen production technologies	32
3 Prices for imported hydrogen	34
4 Energy efficiencies	36
4.1 Electric vehicles	36
4.2 Heat pumps	37
4.3 Solar thermal collectors	38
5 References	39
6 Appendix A	41
6.1 Calculation of Costs	41
6.1.1 Hydropower	41
6.1.2 Air-source heat pumps	41
6.1.3 Rooftop PV	42
6.2 Calculation of efficiencies	42
6.2.1 Efficiency of electric vehicles	42
6.2.2 Temperature dependency of the efficiency of ASHP and GSHP	43

List of Abbreviations

ASHP	Air-source heat pump
CCS	Carbon capture and storage
COP	Coefficient of performance
DEA	Danish Energy Agency
EIA	U.S. Energy Information Administration (EIA)
EP2050+	“Energieperspektiven 2050+” report (Kemmler et al., 2022)
GSHP	Ground-source heat pump
HP	Heat pump
HSLU	Lucerne University of Applied Sciences and Arts
IEA	International Energy Agency
IRENA	International Renewable Energy Agency
ISE	Fraunhofer Institut für Solare Energiesysteme
JRC	EU Joint Research Centre
kW	Kilowatt
PSI	Paul Scherrer Institut
PV	Photovoltaics
ROR	Run-of-river
SFOE	Swiss Federal Office of Energy

Indexes:

th	Thermal
el	Electrical
AC	Alternating current

Summary

The deliverable report (D1.18) was prepared in the framework of WP 1 “CROSS+” Task 1.6 defined as CoSi Assumptions. It provides estimated reference values and ranges for the investment costs of various energy conversion technologies – covering electricity, heat, combined heat and power (CHP), and hydrogen production – as well as for the import price of hydrogen and the efficiencies of heat pumps and small electric vehicles. The values are estimated for the baseline year 2020 and projected up to 2050.

Investment costs for 2020 are primarily based on market studies for Switzerland. When Swiss data was unavailable, relevant international studies were used to estimate the Swiss market prices. Projections through 2050 are derived from national and international forecast studies, using their learning curves (gradient of price trends) to extrapolate the 2020 market data.

This report will be updated every two years to reflect the latest research, data, and market developments, ensuring its continued relevance for modelling Switzerland's energy future.

1 Introduction

This report is prepared as part of the SWEET project – "Swiss Energy Research for the Energy Transition" – a funding initiative by the Swiss Federal Office of Energy (SFOE). The SWEET program is designed to accelerate innovations that are crucial for implementing Switzerland's Energy Strategy 2050 and achieving the nation's climate goals.

The deliverable aims to harmonize input assumptions such as investment cost outlooks for various technologies, hydrogen import prices, and the efficiency of heat pumps and electric vehicles. These assumptions are critical for the simulation and optimization of energy systems within the Swiss context.

This work is conducted under the framework of work package 1 "CROSS+" Task 1.6, specifically defined as CoSi-Assumptions. In addition to this report the 2025-06 version of the data can be found on the CROSSDAT platform at <https://sweet-cross.ch/data/technologies-investment-costs-cross/2025-06-06/> .

2 Investment costs

2.1 Methodology

The investment costs presented in this report reflect actual or adjusted Swiss market prices for the year 2020, along with projections extending to 2050. Future costs estimated are derived using cost learning curves taken from literature.

These investment costs include all costs incurred by an investor for a turnkey system (section 2.1.1).

When Swiss market data for 2020 was unavailable, the nearest available year with Swiss price data was used and adjusted to 2020 values using Swiss inflation rates. In cases where only international market data was available, the prices were converted with Swiss labour cost adjustments and the corresponding exchange rates (section 2.1.2).

Cost projections to 2050 are based on national and international studies. The studies provide relative cost trends, expressed as percentage changes, which were applied to the baseline Swiss market prices to estimate future developments (chapter 2.1.3).

The specific methodology used to determine the costs for each technology is described in detail in the corresponding chapters.

2.1.1 Considered costs

The investment cost considered in this report include all costs components associated with the purchase and installation of an energy conversion technology in Switzerland, up to the point where the system is fully operational (commonly referred as turnkey costs).

In case of long planning and installation time, overnight costs are used. These represent the total investment assuming the installation occurs instantly, without accounting for inflation or interest rate effects during the construction phase.

In Sections 0 - 2.6, which detail the investment costs by technology, all costs components included in the total investment costs are explicitly listed, as long this information is given in the corresponding data sources.

The following items are **not** considered in the presented costs:

- Cost reductions due to subsidies
- Valued added tax (VAT)
- Operation and maintenance costs (unless otherwise stated)

2.1.2 Conversion of costs

When Swiss market prices for the year 2020 were not available, one or more of the following conversion methods were applied.

I. Conversion over time

If Swiss market prices of a technology were available for years other than 2020, the prices are adjusted for inflation if relevant. The inflation adjustment is done with the Inflation Calculator of the Swiss Federal Statistical Office.¹

II. Currency conversion

For cost data provided in foreign currencies, the average exchange rate (observed between 2019 and 2021) is used to convert to Swiss Francs (CHF):

- Euro to CHF: 1 Euro = 1.10 CHF
- USD to CHF: 1 USD = 0.96 CHF²

III. Labour cost conversion

When only international market studies were available, the labour-related portion of the costs was adjusted to Swiss levels using the labour cost index³ of the Swiss Federal Statistical Office. This approach assumes that material costs are consistent across European countries and that only the labour component varies between regions.

2.1.3 Synthesis of Market data and Projections

For each technology, the investment costs from 2020 to 2050 are presented and derived using the following steps:

I. Market data for 2020

Ranges for Swiss Market prices of year 2020 are presented in data tables, including minimum, reference (average or median), and maximum. If necessary, price conversions are performed as described in Section 2.1.2.

Where available, market price fluctuations for 2020 (i.e. minimum and maximum values) are taken directly from the original literature sources. If a source provides only a single price, the following assumptions are applied:

- Maximum price: +40 % of the reported value
- Minimum price: -30 % of the reported value.

These assumptions are based on market observations for several technology (e.g. PV: Section 2.2.1, Air-source heat pumps (ASHP): section 2.3.1). However, the choice of +40 % and -30 % is acknowledged as somewhat arbitrary and may be revised if a better market overview becomes available.

If a different approach was used for a specific technology, it is explicitly described in the corresponding chapter.

¹ <https://lik-app.bfs.admin.ch/en/lik>

² <https://www.rates.bazg.admin.ch/estv>

³ <https://www.bfs.admin.ch/asset/de/je-d-03.04.05.11>

II. Learning curves of price projections until 2050

The price projections in this report extend to the year 2050 and are based on learning curves extracted from national and international research studies. Where available, price projections are disaggregated by power class.

The relative average price changes over time are calculated based on this learning curves. Depending on the studies, projections are given for the years 2030, 2035 or 2040, and 2050 (example with 2035, see green line in Figure 1). If necessary, a linear interpolation is applied between given years.

To synthesize projections from multiple sources each study is weighted equally, i.e. if a study contains several learning curves (typically an optimistic and a conservative projection), an average is first calculated within the study. Then, an overall average of all studies is determined.

Due to the large uncertainties and differences in the projections, it was decided to use this rather simple approach to merge the different data from the projection studies. Thus, differences in price changes over a period of time shown in some of the studies are not considered separately, e.g. by showing assumed minimum and maximum changes. However, due to the assumed fluctuations in market prices in year 2020, the projections also result in minimum and maximum costs, see next section.

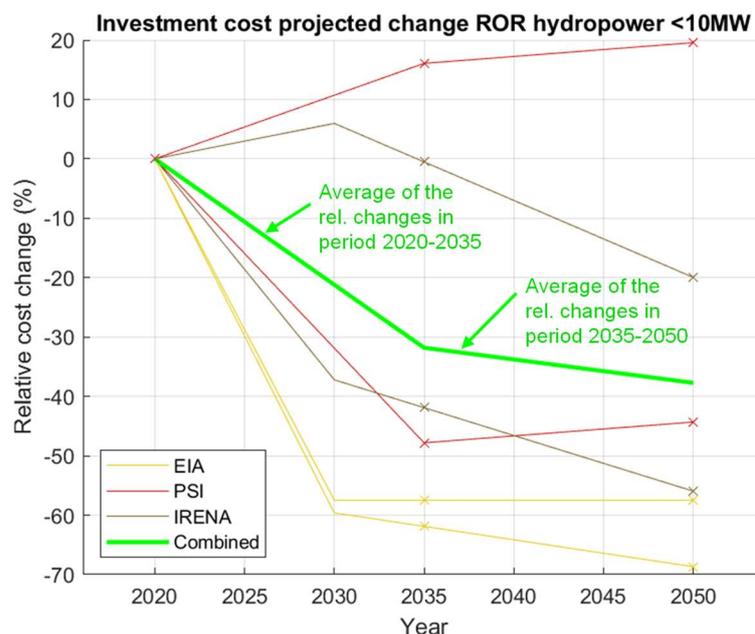


Figure 1: Example for the calculation of relative average price changes from research studies. A merged learning curve (green line) for the two periods 2020 - 2035 and 2035 - 2050 is calculated per power category of the energy conversion technology.

III. Synthesis

The three data points with market data (min, ref., max) serve as starting values for projecting investment costs up to 2050. These projections apply the relative average cost changes derived from the selected research studies, as described in step II.

Price developments over time are assumed to be linear for each of the three data points. This results in three corresponding projections curves (min, ref and max) extending to 2050.

The resulting values from the syntheses are presented in tabular form to ensure a clear and concise overview. The price reference year is 2020, so no inflation is assumed in the projections until 2050.

2.2 Electricity production technologies

2.2.1 Rooftop PV

I. Market Prices 2020

As rooftop PV installations are abundant in Switzerland, market prices are being taken directly from Switzerland. As main resource for data a report by EnergieSchweiz (2021) is taken, where costs are gathered over a vast range of installation sizes. Figure 16 shows average and median prices of every size category for the year 2020. Included in the cost are:

- Cost of the module
- Cost of the inverters
- Cost of the mounting structure
- Cost for site safety measures
- Administrative and planning costs
- Labour costs
- Cost of electrical materials
- Logistics and transportation costs

Multiple market costs have been gathered and listed in EnergieSchweiz, 2021. The report provides a curve fit of the data, which is shown in the appendix on Figure 16. The fit equation is used here to calculate the reference market prices. The minimum and maximum which are depicted in Table 1 are calculated using the interquartile ranges (EnergieSchweiz, page 30) multiplied by 1.5. Because the report of EnergieSchweiz uses ranges for capacities, the average of two numbers are taken for a respective capacity, e.g. 2-10 kW & 10-30 kW will be averaged for 10 kW.

Table 1: Reference, minimum, and maximum investment costs for rooftop PV in 2020.

Installation size	Investment cost (CHF/kWp)		
	Minimum	Reference	Maximum
6 kW	1692	2928	4164
10 kW	1353	2397	3441
30 kW	855	1635	2415
100 kW	552	1167	1782
1000 kW	314	771	1229

II. Learning curves of price projections until 2050

Price trends are depicted from a data update (Bauer, 2019) to the report of PSI (Bauer et al., 2017). The report used actual data from the year 2016 and then made projections for 2020, 2035 and 2050. Since this deliverable is taking the learning curve, the year 2020 is also depicted here but taken as the prognosis from PSI and not as an actual market data. A second study is featured from DEA (DEA, 2024, Version 10).

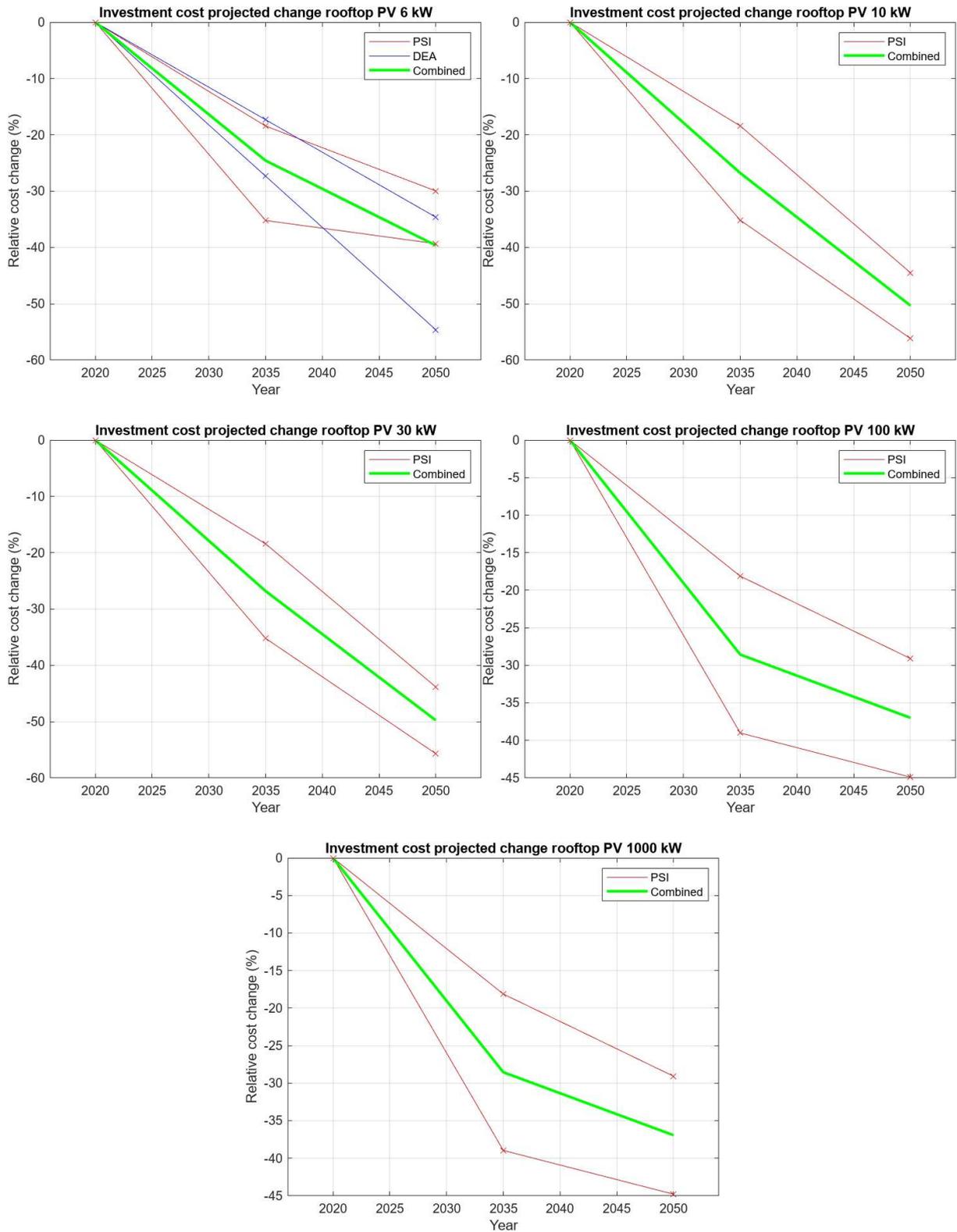


Figure 2: Study data and learning rate of different capacities of rooftop PV.

III. Synthesis

The learning curves from II are taken and matched onto the market data collected in I.

Table 2: Reference, minimum, and maximum investment costs for rooftop PV from year 2020 to 2050.

Installation size	Year	Investment cost (CHF/kW _e)		
		Minimum	Reference	Maximum
6 kW	2020	1692	2928	4164
	2035	1276	2209	3141
	2050	1021	1768	2514
10 kW	2020	1353	2397	3441
	2035	991	1755	2519
	2050	672	1191	1710
30 kW	2020	855	1635	2415
	2035	626	1197	1768
	2050	430	821	1213
100 kW	2020	552	1167	1782
	2035	394	834	1273
	2050	348	735	1123
1000 kW	2020	314	771	1229
	2035	224	551	878
	2050	198	486	775

2.2.2 Wind turbine

I. Market Prices 2020

For the market data, several Swiss institutions have been asked, yet none have been able to deliver actual reliable data. Therefore, the starting points of the PSI study (Bauer et al., 2017) are taken as market evaluation.

Table 3: Reference, minimum, and maximum investment costs for onshore windpower in 2020.

Installation size	Investment cost (CHF/kW)		
	Minimum	Reference	Maximum
Onshore wind turbine	2000	2500	3000

II. Learning curves of price projections until 2050

The following studies have been found:

- PSI (Bauer et al., 2017)
- DEA (DEA, 2024)
- IEA (IEA, 2023)
- IRENA (IRENA, 2019)

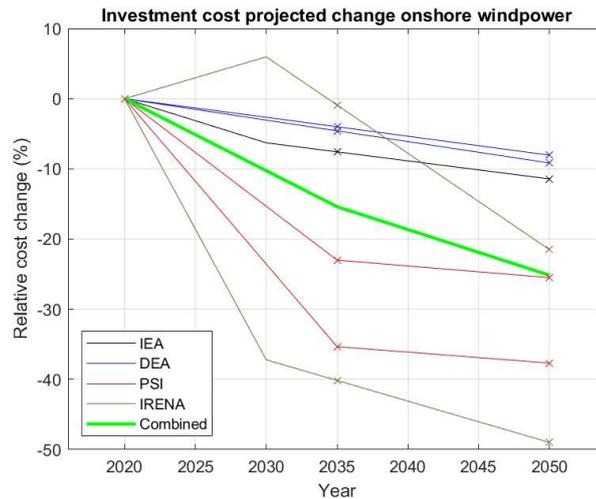


Figure 3: Study data and learning rate of onshore windpower.

III. Synthesis

Table 4: Reference, minimum, and maximum investment costs for onshore wind power from year 2020 to 2050.

Installation size	Year	Investment cost (CHF/kW _e)		
		Minimum	Reference	Maximum
Onshore	2020	2000	2500	3000
	2035	1692	2115	2538
	2050	1497	1871	2246

2.2.3 Hydropower

For hydropower, data is available for small (< 10 MW) and large (> 10 MW) facilities. However, a price trend and trustful data are only found for small hydropower plants. PSI, the only study with a projection, shows no price change for future years. Therefore, the large scale is excluded from this report and only the small scale is shown. In addition, the studies do not declare the composition of the costs, thus no reliable cost structure can be shown.

I. Market Prices 2020

As no actual market data was found, the study data from PSI (Bauer et al., 2017) is considered as market prices 2020.

Table 5: Reference, minimum, and maximum investment costs for run-of-river hydropower in 2020.

Installation size	Investment cost (CHF/kW)		
	Minimum	Reference	Maximum
< 10 MW	6160	9930	13700

II. Learning curves of price projections until 2050

The following studies have been found:

- EIA (2024)
- PSI (Bauer et al., 2017)

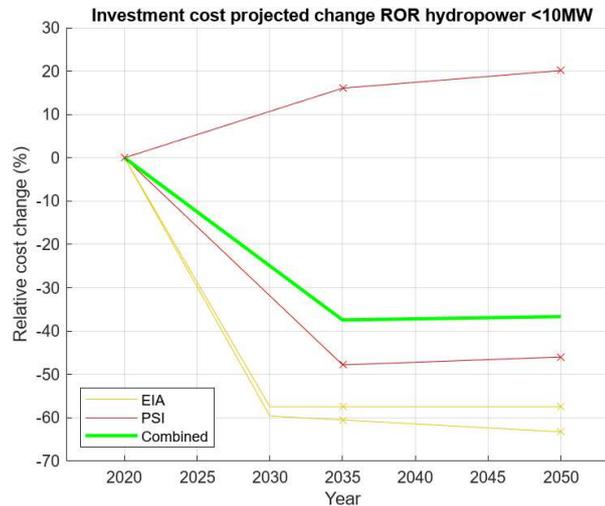


Figure 4: Study data and learning rate of run-of-river hydropower

III. Synthesis

Table 6: Reference, minimum, and maximum investment costs for ROR hydropower from year 2020 to 2050:

Installation size	Year	Investment cost (CHF/kW _e)		
		Minimum	Reference	Maximum
< 10MW	2020	6160	9930	13700
	2035	3854	6213	8571
	2050	3902	6290	8679

2.2.4 Gas turbine

I. Market Prices 2020

As a reference point for market data the gas power plant Birr is considered. Though it must be stated that the facility was built as an emergency reserve facility, hence the price is elevated. The whole power plant costs around 470 million CHF, with a capacity of 250 MW ("Reservekraftwerk Birr - Faktenblatt – Gemeinde Birr," 2022). This results in a price point of 1880 CHF/kW. As this number is rather high, it will be directly considered as the maximum cost, whereas PSI data is taken as the minimum costs.

Table 7: Reference, minimum, and maximum investment costs for a gas turbine in 2020.

Installation size	Investment cost (CHF/kW)		
	Minimum	Reference	Maximum
100-500 MW	770	1170	1880

II. Learning curves of price projections until 2050

The following studies have been found:

- DEA (2024)
- PSI (Bauer et al., 2017)

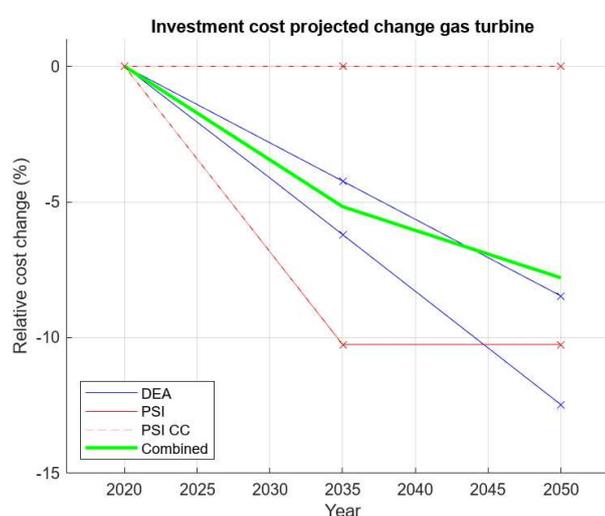


Figure 5: Study data and learning rate of gas turbines

III. Synthesis

Table 8: Reference, minimum, and maximum investment costs for a gas turbine from year 2020 to 2050:

Installation size	Year	Investment cost (CHF/kW _e)		
		Minimum	Reference	Maximum
100 – 500 MW	2020	770	1170	1880
	2035	730	1110	1783
	2050	717	1089	1750

2.2.5 Geothermal

I. Market Prices 2020

For geothermal, no market data has been collected, hence study data is being taken. For the binary cycle, the Swiss PSI study (Bauer et al., 2017) is considered. For flash steam, the IRENA study (IRENA, 2017) is taken, and converted according to Swiss market, as there is no other study available. Similar values can be found in IRENA (2021a).

Table 9: Reference and minimum and maximum investment costs for geothermal in 2020.

Installation size	Investment cost (CHF/kW _{el})		
	Minimum	Reference	Maximum
Binary cycle	2800	4000	5600
Flash steam	2750	4329	5907

II. Learning curves of price projections until 2050

The following studies were found:

- PSI (Bauer et al., 2017)
- IRENA (IRENA, 2017)

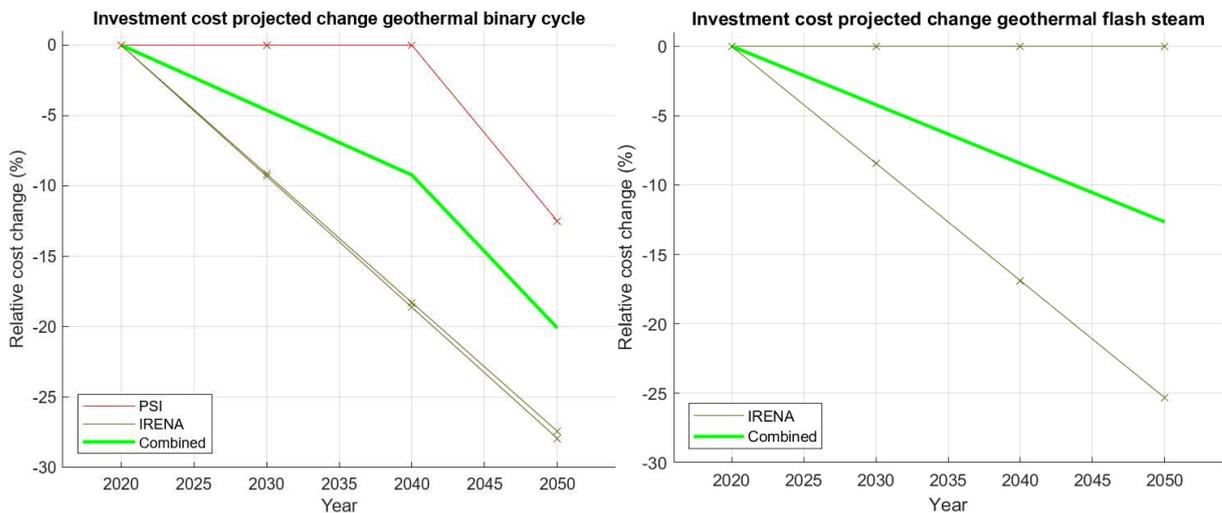


Figure 6: Study data and learning rate for geothermal.

III. Synthesis

Table 10: Reference, minimum, and maximum investment costs for geothermal from year 2020 to 2050.

Installation size	Year	Investment cost (CHF/kW _{el})		
		Minimum	Reference	Maximum
Binary cycle	2020	2800	4000	5600
	2030	2671	3816	5342
	2040	2542	3631	5083
	2050	2238	3197	4475
Flash steam	2020	2750	4329	5907
	2030	2634	4146	5658
	2040	2518	3963	5408
	2050	2402	3780	5159

2.3 Heat production technologies

2.3.1 Air-Source Heat Pump (ASHP)

I. Market Prices 2020

The main data source for the ASHP market prices is the 'Heating cost comparison calculator 2020' (HSLU, 2020). The version with data of 2020 was made available by HSLU via e-mail exchange. Actual versions are available online.⁴ The following items are summarized in the total investment costs (Table 11):

- Heat pump
- Fittings & appliances
- Heating storage tank
- Air duct
- Installation
- Electrical connection
- Surplus-costs electrical box
- Connection fee

Table 11: Thermal capacity and corresponding installation costs of ASHP for the year 2020 (source: "Heating cost comparison calculator").

Thermal capacity	Investment costs (CHF)
5 kW	27'810
10 kW	30'990
20 kW	44'940
70 kW	88'660

Another market study of EnergieSchweiz (Perch-Nielsen et al., 2015) for one size of an ASHP-system (9 kW_{th} @ A-7/W35) is used as basis for comparison of one of the data points of the "Heating cost comparison calculator". The costs of this 9 kW-system for 2020 are derived in Annex 6.1.2. The results are shown further down in Table 12.

Table 12: Variation of installation cost for an ASHP with thermal capacity of 9 kW (source: see Annex 6.1.2.).

	Investment costs (CHF)	Rel. deviation from Median
Minimum price	25'900	-29%
25%-quartile	33'160	-9%
Median	36'320	-
75%-quartile	38'530	6%
Maximum price	48'950	35%

In Table 11, the costs for an ASPH with thermal capacity or 10 kW is approx. 31'000 CHF. This is 15 % below the median of a 9 kW-system according to Table 12 and even slightly below the 25%-quartile in the table. However, the costs according to the Heating cost comparison calculator lie within the range of possible prices in Table 12 and thus, seem reasonable as a low price. As market prices vary quite largely, it is assumed that the difference of 1 kW between the capacities of the HP-systems compared here is neglectable.

⁴ <https://www.hslu.ch/de-ch/technik-architektur/ueber-uns/organisation/kompetenzzentren-und-forschungsgruppen/bau/gebaeudetechnik-und-energie/software-tools/>

The actual market prices suggested (Table 13) are based on Table 11 while the relative fluctuations of the market prices are taken from Table 12 to calculate the minimum and maximum prices.

Table 13: Reference, minimum and maximum investment costs of air-source heat pumps for year 2020.

Installation size	Investment cost (CHF/kW _{th})		
	Minimum	Reference	Maximum
5 kW _{th}	3950	5560	7510
10 kW _{th}	2200	3100	4180
20 kW _{th}	1600	2250	3030
70 kW _{th}	900	1270	1710

II. Learning curves of price projections until 2050

According to EnergieSchweiz (Perch-Nielsen et al., 2015) the share of labour cost in the total investment costs of an ASHP-system with 9 kW_{th} power is approx. 30 %.⁵

Two studies with price projections could be found:

- DEA (2021)
- JRC (2017)

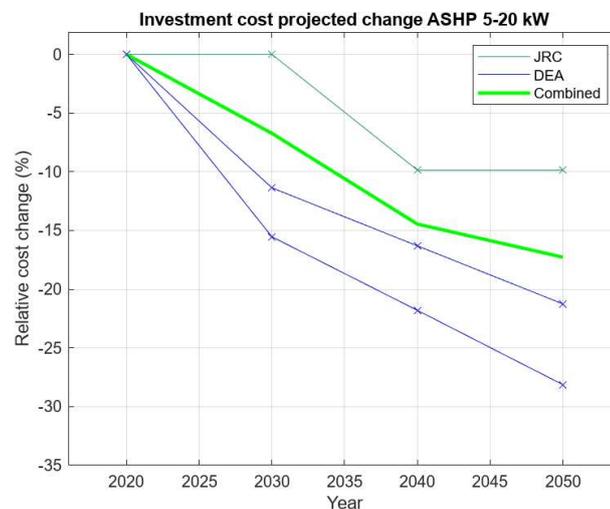


Figure 7: Investment costs assumptions for ASHP.

⁵ See Fig. 17 in Perch-Nielsen et al.; here we assume that additional to the label “Labour”, also 50 % of the costs for “Demolition” (as general additional costs), “Electrician”, and “Bricklayer” are labour costs.

III. Synthesis

Table 14: Reference, minimum, and maximum investment costs for ASHP from year 2020 to 2050.

Installation size	Year	Investment cost (CHF/kW)		
		Minimum	Reference	Maximum
5 kW _{th}	2020	3950	5560	7510
	2030	3684	5186	7005
	2040	3379	4756	6424
	2050	3268	4600	6213
10 kW _{th}	2020	2200	3100	4180
	2030	2052	2891	3899
	2040	1882	2652	3576
	2050	1820	2564	3458
20 kW _{th}	2020	1600	2250	3030
	2030	1492	2099	2826
	2040	1369	1925	2592
	2050	1324	1861	2507
70 kW _{th}	2020	900	1270	1710
	2030	839	1185	1595
	2040	770	1086	1463
	2050	745	1051	1415

For the calculation of heat pump efficiencies, see chapter 4.2.

2.3.2 Ground-Source Heat Pump (GSHP)

I. Market Prices 2020

The investment costs are taken from the 'Heating cost comparison calculator 2020' (HSLU, 2020).

The following items are summarized in the total investment costs:

- Heat pump
- Fittings & appliances
- Heating storage tank
- Geothermal probe drilling
- Installation
- Electrical development
- Additional costs of electrical box
- Connection fees

The fluctuations of the market prices (min. and max. values) are chosen according to the methodology described in chapter 2.1.3I, i.e. they are set at -30 % and +40 % of the reference price.

Table 15: Reference and minimum and maximum investment costs of GSHP of different capacities of thermal power for year 2020.

Installation size	Investment cost (CHF/kW _{th})		
	Minimum	Reference	Maximum
5 kW _{th}	5410	7720	10810
10 kW _{th}	3670	5250	7350
20 kW _{th}	2870	4100	5740
70 kW _{th}	2140	3060	4280
100 kW _{th}	2130	3040	4260
200 - 500 kW _{th}	1810	2590	3630

II. Learning curves of price projections until 2050

The following studies have been found:

- EU JRC (JRC, 2017)
- DEA (DEA, 2024)

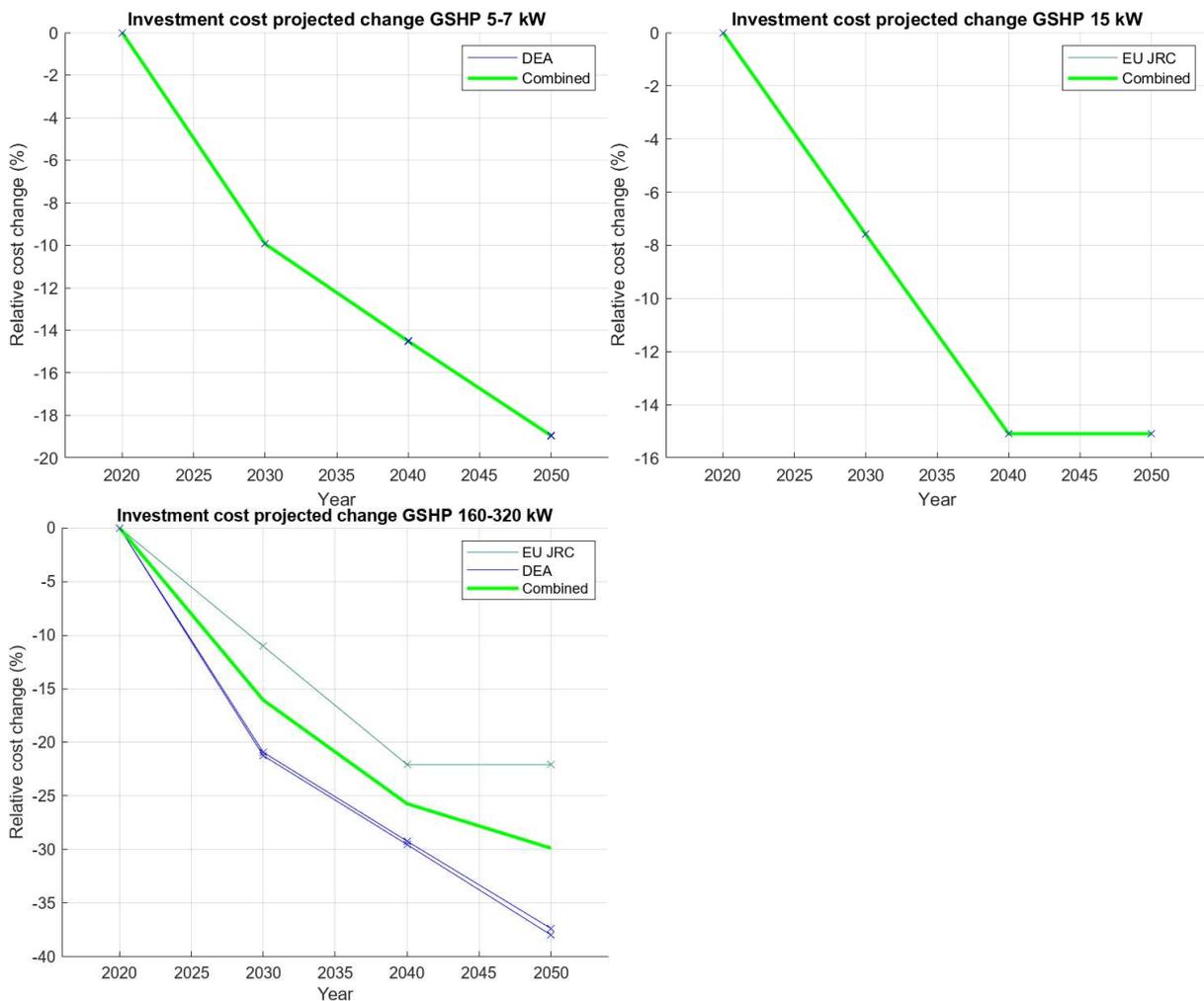


Figure 8 Investment cost assumptions for GSHP

III. Synthesis

Table 16: Reference, minimum, and maximum investment costs for GSHP from year 2020 to 2050.

Installation size	Year	Investment cost (CHF/kW _{th})		
		Minimum	Reference	Maximum
5 kW _{th}	2020	5410	7720	10810
	2030	4872	6953	9735
	2040	4625	6600	9241
	2050	4384	6257	8761
10 kW _{th}	2020	3670	5250	7350
	2030	3305	4728	6619
	2040	3137	4488	6284
	2050	2974	4255	5957
20 kW _{th}	2020	2870	4100	5740
	2030	2652	3789	5304
	2040	2437	3481	4874
	2050	2437	3481	4874
70 kW _{th}	2020	2140	3060	4280
	2030	1978	2828	3956
	2040	1817	2598	3634
	2050	1817	2598	3634
100 kW _{th}	2020	2130	3040	4260
	2030	1968	2809	3937
	2040	1809	2581	3617
	2050	1809	2581	3617
200 - 500 kW _{th}	2020	1810	2590	3630
	2030	1519	2174	3047
	2040	1344	1924	2696
	2050	1269	1817	2546

For the calculation of heat pump efficiencies, see chapter 4.2.

2.3.3 Wood Boilers

I. Market Prices 2020

The investment costs are taken from the 'Heating cost comparison calculator 2020' (HSLU, 2020).

Included costs items in the installation costs of pellet-fired biomass burners (HSLU 2020):

- Boiler incl. commissioning
- Regulation
- Fittings & appliances
- Heating storage
- Pellet discharge
- Pellet store (technology)
- Chimney

- Installation

The fluctuations of the market prices (min. and max. values) are chosen according to the methodology described in chapter 2.1.3I, i.e. they are set at -30 % and +40 % of the reference price.

Table 17: Reference and minimum and maximum investment costs for wood-pellet biomass burners of different capacities of thermal power for year 2020.

Wood-pellets boiler	Investment cost (CHF/kW)			
	Installation size	Minimum	Reference	Maximum
5 kW		3700	5290	7410
10 kW		2750	3930	5500
20 kW		1430	2050	2860
70 kW		510	730	1020
100 kW		540	780	1090
200 kW		390	560	790
350 kW		300	430	610
500 kW		270	380	540

Included costs items in the installation costs of wood-pellet biomass burners (HSLU 2020):

- Boiler incl. commissioning
- Regulation
- Fittings & appliances
- Equipment
- Heating storage
- Chimney
- Installation
-

Table 18: Reference and minimum and maximum investment costs for wood-chips biomass burners of different capacities of thermal power for year 2020.

Wood-chips boiler	Investment cost (CHF/kW)			
	Installation size	Minimum	Reference	Maximum
70 kW		700	1000	1400
100 kW		630	910	1270
200 kW		460	650	910
350 kW		320	460	650
500 kW		300	430	610

II. Learning curves of price projections until 2050

Wood boilers are a well-known technology and according to e.g. DEA (2024), relatively constant prices for installations can be expected.

III. Synthesis

Assuming constant investment costs, the market prices listed above are valid until 2050.

2.3.4 Gas Boiler

I. Market Prices 2020

The investment costs are taken from the 'Heating cost comparison calculator 2020' (HSLU, 2020).

The following items are summarized in the total investment costs:

- Gas boiler
- Fittings & appliances
- Chimney
- Installation
- Connection fees

The fluctuations of the market prices (min. and max. values) are chosen according to the methodology described in chapter 2.1.3I, i.e. they are set at -30 % and +40 % of the reference price.

Table 19: Reference, minimum and maximum investment costs for gas heating systems in year 2020.

Installation size	Investment cost (CHF/kW)		
	Minimum	Reference	Maximum
5 kW	3360	4800	6720
10 kW	1800	2570	3600
20 kW	920	1320	1850
70 kW	340	480	680
100 kW	300	430	600
200 - 500 kW	170	240	340

II. Learning curves of price projections until 2050

There are both, forecast studies that assume slightly falling investment costs, especially for small burners < 50 kW (DEA, 2024), and studies that assume constant prices (JRC, 2017).

In the following, we assume that investment costs will remain constant until 2050, as the market is expected to shrink due to politically desired switch from fossil fuels to renewable heating, which should lead to higher specific material costs for gas burners, and also labour costs will rise in the future. For this reason, we consider it unlikely that costs will fall.

III. Synthesis

Assuming constant investment costs, the market prices listed above are valid until 2050.

2.3.5 Oil Boiler

I. Market Prices 2020

The investment costs are taken from the 'Heating cost comparison calculator 2020' (HSLU, 2020).

The following items are summarized in the total investment costs:

- Oil burner

- Flue gas heat exchanger
- Fittings & appliances
- Neutralisation box
- Tank system
- Chimney
- Installation

The fluctuations of the market prices (min. and max. values) are chosen according to the methodology described in chapter 2.1.3I, i.e. -30 % and +40 % of the reference price.

Table 20: Reference and minimum and maximum investment costs for year 2020.

Installation size	Investment cost (CHF/kW)		
	Minimum	Reference	Maximum
5 kW	4280	6110	8550
10 kW	2300	3290	4600
20 kW	1190	1700	2380
70 kW	430	620	860
100 kW	420	600	840
200 - 500 kW	260	370	520

II. Learning curves of price projections until 2050

There are both forecast studies that assume slightly decreasing investment costs, especially for small burners < 50 kW (DEA, 2024), and studies that assume constant prices (JRC, 2017).

In the following, we assume that investment costs will remain constant until 2050, as the market is expected to shrink due to politically desired switch from fossil fuels to renewable heating, which should lead to higher specific material costs for oil burners, and it can also be assumed that labour costs will rise in the future, like it did in the past. For this reason, we consider it unlikely that costs will fall.

III. Synthesis

Assuming constant investment costs, the market prices listed above are valid until 2050.

2.3.6 Solar Thermal

I. Market Prices 2020

Investment cost for solar thermal systems with flat plate collector fields with sizes of 10, 50, 100, and 200 m² were taken from the results of the online tool “Solarrechner”⁶ of the Swiss solar energy association Swissolar. The costs given by the tool are in a similar range like costs that were gathered for the Swiss study ReSoTech (Philippen et al., 2016), which included a market overview for solar thermal systems. The investment costs that were collected for collector field sizes up to 150 m² in the ReSoTech study from 2016 are about 10 to 20 % higher than the costs given by the Solarrechner for a field size of 100 to 200 m² (influence of inflation: +1 %). Hence, they data from the ReSoTech study gives some confidence about the validity of the data given by the Solarrechner that are used here (Table 21). The fluctuations of the market prices (min. and max. values) are chosen according to the methodology described in chapter 2.1.3I, i.e. they are set at -30 % and +40 % of the reference price.

⁶ <https://www.swissolar.ch/de/angebot/tools-und-vorlagen/solarrechner>

Table 21: Reference and minimum and maximum investment costs for year 2020.

Installation size	Investment cost (CHF/m ²)		
	Minimum	Reference	Maximum
10 m ²	1410	2020	2830
50 m ²	810	1160	1620
100 m ²	690	990	1390
200 m ²	630	910	1270

II. Learning curves of price projections until 2050

The following studies have been found:

- DEA (2024)
- EU JRC (2017)

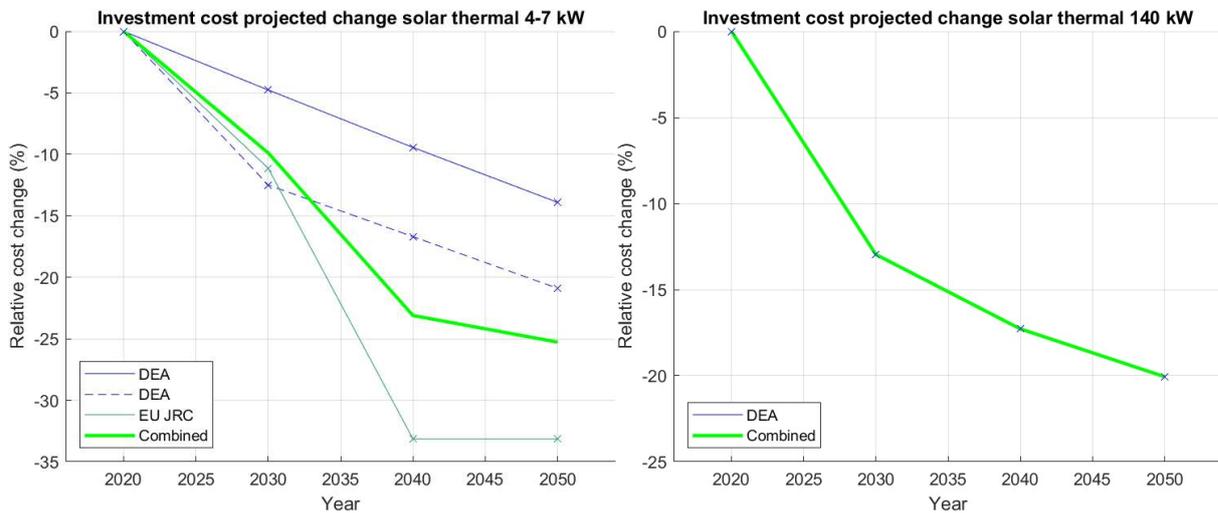


Figure 9: Study data and learning rate for solar thermal.

III. Synthesis

Table 22: Reference, minimum, and maximum investment costs for solar thermal from year 2020 to 2050.

Installation size	Year	Investment cost (CHF/m ²)		
		Minimum	Reference	Maximum
10 m ²	2020	1410	2020	2830
	2030	1271	1820	2550
	2040	1084	1553	2176
	2050	1054	1509	2115
50 m ²	2020	810	1160	1620
	2030	730	1045	1460
	2040	623	892	1246
	2050	605	867	1211
100 m ²	2020	690	990	1390
	2030	601	862	1210

	2040	571	819	1150
	2050	552	791	1111
200 m ²	2020	630	910	1270
	2030	548	792	1105
	2040	521	753	1051
	2050	504	727	1015

For the calculation of the thermal efficiency of solar thermal systems, see chapter 4.3.

2.3.7 District Heating

I. Market Prices 2020

The investment costs are taken from the 'Heating cost comparison calculator 2020' (HSLU, 2020).

The following items are summarized in the total investment costs:

- Transfer station
- Regulation
- Installation
- Connection fees

The fluctuations of the market prices (min. and max. values) are chosen according to the methodology described in chapter 2.1.3I, i.e. they are set at -30 % and +40 % of the reference price.

Table 23: Reference and minimum and maximum investment costs for year 2020.

Installation size	Investment cost (CHF/kW)		
	Minimum	Reference	Maximum
5 kW	1320	1880	2630
10 kW	1060	1520	2130
20 kW	1040	1490	2080
70 kW	860	1230	1720
100 kW	840	1200	1680
200 - 500 kW	770	1100	1530

II. Learning curves of price projections until 2050

The following study has been found:

- DEA (2024)

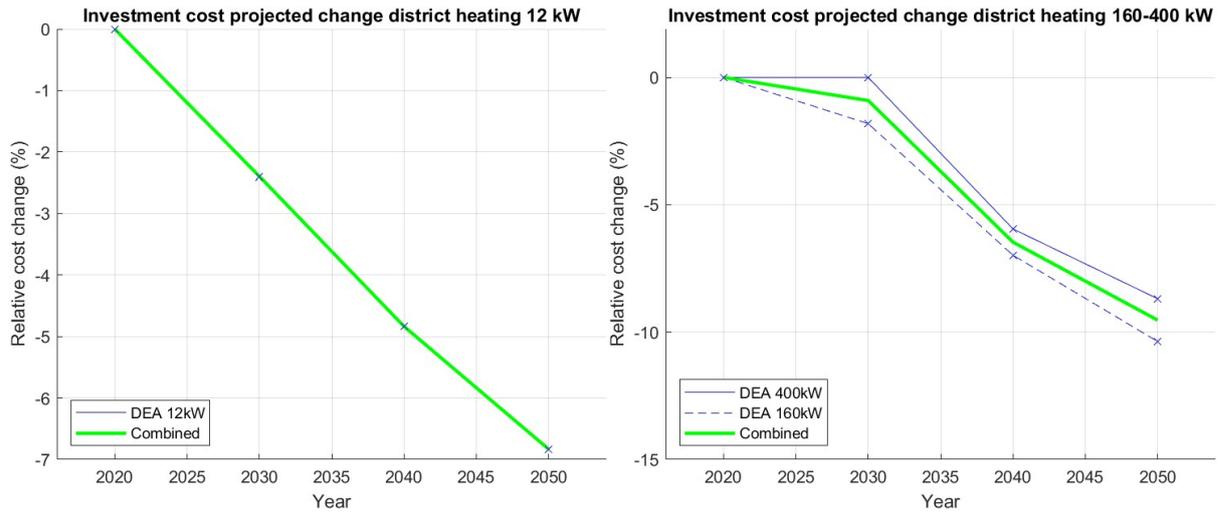


Figure 10: Study data and learning rate curve for district heating

III. Synthesis

Table 24: Reference, minimum, and maximum investment costs for district heating from year 2020 to 2050.

Installation size	Year	Investment cost (CHF/kW)		
		Minimum	Reference	Maximum
5 kW	2020	1320	1880	2630
	2030	1288	1835	2567
	2040	1256	1789	2503
	2050	1230	1752	2450
10 kW	2020	1060	1520	2130
	2030	1035	1484	2079
	2040	1009	1446	2027
	2050	988	1416	1984
20 kW	2020	1040	1490	2080
	2030	1015	1454	2030
	2040	990	1418	1979
	2050	969	1388	1938
70 kW	2020	860	1230	1720
	2030	839	1201	1679
	2040	818	1171	1637
	2050	801	1146	1602
100 kW	2020	840	1200	1680
	2030	832	1189	1665
	2040	786	1122	1571
	2050	760	1086	1520
200 - 500 kW	2020	770	1100	1530
	2030	763	1090	1516
	2040	720	1029	1431
	2050	697	995	1384

2.4 Combined heat and power (CHP) production technologies

I. Market Prices 2020

It has proven difficult to obtain market data on the various CHP technologies. In the case of fuel cells that could be used in buildings or small industry applications, there are only a few commercial suppliers for small and medium-sized systems in Switzerland. Data for fuel cell costs in EU-countries was published by JRC. Prices for waste incineration plants appear to be highly location-specific, and many publications show only preliminary figures from the approval and planning process.

The reliability of market data is to be gradually increased by obtaining further offers from manufacturers.

Literature sources used until now are:

- Fuel cell: JRC (Hofmeister and Guddat, 2017) for a 20 kW_{el} fuel cell installation and a standard offer from Innotest AG, Eschlikon, for a 4 kW_{el} fuel cell installed.
- Wood gasifier: Burkhardt GmbH
- Wood combustion: Caliqua AG (2025)
- Waste incineration: SFOE (Rytec, 2010) and Verband KVA Thurgau (2023)
- Natural gas combined-cycle CHP plant: JRC (Vatopoulos et al., 2012)

Table 25: Reference and minimum and maximum investment costs of several CHP technologies for year 2020.

Technology	Installation size	Reference unit	Investment cost (CHF/ref. unit)		
			Minimum	Reference	Maximum
Fuel cell	4 kW _{el}	kW _{el}	2900	4100	5800
	20 kW _{el}		1000	1400	2000
Wood gasifier CHP	Pellets; 390 kW _{el} , 610 kW _{th}	kW _{el}	2510	2950	3380
	Wood chips, 330 kW _{el} , 485 kW _{th}		3220	3740	4260
Wood combustion CHP	37 MW _{th} (of which 7 MW _{el} .)	kW _{th}	1324	1892	2649
Waste CHP	Range: 40 - 110 MW heat input	kW _{th}	3270	4670	6530
Natural Gas CHP (combined cycle CHP)	approx. 100 MW _{el}	kW _{el}	950	1350	1890

II. Learning curves of price projections until 2050

Since fuel cells are the only relatively new technology among the CHP technologies considered, only fuel cells are expected to follow a learning curve until 2050. Prices for the other technologies are expected to remain stable.

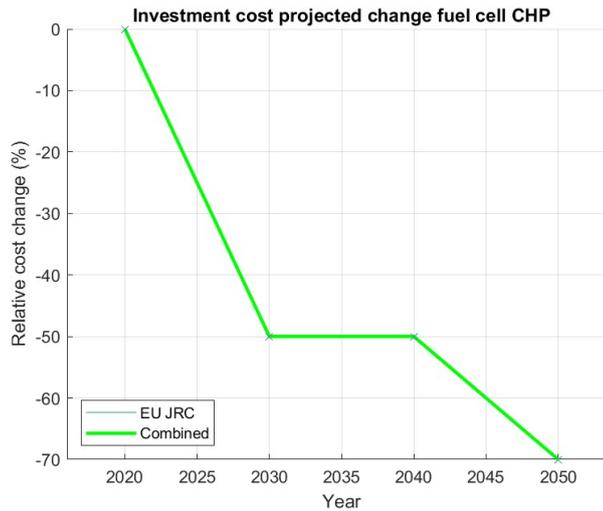


Figure 11: Study data and learning rate for fuel cell CHP.

III. Synthesis

Table 26: Reference, minimum, and maximum investment costs for several CHP technologies from year 2020 to 2050.

Technology	Installation size	Reference unit	Year	Investment cost (CHF/ref. unit)		
				Minimum	Reference	Maximum
Fuel cell	4 kW _{el}	kW _{el}	2020	2900	4100	5800
			2030	1450	2050	2900
			2040	1450	2050	2900
			2050	870	1230	1740
	20 kW _{el}		2020	1000	1400	2000
			2030	500	700	1000
			2040	500	700	1000
			2050	300	420	600
Wood gasifier CHP	Pellets; 390 kW _{el} , 610 kW _{th}	kW _{el}	2020 - 2050	2510	2950	3380
	Wood chips, 330 kW _{el} , 485 kW _{th}			3220	3740	4260
Wood combustion CHP	37 MW _{th} (of which 7 MW _{el} ,)	kW _{th}	2020 - 2050	1324	1892	2649
Waste CHP	Range: 40 - 110 MW heat input	kW _{th}	2020 - 2050	3270	4760	6530
Natural Gas CHP (combined cycle CHP)	approx. 100 MW _{el}	kW _{el}	2020 - 2050	950	1350	950

2.5 Batteries

I. Market Prices 2020

Several institutes, including local suppliers were asked, yet data was either not available or permitted to be shared. Therefore, PSI data is taken for small and large scale, whilst NREL is taken for utility scale.

The fluctuations of the market prices (min. and max. values) are chosen according to the methodology described in chapter 2.1.3I, i.e. they are set at -30 % and +40 % of the reference price, which is used for PSI data, as only a reference number is given. For NREL, there are max min values given, hence why the average is taken as the reference. The NREL values have been converted according to 2.1.2III. Labour costs account for around 6-8 % of the total costs according to NREL.

Table 27: Reference and minimum and maximum investment costs for year 2020.

Installation size	Investment cost (CHF/kW)		
	Minimum	Reference	Maximum
Small scale	1120	1600	2240
Large scale	112	160	224
Utility scale	943	2307	3671

II. Learning curves of price projections until 2050

The following studies have been found:

- PSI (Bauer, 2022)
- NREL (NREL, 2025)
- IEA (IEA, 2023)

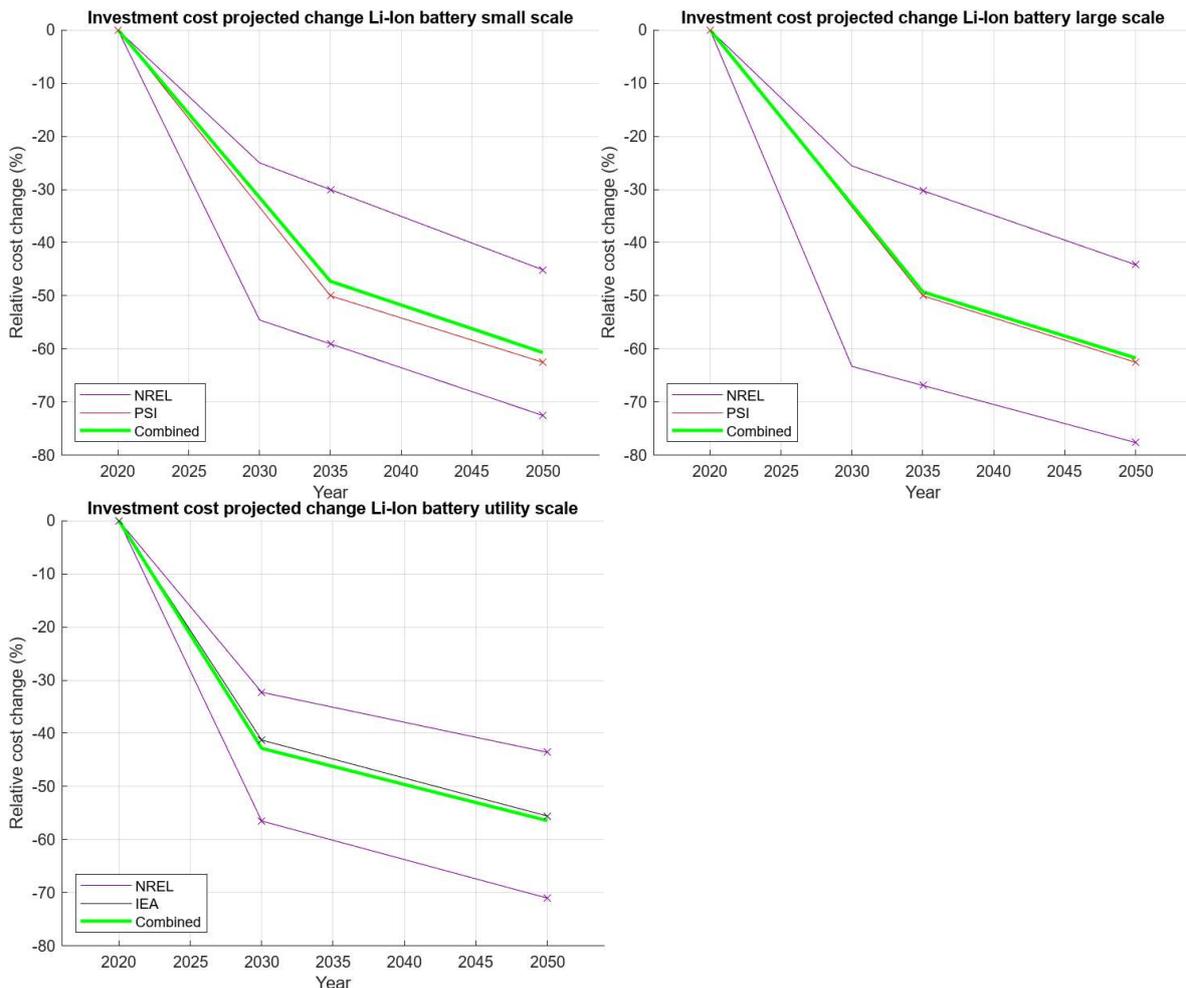


Figure 12: Study data and learning rate for Li-Ion battery storage.

III. Synthesis

Table 28: Reference, minimum, and maximum investment costs for Li-Ion battery storage from year 2020 to 2050:

Installation size	Year	Investment cost (CHF/kW _e)		
		Minimum	Reference	Maximum
Small scale	2020	1120	1600	2240
	2035	591	844	1181
	2050	441	630	881
Large scale	2020	112	160	224
	2035	57	81	114
	2050	43	61	86
Utility scale	2020	943	2307	3671
	2035	539	1319	2099
	2050	411	1005	1600

2.6 Hydrogen production technologies

Several technologies are available for producing hydrogen (H₂).⁷ Steam reforming is a technology to produce H₂ based on fossil fuels which leads to emissions of fossil carbon. In case the fossil carbon is captured and stored (CCS), the H₂ is referred to as “blue H₂” (if the fossil carbon is emitted into the atmosphere, it’s “grey” H₂). If the hydrogen is produced by means of electrolyzers by using electricity from renewable sources, the H₂ is referred to as “green H₂“. In the following, costs for production facilities for blue and green H₂ are listed, as these technologies have low carbon footprints.

I. Market Prices 2020

Costs for blue and green H₂ were often underestimated in the past, especially for the Swiss market. In April 2025, the Association of the Swiss Gas Industry, VSG, has published new cost data for blue and green H₂ for a 100 MW_{el} plant (VSG, 2025). The reported prices are adjusted for inflation in the following (-6.8 % according to 2.1.21) and are 2'980 CHF/kW_{AC} for a plant producing green H₂ and 1'490 CHF/kW_{AC} for a plant producing blue H₂.

Green H₂ is produced with electrolyzers. Different construction types of electrolyzers are possible but only two of them are mature and market-available: polymer electrolyte membrane electrolysis (PEM) and alkaline electrolysis (AEL). As differences in system costs are low for these two technologies⁸, in the following no differentiation is made.

As per primary literature source (Holst et al., 2021), the cost items taken into account in the investment costs of the electrolyser technologies are the following:

- Electrolysis Stacks
- BoP Cathode + H₂ Purification

⁷ See e.g. <https://catalysts.shell.com/en/glossary/blue-hydrogen-vs-green-hydrogen> (English) or <https://www.enbw.com/unternehmen/themen/wasserstoff/wasserstoff-farben.html> (German)

⁸ According to Holst et al. (2021), investment costs for PEM-EL systems are about 3 to 6 % higher than for AEL-systems

- BoP Anode
- Power electronics
- H₂O Purification
- Instrumentation
- Compression
- Housing
- High Voltage Transformer
- System Cooling
- Piping
- Engineering

Carbon capture and storage in case of blue H₂ is not included into the plant costs mentioned below.

Relative cost differences between installation size are derived from Holst et al. (2021) and used to estimate Swiss market prices, that are based on VSG (2025), for another installation size of 5 MW_{AC}. Both installation sizes for green H₂ and also blue H₂, see Table 29.

Table 29: Reference and minimum and maximum investment costs for hydrogen production technologies for year 2020.

Installation size	Investment cost (CHF/kW)		
	Minimum	Reference	Maximum
Electrolysers (green H ₂)			
5 MW _{AC}	2863	4090	5726
100 MW _{AC}	2086	2980	4172
Steam reforming (blue H ₂ , costs for CSS are excluded)			
100 MW	1043	1490	2086

II. Learning curves of price projections until 2050

The market prices for steam reforming technology are assumed to be stable in future as the technology is mature and is used on a large industrial scale.

For the electrolyser technology a cost reduction can be expected. Three studies with price projections are found:

- IRENA (2021b)
- IEA (2023)
- ISE (Holst et al., 2021)

The price projections for electrolysers are converted to CHF-2020 prices, but the labour cost (see chapter 2.1.2III) of the prices from abroad are not converted as the share of the labour cost in total costs is low (Holst et al., 2021, Figure 0-2).

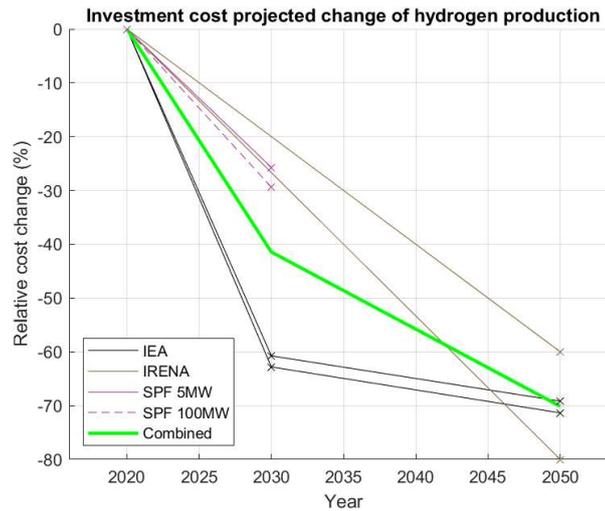


Figure 13: Price projections for electrolyser technologies (PEM and AEL).

III. Synthesis

Table 30: Reference, minimum, and maximum investment costs for hydrogen production technologies from year 2020 to 2050.

Installation size	Year	Investment cost (CHF/kW)		
		Minimum	Reference	Maximum
Electrolyser for green H ₂ , 5 MW _{AC}	2020	2863	4090	5726
	2030	1676	2395	3353
	2050	855	1222	1711
Electrolyser for green H ₂ , 100 MW _{AC}	2020	2086	2980	4172
	2030	1221	1745	2443
	2050	623	890	1246
Steam reforming with blue H ₂ , 100 MW, costs for CSS excluded	2020 – 2050	1043	1490	2086

3 Prices for imported hydrogen

I. Market Prices 2020

Hydrogen import prices to Switzerland are reported in the “Energieperspektiven 2050+” (Kemmler et al., 2022, page 48) for hydrogen delivered at the Swiss border, i.e. without taxes and margins for trade. Assuming for the latter an extra charge of 25 %, very similar costs as mentioned in Kreidelmeyer et al. (2022, page 27) are incurred. The costs from Kreidelmeyer et al. are shown in the following table as reference costs in CHF/MWh. The fluctuations of the market prices (min. and max. values) are chosen according to the methodology described in chapter 2.1.3I, i.e. they are set at -30 % and +40 % of the reference price. The costs in the literature used are given for 2017. Due to the low inflation in Switzerland between 2017 and 2020 (+0.4 %), no conversion is done here.

Table 31: Reference and minimum and maximum investment costs for imported hydrogen in year 2020.

Investment cost (CHF/MWh)		
Minimum	Reference	Maximum
238	340	475

II. Price projections until 2050

The following studies are used for the learning curves:

- EP2050+ (Kreidelmeyer et al., 2022)
- PSI (Bauer, 2022)

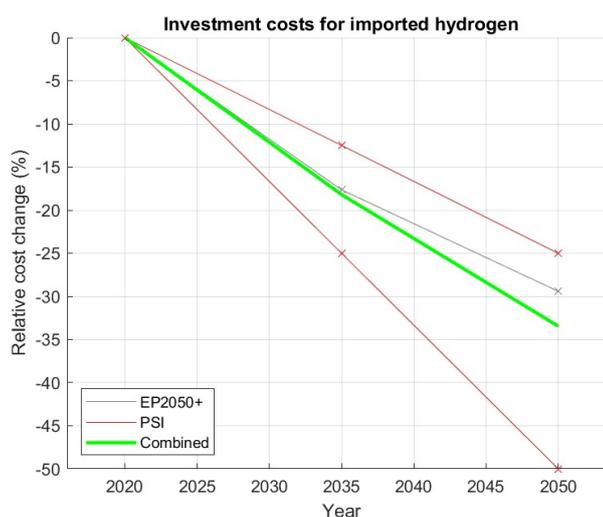


Figure 14: Study data and learning rate for imported hydrogen.

III. Synthesis

Table 32: Reference and minimum and maximum costs for imported hydrogen from year 2020 to 2050.

Year	Investment cost (CHF/MWh)		
	Minimum	Reference	Maximum
2020	238	340	475
2035	195	278	389
2050	158	226	316

4 Energy efficiencies

4.1 Electric vehicles

The efficiency of electrically powered passenger cars is reduced in winter and summer, as there is an increased energy requirement due to:

In winter:

- Heating of the interior of the car
- Reduced recuperation (at low temperatures, the battery has little to no capacity to absorb energy (reduced charging capacity due to increased internal resistance). The battery is also be protected from ageing at cold temperatures (e.g., Tesla with no regenerative braking below -4 °C (Steinstraeter et al., 2021))
- Increased rolling resistance of winter tyres

In summer:

- Cooling of the interior by the car's air conditioning system

The extent to which the energy requirement changes depends heavily on the following factors (Steinstraeter et al., 2021):

- Car model (esp. weight)
- Software version of the car
- Route composition

Quantitative data in the literature varies accordingly. As a basis for the efficiency at moderate ambient air temperatures (and cars with summer tyres) the values in Table 33, which are based on IEA (2024, page 162), can be used. No studies could be found which predict a future reduction of the energy consumption per distance travelled. Hence, we assumed here that the proposed values for efficiency are valid until 2050.

Table 33: Reference values with the range of efficiency for electric passenger cars at moderate ambient temperatures.

	Year	Efficiency (kWh/100 km)		
		Minimum	Reference	Maximum
Passenger car	2020 - 2050	14	19	23

The seasonal changes in efficiency in winter and summer are also subject to variations in literature. According to Hao et al. (2020) the electricity demand of EVs increases by 0.48 kWh per 100 km and per Kelvin of ambient temperature reduction below 10 °C. In summer, the energy demand increases by 0.46 kWh per 100 km and Kelvin above 28 °C. From a paper of Al-Wreikat et al. (2022), an increase of up to 1 kWh/100 km and Kelvin below 10 °C outside temperature can be derived for winter, whereby the values shown in the publication vary greatly. According to the paper, the efficiency decreases are at a similar rate above an ambient temperature of 25 °C. Details for both mentioned studies, see Appendix 6.2.1. As an approximation for the case the ambient temperature is outside the range of 10 °C to 25 °C, it is advisable to assume an increase in the consumption of electric passenger cars of 0.5 kWh per 100 km and per Kelvin of the ambient temperature outside the range of 10 to 25 °C.

4.2 Heat pumps

Since the coefficient of performance (COP) and thus, the electricity consumption of a heat pump (HP) is strongly affected by the temperatures of the heat source and the heat sink of the HP, it is recommended to model the electricity consumption of heat pumps such that it is temperature dependent.

In Annex 6.2.2, an approach is given to calculate the electricity consumption of air-source heat pumps (ASHP) and ground-source heat pumps (GSHP) dependent on the sink and source temperature. Table 34 exemplarily shows the influence of the sink and source temperatures on the COP for the approach suggested in the Annex for some typical pairs of temperatures. The strong influence of the temperatures on the electrical efficiency of an ASHP can be seen.

Table 34: Examples for calculated COP of an ASHP at different incoming air (A) temperature and outgoing water (W) temperature showing the strong temperature dependency of the COP (calculation according to Annex 6.2.2).

Conditions for the air-source HP (the figures indicate temperatures in °C)	Resulting COP
A-7 / W35	2.71
A+2 / W35	3.28
A+7 / W35	3.71

Although it is recommended to calculate the COP of a HP for each timestep of a simulation separately – e.g. with the above presented approach – in the following, typical Seasonal Performance Factors (SPF) are given as reference values for the performance of heat pumps. The SPF of a heat pump is its annual efficiency and is the ratio of heat delivered and electricity needed to deliver this heat.⁹ The SPF for ASHPs installed in a multi-family building for heating and hot water supply was measured in the range of 2.72 to 3 throughout the year in the project “CombiVolt” carried out by (Bamberger et al., 2019). From the study of heat pump test fields by NTB Buchs, the average SPF for ASHP was measured to be 3.4 for supplying both heating and hot water demand (Kuster et al., 2020). For the heating system with GSHP (with geothermal probes), the SPF was measured using Concise Cycle Tests (CCT) for a 12-day test period to meet the heating and hot water demand within the SOL-HEAP project and was observed in the range of 4 to 4.8 (Haller et al., 2013) for five different tested systems. Therefore, the average SPF of 4.42 is taken as the reference value for GSHPs with geothermal probes. For (ground-) water-source HP (WSHP), the reference SPF and its range is taken from the study of NTB Buchs. The average SPF was measured to be 4.6 and the range was observed to be 4.3 and 4.9.

Table 35 shows the reference SPF and its range based on the measured and calculated values within the above-mentioned projects. All values are assumed to be same in the coming decades until 2050.

Table 35: Reference seasonal performance factor for different types of heat pumps.

Heat pump type	SPF		
	Minimum	Reference	Maximum
ASHP	2.72	3	3.4
GSHP	4	4.42	4.8
WSHP	4.3	4.6	4.9

⁹ several choices for the system boundaries are possible, see e.g. [Link](#), page 20

4.3 Solar thermal collectors

As the heat gains of a solar thermal system is strongly dependent of the type of solar collector (plate collector, vacuum tubes, covered/uncovered etc.), of the solar irradiation in the collector plane, the ambient temperature, and the collector fluid temperature, it is necessary to calculate the gains dependent on these quantities. For a simple approach including a linearization of the needed equations see e.g. the oemof-model (on GitHub via ¹⁰; details, see Möller (2020)).

¹⁰ https://oemof-thermal.readthedocs.io/en/latest/solar_thermal_collector.html

5 References

- Al-Wreikat, Y., Serrano, C., Sodr , J.R., 2022. Effects of ambient temperature and trip characteristics on the energy consumption of an electric vehicle. *Energy* 238, 122028.
<https://doi.org/10.1016/j.energy.2021.122028>
- Bamberger, E., Haberl, R., Reber, A., Haller, M.Y., Battaglia, Mattia, 2019. CombiVolt - Steigerung des Photovoltaik Eigenverbrauchs durch intelligente Wärmepumpen (Schlussbericht BFE). SPF Institut für Solartechnik , OST Otschweizer Fachhochschule.
- Bauer, C., 2022. Electricity storage and hydrogen – technologies, costs and impacts on climate change. PSI.
- Bauer, C., 2019. Potentials, costs and environmental assessment of electricity generation technologies - Data update.
- Bauer, C., Hirschberg, S., Y. Bäuerle, S. Biollaz, A. Calbry-Muzyka, B. Cox, T. Heck, M. Lehnert, A., Meier, H.-M. Prasser, W. Schenler, K. Treyer, F. Vogel, H.C. Wieckert, X. Zhang, M. Zimmermann, V. Burg., G. Bowman, M. Erni, M. Saar, M.Q. Tran, 2017. Potentials, costs and environmental assessment of electricity generation technologies. PSI, WSL, ETHZ, EPFL, im Auftrag des Bundesamts für Energie BFE.
- Caliqua, 2025. Holzheizkraftwerk Sisslerfeld, www.caliqua.ch/referenz/hhkw-sisslerfeld-dsm (May 2025).
- DEA, 2024. Technology Data, Heating Installations, Technology descriptions and projections for long-term energy system planning. Danish Energy Agency.
- DEA, 2021. Technology Data for Individual Heating Plants, Version 5 - Data Sheets for Individual Heating Plants [WWW Document]. URL <https://ens.dk/media/3333/download>
- EIA, 2024. Capital Cost and Performance Characteristics for Utility-Scale Electric Power Generating Technologies.
- EnergieSchweiz, 2021. Photovoltaikmarkt: Preisbeobachtungsstudie 2020, Abschlussbericht, 30. Juni 2021.
- Haller, M.Y., Haberl, R., Reber, A., Carbonell Sanchez, D., Frank, E., 2013. Solarthermie-Wärmepumpen-Kombisysteme “SOL-HEAP” (BFE Schlussbericht No. SI/500494-01). SPF Institut für Solartechnik , OST Otschweizer Fachhochschule.
- Hao, X., Wang, H., Lin, Z., Ouyang, M., 2020. Seasonal effects on electric vehicle energy consumption and driving range: A case study on personal, taxi, and ridesharing vehicles. *J. Clean. Prod.* 249, 119403.
<https://doi.org/10.1016/j.jclepro.2019.119403>
- Hofmeister, M., Guddat, M., 2017. 2017 Techno-economics for smaller heating and cooling technologies. European Commission, Joint Research Centre (JRC).
- Holst, M., Stefan Aschbrenner, Tom Smolinka, Christopher Voglstätter, Gunter Grimm, 2021. Cost Forecast for Low Temperature Electrolysis - Technology Driven Bottom-Up Prognosis for PEM and Alkaline Water Electrolysis Systems. Fraunhofer-Institute for Solar Energy Systems ISE.
- HSLU, 2020. Heizkostenvergleichsrechner, Version 25 (2020), Hochschule Luzern, Transmission via e-mail. Hochschule Luzern, Transmission via e-mail.
- IEA, 2024. Global EV Outlook 2024.
- IEA, 2023. World Energy Outlook 2023.
- IRENA, 2021a. Renewable Power Generation Costs in 2021.
- IRENA, 2021b. Making the breakthrough: Green hydrogen policies and technology costs.
- IRENA, 2019. Future of Wind.
- IRENA, 2017. Geothermal power: Technology brief.
- JRC, 2017. Techno-economic projections until 2050 for smaller heating and cooling technologies in the residential and tertiary sectors in the EU [WWW Document]. URL <https://data.jrc.ec.europa.eu/dataset/jrc-etri-techno-economics-smaller-heating-cooling-technologies-2017>
- Kemmler, A., Almut Kirchner, Sven Kreidelmeyer, Alexander Piégsa, Thorsten Spillmann, Hans Dambeck, Hanno Falkenberg, Sebastian Lübbers, Andreas Brutsche, Dina Tschumi, Julia Thurau, Florian Ess, Christoph Thormeyer, Hans-Jörg Althaus, Brian Cox, Benedikt Notter, Martin Jakob, Ulrich Reiter, Giacomo Catenazzi, Benjamin Sunarjo, Lia Weinberg, Jonas Müller, Larissa Lienhard, 2022. Energieperspektiven 2050+. Bern.
- Kreidelmeyer, S., Hans Dambeck, Andreas Kemmler, Alexander Piégsa, Hans-Jörg Althaus, Brian Cox, 2022. Energieperspektiven 2050+, Exkurs Wasserstoff: Hintergrund zum Einsatz in den Szenarien der Energieperspektiven 2050+. Prognos AG, INFRAS AG, TEP Energy GmbH, Ecoplan AG im Auftrag des Bundesamts für Energie, Bern, Schweiz.

- Kuster, W., Prinzing, M., Berthold, M., Eschmann, M., Bertsch, S., 2020. Feldmessung von Wärmepumpen-Anlagen Ergebnisse Periode 2016-2019. . Juni.
- Möller, C., Franziska Pleißner, Christoph Pels Leusden, Jakob Wolf, Jann Launer, Silke Köhler, Editha Kötter, 2020. Integration des Wärmesektors in das Open-Source-Modellierungswerkzeug ,oemof[®] (open energy modelling framework), Abschlussbericht. Reiner Lemoine Institut, Beuth Hochschule für Technik, Berlin.
- NREL, 2025. Utility-Scale Battery Storage | Electricity | 2021 | ATB | NREL [WWW Document]. URL https://atb.nrel.gov/electricity/2021/utility-scale_battery_storage (accessed 5.19.25).
- Perch-Nielsen, S., Müller, M., Zumwald, J., Krüger, M.-J., 2015. Preise von Luft/Wasser Wärmepumpen, Analyse der Preise von Luft/Wasser Wärmepumpen und der Qualität ihrer Installation. Ernst Basler + Partner AG im Auftrag von EnergieSchweiz.
- Philippen, D., Caflisch, M., Brunold, S., Haller, M., 2016. ReSoTech – Reduktion der Marktpreise solarthermischer Anlagen durch neue technologische Ansätze – Teil 1: Potenzialanalyse und Lösungsansätze (Schlussbericht), Im Auftrag des Bundesamts für Energie BFE. SPF Institut für Solartechnik, Bern.
- Reservekraftwerk Birr - Faktenblatt – Gemeinde Birr [WWW Document], 2022. URL <https://www.bfe.admin.ch/bfe/de/home/versorgung/stromversorgung/winterreserve.exturl.html/aHR0cHM6Ly9wdWJkYi5iZmUuYWRTaW4uY2gvZGUvcHVibGljYX/Rpb24vZG93bmxvYWQvMTEuNjA=.html> (accessed 7.7.25).
- Rytec, 2010. Berechnung der Referenzanlagen KVA für die kostendeckende Einspeisevergütung, Rytec AG im Auftrag des Bundesamts für Energie.
- Steinstraeter, M., Heinrich, T., Lienkamp, M., 2021. Effect of Low Temperature on Electric Vehicle Range. World Electr. Veh. J. 12. <https://doi.org/10.3390/wevj12030115>
- Vatopoulos, K., Andrews, D., Carlsson, J., Papaioannou, I., Zubi, G., 2012. Study on the state of play of energy efficiency of heat and electricity production technologies. Publ Off. Eur Union 1–102.
- Verband KVA Thurgau, 2023. Ersatz KVA Thurgau - Zuverlässige Entsorgung und klimafreundliche Energie für die Bodenseeregion, Abstimmungsbotschaft zuhanden der Verbandsgemeinden.
- VSG, 2025. Barometer erneuerbare Gase, Unabhängige Bewertung der Entwicklungen zu erneuerbaren Gasen in der Schweiz (No. 7). Verband der Schweizerischen Gasindustrie.

6 Appendix A

6.1 Calculation of Costs

6.1.1 Hydropower

For small installation types ($\leq 10\text{MW}$) the source [Hydropower | Electricity | 2023 | ATB | NREL](#) was used where in the first interactive table following values for the costs were found if the parameter CAPEX is used.

The Conservative Curve shows the maximal Investment costs, and the Advanced curve shows the minimal Investment curve.

In [Capital Cost and Performance Characteristics for Utility-Scale Electric Power](#) Generating Technologies on Page III in Entry 12 of the Table 1-2, average costs for small hydropower can be found there. Since the study was conducted by an American company, the costs may vary when applied to Switzerland due to differences in salary levels.

For the section Hydropower – Run of river, the PSI study was used:

<https://www.psi.ch/sites/default/files/import/lea/HomeEN/Final-Report-BFE-Project.pdf>

For small scale plants, data can be found on page 153.

And for large scale plants on page 151.

6.1.2 Air-source heat pumps

Reasons why the costs for ASHP from Perch-Nielsen et al. (2015) for the year 2015 should also be valid for 2020:

- According, to the “Swiss Construction Price Index” statistics (Figure 15) the costs stayed stable between 2015 and 2020
- The Swiss inflation rate between 2015 and 2020 was at a very low level of 0.7 % within 5 years (BfS)
- The fact that the prices for ASHP were stable during this period corresponds to the experience of the FWS (Fachvereinigung Wärmepumpen Schweiz) (communicated via e-mail). As well after 2020: the sharp increase from 2020 to 2024 in Figure 15 (+15%) is also in line with the FWS’s experience (+18%).

This means that it is justified to use the prices from the SwissEnergy study in our study for 2020.

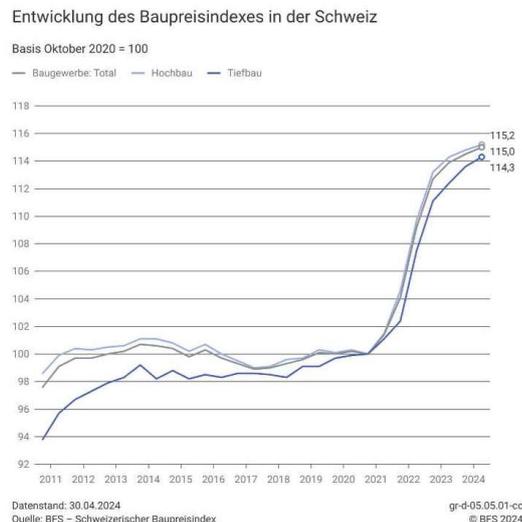


Figure 15: Swiss Construction Price Index (BFS).

6.1.3 Rooftop PV

Figure 16 shows the data from the report of EnergieSchweiz (2021), page 27.

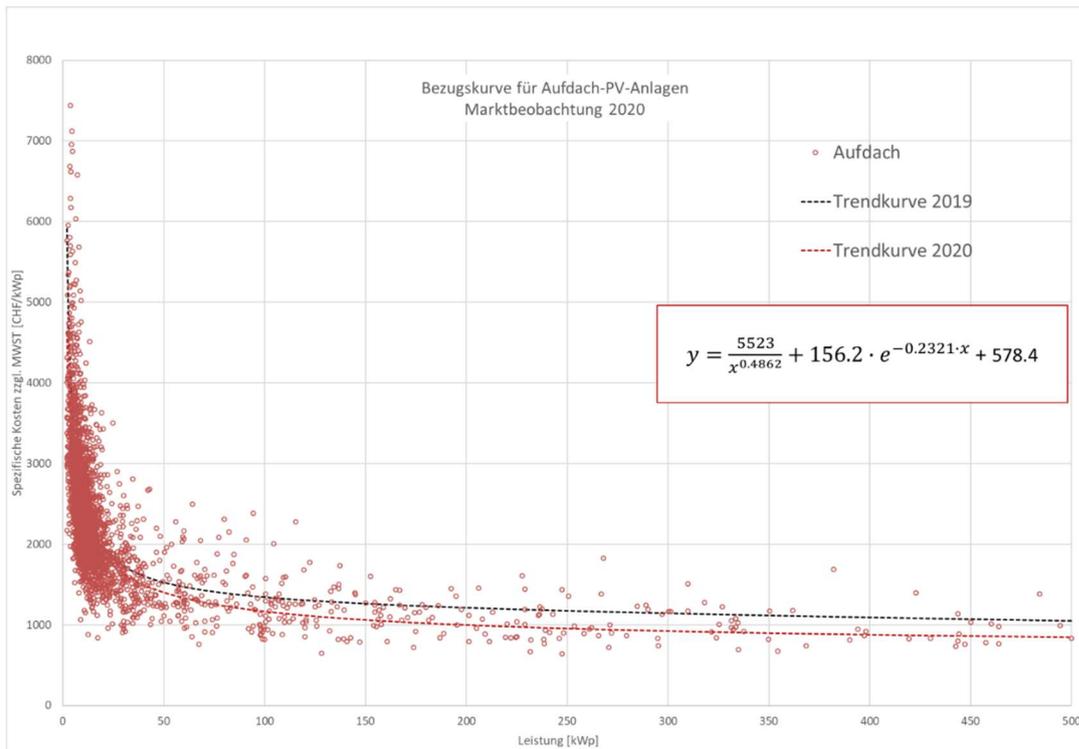


Figure 16: Cost gathering by EnergieSchweiz for the year 2020.

6.2 Calculation of efficiencies

6.2.1 Efficiency of electric vehicles

For the estimation of the influence of the season on the energy consumption of electric cars, the following graphs were used from the references. The slopes of the averages (black lines) were estimated and are used in the report as a basis for the dependence of the efficiency of EVs on the outside temperature.

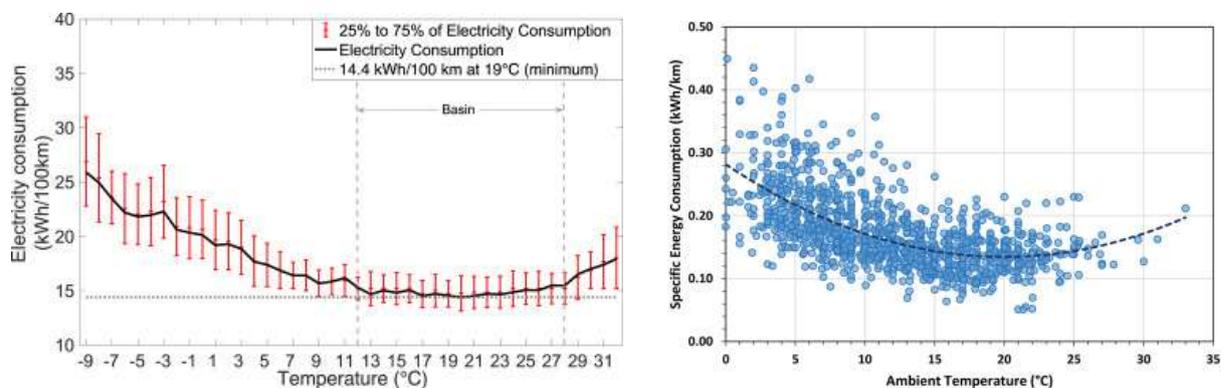


Figure 17: Examples from literature for the influence of the ambient temperature on the efficiency of electric cars (left: (Hao et al., 2020), right: (Al-Wreikat et al., 2022)).

6.2.2 Temperature dependency of the efficiency of ASHP and GSHP

To calculate the electricity consumption of air-source heat pumps and ground-source heat pumps depending on the temperatures of the heat source and sink at a given time, we suggest the following approach:

General definitions:

The temperature of the refrigerant (ref) in the evaporator (evap) and condenser (cond) is given by:

$$T_{\text{ref,evap}} = T_{\text{source,in}} + T_0 - \Delta T_{\text{hpHX}}$$

$$T_{\text{ref,cond}} = T_{\text{sink,out}} + T_0 + \Delta T_{\text{hpHX}}$$

where:

- $T_0 = 273.15$ K (absolute temperature conversion)
- $T_{\text{source,in}}$ is the evaporator inlet temperature of the heat source (air or ground)
- $T_{\text{sink,out}}$ is the condenser outlet temperature of the heating water
- ΔT_{hpHX} is the temperature loss in the heat exchanger, where typical values are:
 - $\Delta T_{\text{hpHX, air}} = 5$ K
 - $\Delta T_{\text{hpHX, ground}} = 3$ K

The temperature difference of the refrigerant ($\Delta T_{\text{HP,ref}}$) between the evaporating temperature and the condensing temperature is defined as:

$$\Delta T_{\text{HP,ref}} = \max(T_{\text{ref,cond}} - T_{\text{ref,evap}}, 15\text{K})$$

This ensures a minimum temperature difference of 15 K to prevent unreasonably high efficiency values.

The Carnot efficiency of the heat pump is then calculated as:

$$\varepsilon_{\text{Carnot}} = \frac{T_{\text{ref,cond}}}{\Delta T_{\text{HP,ref}}}$$

The coefficient of performance of a real heat pump is given by:

$$COP = \eta_{\text{HP}} \cdot \varepsilon_{\text{Carnot}}$$

where:

- η_{HP} is the heat pump quality factor, where we assume here:
 - $\eta_{\text{HP,air}} = 0.45$
 - $\eta_{\text{HP,ground}} = 0.5$

Electrical power calculation:

The electrical power required by the heat pump is computed as:

Air source heat pumps:

$$P_{\text{el,HP}} = \begin{cases} \frac{P_{\text{Heating}}}{COP^{0.5}}, & \text{if } T_{\text{evap}} < 5^{\circ}\text{C} \text{ and } P_{\text{Heating}} \neq 0 \\ \frac{P_{\text{Heating}}}{COP} & \text{if } P_{\text{Heating}} \neq 0 \\ 0, & \text{if } P_{\text{Heating}} = 0 \end{cases}$$

where P_{Heating} is the thermal power supplied by the condenser. The definition by cases ensures a performance correction when the evaporator temperature is below 5 °C (defrosting needed) and makes sure division with 0 is avoided.

Ground source heat pumps:

Ground-source heat pumps are not affected by low outside temperatures, but a division with 0 is also avoided, in this case:

$$P_{\text{el,HP}} = \begin{cases} \frac{P_{\text{Heating}}}{COP} & \text{if } P_{\text{Heating}} \neq 0 \\ 0, & \text{if } P_{\text{Heating}} = 0 \end{cases}$$