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Supporting building heat decarbonization with heat Pumps: Analysis of subsidy schemes in Swiss leading cantons

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ABSTRACT

Heat pumps (HP) are a key solution for decarbonizing building heating systems. However, their adoption remains slow due to high upfront costs, technical challenges, and limited financial support. This study examines the impact of mandatory requirements to transition to HPs, combined with subsidy schemes, based on real-world case studies from two Swiss cantons. Two approaches of establishing the subsidy level are distinguished: i) LCOH-based subsidies, bringing down the levelized cost of renewable heating to the level of a gas boiler; and ii) Capital expenditure-based (CapEx-based) subsidies, which, in pure form, are designed to entirely repay the extra investment cost for installing the renewable heating system relative to a gas boiler. We find that current subsidy levels cover only a small portion of the additional investment costs compared to gas boilers and in most cases, they somewhat exceed the LCOH-based subsidy level. Today's subsidy levels can be considered as good compromise between the two ways studied (i and ii), while opportunities are shown for some adaptations in the studied regulatory frameworks. These findings provide practical guidance for designing effective subsidy schemes for other Swiss cantons and other countries aiming to decarbonize building heating systems.

1. Introduction

1.1. Background

In response to the Paris Agreement, many countries, regional authorities and cities have set ambitious goals to achieve climate neutrality (Agreement, 2015). A critical component of these goals is the decarbonization of heating of buildings, which are nowadays predominantly fuelled by oil and gas and are responsible for more than a third of the greenhouse gas emissions in Europe (European Commission, 2023a). There is hence an urgent need to transition from fossil fuel-based heating to decarbonised alternatives.

Heat pumps (HPs) have been proposed as a pivotal solution for reducing greenhouse gas emissions (GHG) (Abbasi et al., 2021). When applied for buildings, they mostly utilize ambient heat and offer improved efficiency. When paired with low-carbon electricity, HPs nearly completely avoid GHG emissions per kWh of thermal energy delivered compared to traditional oil or gas boilers (Thomaβen et al., 2021). Among the types of HPs, air source heat pumps (ASHP) are the most common, extracting heat from ambient air, while ground source heat pumps (GSHP) are equipped with ground heat exchangers, such as boreholes, to harness geothermal energy (Karytsas, 2018). Other ambient heat sources which can be used by heat pumps are lake water, river water and groundwater. The EU's REPowerEU plan, aligning with the Green Deal goals, aims to cut fossil fuel imports, double the deployment rate of heat pumps in buildings, and speed up the deployment of large district heating and cooling networks (European Commission, 2022). The Green Deal Industrial Plan also targets the installation of at least 30 million additional heat pumps by 2030 (European Commission, 2023b).

Zuberi et al., 2021 show that individual heat pump systems (and some district heating systems) are close to economic viability based on levelized cost in comparison to fossil fuel boilers; they conclude that barriers such as high upfront costs need to be addressed by suitable policy measures. Based on an extensive review, Gaur et al., 2021) prepared an overview of policies related to heat pumps in thirteen countries, and they summarize the main barriers faced by heat pump systems (including policy uncertainty, insufficient public understanding, financial factors, regulatory barriers and technological challenges); however, they do not evaluate individual policies in detail and instead draw more

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generic conclusions. Barnes and Bhagavathy (2020), on the other hand, specifically analyse the effect of taxes and levies in UK on the economic viability of heat pumps. They also discuss further challenges, in particular the high upfront cost, heat pump efficiency as well as the need to reduce investment costs through increased deployment (e.g., by public procurement).

While the Nordic countries, especially Finland, Norway and Sweden, are known for their high diffusion of heat pumps (Rosenow et al., 2022), there is very little international literature on the experience made with specific policy measures which enabled the transition. Among the limited information that can be found, Rosenow, 2023 identified as drivers the sustained commitment to reduce heating oil dependency since the 1970s, relatively low electricity prices and high levels of carbon taxation next to government incentives. Further important policy measures are regulations (building standards or bans), as well as consumer acceptance (e.g. information campaigns, training, quality standards; Rosenow et al., 2022; see also (Majuri, 2016).

Overall, most of the studies point to the need for subsidies but do not discuss which subsidy level would be adequate; they typically neither share experience made with the chosen policy design and tend to limit themselves to rather generic comparisons. Against this background, the experience made in Swiss cantons leading the decarbonization of the heating sector can offer valuable insights.

Switzerland's building stock primarily consists of older buildings. While new constructions comply with stringent energy efficiency standards, existing buildings typically are characterized by higher thermal energy demand and they predominantly make use of oil and gas heating systems. For instance, around two-thirds of properties in the Canton of Basel-Stadt (Basel City) still rely on fossil fuel-based heating systems (Office, n.d.). Yet, the adoption of HPs in Switzerland has been slow, and without dedicated policies to support decarbonization, there is a risk that aging fossil fuel-based systems will be replaced with similar technologies. In the last ten years, for the entire Swiss residential building stock, the existing heating systems were replaced by heat pumps in only 20 % of the energy retrofits performed (Cozza et al., 2022).

The cost of heat pumps, both capital and operational, has been identified as a major factor influencing consumer demand, alongside education, income, environmental values, comfort, and performance issues (Barnes and Bhagavathy, 2020; Kokoni and Leach, 2021). Generally, the investment costs of HPs are higher than those of comparable fossil fuel boilers. On the other hand, HPs typically offer reduced operating costs through increased system efficiency, which can offset the high upfront cost in the long term. GSHPs cost more than ASHPs due to the drilling required for boreholes but GSHP are more energy efficient than ASHPs and consequently also contribute more to supply security while reducing the impact on electric grids and the associated need for grid reinforcement.

Recognizing these barriers, subsidies and other incentives have become crucial for promoting the adoption of renewable heating systems. In Switzerland, the Federal Council's Swiss Energy Strategy (Energieperspektiven 2050) predicts that by 2050, heat pumps in private households and the service sector will increase from 0.3 million today to approximately 1.5 million. Several policy measures have been introduced to boost the uptake of HPs. Within the Swiss federalist system, energy and climate policy measures with respect to buildings are predominantly implemented at the cantonal level, with harmonisation efforts across the 26 cantons. The Conference of Cantonal Energy Directors (EnDK) (Energiedirektoren konferenz) plays a vital role in aligning approaches and developing common policies. Individual cantons can implement stricter regulations based on local needs and ambition.

The Canton of Basel-Stadt, for instance, has been a pioneer in Swiss energy policy, adopting progressive environmental and climate strategies for decades. Its 2017 Energy Act mandates a switch to a renewable heating system whenever a heating system is newly constructed or replaced, with the installation of oil or gas systems only being permitted under exceptional circumstances (SG 772.110). Subsidies in the Canton of Basel-Stadt help compensate the additional investment costs for transitioning to renewable heating systems. Exemptions are allowed only if the renewable energy solution is technically not "feasible" or if it leads to additional costs. To apply for an exemption for financial reasons, building owners must prove that the subsidy cannot fully compensate for the additional investment costs of renewable systems compared to the reference investment costs of a fossil fuel-based system. The comparison also includes extra costs for covering at least 50 % of domestic hot water use by a renewable energy source. If a fossil fuel heating is allowed to be reinstalled due to this exemption clause, building owners are additionally required to carry out "suitable efficiency measures" on the building envelope or the building's energy system with the objective to reduce the use of fossil fuels by 20 % compared to the initial situation without improvements in the energy performance of the building. Such additional measures include for example the insulation of the roof or window replacement. Energy efficiency measures already carried out previously are taken into account and can allow for not undertaking further measures. The efficiency measures required to be undertaken are defined on a case-by-case basis by the cantonal authorities based on a variety of options together with the decision to grant an application of the exemption clause, following a related request by the building owner. Since implementing the Energy Act, the Canton of Basel-Stadt has gathered data on adopters of renewable heating solutions, exemptions granted, and project costs, providing invaluable insights for other cantons and countries with similar climatic and building profiles.

Similarly, the Canton of Geneva offers subsidies for the installation of ASHP and GSHP, but building owners were still allowed to re-install fossil fuel boilers in the period studied (2017–2023) and the level of financial support has been generally lower than in the Canton of Basel-Stadt. In contrast, the Canton of Zurich's regulations stipulate that only renewable energy systems must be used when replacing heating systems in existing buildings, provided that it is technically feasible and does not increase life cycle costs by more than 5 %. Contrary to the Cantons of Basel-Stadt and Geneva, the Canton of Zurich hence applies an exemption criterion based on the Levelized Cost of Heat (LCOH) rather than investment costs (Heating cost calculator). A life cycle cost calculator (Heating cost calculator) is provided to compare the LCOH of renewable systems with that of fossil fuel-based heating systems.

1.2. Aim and scope

This study first describes the adoption of renewable heating in the Canton of Basel-Stadt and then evaluates the cost-effectiveness of heat pumps compared to gas boilers in both the Canton of Basel-Stadt as well as the Canton of Geneva. Our research addresses the following questions.

- How did the replacement of oil and gas boilers by renewable heating evolve in the Canton of Basel-Stadt after its 2017 Energy Act and what are the characteristics of buildings which have been equipped with renewable heating as opposed to exempted buildings?
- How much subsidy is required to ensure the cost-effectiveness of heat pumps for building owners, considering financial viability based on investments costs or levelized cost (LCOH)?

By addressing these questions, the study aims to contribute to the broader discussion on sustainable energy policy and to the provision of practical solutions for facilitating the decarbonization of building heating systems. Among the renewable heating options, connection to district heating is often the most favored solution but it is subject to availability of infrastructure. Wood combustion in individual heating systems is less common in cities for reasons of air pollution, related regulation (location-specific) and space requirement for wood storage. In view of the rise of wood-based heating systems (especially in district heating), a potential future wood shortage and the risk of surging prices are further concerns. This study therefore focuses on exploring the potential of ASHP and GSHP as decentralized solutions to decarbonize heat supply in Swiss buildings.

2. Material and methods

2.1. Methods

In this section, the methods used in the study are introduced.

2.2. LCOH calculation

To compare the life cycle costs between different heating systems, the levelized cost of heat (LCOH) is calculated for heat pumps and gas boilers. This framework provides the basis for evaluating the cost-effectiveness of heat pumps. The following formula is used:

$$LCOH = \frac{CapEx \times f_{annu} + OpEx}{Q_{annu}} \quad (1)$$

where Q_{annu} indicates the annual heat output by the heating system. *CapEx* represents the investment costs, including both the device cost and the installation cost. f_{annu} is the annuity factor, which depends on the lifetime of the system n and the discount rate i. *OpEx* indicates the annual operational costs, including energy costs and maintenance costs.

The annuity factor f_{annu} is calculated as follows:

$$f_{annu} = \frac{i}{1-(1+i)^{-n}} \quad (2)$$

The operational costs *OpEx* are calculated as:

$$OpEx = CapEx \times f_m + \frac{Q_{annu}}{\eta} \times c \quad (3)$$

Where f_m is the annual maintenance factor of the system, η is the efficiency and c is the unit cost of final energy, i.e., electricity or gas.

The investment costs *CapEx* for ASHP, GSHP, and gas boilers are derived by fitting empirical data on investment costs and heating system capacity acquired in the Canton of Basel-Stadt and the Canton of Geneva. The results are presented in Section 3.1.

Other parameters used for LCOH calculation are presented in Table 1. The energy prices for electricity and gas are based on 2024 rates. For electricity, the prices vary across consumption categories depending on the building type (household or commercial) and the annual consumption. The energy prices of 2024 are considered to reflect average future prices, as they are already relatively high, considering the extraordinary development in previous years. The range of electricity prices across all consumption categories are shown in Table 1. Detailed electricity prices are presented in Appendix A.

2.3. Subsidy scenarios: based on investment costs and LCOH

To quantify the required subsidies ensuring unrestricted economic viability of renewable heating systems, i.e., avoiding any additional costs for building owners, two approaches are considered: CapEx-based subsidies and LCOH based subsidies.

For CapEx-based subsidies, the subsidy is designed to entirely repay the extra cost for installing the renewable heating system, i.e. ASHP or GSHP, compared with an equivalent gas boiler, calculated as:

$$Sub_{CapEx} = CapEx_{renew} - CapEx_{boiler} \quad (4)$$

For LCOH-based subsidies, it is assumed that the subsidized LCOH of renewable heating system matches that of an equivalent gas boiler. The required LCOH-based subsidy can be calculated using the following equation:

$$(CapEx_{renew} - Sub_{LCOH}) \times f_{annu,renew} + OpEx_{renew} = CapEx_{boiler} \times f_{annu,boiler} + OpEx_{boiler} \quad (5)$$

Table 2 lists the subsidies provided by the Cantons of Basel-Stadt and Geneva. Special subsidies are available for the installation of heat distribution systems (piping) in order to incentivize the transition from electric resistance heating to heat pumps. This case is not considered, as the focus of the present research is on the transition from fossil fuels to renewable energy.

2.4. Estimating heat demand

To evaluate the cost-effectiveness of renewable heating systems at cantonal level, it is necessary to estimate the annual heat demand and required power capacity for each building. An existing model (Schneider

Table 1
Parameters used for LCOH calculation.

	ASHP	GSHP	Gas boiler	Source
Discount rate i	1.75 %	1.75 %	1.75 %	(BWO and für, n.d.)
Lifetime n	20-year	HP: 20-year Borehole: 40-year	20-year	("Heating cost calculator," n. d.)
Maintenance factor f_m	1 %	1 %	2 %	("Heating cost calculator," n. d.)
Efficiency η	2.5[a]	3.5[a]	0.85	("Heating cost calculator," n. d.)
Final energy price c (electricity or gas)	Basel-Stadt: 0.31–0.35 CHF/kWh Geneva: 0.25–0.30 CHF/kWh	Basel-Stadt: 0.31–0.35 CHF/kWh Geneva: 0.25–0.30 CHF/kWh	Basel-Stadt: 0.1779 CHF/kWh Geneva: 0.1406 CHF/kWh	(SFSO (Swiss Federal Statistical Office), 2024)

CHF = Swiss Franc (In average, 1 CHF was equivalent to 0.98 EUR between 2021 and 2023.).
[a] This value represents the coefficient of performance (COP) which represents the ratio of heat supplied to electricity consumed.

Table 2
Current cantonal subsidies for replacement of fossil fuel-based heating systems by heat pumps.

	Canton of Basel-Stadt	Canton of Geneva
ASHP	CHF 8′000.- + CHF 250.-/kW	CHF 3′000.- + CHF 400.-/kW
GSHP	CHF 25′500.- + CHF 450.-/kW	CHF 3′000.- + CHF 800.-/kW
Initial installation of heat distribution system CHF	3′000.- + CHF 200.-/kW	3′000.- + CHF 400.-/kW
Upper limit	No more than 40 % of investment cost	

Note: The subsidies are calculated for a maximum of 50 W_{th} installed nominal power per m^2 of energy reference area (which is defined as the heated floor area and is abbreviated as ERA). No subsidy is granted beyond this threshold level.

et al., 2017) is employed to simulate the hourly heat demand load curve for space heating and domestic hot water across different buildings. This bottom-up model links heat demand statistics to building categories and construction periods based on large datasets of measured heat demand of around 27,000 buildings. The predicted heat demand is adapted considering the local climatic conditions, ensuring realistic estimations of energy needs. The model has been validated through comparisons between estimated and actual energy consumption values at different geographical scales. At the national and cantonal levels, the model's aggregated results align closely with statistical values, indicating its robustness in capturing overall heating demand trends. A bootstrap resampling algorithm was employed to quantify uncertainty and establish confidence intervals around the estimated heat demand, further enhancing the model's reliability. Given the detailed calibration and validation efforts, the model is considered a reliable tool for assessing building heat demand in this study.

The required power capacity (installed power) is determined by the peak heating load from the load curve. The model has been validated and demonstrates good performance in reproducing power and energy in comparison with measured data.

2.5. Building stock modelling

The evaluation is conducted at the building level. However, not all buildings in the two regions are included in the analysis. Filters are applied to select buildings based on specific criteria, ensuring that the results refer to buildings in the real-world building stock in both cantons in which a transition to renewable energy-based heating systems is normally relatively easily feasible. First, buildings with fossil-based heating systems, such as gas boilers and oil combustion, are included in the analysis. Next, buildings with an installed thermal power exceeding 50 kW are excluded (most of the larger buildings are connected to district heating).

2.6. Data

The main datasets used in this analysis are presented in the following. The data were kindly provided by the cantonal authorities in the context of the project RENEW-HEAT funded by the Swiss Federal Office of Energy and the Canton of Geneva.

2.6.1. Basel subsidy programme

Between August 2018 and April 2024, in total 2132 buildings in the Canton of Basel-Stadt applied for subsidies to replace fossil fuel-based heating system with renewable heating systems which had become mandatory following the canton's 2017 Energy Act. These applications include also cases in which a connection to a district heating system was made. The dataset includes detailed information on each replacement, including the year of application, the type of old and new heating systems, energy reference area, system power capacity, investment costs, and granted subsidy.

2.6.2. Geneva subsidy programme

Similarly, the Canton of Geneva provided a dataset on subsidies granted for replacing fossil fuel-based heating system with ASHP or GSHP in the period from 2017 to 2023. This dataset includes essential details about the buildings and the subsidy program, allowing to compare the deployment of renewable heating systems in Basel-Stadt to the Canton of Geneva, where it was not yet mandatory to install a renewable heating system when replacing oil and gas boilers (the mandatory replacement was only introduced early in 2024).

2.6.2.1. Exempted buildings in Basel. Between 2018 and 2022, a total of 322 buildings in the Canton of Basel-Stadt were granted exemptions, allowing their owners to reinstall a fossil fuel-based heating system due to technical or economic difficulties for switching to a renewable energy-based heating system or as a temporary solution for a subsequent connection to a district heating system. This represents 18 % of the heating systems replaced during this period. For 155 of these buildings so far, comprehensive information is available, including documents on exemption applications, the exemptions granted, documentation of on-site energy consultations, internal correspondence, and an excerpt from the register of heating systems. This dataset can provide critical insights into the barriers to adopting renewable heating systems and is being investigated within the ongoing project RENEW-HEAT.

2.7. Swiss building registry

The Swiss Federal Register of Buildings and Dwellings (RBD) (Office, n.d.) contains data on all buildings in Switzerland, including residential and non-residential buildings. It provides important information for our analysis, including general metadata (e.g., location, construction year, building category), geometry (e.g., ground area, number of floors, energy reference area), and type of heating system. This dataset is used to identify the buildings in the study area and to model their heat requirements.

3. Results

3.1. Evolution of heating systems in the Canton of Basel-Stadt and comparison between buildings equipped with renewable heating and exempted buildings

In this section, the data on heating system replacements following the introduction of the 2017 Ordinance on the Energy Act in the Canton of Basel-Stadt is evaluated.

Between the years 2018 and 2023, subsidies were granted for the replacement of fossil fuel heating systems by renewable heating in 2132 buildings in the Canton of Basel-Stadt, resulting in a total installed capacity of 62 MW_{th}. As illustrated in Fig. 1, the installed capacity of renewable heating systems is dominated by District Heating (DH), which shows a steady upward trend, starting at around 2 MW_{th} in 2018 and rising to nearly 10 MW_{th} by 2023. DH accounts for 67 % of the total installed capacity. Both ASHP and GSHP show a less pronounced increase in installed capacities over the six years, with similar installation levels. ASHP accounted for 15 % of the total installed capacity, while GSHP contributed 12 %. Decentralized wood-fired heating systems remained consistently low, representing 6 % of the total installed capacity.

Fig. 2 displays the distribution of buildings that adopted various renewable heating systems, categorized by their power capacities. District Heating was installed in most buildings, with 826 buildings connected. The distribution of DH is relatively balanced across all power

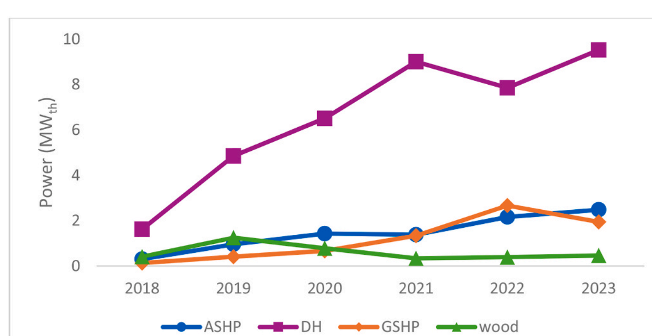

Fig. 1. Installed power of subsidy-supported installations for renewable heating systems to replace fossil fuel-based systems in the Canton of Basel-Stadt (n = 2132).

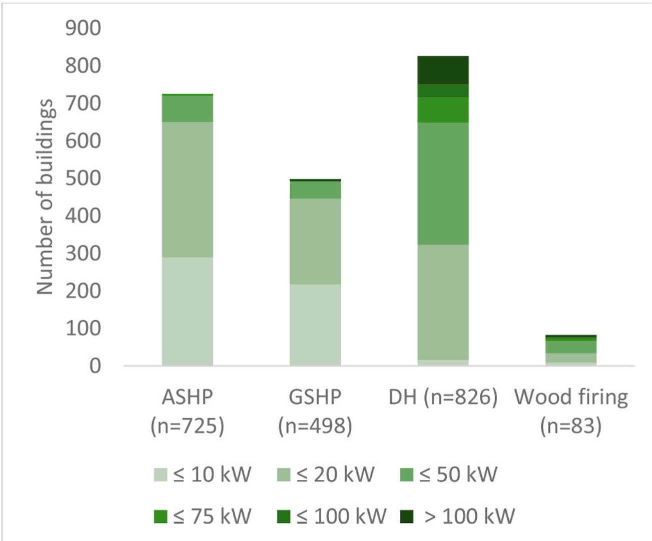

Fig. 2. Number of subsidy-supported renewable heating systems replacing fossil fuel-based systems in the Canton of Basel-Stadt,by the type of new system and capacity.

capacity categories (except for the lowest power range, i.e. ≤ 10 kW). A significant portion of buildings in this group have systems above 50 kW. In contrast, ASHP and GSHP are more commonly installed in smaller buildings with lower capacities (≤ 50 kW). A total of 725 buildings were equipped with ASHP systems, with the majority below 20 kW. Similarly, 498 buildings adopted GSHP systems, with most buildings in the lower power capacity categories. Wood-fired systems were implemented in 83 buildings, making it the least common option among the four systems. The majority was installed in the lower power capacity categories.

Between 2018 and 2022, a total of 322 permits were granted for exemptions allowing the reinstallation of fossil fuel heating systems. To date, 155 exempted buildings have been evaluated. Among these, the power capacity of the heating systems was reported for 89 buildings, 58 % of which have a capacity below 20 kW and 90 % below 50 kW (see Fig. 3). This highlights that the majority of buildings reinstalled with fossil fuel heating systems are relatively small in scale. This finding contrasts the national statistics, according to which 85 % of all heat pump systems for space heating have an installed capacity up to 20 kW (SFSO, 2024), while only 15 % are larger (percentages represent shares of building stock in 2023). In Switzerland, heat pumps have hence been primarily implemented in single-family houses. The request for

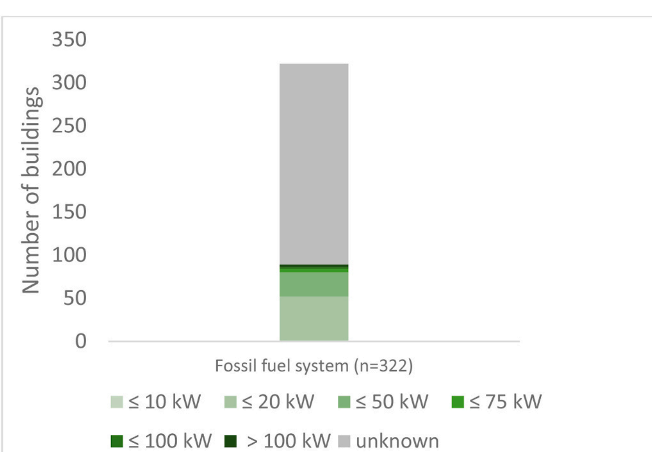

Fig. 3. Number of fossil fuel heating systems reinstallation in the Canton of Basel-Stadt by capacity.

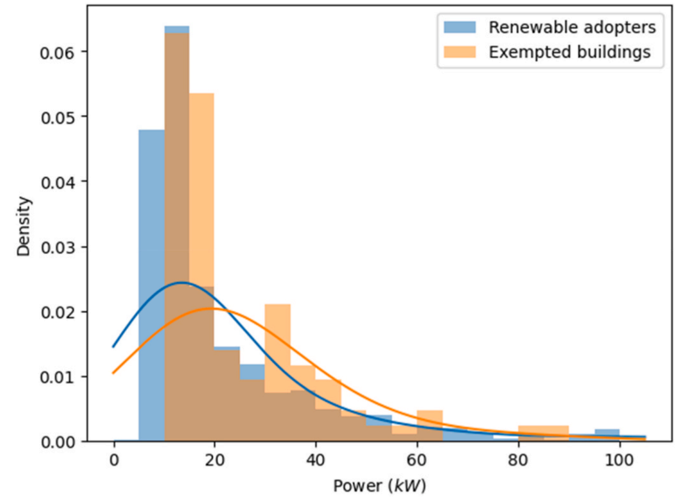

Fig. 4. Comparison of absolute heating power between renewable adopters and exempted buildings in in the Canton of Basel-Stadt.

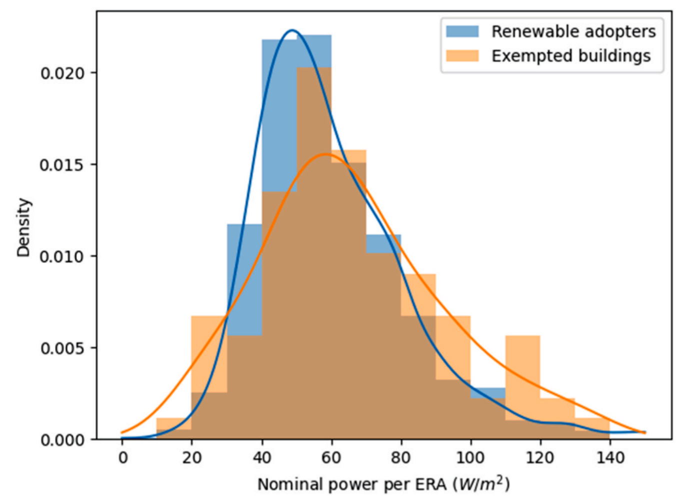

Fig. 5. Comparison of heating power per energy reference area (ERA) for renewable adopters and exempted buildings in the Canton of Basel-Stadt.

exemptions could therefore have been expected mainly for larger buildings. The reason for the shares in Basel-Stadt is that most larger buildings are connected to district heating. Re-installation of fossil fuel boilers therefore occurs primarily among smaller heating systems.

To understand what causes building owners to claim for exemption for the reinstallation of a fossil fuel system, the exempted buildings and renewable energy adopters are compared. Fig. 4 and 5 present the comparison in terms of heating power and specific heating power (calculated by dividing heating power by the energy reference area). Overall, both groups show similar distributions in absolute heating power and specific heating power. However, exempted buildings exhibit slightly higher values than those that have adopted renewable systems. More than half of the exempted buildings in the stock have a specific heating power exceeding the 50 W/m^2 threshold (Fig. 5). These buildings are often older and are characterized by less energy efficient building envelopes. They face greater financial challenges as the subsidy system limits support for their higher power needs (50 W/m^2, see note below Table 2).

Additionally, the investment costs for ASHP systems are compared between the two groups. Out of the 155 exempted buildings evaluated, only 48 report quoted prices for installing ASHP and gas boiler systems as evidence of an economic barrier to adopting renewable heating

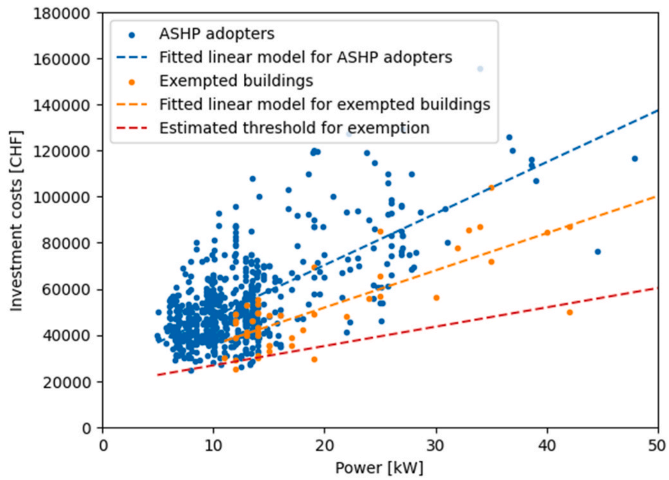

Fig. 6. Comparison of ASHP investment costs between renewable adopters and exempted buildings (values for Canton of Basel-Stadt).

systems. These costs are compared with those of buildings that have successfully adopted ASHP. As shown in Fig. 6, unexpectedly, the costs for exempted buildings fall within the lower range of costs reported by ASHP adopters. This may be due to the fact that the sample of exempted buildings is biased, as it only includes cases related to economic barriers. Buildings exempted due to technical barriers did not report their quoted investment costs for ASHP but they can be expected to be characterized by higher investment costs compared to standard cases. Overall, Fig. 6 suggests that ASHP adopters face roughly similarly high investment costs as those of exempted buildings. The red dashed line in Fig. 6 represents the estimated threshold for exemption. The vast majority of both ASHP adopters and exempted buildings fall above this threshold, indicating that they meet the conditions for exemption. However, ASHP adopters chose to install ASHP despite the high investment costs. No similar comparison of GSHP investment costs was conducted due to the limited data available on exempted buildings.

3.2. Cost effectiveness of ASHP and GSHP systems

In this section, the cost-effectiveness of installing ASHP and GSHP systems is analysed for the building stocks in the Cantons of Basel-Stadt and Geneva. First, the investment costs of these systems are estimated based on data from buildings that have successfully adopted ASHP and GSHP in both regions. Next, the LCOH is calculated using the method outlined in Section 2.1 and compared to gas boilers. Finally, the required amounts of subsidies to ensure the cost-effectiveness of HPs with respect to LCOH are established.

Fig. 7 presents the investment costs for ASHP systems as a function of power capacity in both regions. Outliers are excluded using the Bonferroni Outlier Tests. Investment costs in the Canton of Basel-Stadt are typically 15–20 % higher than those in the Canton of Geneva. The linear models fitted to the estimated ASHP investment costs (in Swiss Francs, CHF) are as follows:

$$ASHP\ in\ Basel : CapEx = 2239 * p + 25503, R^2 = 0.50$$

$$ASHP\ in\ Geneva : CapEx = 1796 * p + 23397, R^2 = 0.60$$

The difference in cost levels between the two cantons may partly be explained by the leading role of Basel-City, which may explain higher cost due to the higher demand as a consequence of the more stringent legal setting and the higher subsidy level (windfall profits). Another reason for the significant differences in cost levels may be the fact that Swiss building regulation is subject to the authority of the individual cantons, which leads to market barriers for installers to offer their services in more than one canton, hence resulting in imperfect market conditions.

Similarly, Fig. 8 illustrates the investment costs for GSHP systems as a function of installed capacity in the Cantons of Basel-Stadt, Geneva, and Zurich. The investment costs for GSHP systems across the three regions show good agreement, indicating consistent price levels. The linear models fitted for GSHP investment cost (in CHF) are as follows:

$$GSHP\ in\ Basel : CapEx = 3491 * p + 39364, R^2 = 0.72$$

$$GSHP\ in\ Geneva : CapEx = 5123 * p + 14987, R^2 = 0.48$$

Notably, the piecewise linear GSHP cost model for the Canton of Zurich considers the breakdown of investment costs, including the installation of heat pumps and borehole drilling. The breakdown is particularly useful for calculating the LCOH, as it allows for a more accurate assessment of the individual cost components. Therefore, the GSHP model for the Canton of Zurich, as defined below,has been adopted for our evaluation.

$$Heat\ pump\ installation : CapEx = \begin{cases} 2733 * p + 29467, if\ p \le 28\ kW \\ 1630 * p + 60360, if\ 28\ kW < p \le 50\ kW \end{cases}$$

$$Borehole\ drilling : CapEx = \begin{cases} 1424 * p + 4433, if\ p \le 28\ kW \\ 1240 * p + 9580, if\ 28\ kW < p \le 50\ kW \end{cases}$$

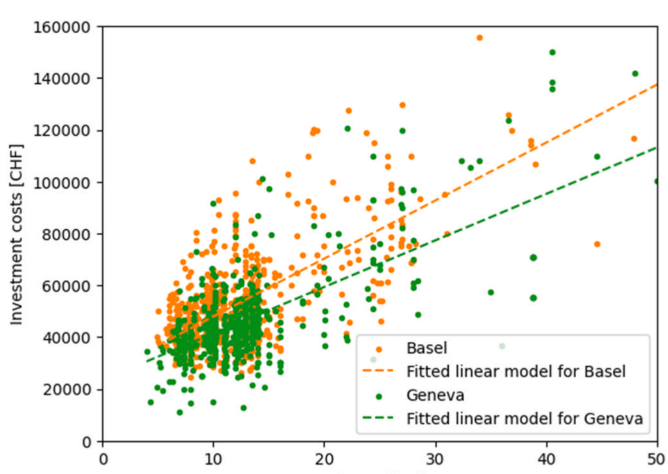

Fig. 7. Relationship between investment costs and the power capacity of ASHP in Basel-Stadt and the Canton of Geneva.

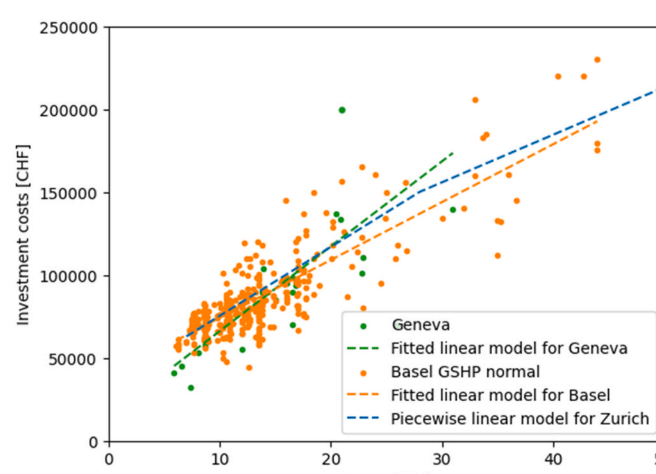

Fig. 8. Relationship between investment costs and the power capacity of GSHP in Basel-Stadt and in Geneva.

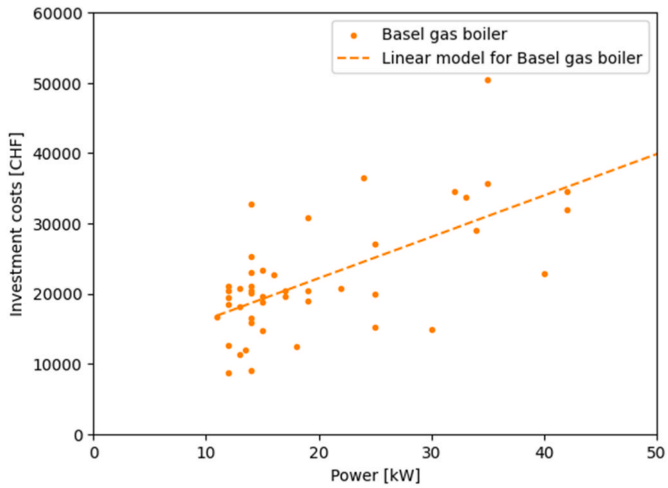

Fig. 9. Relationship between investment costs and the power capacity of gas boiler in the Canton of Basel-Stadt.

The investment costs for gas boilers are also evaluated, since they are the most commonly installed fossil fuel heating system. Fig. 9 presents the investment costs in the Canton of Basel-Stadt. Related costs often include extra costs for covering at least 50 % of domestic hot water use by a renewable energy source, due to the related requirement in the canton of Basel-Stadt; associated costs typically amount to approximately CHF 5′000 for a hot water heat pump. Without such a requirement, investment costs for a fossil fuel heating system would be even lower. Due to insufficient data for the Canton of Geneva, it is assumed that both regions exhibit similar pricing, given the maturity of the gas boiler market. The linear model fitted for gas boiler investment costs (in CHF) is as follows:

$$Gas\ boiler\ in\ Basel : CapEx = 590 * p + 10384, R^2 = 0.64$$

Following the estimation of investment costs for heating systems, the LCOH of ASHP and GSHP systems are evaluated for the building stock in the Cantons of Basel-Stadt and Geneva. It is important to note that only buildings with an installed thermal power of less than 50 kW are included in the analysis. In total, 12,635 buildings in the Canton of Basel-Stadt and 31,031 buildings in the Canton of Geneva are assessed.

The results for the Canton of Basel-Stadt are presented in Fig. 10. Most gas boilers have a consistent LCOH, averaging around 0.25 CHF/kWh_{th}. GSHP systems show a wider distribution of LCOH, with an average around 0.25 CHF/kWh_{th}. ASHP systems also show a wider distribution, with an average around 0.24 CHF/kWh_{th}, slightly lower than that of GSHP and gas boilers. Overall, ASHP tends to be the most cost-effective of the three systems in terms of LCOH, although there is more variability compared to gas boilers.

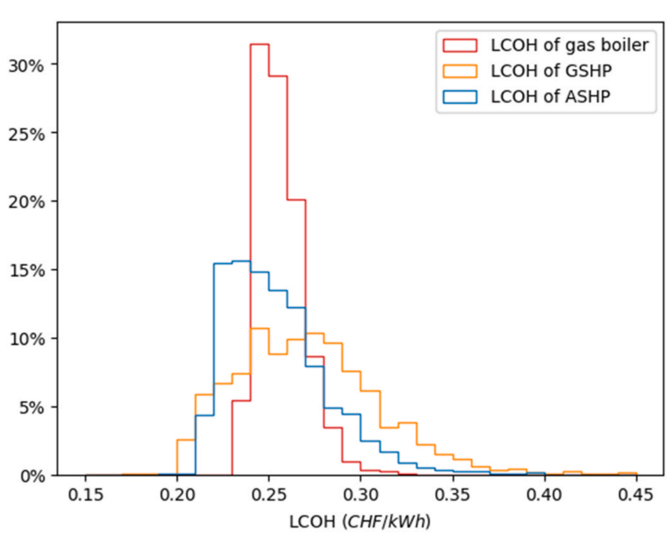

Fig. 10. Comparison of LCOH for ASHP, GSHP, and gas boiler in Basel-Stadt.

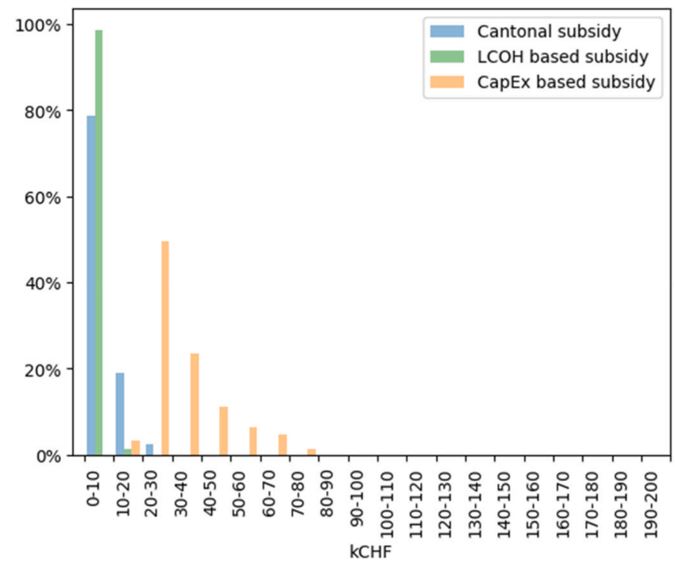

Fig. 11. Comparison of LCOH for ASHP, GSHP, and gas boiler in the Canton of Geneva.

The situation in the Canton of Geneva is shown in Fig. 11. Similarly, the distribution of LCOH for gas boiler is narrow, while GSHP and ASHP systems show wider spreads. Gas boilers appear to have a relatively low LCOH, with an average of 0.21 CHF/kWh_{th}. ASHP maintains a low average LCOH of 0.22 CHF/kWh_{th}, while GSHP shows the highest average LCOH of 0.26 CHF/kWh_{th}.

To further investigate the factors contributing to LCOH for different heating systems, the average LCOH in both regions are broken down into three components: CapEx, final energy costs, and maintenance costs. In the Canton of Basel-Stadt, ASHP and GSHP systems have comparable LCOH to those of gas boilers, as shown in Fig. 12. The majority of the LCOH for gas boilers is caused by costs for final energy (gas), followed by CapEx. For ASHP systems, CapEx represents a larger share of the total LCOH compared to gas boilers, while final energy costs are lower. GSHP systems show the highest proportion of CapEx, while final energy costs are lower than both gas boilers and ASHP systems. Maintenance costs account for a small portion of the total LCOH for all three types of

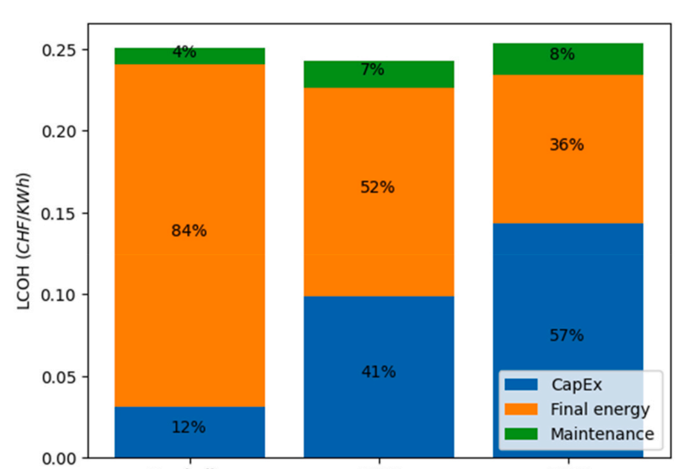

Fig. 12. Average LCOH (without subsidies) by heating systems in Basel-Stadt.

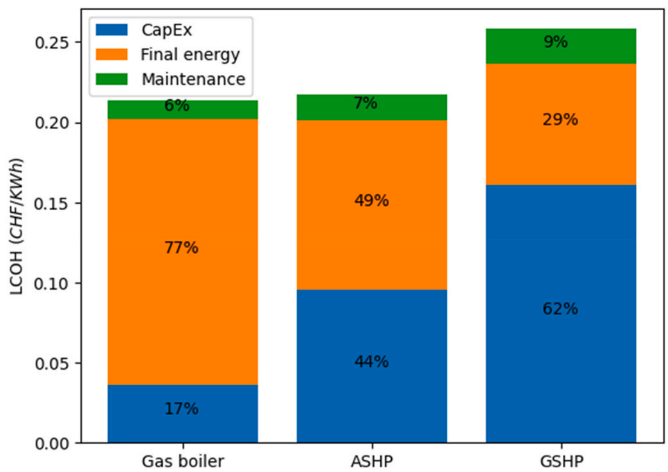

Fig. 13. Average LCOH (without subsidies) by heating systems in the Canton of Geneva.

systems. Overall, these results demonstrate that the high CapEx of both types of HPs can be offset by long-term savings in operational costs.

In the Canton of Geneva (refer to Fig. 13), the overall trends are similar to the Canton of Basel-Stadt: ASHP and GSHP systems have higher initial capital expenditures but benefit from lower final energy costs compared to gas boilers. However, the proportions of final energy costs are reduced due to lower fuel prices (for gas and electricity) in the Canton of Geneva. This results in a lower average LCOH for gas boiler and ASHP than GSHP, due to its higher initial capital expenditures.

Finally, the required subsidies to ensure unrestricted economic viability of ASHP or GSHP systems are quantified based on two scenarios: CapEx-based subsidies (resulting in the same investment cost as a gas boiler for the owner after receipt of the subsidy) and LCOH-based subsidies (resulting in the same levelized cost as a gas boiler for the owner after receipt of the subsidy). Table 3 summarises the total required subsidies (in million CHF) and the average specific subsidies (per Energy Reference Area, ERA, i.e. the heated floor area). The distributions of the required subsidies across buildings are presented in Fig. 14 to 17. The results regarding subsidies for adopting ASHP and GSHP in the Canton of Basel-Stadt (Fig. 14 and Fig. 15) highlight that LCOH-based subsidies require significantly less funding than the current cantonal subsidies. In contrast, CapEx-based subsidies represent very high levels, particularly for GSHP installations.

In comparison to Basel-Stadt, the level of subsidies for ASHP installation currently provided by the Canton of Geneva is much closer to the LCOH-based level (compare Fig. 14 and 16). These subsidies for ASHP are, however, much lower than required for a CapEx-based subsidy system. Regarding GSHP installation, the Canton of Geneva currently provides lower subsidies than the Canton of Basel-Stadt and than required according to LCOH (Fig. 15 and 17; see also Table 3). The subsidy levels in Basel-Stadt are beyond the required level if defined

Table 3
Cantonal subsidy versus required subsidy (based on LCOH and CapEx) to ensure unrestricted economic viability of ASHP and GSHP without additional costs for building owners.

	Canton of Basel-Stadt		Canton of Geneva	
	Average per ERA (per m^2)	Total	Average per ERA (per m^2)	Total
Number of buildings		12635		31031
Power	60 W	279 MW	61 W	525 MW
ERA	1 m^2	4.67E6 m^2	1 m^2	8.63E6 m^2
Cantonal subsidy for ASHP	34 CHF	158 million CHF	30 CHF	255 million CHF
LCOH-based subsidy for ASHP	5 CHF	21 million CHF	15 CHF	126 million CHF
CapEx-based subsidy for ASHP	139 CHF	651 million CHF	120 CHF	1037 million CHF
Cantonal subsidy for GSHP	91 CHF	424 million CHF	48 CHF	418 million CHF
LCOH-based subsidy for GSHP	22 CHF	103 million CHF	91 CHF	785 million CHF
CapEx-based subsidy for GSHP	269 CHF	1258 million CHF	295 CHF	2544 million CHF

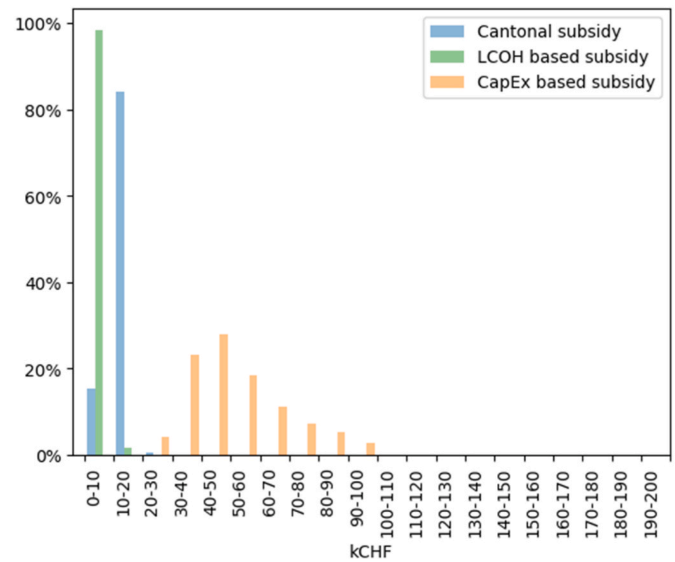

Fig. 14. Distribution of required subsidy (per installation) to ensure unrestricted economic viability of ASHP without additional costs for building owners in the Canton of Basel-Stadt, based on CapEx approach or LCOH approach, in comparison with currently available cantonal subsidy.

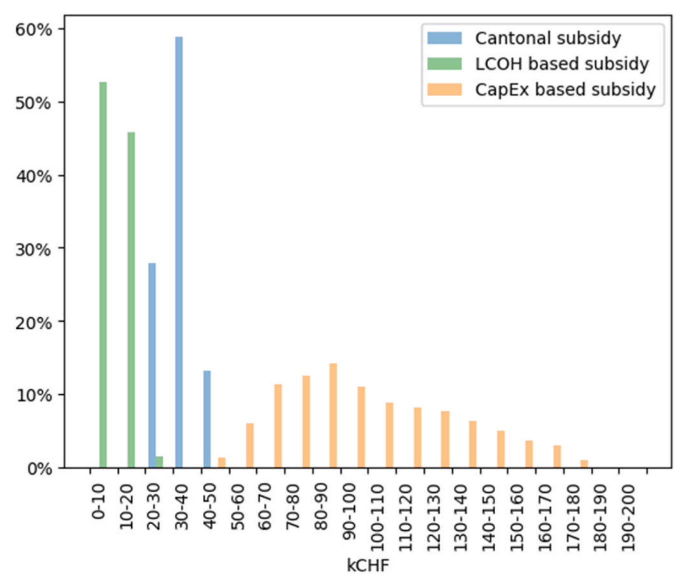

Fig. 15. Distribution of required subsidy (per installation) to ensure unrestricted economic viability of GSHP without additional costs for building owners in the Canton of Basel-Stadt, based on CapEx approach or LCOH approach, in comparison with currently available cantonal subsidy.

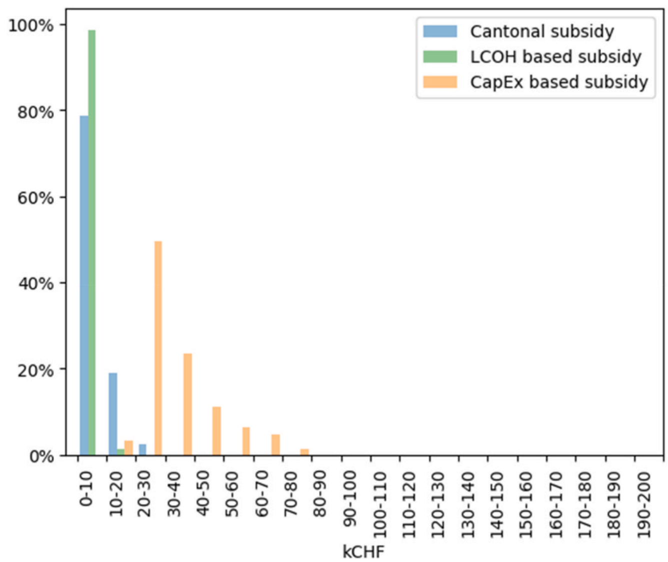

Fig. 16. Distribution of required subsidy (per installation) to ensure unrestricted economic viability of ASHP without additional costs for building owners in the Canton of Geneva, based on CapEx approach or LCOH approach, in comparison with currently available cantonal subsidy.

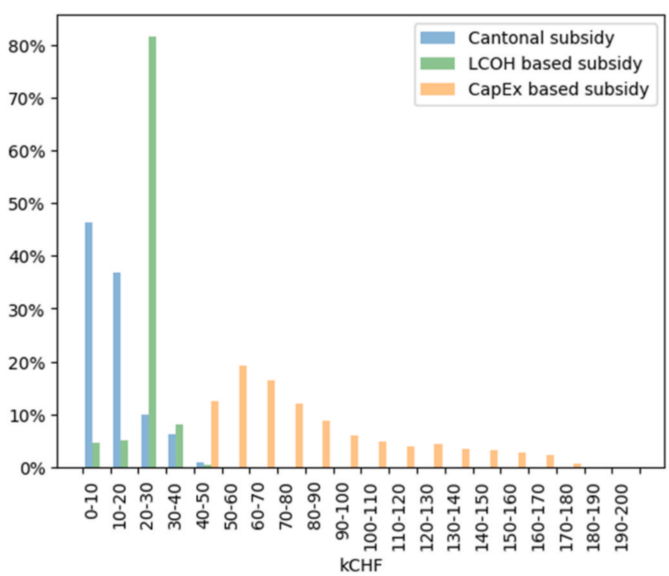

Fig. 17. Distribution of required subsidy (per installation) to ensure unrestricted economic viability of GSHP without additional costs for building owners in the Canton of Geneva, based on CapEx approach or LCOH approach, in comparison with currently available cantonal subsidy.

based on LCOH. In both cantons, the public support would need to be raised by factors to reach the level of CapEx-based subsidies (Fig. 17).

As summarized in Table 3, cantonal subsidies by far exceed LCOH-based subsidy levels in the Canton of Basel-Stadt for both types of heat pumps and, to a lesser extent, for ASHP in the Canton of Geneva, while not reaching the LCOH-based level for GSHP in the Canton of Geneva. To reach the CapEx-based subsidy levels in the Canton of Basel and in the Canton of Geneva, today's subsidies for ASHP and GSHP would need to be raised by factors lying between 3 and 6. It is unlikely that this would be affordable for the cantons.

It could be argued that the cantonal support could be optimised by aligning it to the LCOH-based level which would cover the cost for the owner and at the same time free resources for other purposes (e.g., to prioritize GSHP over ASHP). On the other hand, the additional investment cost for renewable heating is significant (e.g., 25 kCHF in the least expensive case of replacing a 10 kW gas boiler by an ASHP in Geneva according to the linear fits provided above). According to our LCOH calculations (see Table 1) the investment cost (and hence also the additional investment cost) is discounted with 1.75 % p. a., which can be interpreted as mortgage cost. Nevertheless, the high investment costs imply financial risks. In addition, there may be opportunity costs (potentially higher return from other investments) and owners are faced by reduced financial flexibility as a consequence of the higher investment costs. These are arguments speaking for a subsidy level exceeding the bare LCOH-based level.

Inspection of the real subsidy levels in the Cantons of Basel-Stadt and of Geneva show that the share of subsidies relative to the capital expenditure ranges mostly between 17 % and 22 % (for ASHP in Basel and Geneva and for GSHP in Geneva), reaching up to 40 % for GSHP in the canton of Basel (see Appendix 1B). Expressing this subsidy as annual rent (over the lifetime) results in rates between 1.0 % and 1.3 % (for ASHP in Basel and Geneva and for GSHP in Geneva) and 2.4 % for GSHP in the Canton of Basel. These values may be considered as reasonable in view of the abovementioned drawbacks they help to overcome.

3.3. *Sensitivity analysis*

To investigate the impact of uncertainties in input parameters on LCOH-based subsidies, a sensitivity analysis was conducted. The parameters analysed include the CapEx of the specific type of HP, discount rate, efficiency of the specific type of HP, and prices for electricity and natural gas. The results of the sensitivity analysis are presented in Fig. 18 to 21, covering ASHP and GSHP installations in the Canton of Basel-Stadt and in the Canton of Geneva, respectively. The four cases show similar trends. CapEx has a notable impact on the average LCOH-based subsidies, with higher CapEx resulting in increased subsidies. The required power capacity (installed power) was determined by the peak heating load from the load curve, while Bosshard et al. (2023) found that the installed power is typically overdimensioned by 40 % (relative to the measured data). As Fig. 18 to 21 show, a 40 % higher CapEx value increases the required average LCOH-based subsidies by 80–100 CHF/m^2 for ASHP and by 140–240 CHF/m^2 for GSHP. Similar to CapEx, rising electricity prices call for higher subsidies, with ASHP being much more sensitive to high electricity prices than GSHP. On the contrary, efficiency and natural gas price show a strong inverse relationship with subsidy requirements. Finally, changes in the discount rate result in minimal

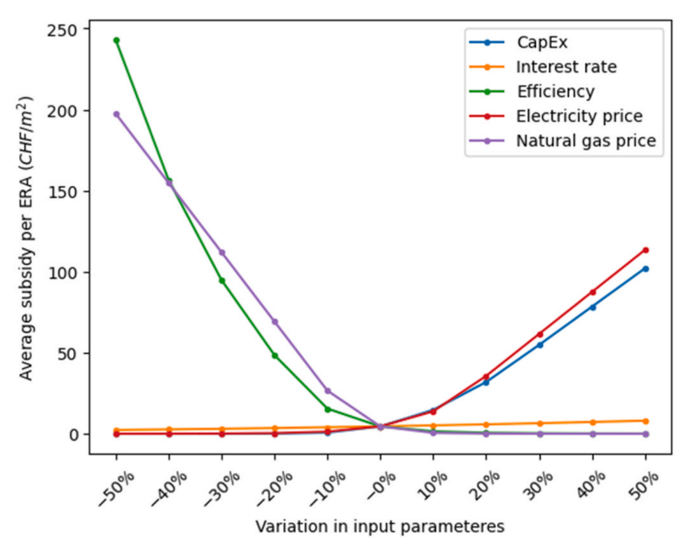

Fig. 18. Average LCOH-based subsidy as a function of variations in input parameters for ASHP installation in the Canton of Basel-Stadt.

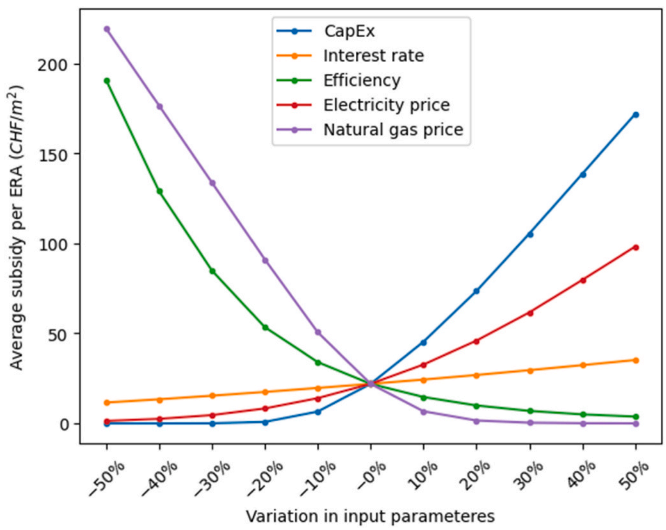

Fig. 19. Average LCOH-based subsidy as a function of variations in input parameters for GSHP installation in the Canton of Basel-Stadt.

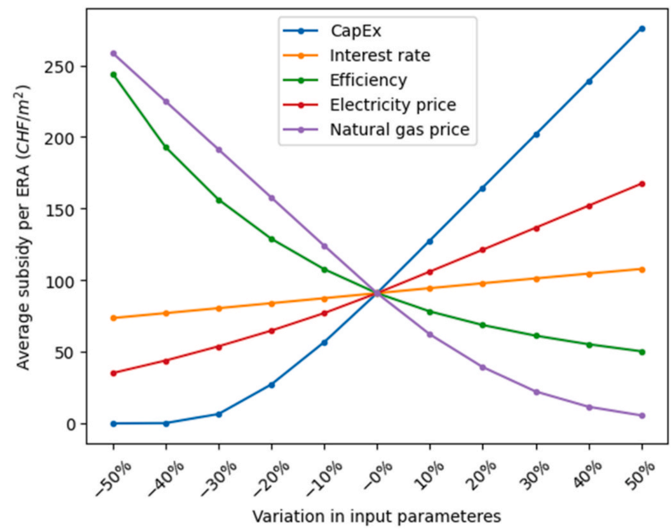

Fig. 3.21. Average LCOH-based subsidy as a function of variations in input parameters for GSHP installation in the Canton of Geneva.

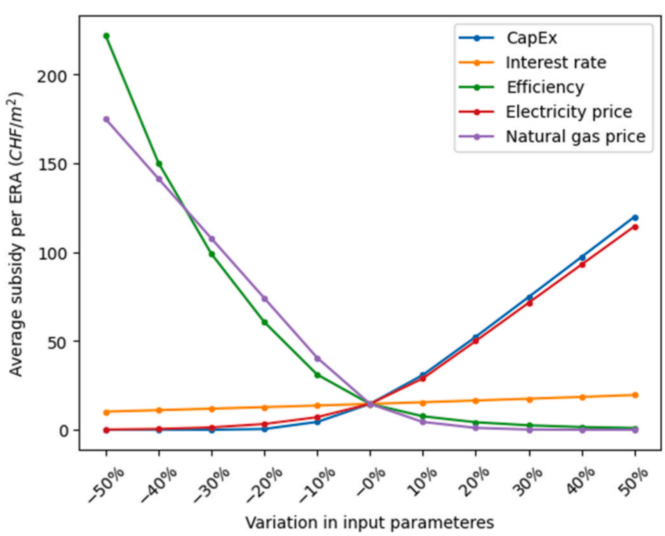

Fig. 20. Average LCOH-based subsidy as a function of variations in input parameters for ASHP installation in the Canton of Geneva.

variation in the subsidy (however, the default discount rate of 1.75 % is low, implying that a ±50 % change may be by far too conservative).

4. Discussion

4.1. Barriers to heat pump adoption

Mandatory requirements in the Canton of Basel-Stadt and subsidy programs in both the Canton of Basel-Stadt and the Canton of Geneva have played a key role in the adoption of renewable heating systems. While subsidies help reduce the capital expenditure required for heat pumps, approximately 20 % of building owners replacing their heating system in the Canton of Basel-Stadt still found it economically or technically challenging to adopt heat pumps in the first years after introduction of a requirement to switch to renewable heating systems and have consequently reinstalled fossil fuel systems, making use of related exemption clauses. Policymakers could explore additional incentives, such as technical support and skill-training programmes for HP installers, to overcome these barriers (Decuypere et al., 2022) and they may introduce additional subsidies in specific cases.

4.2. LCOH-based subsidies as an alternative

LCOH-based subsidies could be seen as alternative to subsidies designed to ensure cost-effectiveness purely based on investment costs. Our analysis shows that ASHP systems generally have a comparable LCOH to gas boilers, despite higher investment costs, due to their higher energy efficiency and the resulting lower energy costs. Switching from today's subsidy levels to LCOH-based subsidies would accordingly allow to spend less financial resources for ensuring the cost-effectiveness of ASHP. This could make additional financial resources available for other targeted subsidies. On the other hand, it can be argued that LCOH-based subsidies only insufficiently compensate the clearly higher upfront cost of ASHP and even more so of GSHP in comparison to gas boilers. Furthermore, this study suggests increasing subsidy levels for GSHP installations in the Canton of Geneva to promote their adoption by at least reaching the LCOH-based subsidy level.

4.3. Voluntary action and significance of additional requirements

Interestingly, the analysis for the Canton of Basel-Stadt shows that the current cantonal subsidies, intended to be based on investment costs, cover only a part of the additional investment costs in comparison with a gas boiler, even if subsidies are particularly high in comparison with other cantons in Switzerland. Many building owners accordingly switched to a renewable energy-based heating system despite of their higher investment costs compared to a fossil fuel-based system and even though exemption clauses might have provided an opportunity for them to reinstall a fossil fuel-based heating system.

There can be various reasons for building owners to switch to a renewable energy-based heating system, despite the lack of full compensation by subsidies for the additional investment costs compared to a fossil fuel-based heating system.

The exemption clause may have played animportant role according to which building owners must implement significant energy efficiency measures (e.g., insulation of the roof or the cellar ceiling) as a prerequisite for reinstalling a fossil fuel heating system While such additional measures are often cost-effective from a life-cycle perspective (see for example Bolliger et al., 2015), they do imply additional investment costs for building owners, making the exemption to reinstall a fossil fuel system less attractive. As without such an additional requirement, investment costs are found to be usually significantly higher for a renewable energy-based heating system compared to a fossil fuel-based heating system, even when subsidies are taken into account, such a requirement may have an important deterrent effect of making use of the exemption clause.

Another important factor could have been that building owners preferred to switch to a renewable energy-based heating system despite higher investment costs. The fact that there has been a long-standing political support for climate protection in the Canton of Basel-Stadt may have played a role. Furthermore, a democratic process took place through a popular initiative and a counter-proposal which resulted in a popular vote on November 27, 2022. In that vote, citizens adopted an article in the constitution of the Canton of Basel-Stadt requiring the canton to be carbon neutral by 2037.

Additional factors for accepting higher investment costs and for not asking for an exemption may also have been the good information level of building owners about renewable energy, due to the comprehensive adviceprovided by the canton to building owners, or the unawareness of some building owners about the exemption clauses.

The requirement that at least 50 % of domestic hot water use is provided by a renewable energy source, even when an exemption is granted to reinstall a fossil fuel based heating system, probably played only a small role in building owners' choice of heating system, due to the relatively small amount of additional investment costs this involved. The requirement has allowed to reduce emissions, however, also in such cases.

4.4. Limitations

This study is subject to several limitations. First, the study focuses on ASHP and GSHP systems, as these are the most widely applicable renewable heating options. Other renewable systems, such as district heating are less explored due to limited data. This focus may overlook opportunities related to other renewable technologies. Moreover, since the required power capacity (installed power) was determined based on the peak heating load from the load curve, identified costs can be considered as minimal costs. In practice, heat pumps are typically oversized to ensure sufficient capacity during peak demand periods (Bosshard et al., 2023), leading to higher investment costs. However, the required peak capacities for heat pumps are usually reduced by incorporating buffer tanks, which store thermal energy and help smooth out demand fluctuations. This does not only reduce upfront investment costs but also enhances long-term operational efficiency. Future studies could explore the impact of buffer tanks on heat pump sizing and cost-effectiveness in greater detail.

Basing the calculations on the analysis done by Schneider et al. (2017) we assume current average levels of thermal energy use and thereby ignore the potential of highly cost-effective energy efficiency measures (e.g., Altieri et al., 2023)), which unfold their full effect when implemented prior to heat pump installation. Also the evolution of the regulatory context (e.g., setting minimal energy performance for the least efficient buildings, as implemented in France and also in Geneva) could favour the introduction of heat pumps. In fact, Lamb and Elmes (2024) point out the need to make the UK's housing stock (being one of the oldest in Europe) more energy efficient before implementing heat pumps; they analyse the extent of the challenge and its characteristics and conclude that policy has been insufficiently addressing the need to make buildings heat pump-ready. The HP subsidy schemes in the Cantons of Basel-Stadt and Geneva do not explicitly define any minimum thermal performance level of buildings as prerequisite for HP implementation. However, by cutting off any subsidy for a heat demand beyond $50W_{th}/m^2$ (see note of Table 2), they limit the incentive for HP implementation in buildings with very low thermal performance. In addition, the Canton of Geneva introduced a general policy (independent of HP implementation), according to which owners of buildings exceeding the final energy demand level of 125 kWh/m^2/year must take measures to fall below this threshold. The opportunity of efficiency gains by improving the thermal performance of the building envelope is visible from Fig. 5, according to which the installed heating power exceeds 50 W/m^2 for more than half of all buildings.

As further limitation, the LCOH calculations are based on available data from 2024, which may not reflect future changes in energy prices or system costs. For example, energy prices may rise more quickly in future than investment costs for heat pump systems, which could actually decrease as a consequence of economies of scale and technological process. Also tariff systems are likely to change, by replacing flat tariffs and time-of-use tariffs (e.g., day vs. night) by dynamic tariffs. The evolution of carbon taxes (which are already at 120 CHF/tonne CO_2 in Switzerland) and other factors influencing the ratio of electricity-to-heat price can also have a significant impact. Furthermore, the present study estimates required subsidies by assuming that building owners' decisions to adopt renewable heating systems are primarily based on economic factors. However, factors such as awareness, confidence and market maturity could play a significant role in the adoption process. This is, among other aspects, related to the legal framework and the related political process in Switzerland which were studied by (Meyer, 2023) (on the interplay between soft law and hard law in Switzerland). The development of required exemptions over time was not part of the present study. Future research could explore these aspects as well as the question why many adopters of renewable heating did not request an exemption although the investment cost they faced would have entitled them to do so. In addition, future work could study heat pump systems with an installed power above 50 kW, once sufficient data will become available.

Finally, the present paper focused on heating while reversible HPs can, in principle, be used not only for heating but also for cooling (the importance of cooling will grow in future as a consequence of climate change). The potential advantage of GSHP for free cooling was not taken into account. However, the direct use of reversible heat pumps in combination with pre-existing radiators is hardly possible due to condensation problems (leading to humidity and mold). The larger surface of floor heating makes it more viable to achieve a cooling effect which nevertheless remains limited due to the relatively low temperature gradient (personal communication with L. Parisse, SIG, Geneva, March 25, 2025).

5. Conclusions and policy recommendations

This study investigated the features of the adoption of renewable energy-based heating systems ias well as its economic viability, specifically for air source heat pumps and ground source heat pumps in the Cantons of Basel-Stadt and Geneva. Under the new regulation and subsidy scheme, around 80 % of all buildings, for which the heating system was replaced, transitioned to renewable heating, while the remainder was exempted, allowing them to reinstall a fossil fuel based heating. In terms of numbers of newly installed heating systems, the majority were heat pumps (57 %, consisting of 34 % ASHP and 23 % GSHP), 39 % were district heating systems and 4 % wood-fired systems (Fig. 2). In terms of installed power, on the other hand, district heating systems dominated (67 %), followed by HP (15 % AHSP and 12 % GSHP) and finally wood-fired systems (6 %).

Without considering subsidies, ASHP systems generally have a comparable levelized cost (LCOH) to gas boilers, while GSHP may be characterized by a somewhat higher LCOH. Economic factors, such as high upfront costs and limited financial support, particularly for GSHP systems, have limited their wider adoption of HP and led to the application of exemption clauses. Technical challenges further contribute to the barriers.

Our analysis shows that establishing mandatory renewable heating in combination with capital expenditure based subsidies fully compensating the difference in investment costs between HP and gas boilers would result in a surge of public expenses compared to today's subsidy levels. In contrast, defining the subsidy level based on levelized costs, as implemented for example in the Canton of Zurich, would significantly reduce the public expenses compared to today's subsidy levels. This would make additional financial resources available for other targeted subsidies. An example for such a targeted subsidy could be to increase the attractiveness of GSHP, which would allow to reduce electricity consumption in comparison with ASHP; without such additional subsidies, GSHP were found to be less attractive from an LCOH perspective than ASHP. Furthermore, additional subsidies could be made available to address extraordinary obstacles to heat pump installations in specific situations.

As pointed out, the analysis for the Canton of Basel-Stadt shows that the current cantonal subsidies, intended to be based on investment costs, cover only a relatively small part of the additional investment costs in comparison with a gas boiler. Thus, the effect of saving financial resources when switching from current subsidies to LCOH based subsidies is not as large as if the current subsidies were designed to fully ensure cost-effectiveness based on investment costs. The study shows that when subsidies do not fully cover the difference in investment costs between a renewable energy-based heating system as compared to a fossil fue-based heating system, additional requirements to carry out energy efficiency measures, if a fossil fuel heating is allowed to be reinstalled due to the exemption clause, may play an important role. Also a requirement that at least 50 % of domestic hot water use is provided by a renewable energy source, when an exemption is granted to reinstall a fossil fuel based heating system, can contribute to making a switch to renewable energy attractive, yet probably plays a small role in building owners' choice of heating system.

The remaining differences in investment costs between renewable energy-based heating systems and fossil fuel-based heating systems, despite high subsidies, underline the importance of informing building owners on the life-cycle cost perspective, as well as on emphasizing benefits for climate protection for justifying the switch to renewable energy-based heating systems.

Furthermore, there are reasons which speak in favour of keeping current subsidy levels, possibly with some adaptations. Apart from insufficient compensation of the higher upfront cost by LCOH-based subsidies, a further argument is that investment costs vary strongly from case to case. While on average no subsidies are necessary to ensure cost-effectiveness based on an LCOH approach, it may be necessary to have subsidies to ensure cost-effectiveness in cases where investment costs are higher than on average. Another reason is that subsidies have benefits which go beyond their financial nature. They are also a signal of meaningful support by the government for the adoption of renewable heating systems, enhancing the trust building owners have in these technologies. In addition, subsidies may increase overall acceptance of the rule to switch to renewable energy when replacing a heating system. Results show that despite higher investment costs than for a gas boiler, many building owners have nevertheless installed heat pumps, without making use of their right for an exemption. The fact that at least some subsidy was available to building owners, may have been key for them to decide in favour of a renewable energy-based heating system, even if they would have not been obliged to do so based on the available exemption clauses. Offering some subsidies can potentially trigger a much larger willingness to support the target than the associated improved cost-effectiveness of renewable heating systems. Subsidies may also have been key to ensure acceptance of the original introduction of the legal obligation to switch to renewable energy when a heating system is replaced. A continuation of subsidies once introduced may be necessary due to ensure fairness of benefits given to different building owners.

Overall, it is therefore recommended to offer some subsidy, reaching or somewhat exceeding the level required for cost-effectiveness based on an LCOH approach while remaining significantly below a subsidy level based on capital expenditure (CapEx). Given the much higher subsidy volume of investment cost based subsidies compared to levelized cost based subsidies (factor of 3–6), a full compensation of the additional cost in the case of investment cost-based subsidies is not recommended since it would most likely lead to high public expenses. Given the lower electricity demand of GSHP compared to ASHP particularly in winter time in combination with their higher investment costs and lower cost-effectiveness, higher subsidies are justified for GSHP from an energy policy perspective. (This suggests to increase the subsidies for GSHP in the Canton of Geneva). It is furthermore considered to be important to avoid oversizing of the installed power of heat pumps through appropriate training and information of heating professionals and building owners, as this can potentially save a significant amount of financial resources.

The experience in the Swiss Cantons of Basel-Stadt and Geneva provide indications of effective and affordable subsidy levels and suitable approaches for defining cost-effectiveness in the context of a mandatory transition to renewable energy when a heating system is replaced. This could be further studied for other Swiss cantons or other countries.

CRediT authorship contribution statement

Xiang Li: Writing – original draft, Visualization, Methodology, Formal analysis, Conceptualization. **Roman Bolliger:** Writing – review & editing, Validation, Project administration. **Monika Hall:** Writing – review & editing, Validation, Data curation. **Martin Patel:** Writing – review & editing, Supervision, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Electricity prices

Table A.1
Electricity prices (in CHF/kWh) across consumption categories in the Canton of Basel-Stadt and in the Canton of Geneva *in 2024* (SFSO (Swiss Federal Statistical Office), 2024)

Consumption category	Canton of Basel-Stadt	Canton of Geneva
H6	0.3074	0.2521
H7	0.3241	0.2804
C3	0.3516	0.3050

Appendix B. Cost aspects of HP implementation

Table B.1
– Cost aspects for gas boiler replacement by ASHP or GSHP (both with installed capacity of 10 kW and 35 kW) in the Cantons of Basel-Stadt and of Geneva

ASHP		10 kW	10 kW	35 kW	35 kW
		Geneva	Basel	Geneva	Basel
CapEx ASHP	CHF	41357	47893	86257	103868
CapEx Gas boiler	CHF	16284	16284	31034	31034
Delta CapEx	CHF	25073	31609	55223	72834
Subsidy ASHP	CHF	7000	10500	17000	16750
Annualized subsidy	CHF/year	418	627	1015	1000
Subsidy ASHP/CapEx ASHP	%	17 %	22 %	20 %	16 %
Subsidy expressed as annual rent relative to CapEx of ASHP	%	1.0 %	1.3 %	1.2 %	1.0 %
Annualized Delta CapEx after subsidy (yearly)	CHF/year	1079	1260	2282	3348
Annualized Delta CapEx after subsidy (monthly)	CHF/month	90	105	190	279
(Delta CapEx after subsidy)/(CapEx gas boiler)	%	111 %	130 %	123 %	181 %
GSHP		10 kW	10 kW	35 kW	35 kW
		Geneva	Basel	Geneva	Basel
Total CapEx GSHP	CHF	75470	75470	170390	170390
CapEx Gas boiler	CHF	16284	16284	31034	31034
Delta CapEx	CHF	59186	59186	139356	139356
Subsidy GSHP	CHF	11000	30000	31000	41250
Annualized subsidy	CHF/year	657	1791	1850	2462
Subsidy GSHP/CapEx GSHP	%	15 %	40 %	18 %	24 %
Subsidy expressed as annual rent relative to CapEx of GSHP	%	0.9 %	2.4 %	1.1 %	1.4 %
Annualized Delta CapEx after subsidy (yearly)	CHF/year	2876	1742	6468	5856
Annualized Delta CapEx after subsidy (monthly)	CHF/month	240	145	539	488
(Delta CapEx after subsidy)/(CapEx gas boiler)	%	296 %	179 %	349 %	316 %

Data availability

The data that has been used is confidential.

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