



Powering Future Buildings: An Analysis of Energy Investment Preferences and Policy Impacts

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Powering Future Buildings: An Analysis of Energy
Investment Preferences and Policy Impacts

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Abstract

Residents are responsible for a considerable part of the total energy consumption and the resulting CO₂ emissions. These can be reduced by energy investments. Technologies are improving, prices decrease, the number of options is growing, and subsidies create incentives. All these factors can lead to a change in preferences. In a series of discrete choice experiments, I investigate what residents' preferences are for energy investments and what determinants play a role in this.

The thesis consists of three chapters. The first analysis uses data of 971 Swiss homeowners to identify their energy investment preferences. The aim is also to find out how collective investment opportunities and optimisation technologies influence these preferences. The results show a preference for renewable energy opposed to energy efficiency investments. Despite the potential to change the investment situation, collective financing is less preferred than investing in the own building. No effect can be found for storage, whereas load-management is disliked. Also, investment choices are not affected by most policy scenarios. Only net metering shows a significant positive effect on PV selection. In the second Chapter, on the basis of a sample of 2,890 Swiss house owners, the effect of subsidies and the associated application process is analysed. In addition, the effect of a hypothetical one stop shop (OSS), which is supposed to simplify the application process, is examined. The results point out the importance of subsidies. Their effect actually goes beyond purely monetary benefits. Subsidies also seem to be especially crucial for PV, as most PV installation have been supported by subsidies, whereas other investments are regularly carried out without policy support. Furthermore, the current subsidy procedure is not perceived as too complicated by most respondents. Accordingly, the offered OSS shows no impact on decision-making behaviour. In the last chapter of this thesis, 543 Swiss tenants also show interest in energy investments. However, there is no clear preference for renewable energy. They also show interest in efficiency upgrades for their rental building. Even though collective investment can empower them to invest without depending on the landlord, they rather value contributing to investment in the own building.

JEL Classification: D1, D12, H23, Q4, Q55, Q58.

Keywords: Keywords: Climate policy; Energy efficiency; Low-carbon technologies; Split incentives; Informational interventions

Résumé

Les résidents sont responsables d'une part considérable de la consommation totale d'énergie et des émissions de CO₂ qui en résultent. Celles-ci peuvent être réduites par des investissements dans le domaine de l'énergie. Les technologies s'améliorent, les prix diminuent, le nombre d'options augmente et les subventions créent des incitations. Tous ces facteurs peuvent entraîner une modification des préférences. Dans une série d'expériences de choix discrets, j'étudie les préférences des résidents en matière d'investissements énergétiques et les déterminants qui jouent un rôle à cet égard.

La thèse se compose de trois chapitres. La première analyse utilise les données de 971 propriétaires suisses pour identifier leurs préférences en matière d'investissement énergétique. L'objectif est également de déterminer comment les opportunités d'investissement collectif et les technologies d'optimisation influencent ces préférences. Les résultats montrent une préférence pour les énergies renouvelables par rapport aux investissements dans l'efficacité énergétique. Malgré la possibilité de modifier la situation de l'investissement, le financement collectif est moins préféré que l'investissement dans le propre bâtiment. Aucun effet n'est constaté pour le stockage, alors que la gestion de la charge n'est pas appréciée. Par ailleurs, la plupart des scénarios politiques n'ont pas d'incidence sur les choix d'investissement. Seule la facturation nette a un effet positif significatif sur le choix de l'énergie photovoltaïque. Le deuxième chapitre analyse, sur la base d'un échantillon de 2 890 propriétaires suisses, l'effet des subventions et du processus de demande associé. En outre, l'effet d'un hypothétique guichet unique, censé simplifier le processus de demande, est examiné. Les résultats soulignent l'importance des subventions. Leur effet va au-delà des avantages purement monétaires. Les subventions semblent également être particulièrement cruciales pour l'énergie photovoltaïque, car la plupart des installations photovoltaïques ont été soutenues par des subventions, alors que d'autres investissements sont régulièrement réalisés sans soutien politique. En outre, la procédure de subvention actuelle n'est pas perçue comme trop compliquée par la plupart des personnes interrogées. Par conséquent, le guichet unique que nous proposons n'a pas d'influence sur le comportement décisionnel. Dans le dernier chapitre de cette thèse, 543 locataires suisses ont également montré de l'intérêt pour les investissements énergétiques. Cependant, il n'y a pas de préférence claire pour les énergies renouvelables. Ils s'intéressent également à l'amélioration de l'efficacité de leur immeuble locatif. Même si l'investissement collectif peut leur permettre d'investir sans dépendre du propriétaire, ils préfèrent contribuer à l'investissement dans leur propre immeuble.

JEL Classification: D1, D12, H23, Q4, Q55, Q58.

Mots-clés: Politique climatique; efficacité énergétique; technologies à faible teneur en carbone; incitations fractionnées; interventions informationnelles

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List of Abbreviations

CHF	Swiss Franc
DCE	Discrete choice experiment
EE	Energy efficiency
NEM	Netmetering
OSS	One-stop shop
PV	Photovoltaic
RE	Renewable energy
SD	Standard deviation
SFH	Single-family house
SQ	Status-quo (in this dissertation: non-energy-related options)
TJ	Terajoule
WTP	Willingness to pay

Introduction

Residential buildings are responsible for a significant share of all energy consumption and associated CO₂ emissions in countries such as Switzerland (Swiss Federal Office of Energy, 2022a). Thus, energy investments on residential buildings are deemed essential to reach the climate goals (Swiss Federal Office of Energy, 2020; Kastner and Stern, 2015). However, investment rates are still low despite potential economic and environmental benefits (Burger et al., 2019; Gillingham and Palmer, 2014). Therefore, it is of interest to examine energy investment decisions in more detail in order to identify preferences, drivers but also, and above all, hurdles. The insights gained can then be used by policymakers to refine policies that are often considered essential to ultimately stimulate investment behaviour to counteract or slow down climate change.

There is a rich scientific literature on the topic of residential energy investments. Thereof, a large part is focussed on house owners and specific energy investment types (Kastner and Stern, 2015). Banfi et al. (2012) analyse the attitude towards certain energy efficiency investments like retrofits for multifamily houses, whereas Michelsen and Madlener (2012); Lang et al. (2022) investigate adoption of new heating systems. Gerarden et al. (2017) discuss potential reasons for the decreasing interest in energy efficiency upgrades. Hille et al. (2018) and Petrovich et al. (2019) examine decisive factors for photovoltaic (PV) investment decisions. Scarpa and Willis (2010) study preferences for microgeneration of renewable energy. The fact that investments are not always made despite economic benefits shows that it is not only financial advantages that motivate such investments (de Vries et al., 2020; Alberini et al., 2018).

Broadly speaking, investments that can foster sustainable energy usage and reduce CO₂ emissions can be classified in two different categories: energy efficiency measures and prosum-

ing of renewable energy (see e.g. Gillingham et al., 2016). Energy efficiency measures, such as insulation of the facade or replacement of inefficient windows, can help to consume less energy without changing the actual consumption behaviour (Fan and Xia, 2017; Gerarden et al., 2017; Stieß and Dunkelberg, 2013). The determinants of energy investment decisions have been studied in the Swiss context, for instance by Banfi et al. (2012, 2008). They find that households appreciate energy efficiency measures, such as insulation of windows and facades, and their benefits. Those benefits are environmental benefits, personal savings, but also increased comfort due to such measures. Yet, there is evidence for under-investment in energy efficiency upgrades and a resulting energy efficiency gap (Allcott and Greenstone, 2012; Gerarden et al., 2017). Lower valuation of insulation despite potential benefits can also be explained by high costs of such investments, dirt and stress coming with such measures, or a lack of civic involvement when it comes to energy efficiency (Stieß and Dunkelberg, 2013; Weiss et al., 2012; Weiss and Dunkelberg, 2010). Especially rental buildings are often inefficient, which can also be due to split incentives problem (Davis, 2023; Melvin, 2018). This means that the landlord, who owns the property, is responsible for investments in the building, while the tenants would be the beneficiaries of such investments, but usually have no decision-making power. This asymmetry can lead to under-investment, also because it can be difficult to recoup investment costs (Castellazzi et al., 2017).

The second type of investment is renewable energy production and consumption. For example, a renewable heating system is a more environmentally friendly alternative to heating systems that are otherwise often fuelled by fossil fuels (Lang et al., 2021; Stieß and Dunkelberg, 2013). Renewable space heating can be done with heat pumps or district heating, even though there are more options available¹. Prosumption on the other hand means that renew-

¹In the upcoming chapters, only heat pumps and district heating are considered as renewable heating options, as the aim of the research projects is rather to compare different energy efficiency and renewable energy investments without narrowly focussing on heating. Heating-specific studies were carried out by Lang et al. (2021), for example.

able energy is produced with the help of photovoltaics, for example, and then also consumed (Inderberg et al., 2018; Kesting et al., 2013). New opportunities such as collective financing projects and innovative technologies may further increase the renewable energy investment. Excess electricity can be fed back into the grid and households can benefit from remuneration (Petrovich et al., 2019; Kesting et al., 2013). Alternatively, excess energy can be stored in batteries for later use, for example during the night, when solar energy cannot be generated (Hoppmann et al., 2014). Yet, from an economic point of view, such investments in batteries are not always economically viable (Swissolar, 2019).

Most studies focus either on energy efficiency or on renewable energy investments (Kastner and Stern, 2015). One study that covers both is conducted by Fan and Xia (2017). Alberini et al. (2018) also consider energy efficiency and renewable energy investments. They use a choice experiment to elicit the willingness to pay (WTP) for CO₂ reduction. In their study, they identify a preference for producing renewable energy rather than for energy efficiency measures. Yet, more insights are required to get a better picture of energy investment preferences, especially in a dynamic market that is changing due to new opportunities. Such insights can be used to adapt policies and thus help achieve the climate goals.

Owners are of special interest because they can decide on their own about investments in their building and tend to have a higher income, which gives them more opportunities to invest in energy upgrades (de Vries et al., 2020; Davis, 2011). Their connection to their building is also usually different from that of tenants (Black et al., 1985). However, with 58% (in 2021) of all residents, tenants make up the majority of all residents in Switzerland (Federal Statistical Office, 2022). Their behaviour and opportunities differ from homeowners due to the fact that they lack rights to sovereignly decide on energy investments on the rental building. Some studies analyse tenant behaviour. Farsi (2010) and Reichardt (2014) concentrate on the willingness of tenants to contribute to energy efficiency measures in their rental flats. Their findings show that tenants indicate their willingness to contribute to energy

efficiency upgrades. As a rule, landlords decide whether to invest, while tenants may have to contribute to costs and have to pay their energy bills (Davis, 2023; Gillingham et al., 2012).

New opportunities and challenges

Recently, the interest in prosumption of renewable energy increases (Swiss Federal Office of Energy, 2021b). More and better innovative options for prosumption exist, a preference shift in energy investment may occur. This may mean that instead of traditional efficiency investments in their own building, residents tend to invest more in prosumption (Parag and Sovacool, 2016). More investment opportunities and technological innovations make the market dynamic and might make prosumption more attractive. This can further promote such a potential tendency. Understanding how new investment options affect investment behaviour, energy supply and, therewith, also existing policies is fundamental for solving existing problems and facing resulting challenges, as decentralized energy supply (Burger et al., 2019; Petrovich et al., 2019).

New opportunities to invest, that do not necessarily depend on the own housing situation, are collective investment projects. Amongst other opportunities, investing together with neighbours can establish prosumer communities. Self-consumption communities and crowd investment projects bear potential to play an important role for the transition to sustainable energy consumption (European Commission, 2019; Bonzanini et al., 2016). Such options can enhance the potential tendency towards renewable energy and present an alternative to traditional investments on the own residential building. Prosuming communities are expected to rise in the years to come (Riveros et al., 2019; Kubli and Ulli-Beer, 2016). By their nature, such collective investment projects can help to circumvent some barriers of traditional energy investments, such as high investment costs (Viardot, 2013). Such projects can make investing

more flexible, easier and cheaper (Bonzanini et al., 2016). However, even though it can be economic to contribute to collective prosumption, it remains yet to be seen whether such rather new options are appreciated or even preferred over traditional investments if residents have the choice between these different options. Drawbacks of such collective consumption can be transaction costs or rivalry in consumption, which can decrease their attractiveness (Gui et al., 2017). Thus, monetary benefits may not be sufficient to actually facilitate such investments (Büscher and Sumpf, 2015).

Rather low flexibility of prosumption was a factor that could influence attractiveness. Yet, ever improving smart technologies can help to optimise energy consumption and make prosumption more flexible. Battery storage and load management can be important factors to use energy more efficiently. Storage allows decoupling of production and consumption. For instance, energy that is produced by a PV installation can be stored and used even after the sun set. This enriches the opportunities and makes prosumption more convenient. Yet, storage is not yet always economically feasible, which may affect incentives to invest in such technologies (Hoppmann et al., 2014; Swissolar, 2019). Load management on the other hand can help to consume energy cheaper and more efficiently (Perger et al., 2021; Soland et al., 2018). This can also be beneficial for prosumer communities in order to avoid some potential issues like instability and can help to avoid costly upgrades (Hain et al., 2005). Yet, acceptance and economic feasibility of the optimisation options are not always given (Riveros et al., 2019; Fell et al., 2015).

Probably the easiest way to make own energy consumption more sustainable is purchasing “green” electricity from utilities, which can decrease the own CO₂ footprint. Often times this is possible irrespective of the housing situation (Tabi et al., 2014). Therewith, it is a convenient way to consume sustainable energy without having to invest in renewable energy installations (Goett et al., 2000).

A potential downside of the increasing amount of investment possibilities can be the more complex decision-making process. Multiple options, specifications and influential factors can make decisions harder. This can be an obstacle as energy investment decisions can already be difficult due to different possibilities and associated attributes, like costs and benefits, that have to be considered (Allcott, 2013). Findings show that people have a hard time correctly calculating outcomes of energy investments (Blasch et al., 2018).

Decision-making becomes even more difficult because of policies and assistance programmes that required effort and come with transaction costs (de Vries et al., 2020). Such programs exist in many countries, such as Switzerland, to enhance the uptake of energy investments (Swiss Federal Office of Energy, 2021a). To benefit from policies such as subsidies, different relevant factors and aspects have to be considered. This results in further complication of the decision-making process due to the organisational effort required to obtain the often essential subsidies (Patel et al., 2021; de Vries et al., 2020). Complexity and uncertainty increase transaction costs, which can cause inefficient solutions (O'Connor et al., 1996). Yet, there is not much evidence about effects of such complexity on energy investment behaviour.

Uncertainty can be a barrier to energy investment (Fawcett, 2014; Zahedi, 2011; Caird and Roy, 2010). It can be reduced by positive experience with a similar investment or process. The literature indicates that experience with energy investments increases the chance of choosing similar measures again (Berry et al., 2014; Hrovatin and Zorić, 2018). This can be the case if misperceptions are lowered due to experience (List, 2003). On the other hand, negative experience can hinder further investments (Fawcett, 2014). This and a lack of knowledge about energy costs, but also the often low attention paid to energy expenditure due to the small share of disposable income, can reduce interest in energy investments (Burger et al., 2018).

Evolving investment possibilities may make policy adaptations necessary (Petrovich et al., 2019). This can make investment decisions even more difficult, as residents may be unfamiliar with both the new investment opportunities, but also the policies that affect them. Changes lead to transaction costs resulting from the procurement of information and might make decisions more difficult (Patel et al., 2021). This is especially the case when assuming bounded rationality of potential investors, meaning that they have limited capabilities to process information. Some research projects discuss behavioural biases that affect investment decisions (see e.g. Frederiks et al., 2015; Gerarden et al., 2017). The same is expected to be true for tasks that are accompanying investment decisions, such as subsidy applications (de Vries et al., 2020).

Even though prosumption technologies such as PV are on the rise (Swiss Federal Office of Energy, 2023c), the current investment behaviour without additional incentives would possibly be too slow to achieve the climate goals. As a result, policymakers are keen on promoting such investments. But there is still uncertainty, which is the optimal approach to do that. In the literature, different policies ranging from taxes to subsidies are discussed. So do Alberini et al. (2018) find in their choice experiment conducted amongst homeowners in Italy and Czech that taxes are negatively perceived, whereas incentives are valued. Similar choice experiments conducted in Switzerland show a valuation of subsidies that go even beyond actual cost savings (Alberini et al., 2013). Yet, complexity of administrative tasks for subsidy applications may affect decision-making and attractiveness of such policies. In the application process, administrative hurdles and tasks to benefit from such subsidies can lead to transaction costs. These can affect the willingness to apply for subsidies, and can even lead to abandoning of applications and investments (Lades et al., 2021; de Vries et al., 2020). Experience with the processes can also reduce potential obstacles when it comes to attitudes towards subsidies. However, there is still a lack of evidence for the effects in relation to subsidies and the associated advertising process (de Vries et al., 2020). This also means

that potential for possible improvements of the current process remains unclear. However, findings on this could be important for policymakers to adapt approaches if necessary and ultimately achieve the climate goals.

Simplifications are deemed effective in decreasing non-monetary costs. Such simplifications can be achieved, for example, by means of an OSS. An OSS can take over certain investment-related tasks or even the entire investment process (Biere-Arenas et al., 2021; Reid and Wettenhall, 2015). Studies show that the value of an OSS cannot always be ascertained (Mahapatra et al., 2019; Pardalis et al., 2019). As the impact of complexity in the subsidy application process on investment decisions is largely unstudied, and the effect of a simple OSS that only facilitates the subsidy process has not yet been investigated, there is still a need for research in this area.

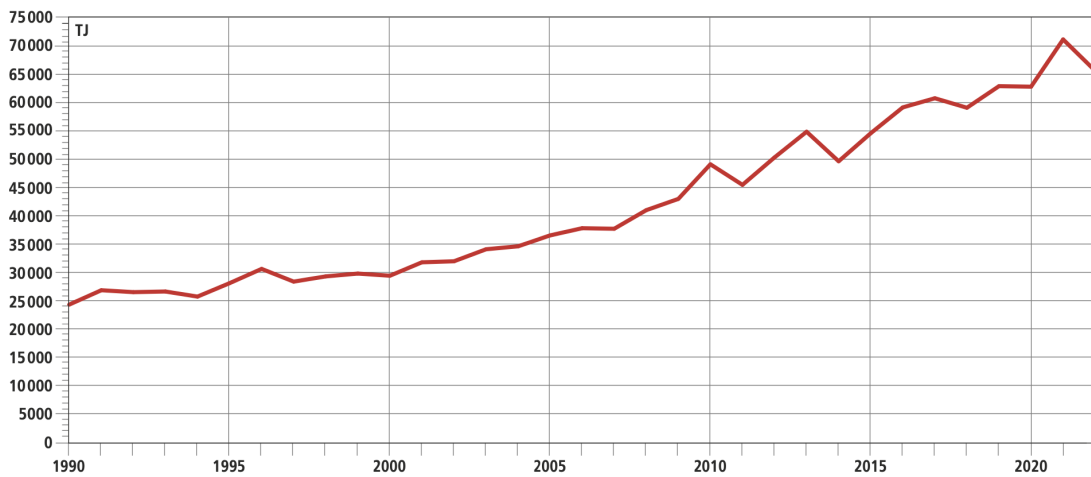
Situation in Switzerland

The residential building stock is responsible for a substantial share of all CO₂ emission in Switzerland (Swiss Federal Office of Energy, 2022a). Out of the almost 1,8 million residential buildings, 57% were single-family houses in 2020. This illustrates how important owners of such buildings are for achieving the climate targets. However, despite the high proportion of all buildings, these single-family houses are only occupied by 27% of the total population. Tenants make up a significant proportion of all residents. 58% of all households lived in rented flats in 2020 (Federal Statistical Office, 2022). Consequently, their involvement can have a large effect on CO₂ emission.

In recent years, renewable energy, for instance produced by PV or with heat pumps, has become more popular in Switzerland (Swiss Federal Office of Energy, 2023d). Figures 1 and 2 show the trend in heat production and electricity production (in terajoule (TJ)) from re-

newable sources in recent years². Both figures show an increase, even though heat production from renewable energy recently experienced a drop. In these statistics, only systems that are operated with renewable energy sources were taken into account. This also includes wood and waste. In recent years, renewable energies cover around 20% of final energy consumption. Residential renewable energy production, such as PV, still plays a subordinate role, however, as hydropower and the use of wood are the main sources of renewable energy production (Swiss Federal Office of Energy, 2023d).

Figure 1: Heat production from renewable energies



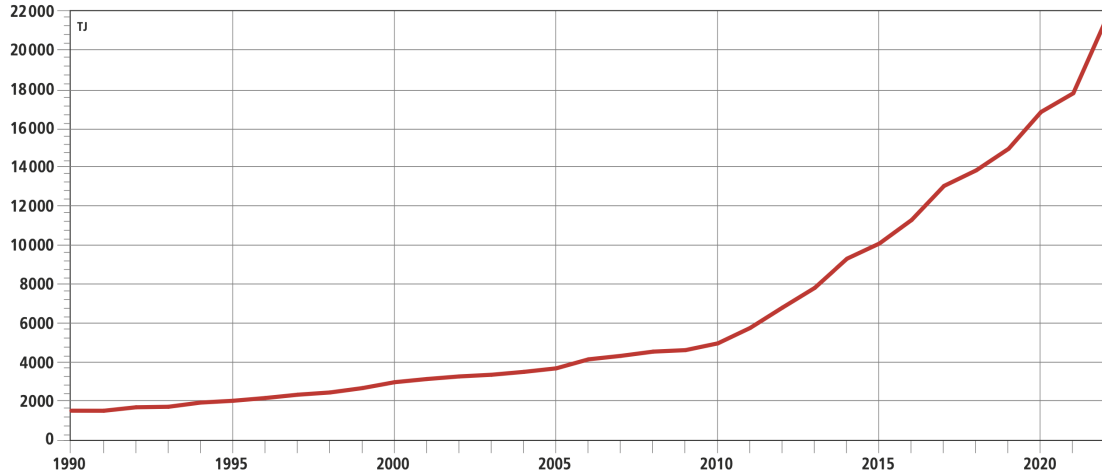
Source: Swiss Federal Office of Energy (2023d), page 33

Figure 3 shows that even if PV is not yet a major source of energy, there has been growing interest in such systems in recent years³. Even though there are now almost 200,000 PV systems installed in Switzerland, the proportion of energy generated is still comparatively low compared to hydropower, for example (Swiss Federal Office of Energy, 2023c). Because this is the total number of PV systems in Switzerland, the proportion of PV systems installed

²Figures 1 and 2 are not created by myself. Rather, they are from Swiss Federal Office of Energy (2023d) (pages 33 and 34).

³Figure 3 is not created by myself. It is from Swiss Federal Office of Energy (2023c).

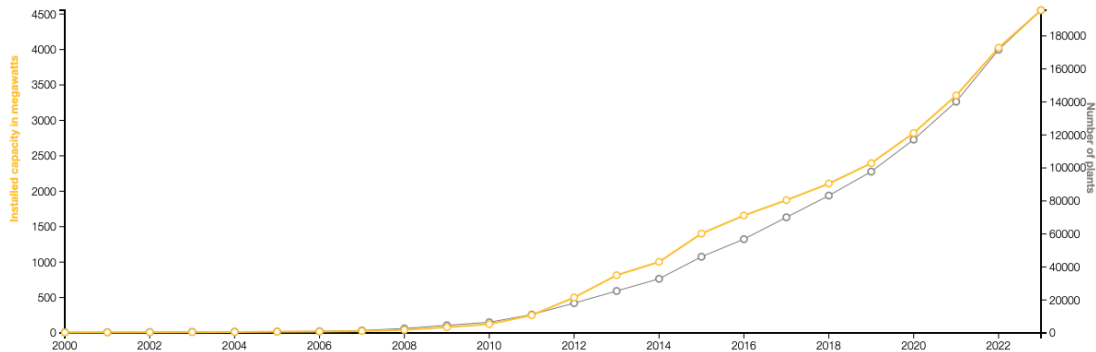
Figure 2: Electricity production from renewable energies



Source: Swiss Federal Office of Energy (2023d), page 34

on residential buildings is probably significantly lower, even if there are no more precise figures on this.

Figure 3: Expansion of PV



Source: Swiss Federal Office of Energy (2023c)

Many old houses in Switzerland need to be renovated to save energy and reduce CO₂ emission. However, these renovations are often not done, even though they can be beneficial for the environment and residents (IEA, 2021). In Switzerland, the annual retrofit rate is

only 1% (Federal Council, 2021). This is considered too slow for the energy transition, and that despite the fact that there is financial support for such renovation measures through the building program (Swiss Federal Office of Energy, 2022b).

Swiss policymakers try to promote residential energy investments to ensure a secure and sustainable energy usage in the future. Such investments are necessary because nuclear power is to be phased out in upcoming years. Swiss energy law has been adapted in recent years to meet the climate goals, and policies such as subsidies are available to investors in order to promote energy upgrades on residential buildings (Swiss Federal Office of Energy, 2021a, 2020).

Renewable energy is deemed to be an important source for future energy supply. In order to make investments in renewable energy production, for example through PV or geothermal energy, more attractive, policymakers have introduced incentives. Feed-in tariffs, that have been in place since 2008, were recently replaced by subsidy schemes. These subsidies mean that investors get reimbursement of a certain share of their investment costs. Currently, subsidies cover up to 30% of investment costs (Swiss Federal Office of Energy, 2019). This is deemed effective as costs have been identified to be one of the major obstacles to residential energy investments and subsidies have been proven to drive investment decisions in choice experiments (Heiskanen and Matschoss, 2017; Alberini et al., 2013). Despite subsidies, developing technologies, falling prices and increasing interest in such technologies, the number of residential buildings equipped with photovoltaics and the energy generated by PV is still low (Swiss Federal Office of Energy, 2023c; Charts, 2023). In terms of the number of PV installations on the total of 1.8 million residential buildings in Switzerland, less than 10% of them are equipped with PV. Despite rising PV investment rates, it is unclear whether the current system works effectively or whether the subsidy process itself comes with hurdles, leaving untapped potential.

Additionally, a CO₂ tax amounting to 120 Swiss Franks (CHF) per tonne of CO₂ applies in Switzerland in 2022. The CO₂ tax was introduced in 2008 to incentivise reduction of CO₂ levels. This tax applies to thermal fuels, but not to transport fuel (Federal Office for the Environment, 2021b).

In the Swiss context, energy efficiency upgrades are relevant because only 23% of the total population live in buildings build after 2000. On the other hand, 32% live in buildings constructed before 1960 (Federal Statistical Office, 2022). However, the energy retrofit rate remains at around 1% per year, which is insufficiently low to meet the targets (Federal Council, 2021; Swiss National Science Foundation, 2019). It is also mainly single-family houses that undergo energy-efficient retrofits (Swiss Federal Office of Energy, 2022b). This may also indicate a split incentive, as it is often the residents who benefit from such retrofits in the case of multi-family- and especially rental buildings, while the owners are often only investors but not direct beneficiaries (Davis, 2023). The fact that even though investing can be economically sound and beneficial for the environment actual investment rates are still relatively low, and that in presence of promoting policies, shows that not all factors are yet identified and accounted for.

Research objectives

Some questions about residential energy investment preferences remain unanswered in the literature. Most of the literature focuses on individual investments, as well as associated decisions and determinants (Kastner and Stern, 2015). However, different types of investment may well be suitable for achieving a specific goal, such as savings in previously consumed energy and associated costs. It therefore makes sense to offer residents different energy investments and analyse their choice.

For this reason, multiple investments for residential buildings are considered in the experiments that form the basis of the chapters in this thesis. Certain investments must be made in residential buildings to ensure their maintenance. For example, an overhaul of the façade or the heating system is essential from time to time. However, it can also make sense to switch to a more sustainable system such as renewable heating, for example a heat pump, instead of a simple overhaul of the fossil-fuel operated heating system (Lang et al., 2021). This can save heating costs and taxes. On the other hand, heating energy can also be saved without replacing the heating system. Insulating the building can increase energy efficiency and thus reduce consumption and energy costs (Gillingham et al., 2016). A combination of insulation and switching to a renewable heating system, such as a heat pump, can increase benefits for residents (Xing et al., 2011). This shows that various options are conceivable in order to achieve a specific goal, such as saving heating energy and the associated costs. Residents can therefore take these different options into consideration when thinking about an upgrade. Consequently, it makes sense to consider all of these options in our experiment to identify preferences and respective determinants.

Another way of making energy consumption more sustainable and save costs can be to invest in prosumption. This means that, for instance, by means of photovoltaics energy is produced and also consumed (Inderberg et al., 2018). Collective investment in production of renewable energy or purchasing “green” energy instead of conventional energy offer opportunities to use energy more sustainably, even without working on the own home. Such options can therefore be attractive for residents and also make an important contribution to the energy transition. So also when it comes to consuming renewable energy, there are various ways to invest in sustainable energy.

Due to the large number of possible energy investments, some of which have a similar effect, the decision-making process can be complicated. The literature does not fully shed light on the extent to which residents consider these different options, and whether certain

preferences prevail. By considering this wide range of partially innovative energy investment options, instead of just focussing on specific investments, my analysis provides new insights. For example, the attributes on which the choice depends and whether the decision can change based on these attributes or whether the preferences remain the same are investigated. All previously mentioned investment options in residential buildings, from simple painting without a noticeable energy saving effect, to complete energy retrofits or prosumption, are considered. Influential aspects such as innovative technologies and policies and their effect on decisions are also analysed. By looking at both tenants and owners, similarities and differences can be observed. In general, I examine their energy investment preferences and respective determinants of their decisions.

In addition, although many policies and their impact on investments have been examined in the literature to date, it has not been investigated in more detail what role the application process for subsidies plays. Therefore, I do not only investigate the effect of subsidies on energy investment decisions, but also how the application process is perceived. Also, it remains to be seen whether an OSS, that aims to simplify the subsidy application process, is appreciated. To my knowledge, such an OSS has not yet been investigated in the Swiss context. In addition, the literature focuses mostly on OSS concepts that significantly impair the investment process. In this thesis, a simpler concept that only reduces the complexity of the subsidy application process is examined to see if this can already be beneficial.

The research objectives addressed in this thesis are the following: Analysis of the energy investment preferences of homeowners and tenants. The aim is also to find out what role innovative solutions such as collective investments and smart technologies play. It is also of interest to find out to what extent different policy scenarios influence preferences. As subsidies are intended to stimulate energy investments in Switzerland, particular attention will be paid to the influence of subsidies and the associated application process. The aim

is to find out how this process is perceived, whether it is perhaps too complex, which could limit its effectiveness, and whether a simplifying program is seen as beneficial.

Thus, this PhD thesis is focused on the motivations and barriers to a wide range of residential energy investments, both for tenants and owners. Chapters 1 and 2 focus on single-family house (SFH) owners, their energy investment preferences and influential factors such as new investment opportunities and subsidies. Chapter 3 addresses tenants and their energy investment preferences. All chapters are based on discrete choice experiments (DCE) conducted in Switzerland. The data sets are analysed with mixed logit models⁴. Additionally, the WTP for energy investment options is calculated either by dividing investment coefficients by the cost coefficient, or by directly estimating the mixed logit in the WTP in Chapters 1 and 3.

Chapter 1 is based on a choice experiment conducted in 2020. Therein, energy investment preferences of SFH owners are analysed. More specifically, we examine whether we find preferences for prosumption. If so, it is of interest to see whether emerging collective investment opportunities and technological innovations drive this preference. More so, the effects of different policy scenarios on the respondents' choice behaviour are explored. Therefore, a sample of 971 Swiss SFH owners is analysed with a mixed logit model. Taking into account a large variety of potential energy investments for residential buildings, as well as new opportunities, allows getting a general idea about preferences and hints whether these are showing a preference for prosumption and collective investment. The results show a preference for prosumption rather than for energy efficiency upgrades. This is also reflected in their WTP, which often times exceeds actual investment costs. Despite potential advantages, collective investment options are comparably less appreciated than investments on the own building. Even though innovative technologies and optimisation options can promote pro-

⁴For tenants, mixed logit in WTP space results are also reported. For Chapters 1 and 2, latent class results are presented in the respective appendices.

sumer preferences, storage shows no significant effect, and load management is clearly not appreciated. When it comes to the policy scenarios, only net metering affects choices and leads to a greater appreciation of PV. More so, the results show a rather large heterogeneity amongst respondents. This means that preferences differ, and so can policy effects. It implies for policymakers that there might be not one perfect solution, but rather that different groups have to be targeted in order to increase effectiveness of policies.

SFH owners are also the target group in Chapter 2. This chapter is about finding out what role subsidies, complexity in the corresponding application process and experience play for energy investments. Subsidies, for example for PV, are available in many countries. However, it is not yet evident whether the complexity in the subsidy application process deters potential investors. Therefore, this study focuses, among other things, on the perception of subsidies and the related application process. In addition, the aim is to find out whether an “one-stop shop” that takes care of subsidy-related tasks and, as a result, decreases complexity and transaction costs for applicants, is valued. The unique sample of 2,890 Swiss homeowners consists of both completely inexperienced owners and owners who have already invested and received subsidies. The aim was to find out for both groups what their preferences are, what role subsidies play for them, and whether simplifications seem necessary. In this experiment, too, a tendency towards renewable energy can be seen. In general, the particularly effective investment options are positively perceived. The results show that subsidies play an important role. Their effect goes beyond the pure cost advantage. Moreover, the revealed statistics show that subsidies seem to be especially important for PV, whereas other upgrades, such as insulation, are regularly carried out without policy support. The current process is not perceived as being overly complicated by most respondents. This is also reflected in the estimation results, as the OSS treatment does not show a significant effect on their decision-making. The difference between cost and subsidy effect is greater among

experienced individuals than among residents who have not yet experienced subsidies. This suggests that prejudice and uncertainty about subsidies may play a role.

Chapter 3 focusses on tenants, which are due to their substantial share of all residents and their respective CO₂ emission meaningful for the energy transition. Yet, they have been rather limited in their options as investment decisions are usually taken by the landlord, which can lead to split incentive problems and resulting under-investment in energy upgrades. However, upcoming collective investment projects can empower them to circumvent such problems. Thus, this study aims to find out whether tenants have a preference for renewable energy or if potential split incentive problems lead to a greater interest in efficiency upgrades. Furthermore, it is of interest how such rather new collective investment and optimisation options are perceived and if they can promote a potential preference for prosumption. By means of a discrete choice experiment (DCE) conducted in 2020 we obtained data from a sample of 543 Swiss tenants. The results of the mixed logit estimation show that tenants value different energy investments. Even though renewable energy options are highly valued, also some efficiency upgrades are of similar importance. Thus, a clear preference for renewables cannot be derived. Despite collective investment opportunities, they show the highest valuation for contribution to investments carried out by the landlord. Thus, collective investment does not appear to be a game changer right now. Anyhow, their valuation shows that collective investment may be of interest if the landlord does not invest. Policies and optimisation show no significant effect, which can be due to a lack of knowledge or limited importance of energy related costs. Yet, the positive WTP for most energy investments shows that potential split incentive problems can be solved. By that, tenants can play an important role in reaching the climate goals.

Experiments

For all three chapters, different DCEs have been utilised to obtain the data necessary for the econometric analysis. Basically, two different types of data are feasible for analysing the research questions on hand: revealed and stated preference data. Both come with pros and cons (see e.g. Alberini et al., 2018; Newell and Siikamäki, 2014; Louviere et al., 2000).

The strength of stated preferences as opposed to revealed preferences data is that not only the eventually selected energy upgrade is examined, but the decision-making and its determinants can be deciphered for a variety of potentially relevant investments (Bessette and Arvai, 2018; Bidwell, 2013).

Therefore, for the purpose of this work, DCEs are beneficial to gather data about investment preferences and their determinants, that could not otherwise be obtained (Louviere et al., 2000). Even though revealed data represents actual behaviour, while stated preferences are only given in a hypothetical set-up, for the purpose of this dissertation the latter approach is advantageous. This is also the case because innovative options in a dynamic market are investigated. When it comes to recent developments and changes, revealed data is scarce and not necessarily informative for future developments, as the whole situation is potentially changing (Golden, 1992). The stated preference approach allows examining these potential changes and how they are affected by which factors, before revealed data is available. This is also beneficial for policymakers in order to target policies if deemed necessary to steer a potential change.

DCEs also allow control of the information provided to the person for decision-making (Alberini et al., 2018). This makes it possible to investigate which factors play which role. It also enables trade-offs to be mapped. Different relevant options are offered to be able to analyse the respondents' decision-making process between these options with their respec-

tive attributes. Thereby, it is possible to get a comprehensive picture of energy investment decisions, even if only in a hypothetical set-up (Bessette and Arvai, 2018; Bidwell, 2013).

To get the most meaningful insights, investment- and policy-related information is provided before the actual experiments and only realistic and relevant investment options are offered. A priming script is displayed before each choice experiment to get truthful and relevant responses. Participants are informed that they will be offered hypothetical alternatives, and they are asked to choose according to their preferences and personal circumstances. In addition, they are told to choose as if they could decide again on investments they have already made. This is to avoid a potential bias. It also allows observing their satisfaction with previous investments and what implications this has for their choices in the experiment. Moreover, commonly applied DCE practices, such as reminding respondents of their budget constraints, are used in the experiments to determine actual preferences (Vossler et al., 2012; Johnston et al., 2017). It is mentioned to respondents that the results of the experiment are used to adapt actual policies in Switzerland. This conveys to them how important it is that they give answers according to their actual preferences. As a result, the answers given should reflect the true priorities of the participants (Vossler et al., 2012; Newell and Siikamäki, 2014).

The DCEs for Chapter 1 and 3 were launched in 2020. In 2021, the DCE for Chapter 2 was conducted. All experiments were part of “The Swiss Household Energy Demand Survey” SHEDS waves of the respective years (see also Weber et al., 2017). SHEDS is an annual survey that deals with energy-related topics. These surveys featured not only the actual choice experiments but also additional questions about living situation and other related topics. The respondents of SHEDS surveys come from the pool of Swiss residents, managed by the private survey company Intervista⁵. In addition, our surveys for Chapters 1 and 2 were also part of other surveys in various Swiss cantons. Additionally, a sample of subsidy

⁵Further information available at <https://www.intervista.ch>

recipients come from the pool of applicants from the subsidy agency Pronovo. This is also described in more detail in the corresponding chapters. As a result, we obtained unique and large samples that helped us to gain new insights.

The set-up of all experiments was tailored to the specific purpose. For all DCEs, the software programs Ngene and Qualtrics were used for the set-up (see also Weber, 2021). All choice experiments featured multiple choice situations where respondents had the choice between two energy investment options and one non-energy-related option. If the latter option was chosen, a follow-up question asked for what other purpose they would spend the money that would otherwise be used for the energy investment option. This approach allows identifying preferences, but also trade-offs, not only between energy investments, but also between energy and outside options.

The approach for Chapters 1 and 3 differs from the one for Chapter 2. These experiments came with between group but also within experiment variation due to the introduction of hypothetical scenarios or “treatments” after the first two choice tasks (Charness et al., 2012). These treatments were messages about hypothetical policy changes. In the experiment for Chapter 2, a treatment was introduced for a share of respondents ahead of the actual choice experiment. Here, the treatment introduced an OSS concept to simplify the subsidy application process to see if and in how far this affects the respondents’ appreciation of subsidies.

Econometric strategy

The econometric analysis is based on the random utility framework (McFadden, 1974). Individuals derive utility from the investment option itself and the corresponding attributes. According to this, respondents choose in order to maximise their utility. Accordingly, we estimate the respondents’ utilities as a function of investment-specific attributes (Louviere

et al., 2010; Alriksson and Öberg, 2008). Our samples consist of N individuals, who choose between $J = 3$ alternatives in T choice tasks. Individual n derives utility U_{njt} from choosing alternative j in choice task t :

$$U_{njt} = V_{njt} + \varepsilon_{njt} \quad \text{with} \quad n = 1, \dots, N, \quad j = 1, 2, 3, \quad t = 1, \dots, 6 \quad (1)$$

Respondents choose in order to maximise the own utility: $U_{nit} > U_{njt}$ ($\forall j \neq i$). In order to avoid critical assumptions about the independence from irrelevant alternatives (IIA) of the error term, we use mixed logit models for the estimation (Train, 2009; McFadden and Train, 2000).⁶ The representative utility V_{njt} is modelled as a linear function of observable explanatory variables:

$$V_{njt} = \alpha A_{njt} + \beta_n X_{njt} + \gamma_i Z_{njt}, \quad (2)$$

Therein, A_{njt} represents the vector of attributes, to which a fixed coefficient is applied. All alternative-specific variables come with random coefficients represented by X_{njt} . As a result, coefficients β_n vary over respondents. The coefficients follow a normal distribution. The only exception is the log-normally distributed cost coefficient when the mixed logit model is directly estimated in the WTP space. For this approach, the cost coefficient scales the utility function (see Hole and Kolstad, 2012; Train and Weeks, 2004). Vector Z_{njt} contains characteristics of respondents. These have to be interacted with investment specific variables in order to be integrated. The mixed logit choice probability can be formally expressed as:

⁶I also used a latent class model for the analysis in Chapter 1 and 2. However, I encountered convergence problems with the latent class model. Therefore, I use a mixed logit model, also, because it does not require the same kind of assumptions as conditional logit models. For further discussion of the latent class model, also in comparison to the mixed logit model, see (Greene and Hensher, 2003).

$$P_{njt} = \int \prod_{t=1}^T \left(\frac{\exp(V_{njt})}{\sum_i \exp(V_{nit})} \right) f(\beta) d\beta \quad (3)$$

The sum of i refers to the set of potential energy investments offered. Choice probabilities are approximated by using $R = 500$ Halton draws and can be estimated by maximising the simulated log-likelihood function (Train, 2009):

$$SLL = \sum_{n=1}^N d_{ni} \ln \left[\frac{1}{R} \sum_{r=1}^R \prod_{t=1}^T \prod_{i=1}^I \left(\frac{\exp(V_{njt}(\beta_r))}{\sum_i \exp(V_{nit}(\beta_r))} \right) \right] \quad (4)$$

In there, $d_{ni} = 1$ if respondent n chooses alternative i and 0 otherwise. β_r refers to the r -th draw from the distribution.

By posing multiple choice tasks, it is possible to calculate the willingness to pay (WTP) based on trade-offs rather than on simple numbers stated by the respondents. To calculate the WTP for energy investments, two different approaches can be used. When a fixed cost coefficient is estimated, the WTP for investment k is calculated as the ratio of the attribute coefficient to the cost coefficient, as it can be seen in Equation 5.

$$WTP_k = \frac{-\beta_k}{\beta_{cost}} \quad (5)$$

The resulting figures show how much on average an individual is willing to pay for a certain investment option. Another way of calculating the WTP is to estimate the mixed logit in the WTP space Hole and Kolstad (2012); Train and Weeks (2004). To do so, costs are used to scale all other attribute coefficients in Equation 2. Then again, the simulated log-likelihood function is maximised following the previously described scheme⁷.

⁷Results of mixed logit in WTP space estimations are reported in Chapter 3. No mixed logit in WTP space results could be obtained in Chapters 1 and 2 due to convergence problems with the final models. However, since in Chapter 3 similar WTP results are obtained for the estimation in the WTP space and the calculation based on the estimation coefficients, this does not seem to be a drawback.

Policy relevance

Relatively low investment rates and the necessity to take action in order to achieve the transition towards sustainable energy usage make policy interventions necessary. It has been shown that policy measures, such as subsidies for energy investments, appear to be crucial (Alberini et al., 2013; Granade et al., 2009). The fact that these policies are appreciated and functioning, as also identified in Chapter 2, attests to the success of such interventions. Yet, even though these policies seem to work sufficiently well, uncertainty about scope for improvement makes it worthwhile to investigate whether their effectiveness can be improved. This has also not yet been extensively studied in the literature. Even so, for instance, simplifications aiming to reduce transaction costs may be effective in reducing remaining hurdles (de Vries et al., 2020). As a result, the “one -stop shop” concept featured in the choice experiment in Chapter 2 can be of interest for policymakers. The results of this study can be considered by policymakers. They may prove valuable in adapting policies to increase their effectiveness, or they may reassure them that their current approach is appropriate.

Chapter 1

Analysis of homeowners' energy investment preferences, taking into account collective investments and smart technologies

This chapter is based on a working paper co-authored by Mehdi Farsi (University of Neuchâtel, Institute of economic research), Sylvain Weber (University of Applied Sciences and Arts Western Switzerland (HES-SO), Haute école de gestion de Genève (HEG)) and Martin Jakob (TEP Energy). This paper has been published as part of the IRENE Working Paper Series (WP 22-06).

1.1 Introduction

Residential buildings are associated with a substantial share of overall CO₂ emissions due to their substantial electricity and heating consumption (IEA, 2021). Investments in both energy efficiency and renewable power generation can improve the situation by reducing overall energy consumed or limiting the share of non-renewable energy (IEA, 2020).¹ Whilst there are indications for an energy efficiency gap due to low investment rates (Baumhof et al., 2018; Gerarden et al., 2017), renewable energy investments enjoy greater popularity (IEA, 2021; Swiss Federal Office of Energy, 2021b). This has led to a number of studies focused on prosuming, which means that residents not only consume energy but also produce some. The energy investment possibilities evolve thanks to novel technologies and business models (Oberst and Madlener, 2014). Major potential changes affecting energy investment behaviour are currently: (i) financial innovations, (ii) improving optimisation technologies, and (iii) implementation of stringent policies.

Financial innovations may boost energy investment by creating new opportunities (Moret and Pinson, 2018; Bonzanini et al., 2016). In particular, collective investment projects allow households to benefit from energy investments without any work being done on their own buildings (Vasileiadou et al., 2016; Bomberg and McEwen, 2012). Such projects also lower upfront costs, which may otherwise discourage households. Technologies such as smart management as well as storage can make production and consumption of renewable energy more convenient by increasing flexibility. While the economic viability of storage facilities is not always granted (Swissolar, 2019), load management provides a relatively low-cost solution for optimizing consumption (Kostková et al., 2013). Finally, current and upcoming policies, which can either provide financial incentives or regulate behaviour, can make energy invest-

¹Purchasing renewable energy from a provider is another alternative to reduce CO₂ emissions without investment in a strict sense. For the sake of convenience, we assimilate the purchase of renewable energy as an “energy investment”, and use this expression in a broad sense thereafter.

ments more attractive and, thereby, help countries such as Switzerland reach their climate goals (Swiss Federal Office of Energy, 2020; Walls, 2014). It has been shown that policy is a major factor in promoting sustainable investments (Inderberg et al., 2018).

While many experts consider these changes as a shift resulting in substantial lowering of investment barriers (see e.g. Stadler et al., 2016), there is little empirical evidence regarding changes in investment behaviour. In particular, identifying the effect of these changes on energy investment decisions and the investors' willingness to pay (WTP) for specific attributes is an empirical challenge that requires a comprehensive understanding of homeowners' preferences regarding a variety of energy investments available to those investors. The stated preferences approach provides a useful framework to address the question. However, most studies focus on specific energy efficiency upgrades (Banfi et al., 2012), investigate heating-related investments (Lang et al., 2021; Michelsen and Madlener, 2016), or focus on renewable energy investments such as PV or heat pumps (Petrovich et al., 2019; Heiskanen and Matschoss, 2017; Hille et al., 2018). Specific aspects of investment options or personal characteristics or potential investors are usually investigated in details. Yet, multiple alternatives and all of these factors can be simultaneously relevant in the decision-making process. Also, the role that innovative solutions play for investment decisions is insufficiently considered so far.

In this paper, we analyse single-family house (SFH) owners' energy investment decisions, and how these are affected by different factors. The focus on owners is motivated by the fact that single-family houses represent the majority of Swiss residential buildings (57% in 2021) and therefore have considerable potential for savings (Swiss Federal Office of Energy, 2023a; Federal Statistical Office, 2022). In addition, their owners generally have a higher income and the freedom to decide independently on changes to their building (Davis, 2011). There is still a literature gap, as there is no comparable study that examines a wide range of possible energy investments for residential buildings or as a collective, which also includes innovative options that can potentially change conventional investment behaviour. Thus, we investigate

the following research questions: Do consumers generally wish to become prosumers? Do collective forms of investment show the potential to promote a preference for prosumption, independently of the building itself? What role do smart technologies and optimisation play in decision-making? How do policies affect behaviour?

Considering novel solutions implies that revealed data is scarce. Even when available, they do not usually provide a picture of the whole decision process, allowing to deduct trade-offs and influential factors. We therefore carry out a discrete choice experiment (DCE) to elicit stated preferences from 971 single-family house owners living in Switzerland. We apply mixed logit models to evaluate the willingness to pay for various energy investment types. Our results show an overall positive perception of energy investments, and a preference for prosumption by means of PV can be detected. However, the results do not suggest that collective investment projects or smart technologies induce more investment; in some cases, they even have the opposite effect. Netmetering is the one policy treatment that seems to have a relevant effect on investment decisions. Yet, the results show considerable heterogeneity across households, which shows that it is difficult to make general statements about investment preferences.

Our findings add to the literature by not only considering certain investment, but rather investigating owners' preferences when they can choose between multiple investment and financing options. This broader picture is also interesting for policymakers, as achieving the climate goals also depends on energy investments and adaptations of policies may be necessary as new opportunities emerge (Swiss Federal Office of Energy, 2020).

The remainder of this paper is structured as follows. Section 1.2 presents the background and reviews the relevant literature. The discrete choice experiment is described in Section 1.3, and the methodology is presented in Section 1.4. The results are discussed in Section 1.5. Section 1.6 concludes and formulates policy implications.

1.2 Background and literature review

Energy investments are shifting away from energy efficiency and towards renewables and prosumption. Annual renewal rates for residential buildings indeed remain low (IEA, 2021; Federal Council, 2021). In Switzerland, the annual retrofit rate is only 1% despite the fact that more than one million buildings are insufficiently insulated (Federal Council, 2021). This contributes to the 40% of energy demand and the resulting 30% of CO₂ emissions from residential buildings (Swiss Federal Office of Energy, 2023a). Aversion to energy retrofits may, for instance, result from inconvenience in the form of dirt, noise, and other restrictions (Alberini, 2019; Scarpa and Willis, 2010).

On the other hand, prosumption of renewable energy by means of PV is on the rise (Swiss Federal Office of Energy, 2021b). Inderberg et al. (2018) investigate whether there has been a similar prosumer trend in Germany, Norway, and the United Kingdom in recent years. They find that policies, information and other factors affected renewable energy investment. Even if the current status in the three countries differs due to the different introduction of technologies and policies, there is a strong prosumer trend in all countries. Likewise, PV installations have recently become more popular in Switzerland (Swiss Federal Office of Energy, 2021b).

Yet, why this is the case is often difficult to assess based on revealed data because decisive factors are not easily observable. Thus, choice experiments are frequently used to analyse energy investment decisions, because it is possible to control attributes and disentangle their impact. The stated preference approach not only allows considering the investments that are selected, but also to learn about the ones that are discarded, which is virtually impossible with revealed data. By randomizing investments and their attributes, preferences can be elicited (Louviere et al., 2000). Thus, considering the wide array of existing energy investments available to homeowners and the small frequency at which such investments are implemented,

it is difficult to assess what aspects are actually considered when making decisions using observed data. Stated preference approaches, and in particular discrete choice experiments, are therefore regularly used to analyse energy investment decisions.

A number of studies focus either on energy efficiency or on renewable energy investments (Kastner and Stern, 2015). For instance, Scarpa and Willis (2010) use a discrete choice experiment and focus on residential renewable energy production. They find a positive WTP for investments in PV or heat pumps. Yet for most households, this WTP appears insufficient to cover realistic installation expenses. Michelsen and Madlener (2012) conduct choice experiments amongst German homeowners to analyse drivers and barriers for renewable heating investment. Preferences and influential factors are found to vary across different types of homeowners and heating systems. Some are more interested in savings, whereas others value autonomy. Characteristics like income, age, and education affect the respondents' heating investment decisions. Lang et al. (2021) conduct a choice experiment in Switzerland to investigate energy efficiency valuation and whether households are willing to switch to renewable heating systems. They find a general interest in energy efficiency measures, even though preferences are heterogeneous. Yet, WTP for renewable systems is not necessarily high enough to yield switches from fossil fuel heating to renewable heating systems. Petrovich et al. (2019) analyse stated preferences of Swiss homeowners with regard to PV investments. They find that aesthetics and peers affect PV investment decisions. Banfi et al. (2008) obtain a positive WTP for energy efficiency measures, such as residential building insulation, in Switzerland. According to their findings, residents not only value efficiency gains and environmental benefits, but also increased comfort.

Fewer studies consider both energy efficiency and renewable energy investments. Alberini et al. (2018), using a choice experiment to identify the WTP for CO₂ reduction, find a preference for renewable energy production compared to energy efficiency measures. Ameli and Brandt (2015) consider a variety of both efficiency and renewable energy investments. Their

research investigates how investment decisions are affected by socio-economic characteristics, dwelling characteristics, attitudes, and beliefs. They show that ownership, income and environmental attitudes affect households' propensity to invest in clean energy technologies. Their analysis does not, however, consider specific attributes of the investments themselves, such as costs or benefits. Thus, there is a lack of evidence on the preferences and how they are affected in the currently changing investment situation.

A potential increase in energy investment can also be enhanced by collective investment projects. They present an alternative to traditional investments on the own residential building and can lower some typical barriers, such as high upfront costs (Viardot, 2013). Investing together with neighbours may allow establishing prosumer communities, which are expected to develop in upcoming years (Riveros et al., 2019; Kubli and Ulli-Ber, 2016). Such communities are not only beneficial for the investors themselves, but are also interesting for the transition towards sustainable and decentralised energy systems (European Commission, 2019). Yet, whether homeowners prefer to invest alone or as part of a community remains unclear. Potential downsides of collective prosumption can arise, for instance, from transaction costs or rivalry in consumption (Gui et al., 2017). Such downsides may affect the attractiveness of communities.

An alternative to private investment, without sacrificing the possibility of prosuming, is offered by leasing. Under this scheme, the provider, or another party invests in a renewable energy system, such as a heat pump, and the end user pays in monthly or annual instalments. Such a financing option can lower burdens of upfront costs while giving households more flexibility and less maintenance work (Liu et al., 2014). A variety of own and collective investment options are thus available to potential investors.

Energy consumption can be optimised thanks to smart technologies in the form of battery storage and load management (Perger et al., 2021; Soland et al., 2018; Hoppmann et al., 2014).

This can also be beneficial for prosumer communities in order to avoid potential issues like instability (Hain et al., 2005). Yet, acceptance and economic feasibility of the optimisation options cannot be taken for granted (Riveros et al., 2019; Fell et al., 2015).

Yet another way to contribute to a sustainable energy system is to opt for “green energy”. Renewable electricity, for example produced with solar panels, can be purchased from providers (Tabi et al., 2014; Kaenzig et al., 2013). Different stated preference studies identify consumers are ready to pay a premium for renewable energy (see e.g., Wu et al., 2022). However, there are significant differences in the WTP for different renewables, and hydropower, by far the largest source of electricity production in Switzerland, appears to be the least valued by consumers (Sundt and Rehdanz, 2015). Electricity products encompassing solar power and other renewables might therefore be more attractive to Swiss consumers than standard products offered by default.

Environmental policies and regulations can also influence investment behaviour (see e.g. Inderberg et al., 2018). Most prominently, CO₂ taxes raise the price of fossil fuels, thereby increasing the incentives to reduce fossil fuel consumption and ultimately reducing carbon emissions (Köppl and Schratzenstaller, 2022). However, some studies show that there is not necessarily an effect of such taxes on investment behaviour or consumption (Ott and Weber, 2022; Ürge-Vorsatz et al., 2007). CO₂ caps set limits on the overall consumption of fossil energy, for instance for heating energy consumed per square meter. The effects of such policies can be avoided or lowered through energy investments, for example in building insulation or renewable heating. On the other hand, feed-in tariffs and subsidies increase interest in energy investments by reducing upfront costs and the payback period (Castaneda et al., 2020; Mundaca and Samahita, 2020; Lang et al., 2021).

Despite the amount of mostly very specific studies, there is hardly any evidence if there is a preference for prosumption. Thus, we fill the research gap by applying a choice experiment.

Our experiment features different energy efficiency and renewable energy options and thus allows to show trade-offs and preferences. Furthermore, it has the advantage to picture how different attributes affect the decisions. Also, it allows getting insights for new opportunities, which would not be possible because the markets are still immature, and it remains to be seen how they develop.

1.3 Experiment

Even though revealed preferences are often considered to be more meaningful than stated preferences, because they show actual behaviour and not only choices in a hypothetical set-up, the stated preference approach is better suited for our purposes. This is mainly the case because observing real investments does not tell anything about the set of opportunities considered and which factors led to the final decision. Thus, saying something about potential preferences for prosumption based on revealed data is difficult. This is also the case because we consider innovative financing options which are not well established yet. Thus, revealed preference data is scarce. The stated preference approach allows gaining more information about this decision-making process and allows considering even new opportunities Louviere et al. (2000). Thereby, it is possible to investigate potential trends and how they are affected by such innovations even before their impact can be observed in the real world. This is also beneficial for policymakers, who may design policies to promote investment behaviour if deemed necessary to reach their goals.

Moreover, the stated preference approach is appropriate because we are interested in whether investment choices are changing. This can happen because of the new collective investment opportunities and technological innovations that make this market very dynamic.

This makes past behaviour not necessarily valuable in understanding new trends and predicting behaviour in the future (Golden, 1992).

Another advantage of DCEs is that they allow to precisely control the given information and attribute levels, such as the respective costs and benefits. By presenting multiple relevant options, the respondents' decision-making between these options and how it is affected by specific attributes can be quantified and analysed. We therefore offer realistic investment options, in order to facilitate respondents' understanding and collect meaningful data. By considering multiple energy investments with different attributes and levels, it is possible to get a comprehensive picture of actual preferences and their determinants (Bessette and Arvai, 2018; Bidwell, 2013). Moreover, by exposing respondents to a number of choice tasks, it is possible to calculate WTPs based on trade-offs rather than on simple numbers stated by the respondents.

Ahead of the choice tasks, relevant information is presented to the survey participants, and they are questioned about their housing situation, which allows tailoring investment options. Furthermore, we apply standard DCE practices to elicit actual preferences (see e.g. Vossler et al., 2012; Johnston et al., 2017). A priming script is used to foster truthful and realistic choices. Participants are informed that they will be offered hypothetical alternatives, and they are requested to choose according to their preferences, taking costs and their financial limits into consideration.²³ A criticism addressed to stated preference approaches is that they might not reflect actual behaviour. To mitigate that risk, we mentioned to respondents that our research project was relevant for shaping future policies and highlighted the importance for themselves to answer in accordance with their true preferences.⁴ We therefore expect the

²The specific wording of the budget reminder was: "Some of the following questions will involve costs to your own household; please give careful consideration to how these costs would affect your financial budget."



³Further information about the DCE and its design can be found in Appendix 1.7.1.

⁴The project was funded by the Swiss Federal Office of Energy (SFOE), the country's competence centre for issues relating to energy supply and energy use. We therefore highlighted that SFOE would consider our results to make our claim credible.

stated answers to represent the actual preferences of the participants (Vossler et al., 2012; Newell and Siikamäki, 2014).

Each respondent goes through six choice tasks, such as the one displayed in Figure 1.1. The experiment features two baseline choice tasks, followed by a script with a hypothetical policy scenario (called “treatment” hereafter). Then, two similar choice tasks, and two further choice tasks with additional attributes follow.

Figure 1.1: Example choice task

	Option 1	Option 2
	Photovoltaic installation 	Heating system reinstatement 
Costs	CHF 40,000 in total	CHF 5,000 in total
Benefits: Reduction of non-renewable energy and CO₂ emissions	15%	25%
Financing	You as owner	You as owner
Storage in batteries and load management	None	None

Option 1 Option 2 None of the two

Your choice:

In each choice task, respondents are asked to choose between two unlabelled energy investments (options 1 and 2) and a third alternative labelled “none of the two” (called status-quo or “SQ” hereafter), giving respondents the possibility not to select any investment (Alriksson and Öberg, 2008). To facilitate identification by the respondents, investment types are represented by pictograms, as shown in Figure 1.1. All potential investment options, the respective attributes and levels are displayed in Table 1.2. They are set to realistically reflect market prices and the outcomes of the specific investments. Energy investment options are

characterized by five attributes: the specific kind of investment, the related costs, benefits expressed as energy and CO₂ emissions saved through overhaul or prosumption, which leads to a reduction of previous non-renewable energy consumption, and how the investment is financed. Furthermore, in choice tasks 5 and 6 we added whether the investment includes storage and/or is accompanied by load management.

Because we consider both investments, like PV, and purchasing green energy, we have two different cost variables, one for investing and another one for purchasing⁵. The different options came with a range of benefits and costs, which can be seen in Table 1.1.

Different financing options are offered. The default is that the house owner has to bear all costs and reaps all resulting benefits. Yet, because we investigate whether collective investment projects are perceived as alternatives to investments in one's own building, PV and renewable heating options were sometimes available as collective investments with neighbours or as self-consumption communities. Such forms of investment are not typical for overhauls of the own building from which only its residents can benefit, such as insulation of the façade. Therefore, efficiency investments were always own investments, whereas PV and renewable heating were available both alone and with others. Including collective financing options makes it possible to investigate whether such options are seen as attractive alternatives.

We introduce hypothetical “treatments” in the form of political scenarios between the second and third choice tasks. Thus, the first two choice tasks serve as baseline observations, and our data benefit from within-respondent variation as well as between variation across respondents (see Charness et al., 2012). The respondents are assigned randomly to treatment groups with equal probability, so that all groups include a similar number of respondents. In

⁵To make the results comparable and identify whether the valuation of costs is different for investing and purchasing, purchasing costs are translated to respective total costs and not only the premium paid for consuming green energy. Thus, in the regression, purchasing cost cover both the green premium and the usual costs for consuming the respective amount of energy. As a result, results can be compared to investment costs.

Table 1.1: Cost and benefit levels

Investment type	Costs	Benefits (% conventional energy saved)
Investment options	(in CHF 1'000)	
Envelope reinstatement	20; 25; 30; 35	0
Insulation	40; 60; 80; 100	15; 25; 40; 60
Heating replacement	4; 5; 6; 7	5; 10; 15; 25
Heating replacement and insulation	20; 50; 75; 100	15; 25; 40; 60
Renewable heating (investing or leasing)	30; 40; 50; 60	20; 40; 60; 100
Renewable heating and insulation	75; 100; 120; 150	20; 40; 60; 100
PV	15; 20; 30; 40	15; 25; 40; 60
- with storage	20; 27; 40; 55	20; 30; 50; 70
- with load management	20; 27; 40; 50	20; 30; 50; 70
- with storage and load management	27; 35; 50; 60	20; 40; 60; 80
Renewable heating and electricity	45; 60; 80; 100	20; 40; 70; 100
- with storage	50; 67; 90; 115	20; 40; 70; 100
- with load-management	50; 67; 90; 110	20; 40; 70; 100
- with storage and load-management	57; 75; 100; 120	20; 40; 70; 100
Purchasing option	(in CHF/year)	
Premium for “green” electricity	30; 80; 130; 180	15; 25; 40; 60

Investment options come with total costs for a lifetime of 30 years. Purchasing green electricity comes with an annual premium that is added to the electricity costs. For the regression, the purchase costs are converted into total costs, which include both the premium and the costs for the respective amount of conventional energy saved.

total, we have the following five treatments (plus a control group):⁶ (1) a CO₂ tax increase, (2) a CO₂ cap per m² of the accommodation, (3) net electricity metering (NEM) and (4) subsidies for PV or (5) for insulation. These policies either already exist in some form or have been discussed in order to achieve the climate targets (Swiss Federal Office of Energy, 2021a). At the bottom of the treatment script, respondents are asked to keep in mind the hypothetical scenario provided when they answer the following four choice tasks.

Because the relevant policy scenarios already exist or were at least debates in the context of climate targets, respondents should believe in their credibility and should be able to understand potential implications. All treatment scripts look similar, which limits any

⁶The exact texts displayed as treatments can be found in Appendix 1.7.1.

Table 1.2: Attributes and levels

Attributes	Description	Levels
Energy investments	Offered energy investment and purchasing options	Heating reinstatement; Insulation; Insulation and heating reinstatement; Renewable heating; Insulation and renewable heating; PV; PV and renewable heating ; Green electricity
Costs	The costs of buying or investing in a certain measure	Purchasing costs between CHF 30-180 and investment costs between CHF 4,000-150,000
Benefits	Reduction of non-renewable energy and CO ₂ emissions due to energy savings or prosuming / consuming renewable energy	Between 0 and 100%
Financing	The costs can either be incurred by the owner alone or shared between several investors	(1) Investing alone (2) With 2-3 neighbours (3) Self-consumption community with multiple neighbours (4) The provider places a renewable heating system, which is paid off annually renewable heat from the utility (5) Purchasing green electricity from the utility
Optimisation	Renewable energy investments can come with batteries for storing the produced energy or the investment can be accompanied by load management by the utility to consume energy most efficiently	(1) Without (2) Battery (in combination with PV) (3) Load-management (4) Battery and load-management

possible effect to the content. The subsequent choice tasks are not adapted in any way to the treatments, so any systematic difference across groups can be causally attributed to the treatments.

The software *Ngene* is used to create the experimental design and the choice experiment is set up with *Qualtrics* (Weber, 2021). The sample stems from two surveys conducted in 2020: it was introduced as a module in the Swiss Household Energy Demand Survey (SHEDS)⁷ (see Weber et al., 2017) and in a survey conducted in the Swiss cantons of Obwalden, Zug, Basel

⁷Participants stem from a pool of subjects managed by the private survey company Intervista. The panel holds over 100,000 subscribers in Switzerland. Participants are contacted via mail and receive a small token for their participation. Quotas on gender, age, geographic region, and residential status are targeted in order to obtain a sample representative of the population.

Land, St. Gallen, Luzern, and Zürich (“Cantons’ survey” hereafter). The data from SHEDS was collected between 20 May and 27 June 2020. The Cantons’ survey was conducted from 16 October 2020 until 11 January 2021. Combining the data collected through both surveys, our sample consists of 971 single-family house owners, among which 261 respondents from SHEDS and 710 from the Cantons’ survey.

Characteristics of respondents in comparison with the Swiss population are reported in Table 1.3. Compared to the Swiss population, respondents in our sample tend to be older and more educated. As homeowners need the means to own the property, this is not unexpected. In addition, the proportion of men is comparatively high. In terms of household income, the respondents in our sample also tend to be higher than the Swiss population. However, it should be noted that only few respondents reported their income, which suggests that these figures should be interpreted with caution. Also, the household income for the Swiss population is not specific for house owners but the total population, which can explain the higher income of respondents in our sample.

The living situation of respondents is presented in Table 1.4. In our sample, the household size is a bit larger than in the overall Swiss population, which is no surprise given that more tenants live alone (see also Table 3.4). Respondents in our sample live in rather new buildings. The proportion of houses equipped with PV and renewable heating is higher than for all Swiss buildings.

Table 1.3: Personal characteristics

	Respondents	Switzerland
Age		
18-34	43 (4.48)	(25.31)
35-54	350 (36.46)	(34.41)
55-64	265 (27.60)	(16.90)
65 +	302 (31.46)	(23.39)
Sex		
Male	699 (72.28)	(49.31)
Female	268 (27.72)	(50.69)
Education (highest qualification)		
Compulsory school	25 (2.60)	(13.90)
High school or vocational school	455 (47.25)	(41.40)
University (of Applied Sciences)	483 (50.16)	(44.70)
Household gross income		
Less than 3,000	6 (2.65)	(18.1)
3,001-6,000	33 (14.60)	(34.6)
6,001-9,000	68 (30.09)	(28.9)
9,001-12,000	61 (26.99)	(10.0)
More than 12,000	58 (25.66)	(7.5)

Shares in parentheses (in %). Data for the Swiss population relates to persons of legal age. Data sources: age and sex: Federal Statistical Office (2023e) (Year 2022); education: Federal Statistical Office (2023b) (Year 2022); income: information provided by the Federal Statistical Office for this dissertation, not publicly available (Year 2020).

Table 1.4: Living situation

	Respondents	Switzerland
Household size		
1 person	21 (8.05)	(17.89)
2 persons	110 (42.15)	(38.80)
3 persons	45 (17.24)	(14.68)
4 persons and more	85 (32.56)	(28.64)
Building age		
Built until 1990	425 (43.77)	(68.70)
Built between 1991 and 2020	546 (56.23)	(31.30)
Building with PV		
No	811 (83.52)	(>89.00)
Yes	160 (16.48)	(<11.00)
Building with renewable heating		
No	277 (28.53)	(57.50)
Yes	694 (71.47)	(42.51)

Shares in parentheses (in %).

Data sources: household size: Federal Statistical Office (2023a) (Year 2020, SFH only);

building age: Federal Statistical Office (2023d) (Year 2020, SFH only); buildings with PV: Swiss Federal Office of Energy (2023c) (Year 2023). These numbers are estimations based on the total number of PV installations and residential buildings in Switzerland. However, the number of PV systems refers not only to residential buildings but to all buildings.);

It is probably lower for residential buildings; buildings with renewable heating: Federal Statistical Office (2023c) (Year 2022)

1.4 Methodology

The econometric analysis is based on the random utility framework (McFadden, 1974). Accordingly, we estimate the respondents' marginal utilities as a function of investment-specific attributes (Louviere et al., 2010; Alriksson and Öberg, 2008). We use a mixed logit model for the estimation, as it allows avoiding the critical assumption of independence of irrelevant alternatives (IIA) (Train, 2009; McFadden and Train, 2000). Investment options enter with random coefficients, whereas the other variables come with fixed coefficients. In line with the literature, we assume the random coefficients as normally distributed.

Furthermore, since the cost parameters are assumed to be fixed, it is possible to estimate the WTP by dividing the estimated investment coefficients by the cost coefficients Hole and Kolstad (2012); Train and Weeks (2004). The WTP for purchasing green electricity is translated to the amount for an average lifetime of energy investments of 30 years. This allows comparing estimates to identify whether there is really a prosumer preference and how the WTP differs depending on whether it is an investment or mere purchase of a greener alternative to conventional electricity⁸.

⁸For a detailed and formal description of the econometric approach, see the Section "Econometric strategy" in the Introduction.

1.5 Results and Discussion

Table 1.5 presents the empirical estimations based on the mixed logit model.⁹ WTP values calculated on the basis of the estimation results are presented in Table 1.6.

The results show a prosumer preference, as PV has the largest impact among all investment categories. This is in line with the developments of the past years (Swiss Federal Office of Energy, 2023e; IEA, 2021). The estimated WTPs provide a similar picture, as they are large for PV but negligible for insulation. The PV WTP figures exceed realistic costs. That shows a high valuation of prosumption, especially also in comparison to the energy efficiency investments. On the other hand, the WTP for insulation is insufficiently large to facilitate such investments. This is in line with the low investment rates in recent years (IEA, 2021). The reasons that insulation is not appreciated can be, for example, hassle and the inconvenience due to construction work (Lades et al., 2021; Murtagh et al., 2021). Insulating the buildings often results in dirt and noise, which can lead to people not wanting such work carried out (Alberini, 2019). On the other hand, PV has become cheaper and better, which can explain the greater interest in such investments (Swiss Federal Office of Energy, 2023e)¹⁰.

Reinstating the fossil fuel operated heating system has a significant positive effect, whereas for renewable heating, only the leasing option shows a significant effect. Hence, when it comes to heating, there is no obvious trend towards renewables, which is in line with findings by Lang et al. (2021). Moreover, the WTP for own and collective investments in renewable heating is not large enough compared to the real costs to make such investments. The WTP

⁹We ran separate estimations for both subsamples, but the results are comparable so that we report the analysis for the pooled sample in the remainder of this chapter. Furthermore, we included trend indicators in our estimation to check whether there are any indications of fatigue or learning over the course of the experiment. Yet, the results were insignificant. We also tried to use latent class model for the estimation. Yet, the fully specified model failed to achieve numerical convergence. Latent class results of a differently specified model and unadjusted data set are reported in Appendix 1.7.3.

¹⁰In Chapter 2, the results are similar. Yet, the preference for PV is not as clear as it is here. This and possible reasons for this are therefore discussed in Section 2.6 and in the Conclusion of this thesis.

Table 1.5: Estimation results

	Mean	SD
Energy investments (base: non-energy alternatives):		
Heating reinstatement	0.655** (0.28)	2.739*** (0.45)
Renewable heating		
- own investment	0.445 (0.45)	2.784*** (0.90)
- collective investment	0.127 (0.34)	1.640*** (0.41)
- SCC	-0.432 (0.48)	3.192*** (0.71)
- leasing	2.036*** (0.76)	2.852* (1.56)
PV:		
- own	1.741*** (0.17)	1.549*** (0.29)
- collective	1.145*** (0.16)	0.126 (0.74)
- SCC	1.019*** (0.16)	0.377 (0.50)
Insulation	0.359 (0.24)	2.428*** (0.16)
Purchasing green electricity	0.693*** (0.23)	1.681*** (0.32)
Benefits (% of conventional energy saved):		
Benefits	0.026*** (0.00)	0.049*** (0.00)
Investment and purchasing costs (in 1000 CHF):		
Investment cost	-0.010*** (0.00)	
Purchasing costs (green electricity)	-0.017 (0.01)	
Storage (base: no battery or load-management):		
Battery	0.053 (0.12)	
Load management	-0.800*** (0.24)	
Battery and load management	-0.049 (0.20)	
Treatment effects (base: control group; interacted with relevant investments):		
CO ₂ Tax × Renewable Heating	0.814 (0.56)	
CO ₂ Cap × Renewable Heating	0.242 (0.49)	
NEM × PV	0.232* (0.14)	
Subsidy × PV	-0.273 (0.18)	
Subsidy × Insulation	-0.265 (0.24)	

Sample: 971 respondents, Number of observations = 17,478

Significance levels * p < 0.1, ** p < 0.05, *** p < 0.01. Standard errors in parentheses

for the reinstatement of the heating system is higher than for an investment in renewable heating. Only leasing a renewable heating system shows a high WTP, which even exceeds a realistic level. This hints that owners appreciate such convenient solutions. As leasing seems to be appreciated, it may be a mean to promote switching to renewable heating systems.

Table 1.6: Willingness to pay (in 1,000 CHF)

	Average WTP	Lower limit	Upper limit
Heating reinstatement	48.66	-8.4	105.72
Renewable heat			
- own investment	11.72	-72.02	95.46
- collective investment	-44.84	-116.90	27.22
- SCC	-95.76	-219.46	27.94
- leasing	173.11	1.80	344.41
PV:			
- own	139.30	83.37	195.23
- collective	101.63	52.90	150.36
- SCC	78.18	38.29	118.07
Insulation	0.35	-37.17	37.87
Purchasing green electricity *	13.05	-7.25	33.35

Sample: 971 respondents, Number of observations = 17,478

* To make results comparable, the costs for purchasing green electricity were translated in total costs for 30 years (expected lifetime of an energy investment such as PV

In 2020, when our choice experiment was implemented, 1 CHF \approx EUR 0.93 \approx USD 1.07

Regarding collective investment, we find that all forms have positive and significant effects for PV. Yet, investing alone is still the preferred option. The more potential co-investors are involved, the lower the positive effect. The WTP is highest for investments in the own building and decreases with the number of investors involved. For renewable heating, only leasing such a system has a significant effect. Overall, there is no evidence that collective investment options are preferred to traditional investment alone in one's own building, despite their potential upsides. Purchasing green electricity from the provider without having to invest shows a significantly positive effect. The estimated WTP for green electricity includes

not only the premium for purchasing green instead of conventional energy, but also the cost for the amount of presented benefits. This is done to make the results comparable, as other investments would also cover the same amount of energy consumption.

In general, some WTP figures are rather high given the typical costs for such investments, which is in line with the observation by Stadler et al. (2016), who conclude that DCEs tend to deliver relatively high WTP results. Moreover, the standard deviation is rather large for many coefficients, indicating that there is substantial heterogeneity amongst respondents.

These results already allow answering the first two of our research questions. First, when comparing energy efficiency and renewable energy investments, it appears that there is a preference for prosumption by means of PV. When comparing traditional and renewable heating, the results are not that clear. Overall, especially when comparing insulation and PV, there are signs of a prosumer preference. Second, the results show that homeowners prefer to invest alone in energy measures for their building. Collective investment options do not seem to be appreciated to the same extent yet.

Reasons for this can be that energy cooperatives with neighbours require collective decisions, contracts, governance and coordination, leading to transaction costs, for instance due to organisational tasks, and uncertainty (Gui et al., 2017). Collective investment also creates rivalry in consumption, meaning that the ability to consume the own produced energy is affected by the behaviour of the co-investors. Thus, reaping benefits is less certain or requires more coordination compared to investing alone. The results may also be linked to our set-up, whereby the trust relationship is unclear. However, trust certainly plays an important role for collective investments, and the lack of trust therefore increases complexity and uncertainty (Büscher and Sumpf, 2015). Other downsides of such collective prosumption from the backyard are the potential lack of environment-friendly image, that can be created by a PV system, for example, and the not necessarily higher resale price of the building as

the installation is not always building-specific. The lower WTP for collective PV investments is also in line with findings showing that households are willing to pay a premium for the visibility of their PV installation. The resulting signal indicates environmental consciousness of the investor and can lead to social recognition. In case of collective investment, this signalling effect is diluted. These negative aspects of prosuming together with neighbours in one's own backyard can be reflected in the lower WTP. Finally, respondents may not be familiar with such energy communities and may be rather reluctant to choose them due to the resulting uncertainty. As a result, collective investment projects seem to be not considered as an equivalent alternative to own investments and, thus, should not be expected to yield major changes in energy investment or in the prosumer trend.

Even though batteries and load management can be rewarding for households, the results indicate no overall appreciation of such measures. The fact that batteries do not have a significant effect may be due, among other things, to the fact that such investments have not really been profitable to date, although this could potentially change in the future (Swissolar, 2019; Hoppmann et al., 2014). Moreover, this may be related to the lack of familiarity with such rather innovative technologies. The negative effect for load management can be explained by distaste for control, which has already been identified by other researchers (Fell et al., 2015). Distrust can also lead to disapprobation of external control of energy (Stenner et al., 2017).

Benefits come with the expected positive effect on selection, meaning that saving conventional energy and the associated costs and CO₂ emission is valued. Costs, both in the form of investment costs and for purchasing green electricity, come with the expected negative effect, which shows that cheaper options are preferred. The investment cost coefficient confirms that high upfront costs can hamper energy investments. But also the purchasing cost coefficient shows purchasing green electricity should be cheap. The corresponding coefficient is large (although not significant) compared to that of investment cost. The lower impact of

investment cost (vs. purchasing cost) may also result from the fact that investing in one's own building increases the value of the property, while purchasing greener energy leaves the former unaffected.

The final objective of our research was to identify whether policy treatments affect choices. Such policies have been identified to promote energy investments (see e.g., Inderberg et al., 2018; Solangi et al., 2011). The fact that the CO₂ tax does not show any significant effect could be explained by the low price elasticity of energy demand and the rather small share energy expenses represent in households' budget (Ott and Weber, 2022; Zhu et al., 2018). Netmetering appears to make PV investments more attractive, as it comes with a significant positive effect in our estimations. Familiarity with this policy, which has been in place in Switzerland before, and economic benefits can lead to the positive result (Swiss Federal Office of Energy, 2021a). Subsidies show hardly any effect. A possible explanation could be that the respondents are not familiar with subsidies or do not have a feeling for the effects. However, the treatment effects must not be overrated due to their hypothetical nature.

The mixed logit model we use also allows us to use standard deviations to make statements about the potential preference for renewable energy. Low standard deviations can show that preferences are rather homogeneous, while large deviations show that the appreciation of such investment options differs significantly. In general, the standard deviations show substantial heterogeneity amongst respondents and their respective WTP. The standard deviation for benefits is relatively low. Thus, benefits are appreciated to a similar extent. On the other hand, the sometimes very substantial standard deviations for most investment options show that there may be respondents who do not value a specific investment at all, while this investment is valued by others.

This is also reflected in Table 1.7, which presents how regularly the various investment options were chosen by respondents when they were displayed. It shows the proportion of

respondents who always, sometimes, or never chose the respective option. This exhibits that there are often clear preferences in favour of or against certain investments that do not change despite varying attributes. The non-energy status-quo option was always chosen by 5% of all respondents, whereas it was never chosen by 66%. In particular, when it comes to leasing renewable heating or purchasing green electricity, preferences tend to be clearly in favour or against, which is reflected in the large proportions of respondents who always or never chose these options when they were available. There is also a substantial proportion of respondents who never chose envelope reinstatement or insulation, although it would be reasonable for their building.

Table 1.7: Preferences for energy options

	Status- quo	Envelope reinstatement	Heating overhaul	Renewable heating	PV	Insulation	Leasing ren. heating	Green electricity
Never	66.22	66.45	34.74	39.11	21.13	47.94	38.35	46.32
Sometimes	28.84	11.46	48.42	39.60	50.31	42.23	15.79	11.19
Always	4.94	22.09	16.84	21.29	28.56	9.83	45.86	42.49
Total number of respondents who received the respective option:								
	971	602	95	202	970	824	133	706

Shares of all respondents who received the respective option in %.

Never: never chosen if available, sometimes: at least once but not always chosen if available, always: chosen whenever available
Investment options offered were tailored based on the respective housing situation

However, his research could be limited by the experimental design. We have endeavoured to strike the best possible compromise between clear choice tasks that do not overwhelm the respondents and the provision of sufficient information for informed choices. Nevertheless, it is possible that not all respondents understood all concepts and attributes, which may impact the analysis. For example, respondents may not understand the benefits we presented. This may be because they are given in percentage savings. However, it is evident that people often do not know how much they are paying for energy (see e.g. Blasch et al., 2018; Brounen et al., 2013). This may mean that respondents are not fully aware of the ultimate benefits of such an investment. However, the results do not give cause for concern in this regard

because benefits come with the expected positive effect on selection. In future studies, the risk of attributes not being properly understood can perhaps be minimized by always giving monetary values, even if the dependence on the respective housing situation poses a challenge. On the other hand, the complexity of the experiment, with the different concepts, attributes and the policy scenario, may be too much for some respondents. However, since we want to depict realistic decision-making scenarios, which can be just as or even more complex, this can hardly be avoided. However, because only a small proportion regularly chooses the status-quo option, we can assume that people really consider the presented options. Another disadvantage could be the length of the entire survey. Possible fatigue may affect the selection. In the course of the analysis, we also checked whether more people chose the status-quo option as the experiment progressed. This could indicate that people are fatigued. However, we find no such evidence. The lack of significant policy effects may also be due to the design. The introduction of the policy scenario within the choice experiment may be challenging for respondents. The policy and resulting implications for the investment may be too complicated. As a result, respondents may not consider the policy scenarios in the way we intended. A different design may be more appropriate. For example, it might be better to show the policy and its implications with the choice tasks, for instance as a change in price. In addition, checking the understanding could be beneficial. For that purpose, additional questions can be useful. Anyhow, the added burden of additional questions has to be considered.

1.6 Conclusion

With this study, we analyse preferences for residential energy investment and how they may be affected by financing options and novel technologies, as well as different policies. To this

end, we conduct a DCE and collect information from a sample of 971 Swiss homeowners, which allows us to estimate their preferences regarding these energy investments.

Our results show that renewable energy investments are generally more attractive than energy efficiency investments, even though this is not necessarily the case in the heating context. The strong WTP for PV but low appreciation of insulation provides evidence in favour of a shift in preferences from energy efficiency towards prosumption, which is in line with recent developments observed in this context.

Even though there are hopes that collective investment projects, for instance in the form of self-consumption communities, could contribute to develop prosumption in the future, we find no indication that such projects are preferred to own investments. The empirical results show that homeowners would rather invest in their own property on their own. WTP and selection chances diminish with the number of potential co-investors. This may be due to the transaction costs incurred, uncertainty and the lower signalled environmental friendliness. Leasing, for instance, of a renewable heating system, appears to be a valued alternative and such financing can help to promote sustainable energy investment.

Additionally, we investigate how smart technologies might affect the prosumer trend. Despite potential benefits, we do not find any significant effect for storage. This is not totally surprising, as such systems are not yet economically viable. On the other hand, load management is clearly disliked. Even though most of the introduced treatments show no meaningful significant effect, we find that netmetering promotes the selection of PV. This indicates that such incentives can help to promote energy investments.

1.7 Appendix

1.7.1 DCE

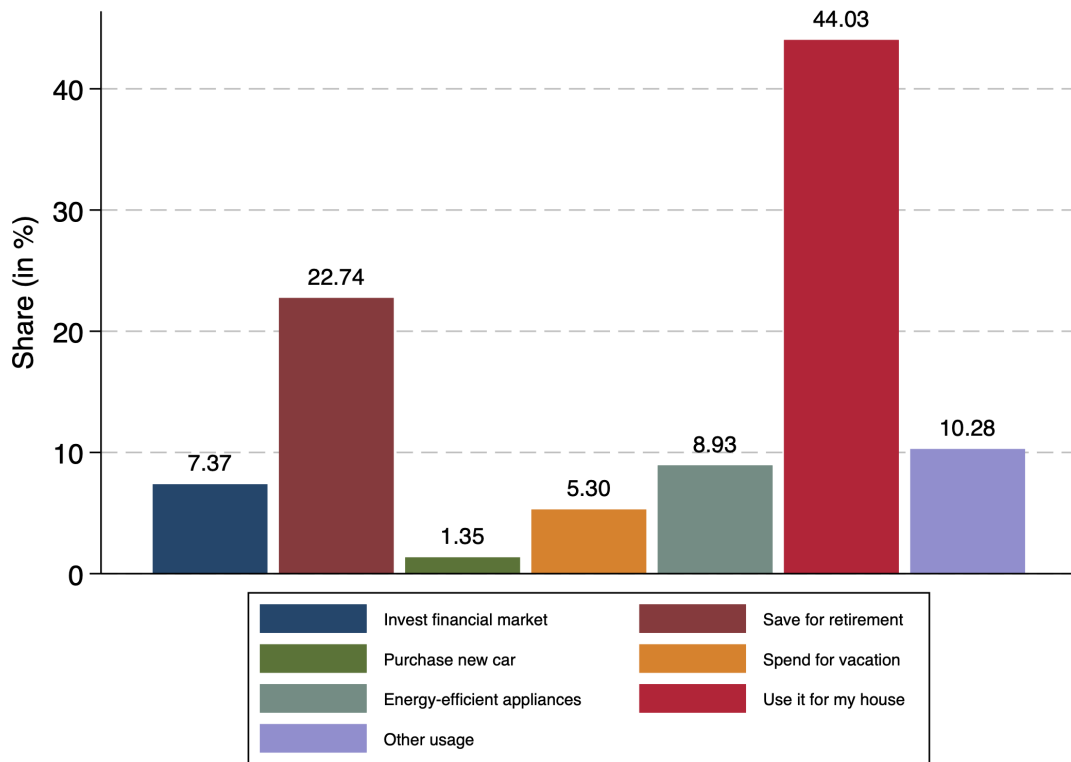
The DCE design was the product of intensive dialogue with experts from the University of Neuchâtel, SHEDS and TEP Energy, as well as policymakers. The basic design was based on earlier experiments and adapted based on the findings of these. It was tested in pretests with scientists involved in the 2020 SHEDS wave. Final errors were identified and rectified and, based on the positive feedback, the design was retained as planned.

Ahead of the actual experiment, respondents receive information about the content and procedure. They are told that the experimental results will be used to inform policymakers. Considering this fact and their financial limits should help us to get true answers according to their preferences. By asking respondents about their housing situation before the actual experiment, the investment options on offer could be adapted to make the selection as relevant as possible. For example, owners of retrofitted buildings are not offered insulation, as there would otherwise be a risk of distorting the results. They are then given an explanation of all the concepts so that people who have not dealt with the subject before can make informed choices.

Because we want to identify their investment preferences, we ask respondent how they would spend an unexpected tax return amounting to CHF 5,000 or 10,000. Their responses can be seen in Figure 1.2. As it can be seen, the largest share of respondents indicates that they would use it for their house. This gives a first indication that respondents are actually interested in investing in their property. Saving money is also popular among respondents.

The people who have declared their willingness to invest the tax refund in their building are asked what exactly they would like to spend it on. This gives us a more precise idea of

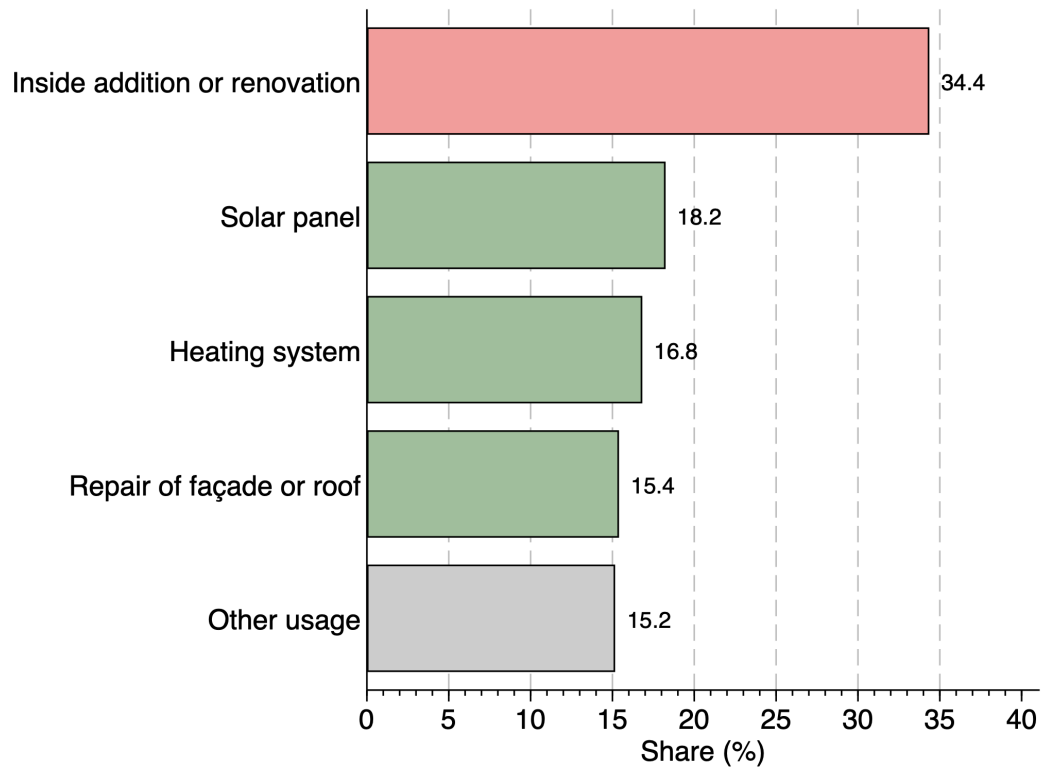
Figure 1.2: Usage of unexpected tax return



whether it is energy investments that people want to make, or if they are rather interested in other upgrades. This helps to predict the interest in energy investments before the experiment. As can be seen in Figure 1.3, the most popular category is to use the money for projects in the building, but there is also interest in energy investments.

For the individual choice tasks, it is important to get as comprehensive a picture as possible of the preferences and trade-offs. For this reason, various energy investments are offered. The order is randomised to avoid bias due to placement. The energy options offered are adapted to the building of the respondents to make the choice and decision as realistic as possible by making both options relevant and realistic. In addition, there is always the status-quo option, which gives respondents the opportunity to choose a non-energy related alternative if the energy options offered are not attractive to them. The first time a respon-

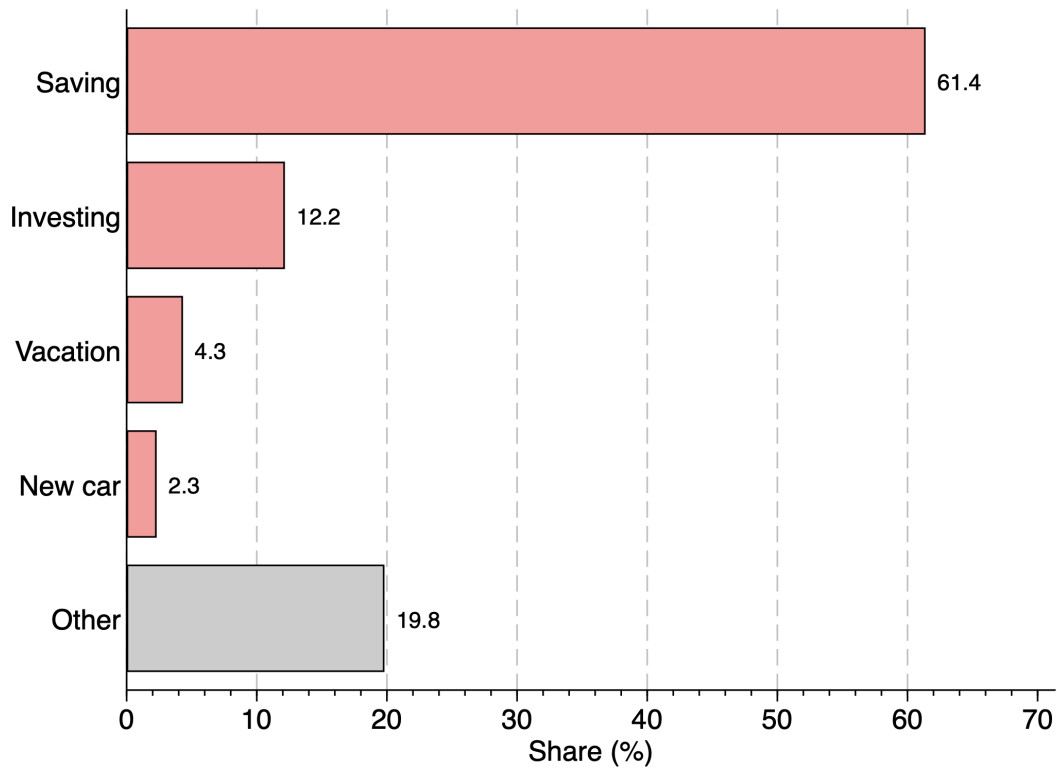
Figure 1.3: Investment intention



dent chooses the status-quo option, a follow-up question is displayed. Therein, respondents have the choice between different alternative ways of spending or saving the money that was otherwise intended to be used for the energy investment. Their responses are displayed in Figure 1.4. As it can be seen, most respondents (61%) chose to save the money, which is in line with their responses to the question regarding the usage of an unexpected tax-refund, presented in Figure 1.2.

The DCE design is focussed on presenting the experiment and the attributes as clearly as possible. The design and attributes were always the same for all choice tasks. Only the offered energy options and attribute level changed to be able to identify the impact of these changes. Even though numerous factors can play a role in the investment decision, it is important not to overwhelm the respondents and still cover important aspects for the decision. So we

Figure 1.4: Follow-up question responses



decided to concentrate on the following aspects: (1) Costs. They play an important role in the investment decision and can be an obstacle. In addition, costs are also understandable for respondents who have never dealt with energy investments before. (2) Benefits. They are the reason for the investment, and respondents need to know what they would get in return for the investment costs. The benefits we present in the form of CO₂ savings and consumption of conventional energy give an indication of what the investment would mean for them. It is also of interest what role these savings play and whether they can persuade respondents to switch from one type of investment to another if it offers more benefits. (3) Collective investment schemes. They can help to circumvent certain barriers, such as not owning a suitable building, and make investing more flexible. They therefore also have the potential to drive the production of renewable energy. They also offer new opportunities for people who do

not own a building or who want to avoid negative impacts such as dirt and noise. As a result, such collective investment options may be an attractive alternative to traditional investment on the own building. In addition, (4) smart technologies can minimise disadvantages such as the inflexible use of self-produced energy and thus increase the attractiveness of prosumption. The explanations provided for the individual attributes should make these four attributes easy to understand, even for inexperienced respondents. At the same time, the focus on few attributes minimises the risk of respondents being overwhelmed by the sheer number of determinants. At the same time, focussing on relevant investments and important attributes allow us to learn more about preferences and the factors that determine them.

In the actual choice tasks, respondents are asked which of the options on offer they prefer. They are also informed that additional information is available by placing the mouse over the elements of the table. This way is chosen to keep the table as lean as possible, but still provide enough information for an informed choice, if needed. As a result, even though the attributes are presented in a simple manner, respondents are able to understand their implications. This is done to avoid misunderstandings.

The policy scenarios (“treatments”), that are presented to the respondents after the first two choice tasks, are the following:

- **CO₂-tax increase:** Today, fossil fuels are taxed at 96 CHF per ton of CO₂. In order to reduce CO₂ emissions, the Swiss government is expected to increase this tax to 200 CHF. If your heating runs on heating oil or gas, your energy costs will increase.
- **Treatment 2: CO₂/m² cap:** In order to reduce CO₂ emissions the Swiss government is expected to introduce a strict cap on CO₂ emissions per square-meter of the building. This makes it necessary to invest in renewable energy in the upcoming years.

- **Treatment 3: Electricity tariff system – Net metering:** The Swiss government is planning to change electricity tariffs to net electricity metering. New tariffs will benefit the households that invest in renewable energy, because it allows them to pay only for their net electricity consumption.
- **Treatment 4: Subsidies for PV:** The Swiss government is planning to substantially increase subsidies for producing renewable electricity (PV). New federal and cantonal contributions will cover about 30% of investment costs.
- **Treatment 5: Subsidies for insulation:** The Swiss government is planning to substantially increase subsidies for building retrofits. New federal and cantonal contributions will cover about 30% of investment costs.

For the treatment text, an orange font is chosen to increase attention and memory (Dzulkifli and Mustafar, 2013). These scenarios represent policies that are either available or have been discussed in Switzerland¹¹ By presenting these policies, we try to identify whether they affect choice behaviour.

In order to obtain further information about the selection and the background, a few follow-up questions are asked after the actual experiment. After the experiment, the respondents who always chose the status-quo option are asked why they did so. Their responses are displayed in Table 1.8. Those who selected “other” said that the investments were not interesting for them, for example because of their age or building.

Those who selected at least once an energy investment in the DCE are asked whether and if so which investment they would like to make in the future. Table 1.9 shows that even though the majority does not intend to invest, a significant part plans to invest in either PV or retrofit. However, these figures must be understood in context. Retrofit options were only

¹¹These are stated in the Introduction of this thesis.

Table 1.8: Reasons for not choosing energy options

	Respondents and shares
I am not interested in energy-related investments	8 (14.82)
I am not familiar with these things	2 (03.70)
I am planning to spend my money on something else	3 (05.56)
The incentives are not strong enough	8 (14.82)
They are too expensive	9 (16.67)
Other	24 (44.44)
Total	54 (100.00)

Shares of respondents (in %)

displayed to respondents who live in buildings which are in need of a retrofit. Even if the proportion of those who stated that they want to invest in a retrofit seems high compared to the preferences in the experiment, a total of 425 respondents live in houses that need a retrofit. This means that only half of those whose building needs better insulation would also like to invest in one. On the other hand, the number of those who want to have a PV system seems relatively low compared to the preferences in the experiment. However, it should be noted that 160 buildings are already equipped with PV and therefore do not require any further PV systems. Ultimately, not all respondents answered the question, so the results must be viewed against this background. Nevertheless, it indicates an interest in energy investments.

Table 1.9: Intention to do energy-related investments in upcoming years

Respondents and shares	
No	274 (40.53)
Yes, in PV	186 (27.52)
Yes, in retrofit	216 (31.95)
Total	676 (100.00)

Shares of respondents (in %)

1.7.2 Estimation results by sample

When comparing the estimation results of the two samples separately, it becomes apparent that although the preferences are often similar, there are also differences. For example, some estimates are not significant for the SHEDS sample, although they are significant for the Cantons' sample. The opposite is true for the policy scenarios, where the SHEDS sample shows significant positive effects for CO₂ taxes and netmetering. There is also a significant negative subsidy effect for PV. For the Cantons' sample, on the other hand, there is no significant policy effect. However, the policy scenario effects and the absence of some other significant effects for the SHEDS sample should not be over-interpreted in view of the fact that this sample is smaller with only 261 respondents compared to the Cantons' sample. Hence, the policy scenario groups are also much smaller. Overall, however, the estimates for both samples show a similar picture with respect to general preferences and tendencies, which are consistent with the results of the estimates for both samples together, which supports the chosen approach.

Table 1.10: Estimation results by sample

	SHEDS		Cantons	
	Mean	SD	Mean	SD
Energy investments (base: non-energy alternatives):				
Heating reinstatement	0.712 (0.46)	2.645 ^{***} (0.78)	0.656 (0.65)	2.852 ^{***} (0.77)
Renewable heating				
- own	-0.400 (1.29)	5.126 ^{***} (1.57)	0.159 (0.67)	3.212 ^{***} (1.13)
- collective	-0.114 (0.63)	2.236 ^{***} (0.71)	-0.757 (0.54)	3.611 ^{***} (0.86)
- SCC	-0.987 (0.80)	-1.789 (1.09)	-3.562 ^{**} (1.59)	7.886 ^{***} (2.23)
Leasing renewable heat	1.077 (1.90)	2.749 [*] (1.55)	2.950 ^{**} (1.19)	6.066 ^{***} (1.74)
PV:				
- own	1.734 ^{***} (0.36)	2.494 ^{***} (0.44)	1.604 ^{***} (0.24)	3.313 ^{***} (0.29)
- collective	0.848 ^{**} (0.42)	2.753 ^{***} (0.68)	1.364 ^{***} (0.29)	3.488 ^{***} (0.53)
- SCC	0.523 (0.42)	2.522 ^{***} (0.66)	1.237 ^{***} (0.25)	3.051 ^{***} (0.42)
Insulation	0.148 (0.46)	3.036 ^{***} (0.42)	0.088 (0.28)	3.268 ^{***} (0.24)
Purchasing green electricity	0.080 (0.69)	3.881 ^{***} (0.92)	0.777 ^{**} (0.38)	3.477 ^{***} (0.56)
Benefits (% of conventional energy saved):				
Benefits	0.039 ^{***} (0.01)		0.023 ^{***} (0.00)	
Investment and purchasing costs (in 1000 CHF):				
Investment cost	-0.017 ^{***} (0.00)		-0.012 ^{***} (0.00)	
Purchasing costs (green electricity)	-0.006 (0.04)		-0.036 [*] (0.02)	
Storage (base: no battery or load-management):				
Battery	0.455 (0.28)		-0.240 (0.18)	
Load management	-0.585 (0.57)		-1.888 ^{***} (0.42)	
Battery and load management	-0.102 (0.44)		-0.144 (0.28)	
Treatment effects (base: control group; interacted with relevant investments):				
CO ₂ Tax × Renewable Heating	2.860 ^{**} (1.25)		0.861 (0.91)	
CO ₂ Cap × Renewable Heating	1.149 (1.21)		0.697 (0.80)	
Netmetering × PV	1.033 [*] (0.56)		0.014 (0.19)	
Subsidy × PV	-1.116 ^{**} (0.48)		-0.232 (0.29)	
Subsidy × Insulation	0.075 (0.57)		-0.358 (0.29)	

Sheds sample: 261 respondents; Cantons' sample 710 respondents.

Significance levels * p < 0.1, ** p < 0.05, *** p < 0.01. Standard errors in parentheses

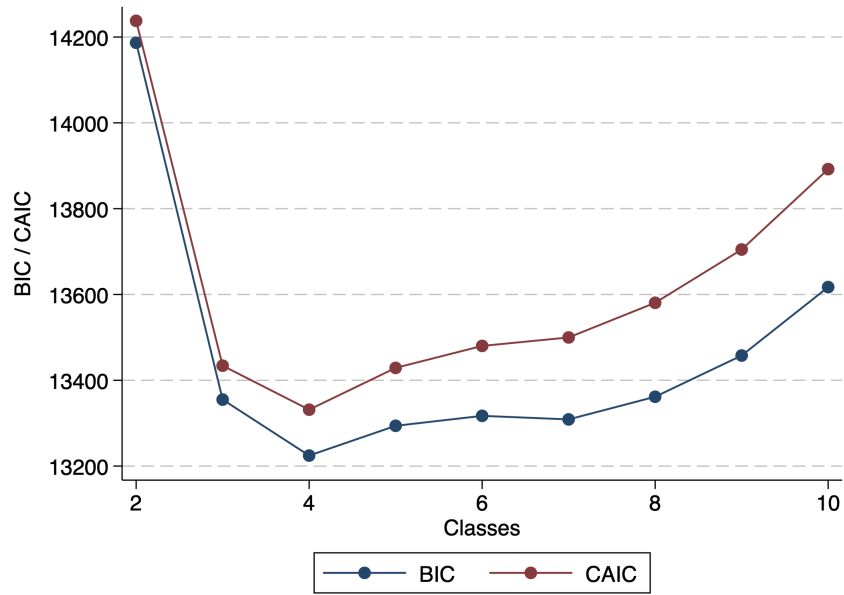
1.7.3 Latent class analysis

Before I decided to use the mixed logit model in this chapter, I also tried a latent class model. Even though the latent class analysis encounters issues when using the fully specified model, I managed to get results with the first data set and a different model specification. The sample used for this analysis consists of 1,364 owners, consisting both of SFH and flat owners. For the final analysis, only SFH owners were analysed, as their possibilities and situation differs from flat owners who may have to coordinate actions with other residents. In this model, the various investments were not used by type of financing, but rather investments and financing in general as a different attribute. This makes it more difficult to analyse precisely and was therefore changed later on. In addition, squared benefits were included to see whether the positive benefit effect is diminishing. Furthermore, two peer pressure scenarios were included, in which the respondents were told that their neighbours invest frequently or rarely in PV compared to the Swiss average. As this was apparently not understood as desired, the respondents who received these scenarios were not included in the final analysis in this chapter. Thus, results are not really comparable to the final mixed logit results in Section 1.5¹².

The following statistics show the results of the latent class analysis. First, Figure 1.5 shows Consistent Akaike Information Criterion (CAIC) and Bayesian Information Criterion (BIC) to find the optimal number of classes.

¹²After the changes to the data set and with the final model specification, the latent class analysis was no longer possible due to convergence problems.

Figure 1.5: CAIC and BIC



In Table 1.11 unconditional and conditional probabilities can be compared to check the model's in sample predictions of actual choice outcomes. The results show that the predictions conditional of respondents being assigned to their respective class are actually higher and well above 0.5, indicating that the model describes the observed choice behaviour well.

Table 1.11: In sample predictions

Obs	Class	Unconditional Probability	Conditional Probability
1680	1	.3536934	.6585916
2682	2	.4756051	.6328815
2502	3	.5173975	.7884887
1320	4	.2532508	.5673586

The latent class estimation results are displayed in Table 1.12. The results show that the groups differ with respect to their taste. Class 1 has a preference for energy efficiency investments rather than renewable related investments. This class represents 20% of all respondents. In line with their preference for retrofits, the respective subsidy scenario has a positive effect. Respondents in class 2 have a preference for renewable heating and PV, but they also show appreciation of insulation. For this class, the cost coefficient is the smallest of all significant results. Compared to base class 4, respondents in class 2 are less likely to be retired and house owners. They also prefer to invest in their own building rather than contribute to collective investment. Respondents in class 3 appreciate renewable energy, either produced by PV or purchased from the utility. They also show interest in heating overhaul and leasing renewable heating. For them, benefits show the greatest effect among all classes. Yet, all policies except for peer pressure (low) and subsidies for PV have significant negative effects. As the scenarios are interacted with benefits, it means that the benefit effect is actually smaller for most of the respondents in this class. Class 4 serves as the base. Respondents in this class show no interest in energy investments. Both, investment coefficients and the fact that the class sizes vary between 16 and 34% indicates heterogenous preferences.

Table 1.12: Results of latent class analysis

	Class 1	Class 2	Class 3	Class 4
Investments (base category: no energy investment):				
Heating overhaul	3.230 ^{***} (0.52)	-0.505 [*] (0.30)	1.956 ^{***} (0.34)	-0.989 ^{**} (0.40)
Renewable heating	2.145 ^{***} (0.57)	1.519 ^{***} (0.27)	0.344 (0.53)	-1.153 ^{**} (0.58)
PV	-0.057 (0.54)	1.736 ^{***} (0.21)	2.691 ^{***} (0.41)	-0.742 [*] (0.38)
Insulation	2.356 ^{***} (0.57)	1.135 ^{***} (0.29)	0.048 (0.54)	-0.946 ^{**} (0.46)
Leasing ren. heat	1.857 (1.14)	2.453 ^{***} (0.66)	2.198 ^{**} (0.99)	-1.256 (0.99)
Purchasing ren. electricity	-0.182 (0.49)	-0.087 (0.26)	2.786 ^{***} (0.74)	-0.641 (0.39)
Costs (in 1000 CHF for period of 30 years):				
Investment cost	0.000 (0.01)	-0.007 ^{***} (0.00)	-0.021 ^{***} (0.00)	-0.029 ^{***} (0.01)
Buying costs	0.031 (0.03)	-0.019 (0.01)	-0.045 ^{**} (0.02)	-0.010 (0.02)
Benefits (in %):				
Benefits	0.011 (0.02)	0.034 ^{***} (0.01)	0.072 ^{***} (0.01)	0.012 (0.02)
Benefits squared	-0.000 (0.00)	-0.000 (0.00)	-0.000 ^{***} (0.00)	-0.000 (0.00)

Significance levels * p < 0.1, ** p < 0.05, *** p < 0.01.

Standard errors in parentheses

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	Class 1	Class 2	Class 3	Class 4
Policy and peer scenario effects (base category: control group; interacted with benefits):				
CO ₂ Tax	0.002 (0.00)	0.000 (0.00)	-0.008** (0.00)	-0.009*** (0.00)
CO ₂ Cap	0.001 (0.00)	0.004 (0.00)	-0.014*** (0.00)	-0.004 (0.00)
Netmetering	0.004 (0.00)	-0.001 (0.00)	0.009*** (0.00)	-0.001 (0.00)
Subsidy PV	-0.000 (0.00)	-0.001 (0.00)	-0.002 (0.00)	0.003 (0.00)
Subsidy insulation	0.014** (0.01)	0.000 (0.00)	-0.016*** (0.00)	-0.005 (0.00)
Peer pressure (high)	-0.125*** (0.02)	-0.000 (0.00)	-0.024*** (0.00)	0.009 (0.01)
Peer pressure (low)	0.005 (0.01)	-0.011*** (0.00)	0.001 (0.01)	-0.005 (0.00)
Financing (base: alone (SFH) with co-owners (Flat)):				
Collective investment as single-family house owner	-0.030 (0.48)	-0.434*** (0.15)	-0.536** (0.25)	-0.746** (0.30)
Self-consumption community	-0.366 (0.41)	-0.536*** (0.13)	-0.590** (0.23)	-0.754*** (0.25)
Crowd investment	0.328 (0.73)	-0.837*** (0.27)	0.349 (0.95)	-2.702*** (1.04)
Storage (base: no battery or load-management):				
Battery	-0.847 (0.55)	0.157 (0.13)	-0.308 (0.22)	0.641*** (0.25)
Load management	-1.879 (1.16)	-0.217 (0.26)	-0.654* (0.37)	-0.491 (0.78)
Battery and load management	0.526 (0.59)	0.228 (0.21)	0.005 (0.38)	0.546 (0.38)

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	Class 1	Class 2	Class 3	Class 4
House owner	0.130 (0.34)	-0.456* (0.26)	0.096 (0.30)	0 0
Respondent age >65	-0.126 (0.23)	-0.694*** (0.19)	-0.418** (0.20)	0 0
Old building (>30 years)	0.049 (0.22)	0.069 (0.19)	-0.300 (0.19)	0 0
University degree	-0.033 (0.24)	0.067 (0.20)	0.214 (0.21)	0 0
Constant	-0.386 (1.00)	2.442*** (0.76)	0.609 (0.88)	0 0
BIC		13499.271		
N (Observations)		24552		
Class Share	0.208	0.339	0.293	0.161

Significance levels * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Standard errors in parentheses

Chapter 2

Impact of subsidies and associated complexity on homeowners' energy investment preferences

This chapter is based on a working paper co-authored by Mehdi Farsi (University of Neuchâtel, Institute of economic research), Sylvain Weber (University of Applied Sciences and Arts Western Switzerland (HES-SO), Haute école de gestion de Genève (HEG)) and Martin Jakob (TEP Energy). This paper has been published as part of the IRENE Working Paper Series (WP 22-07).

2.1 Introduction

Energy investments in residential buildings are deemed important for the energy transition and ultimately to affect climate change. A variety of energy investments are conceivable today, some of which can achieve similar outcomes in terms of energy savings and reduction of CO₂ emission (IEA, 2020). However, investment rates are still below expectations and deemed insufficient to reach the climate goals (Swiss Federal Office of Energy, 2020; Burger et al., 2019). Potentially high upfront costs are amongst the major obstacles to energy investments in residential buildings (see e.g. Gillingham et al., 2009). Policies, such as subsidies, aim to promote energy investments by reducing these investment costs (Mundaca and Samahita, 2020). The positive effect of subsidies has been acknowledged in several studies (see e.g. Heiskanen and Matschoss, 2017; Alberini et al., 2013; Granade et al., 2009). The reasons why investment rates are still low despite subsidies are not fully understood. Bureaucratic hurdles could play a role. Effort and time necessary to fill in forms and complete the required tasks can result in transaction costs. However, such procedures are unavoidable in order to obtain subsidies that are often considered essential for energy investments (Bagaini et al., 2022). As a result, policies may not be as effective as intended and high transaction costs can even lead to abandoning of ongoing applications or the entire investment (Lades et al., 2021; Collins and Curtis, 2017). However, this has not yet been sufficiently investigated in the literature and there is a lack of real-world evidence (Lades et al., 2021; de Vries et al., 2020). Thus, further evidence about the role of subsidies, but also the associated complexities, for investment decision-making is needed.

It is also of interest, if simplifications of the subsidy application process alone may already increase effectiveness of such policies. An “one-stop shop” (OSS) that takes care of all subsidy-related tasks can potentially achieve that. As a result, effectiveness and uptake rates of subsidies could be increased. However, it can also lead to more free-riding and resulting

inefficiency. For an assessment of such an OSS, it is helpful to get first-hand information and also to compare the appreciation of residents with and without experience with subsidies.

Single-family house (SFH) owners are an important group for energy policies because they usually have a higher income than tenants and can decide on their own about investing in their building (Davis, 2011). Furthermore, most residential buildings are single-family houses in Switzerland (Federal Statistical Office, 2022). Consequently, their buildings account for a large part of all carbon dioxide (CO₂) emission: one of the main contributors to global warming (Swiss Federal Office of Energy, 2023a). Furthermore, households have a large variability in energy consumption patterns. In this chapter, we focus on factors that have not been addressed to a similar extent in the literature. Considering a wide range of relevant energy investments, we pose the questions: (1) What role do subsidies play in energy investment preferences? (2) How is the subsidy application process perceived and could a simplifying OSS release potential? (3) Are preferences the same for inexperienced and experienced homeowners?

To answer these questions, we use a discrete choice experiment (DCE) and analyse data from a sample of 2,890 Swiss single-family house owners, some of which have already made energy investments and received subsidies. A mixed logit model is applied to answer the research questions on hand. Thereby, we contribute to the existing literature by providing empirical evidence regarding homeowners preferences and perception of subsidies. In addition, we analyse potential obstacles in subsidies introduced to support such investments and whether simplifications can potentially improve the current process and as a result enhance uptake of energy investments.

The results show that effects of subsidies even go beyond the pure cost benefits, which indicates an additional appreciation of such subsidies. In addition, the evaluation of investments already made shows that subsidies seem to be important, especially for PV. On the

other hand, investments are regularly made in renewable heating and insulation even without subsidies. Thus, subsidies appear to be a driver for selection of certain energy investment options. Complexity in the subsidy application process does not seem to be a major issue, as subsidy application is not perceived as being overly complex. In line with that, the results show no significant valuation of the OSS. This could also be due to the fact that a share of the respondents had their subsidy applications processed by experts. Preferences are similar for inexperienced and experienced homeowners, even though experienced respondents have a lower appreciation of efficiency retrofits, especially if they only lead to minor benefits. All respondents show a comparably high valuation for renewable energy investments.

This chapter is structured as follows. Section 2.2 reviews briefly the related literature. The data of our samples is explained in Section 2.3. Section 2.4 describes the experiment, followed by the methodology in Section 2.5. Section 2.6 presents the results, and Section 2.7 concludes and discusses policy implications.

2.2 Literature review

Different energy investments in residential buildings can be beneficial for investors and the society in general. In general, both energy efficiency upgrades and prosumption of renewable energy can help to reduce CO₂ emission or reducing consumption of conventional energy. A variety of potential solutions and configurations can be feasible, often depending on factors such as financing (Biere-Arenas et al., 2021; Baumhof et al., 2018). However, even if it is economically sensible, energy investment rates remain below expectations (Burger et al., 2019; Gillingham and Palmer, 2014). Even if households are offered free energy upgrades, these are not always appreciated. This hints non-monetary costs of such energy measures (Fowlie et al., 2015). The decision may be negatively influenced by expected inconveniences,

for instance due to construction work on the building (Scarpa and Willis, 2010). However, there are other non-monetary factors that can lead to transaction costs, making trading unattractive. For example, the process and effort required to benefit from subsidies can rise in transaction costs. This in turn reduces the effectiveness of the policy and may have a negative impact on investment decisions themselves (de Vries et al., 2020).

One of the main barriers to energy investments are financial limitations (see e.g. Achtnicht and Madlener, 2014; Gillingham et al., 2009). Subsidy programs in Switzerland and other countries promote energy investment by lowering investment costs (Swiss Federal Office of Energy, 2021a; Mundaca and Samahita, 2020). These programs have been identified to be important for energy investments (see e.g. Heiskanen and Matschoss, 2017; Alberini et al., 2013; Granade et al., 2009). Alberini et al. (2013) even find in their stated preference study that subsidies are valued more than equally high costs. The estimated marginal valuation of subsidies thus exceeds the marginal benefit to the recipient, which points to the behavioural aspects of response to such policies. Despite the central role often attributed to energy investment subsidies, little evidence about how transaction costs in the application process can influence investment decisions is available.

The subsidy application process can be complex in itself, which adds to the already demanding investment decision-making process (Murtagh et al., 2021). Filling in forms and taking care of all required tasks can be time-consuming and requires effort, which leads to an increase in transaction costs (Bagaini et al., 2022; Fowlie et al., 2015). These costs to get over administrative hurdles can become obstacles that may even lead to the abandonment of applications (Lades et al., 2021; Collins and Curtis, 2017). Given that subsidies are deemed important for investment decisions, such obstacles can not only make it more difficult to obtain subsidies, but in the worst case they can also make investing itself unattractive (Amel et al., 2017; Viardot, 2013). Complexity and corresponding hassle, but also uncertainty about the effort necessary to obtain subsidies, can prevent households to apply for them in the first

place (de Vries et al., 2020). Yet, there is hardly any evidence for these effects. One of the studies concerned with administrative burdens by Lades et al. (2021) show by means of simulations negative effects of administrative burden on energy investment decisions. They do also stress the necessity of obtaining real world insights.

Simplification can help to increase uptake of subsidies by lowering such transaction costs. This can be achieved, for instance, by an “one-stop shop” (OSS)¹) that takes care of complex tasks, and as a result can help to facilitate energy investments (Pardalis et al., 2021). Various forms of OSS are conceivable, ranging from basic support to a programme that takes care of all investment decisions. Knowledge and expertise are pooled, which promotes successful investment (Biere-Arenas et al., 2021; Bertoldi et al., 2021; Hunkin and Krell, 2019). A basic version that takes care of subsidy application tasks can already remove some bureaucratic hurdles. This in turn can increase the effectiveness of such policies and, hence, promote investment. However, studies conducted so far have not found a consistently positive response to such OSS solutions. Mahapatra et al. (2019) conduct an online survey and show that the enthusiasm for an OSS remains within bounds. Pardalis et al. (2019) also identify residents’ interest in OSSs for energy investment, even though the majority of their Swedish respondents did not indicate an urge for such a solution. Thus, it remains to be seen whether a simplifying OSS is positively perceived. However, even if this is the case, negative effects can also occur. A procedure that is too simple may encourage free rider problems and associated inefficiencies (Granade et al., 2009; Hassett and Metcalf, 1993). In our context, free riders are those residents who would have made energy investments even without policy support, but who receive additional benefits from the policy and therefore take advantage of them (Joskow and Marron, 1992). Reasonable complexity might serve as a deterrence for potential free riders. Therefore, it is important for policymakers to ensure an appropriate process.

¹For a detailed explanation of the concept of an OSS and examples see Biere-Arenas et al. (2021); Reid and Wettenhall (2015)

Costs, resulting from hassle, inconvenience due to construction work or complicated proceedings, can lead to an aversion to energy investments and subsidies (Lades et al., 2021; Murtagh et al., 2021; de Vries et al., 2020). Experience with such processes can reduce such barriers and potentially negative effects (Hrovatin and Zorić, 2018; Bjørneboe et al., 2017). For instance, List (2003) show that experienced people are less prone to misperceptions. The attitude towards investments and policies can depend on familiarity. This may also affect the attitude towards subsidies and the OSS concept.

Although research has been conducted in this context, issues like complexity in the subsidy application process have not been extensively studied yet. Especially, empirical evidence is missing (de Vries et al., 2020; Buser and Carlsson, 2017). Furthermore, comprehensive insights are lacking because most studies focus on specific investments, but also because of the dynamic nature of the energy investment market. Thus, this study examines the role of subsidies and complexity in the related application process. By doing this, the approach exceeds existing research and breaks new grounds.

2.3 Data

One of the aims of this study is to compare whether experience plays a role for investment preferences. This involves experience with energy investments, but also, above all, experience with subsidies. Homeowners who already have experience with subsidies can provide information on whether the process is considered overly complex and whether there is a need for simplifications. It is also of interest to know whether the OSS we are proposing is appreciated.

To get a large sample consisting of both experienced and inexperienced owners, different surveys were used to gather data. First, our experiment was launched as part of the Swiss

Household Energy Demand Survey (SHEDS)². The respondents stem from the pool of subjects managed by the private survey company Intervista³. The SHEDS data was collected between 15 May and 22 June 2021. Shortly afterwards, our experiment was also conducted as part of a survey in the canton of Zürich from 18 June to 15 August 2021. Finally, it was sent to the subscriber pool of Pronovo, which manages subsidies for PV investments in Switzerland, to get a sample of subsidy recipients. Pronovo subscribers answered the survey from 23 September to 22 November 2021. For the sake of simplicity, the respondents from SHEDS and the survey in Zürich are pooled and referred to as “Sample 1” below, and those from Pronovo as “Sample 2”.

In total, we gathered a sample consisting of 4,122 Swiss homeowners. This consisted of 520 flat owners, 231 private owners of multifamily buildings and 3,371 single-family house (SFH) owners. Since these groups differ to some extent due to their decision-making freedoms and incentives, we focus only on the SFH owners in this study. Accordingly, 3,371 SFH owners remained as a sample. Thereof, a share has already invested in energy upgrades such as insulation, renewable heating or PV. Some of these homeowners have also received subsidies for their investment. The numbers and shares of those who have already invested with or without having received subsidies are detailed in Table 2.1.

In this table, rows show the experience with energy investments and columns for which investment they received subsidies. For each investment experience row, the first line shows the total number of respondents who invested in this upgrade, whereas the line below shows the respective share. As it can be seen in this table, almost everybody in Sample 2 is experienced and a large share (95%) have already received subsidies for at least some of their previous investments⁴. This part is not 100% because although all applicants are

²See also Weber et al. (2017) for further information.

³Further information available at <https://www.intervista.ch>

⁴We have removed those who said they had no experience from Sample 2 as this does not seem realistic due to the nature of the Pronovo sample. The fact that they have applied for subsidies shows that they must have already invested.

Table 2.1: Experience with energy investments and subsidies by sample

Sample 1									
	Experience with subsidies								
Investment experience with	None	PV	PV & RH	PV & EI	RH	RH & EI	EI	PV, RH & EI	Total
None	307	0	0	0	0	0	0	0	307
	25.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	25.60
PV	4	17	0	0	0	0	0	0	21
	0.33	1.42	0.00	0.00	0.00	0.00	0.00	0.00	1.75
PV & RH	6	63	18	0	2	0	0	0	89
	0.50	5.25	1.50	0.00	0.17	0.00	0.00	0.00	7.42
PV & EI	4	26	0	5	0	0	0	0	35
	0.33	2.17	0.00	0.42	0.00	0.00	0.00	0.00	2.92
RH	128	0	0	0	49	0	0	0	177
	10.68	0.00	0.00	0.00	4.09	0.00	0.00	0.00	14.76
RH & EI	133	0	0	0	50	15	17	0	215
	11.09	0.00	0.00	0.00	4.17	1.25	1.42	0.00	17.93
EI	229	0	0	0	0	0	45	0	274
	19.10	0.00	0.00	0.00	0.00	0.00	3.75	0.00	22.85
PV, RH & EI	7	43	8	6	4	0	2	11	81
	0.58	3.59	0.67	0.50	0.33	0.00	0.17	0.92	6.76
Total	818	149	26	11	105	15	64	11	1,199
	68.22	12.43	2.17	0.92	8.76	1.25	5.34	0.92	100.00

Sample 2									
	Experience with subsidies								
Investment experience with	None	PV	PV & RH	PV & EI	RH	RH & EI	EI	PV, RH & EI	Total
None	16	0	0	0	0	0	0	0	16
	0.74	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.74
PV	11	245	0	0	0	0	0	0	256
	0.51	11.28	0.00	0.00	0.00	0.00	0.00	0.00	11.79
PV & RH	28	452	172	0	2	0	0	0	654
	1.29	20.81	7.92	0.00	0.09	0.00	0.00	0.00	30.11
PV & EI	11	288	0	75	0	0	1	0	375
	0.51	13.26	0.00	3.45	0.00	0.00	0.05	0.00	17.27
RH	3	0	0	0	2	0	0	0	5
	0.14	0.00	0.00	0.00	0.09	0.00	0.00	0.00	0.23
RH & EI	2	0	0	0	1	0	0	0	3
	0.09	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.14
EI	4	0	0	0	0	0	0	0	4
	0.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.18
PV, RH & EI	25	412	211	77	11	3	2	118	859
	1.15	18.97	9.71	3.55	0.51	0.14	0.09	5.43	39.55
Total	100	1,397	383	152	16	3	3	118	2,172
	4.60	64.32	17.63	7.00	0.74	0.14	0.14	5.43	100.00

RH: Renewable heating; EI: Insulation

Shares in % below the numbers of respective respondents

eligible, not all of them have received subsidies yet. In contrast, the share of experienced respondents and especially those who have received subsidies for their investments is lower in

Sample 1. 68% of the respondents have never received subsidies so far. This is not surprising given the actual investment rates. In this sample, 26% of respondents have no experience with energy investments. Those who have experience have mostly invested in renewable heating or insulation. However, these investments do not always qualify for subsidies, which explains the low levels of experience with subsidies. This shows that Sample 2 is naturally not representative. Yet, insights from homeowners who have already invested and received subsidies is especially important to identify their perception of the process and potential simplifications.

In our analysis, we investigate whether there are differences between homeowners who have already invested in energy upgrades and received subsidies, and those who have no experience yet. Thus, we excluded respondents with experience with subsidies from the Sample 1. Due to its nature, Sample 2 only contains data from homeowners who have experience with energy investments and subsidies. The comparison between these different groups is of particular interest, as their preferences and perception of the process can provide information on the functioning and potential for improvement of existing proceedings. After dropping respondents with subsidy experience from Sample 1, and keeping only those who have already received subsidies in Sample 2, the final sample used for the econometric analysis consists of 2,890 Swiss SFH owners. The majority (2,072 respondents) stem from Sample 2. Sample 1 consists of 818 respondents.

For comparison, details of the respondents of the different samples are presented in Table 2.2. As can be seen, the respondents of the two samples differ from each other not only in their experience with subsidies. The different age structure in Sample 2 is not entirely surprising, as it is not representative. Compared to Sample 1, the respondents in Sample 2 tend to be older. The share of women is lower than in the Swiss population (50.4%⁵). Especially in Sample 2 women are underrepresented. There is also a larger share of older

⁵see Federal Statistical Office (2020)

Table 2.2: Characteristics of respondents by sample

	Respondents		Switzerland
	Sample 1	Sample 2	
Age			
18-34	92 (11.25)	29 (1.42)	(25.31)
35-54	265 (32.40)	554 (27.20)	(34.41)
55-64	310 (37.90)	817 (40.11)	(16.90)
65 +	151 (18.46)	637 (31.27)	(23.39)
Sex			
Male	481 (58.80)	1847 (89.44)	(49.31)
Female	337 (41.20)	218 (10.56)	(50.69)
Education (highest qualification)			
Compulsory school	20 (2.45)	32 (1.56)	(13.90)
High school or vocational school	403 (49.33)	1385 (67.40)	(41.40)
University (of Applied Sciences)	394 (48.23)	638 (31.05)	(44.70)
Building age			
Built until 1990	483 (59.05)	1127 (54.39)	(68.30)
Built after 1991	335 (40.95)	945 (45.61)	(31.70)
House with PV			
No	783 (95.72)	0 (0.00)	(>89.00)
Yes	35 (4.27)	2072 (100.00)	(<11.00)
House with renewable heating			
No	404 (49.39)	466 (22.49)	(57.50)
Yes	414 (50.61)	1606 (77.51)	(42.51)

Shares in parentheses (in %). Data for the Swiss population relates to persons of legal age.

Data sources: age and sex: Federal Statistical Office (2023e) (Year 2022); education: Federal Statistical Office (2023b) (Year 2022); building age: Federal Statistical Office (2023d) (Year 2021, SFH buildings); houses with PV: Swiss Federal Office of Energy (2023c) (Year 2023; these numbers are rough estimations based on the total number of PV installations and the amount of residential buildings in Switzerland. However, the number of PV systems refers not only to residential buildings but to all buildings. It is probably lower for residential buildings); houses with renewable heating: Federal Statistical Office (2023c) (Year 2022).

respondents in Sample 2, whereas more respondents have a university degree in Sample 1. Again, Sample 2 is not representative of the entire Swiss population, as people with a high school or vocational school degree are overrepresented. The share of newer buildings, that do not necessarily require energy efficiency upgrades, is comparably high in both samples. Naturally, buildings with PV installation are overrepresented in Sample 2. The proportion of buildings with renewable heating is higher in both samples than in all Swiss residential buildings, although it is even higher in Sample 2 than in Sample 1.

2.4 Experiment

Energy investment preferences can be mainly studied in two ways: revealed and stated preferences (Newell and Siikamäki, 2014; Louviere et al., 2000). While revealed preference data give a realistic picture of the investments made, stated preferences have the advantage of providing more information on which factors play which role in investment decisions. The decisive drawback of revealed preference data is that they generally provide little information about the choice set considered at the time of decision by each individual. The choice experiment approach allows including not only selected energy investments but other possible options, thus providing a better understanding of various trade-offs and relative preferences among the attributes (Bessette and Arvai, 2018; Bidwell, 2013). Considering all important influential variables and their implications also speaks in favour of the stated preference approach (Alberini, 2019). Moreover, stated preferences make it possible to also examine the preferences and possible obstacles for potential future investors, a group that could be different from those who have already made an investment. Given the emergence of new investment opportunities, especially in a dynamic market, future potential investors are of particular relevance for policymakers. Thus, despite the fact that stated preferences are based

on merely hypothetical choices, the approach is suitable to get more information about energy investment preferences and respective influential factors.

We conduct a discrete choice experiment (DCE) to gather data for our analysis (Louviere et al., 2000). In our experiment, we offer a wide range of relevant investment options with realistic attributes. Thereby, we aim to get a comprehensive picture of investment preferences and respective trade-offs (Bessette and Arvai, 2018; Bidwell, 2013). Furthermore, we ask respondents questions about their building and experience. Therewith, the choice tasks can be tailored to increase relevance and prevent biasing responses. To ensure relevance, respondents are told in advance that for situations involving investments that have already been made, they should decide as if they could decide again. This also provides information about the satisfaction with the investments made and shows the role of experience.

A brief introduction script sets the tone before the actual choice experiment starts. This ensures a basic understanding of such investments and the factors at play and their implications, even for those who have never invested or even considered energy investments before. That is why also information about subsidies and the associated processes are provided. This explains the current system where different points of contact are relevant when it comes to subsidy concerns. Those who have already invested and received subsidies are asked about their experience, and what problems and opportunities for improvement they see in this context, to get first indications about their perception of the process. The results are detailed in Section 2.6.1.

Before the choice tasks are presented, we introduce the OSS treatment to half of the respondents⁶. To have similar conditions for treatment and control group, both groups received information about the current subsidy situation in Switzerland. For treated respondents, the

⁵For a more detailed discussion of pros and cons of stated and revealed preference approaches see also Newell and Siikamäki (2014); Vossler et al. (2012); Verhoef and Franses (2003); Louviere et al. (2000) and for a precise description of the approach see the Introduction and Paper 1 Section 3



⁶The treatment screen displayed in Figure 2.4 can be seen in the Appendix.

OSS concept is explained thereafter. It is stated, that this OSS simplifies the subsidy application process by taking care of the respective tasks. It is also mentioned that this results in a significant reduction of effort. This should decrease the burden and increase the effectiveness. In contrast to the text for the treatment group, the control group is informed that the situation around subsidies will not change in the coming years. Similar to Allcott and Kessler (2019), our treatment comes with both a verbal script and a figure to promote information transmission. Besides an explanation of the situation and concept, the simple figure of a shopping cart with a check sign within is chosen to visualise the convenience of the procedure by drawing parallels to online shopping.

Thereafter, the real choice experiment starts. It involves four choice tasks. An example of an actual choice task is presented in Figure 2.1. All choice tasks looked identical. Each of them consisted of two energy-related investment options and a non-energy-related spending or saving option (referred to as “status-quo” or short “SQ” in the remainder of this paper). After the first time choosing the status-quo option, they are asked for which alternative they would rather use the money. 31% of the respondents said they would rather save the money, 30% would rather spend it on other renovations, and the rest would use it for other things. The order of the energy investments as well as the offered options are randomized.

Respondents are asked to choose according to their preferences, taking their financial restrictions and living situation into account. This is done to make their choices as realistic and, therewith, relevant as possible. Energy investments come with three attributes: costs, benefits in form of energy savings, either by means of efficiency upgrades or prosumption of renewable energy, as well as subsidies if available for this specific investment. Figure 2.1 gives a picture of this. The offered energy investment options represent all depths, from low impact reinstatements up to major improvements like building insulation (Esser et al., 2019). Thereby, we aim to get a comprehensive picture of their preferences.

Figure 2.1: Example of a choice task

	Alternative 1	Alternative 2
	Envelope insulation and replacement of windows 	Photovoltaic system + Renewable heating system 
Costs	CHF 96,000	CHF 70,000
Benefits	25% of energy saved	40% of renewable energy produced
Subsidies	The subsidy covers 15% of costs	The subsidy covers 35% of costs

Your choice:

Alternative 1
 Alternative 2
 None of the two

Attributes and levels attributed to each investment option correspond to realistic values. They are displayed in Table 2.3. Our experiment includes numerous relevant energy investments: reinstatement of the façade or running fossil fuel operated heating system, insulation, renewable heating, for instance by means of a heat pump, PV as well as combinations of different investments that can be feasible. Because we also analyse the role subsidies play for investment decisions, we include different realistic levels of subsidies for certain investments whenever feasible.

Table 2.3: Investment options, corresponding attributes and levels

Investment option	Costs in 1000 CHF	% of energy saved	Subsidies in % of total costs
Reinstatement and energy efficiency investments			
Envelope reinstatement	9, 20, 28, 32	0, 1, 2, 5	-
Insulation	47, 75, 90, 96	15, 25, 40, 60	8, 15, 25, 35
Heating system reinstatement	5, 10, 15, 20	5, 10, 15, 25	-
Insulation and heating reinstatement	52, 85, 105, 116	15, 25, 40, 60	8, 15, 25, 35
Renewable energy investments			
Renewable heating	22, 33, 45, 60	20, 40, 60, 100	8, 15, 25, 35
PV	15, 19, 20, 23	15, 25, 40, 60	8, 15, 25, 35
PV and renewable heating	35, 50, 70, 85	20, 40, 70, 100	8, 15, 25, 35
Energy efficiency and renewable energy investment			
Insulation and renewable heating	77, 115, 140, 156	20, 40, 60, 100	8, 15, 25, 35

2.5 Methodology

The econometric approach is based on the random utility theory (McFadden, 1974). Respondents are assumed to choose the option with the respective attributes that maximises their utility. It enables to decipher the impact of different attributes and gain a better understanding of how their investment decisions are influenced.

The software *Ngene* and *Qualtrics* were used for the technical implementation (see Weber, 2021). Whilst the experimental design was created with *Ngene*, the set-up of the actual choice experiment was done with *Qualtrics*.

For the econometric analysis, we apply a mixed logit model. It allows avoiding IIA assumptions (Hole and Kolstad, 2012; Train, 2009)⁷. Furthermore, the estimated standard deviations give a better picture of preferences and if these are homogenous or heterogenous. To minimise the amount of assumptions, we keep the applied model simple. In this model, the different investment variables and the benefits enter with random coefficients. All other

⁷For a more detailed explanation of this model, see Section “Econometric strategy” in the Introduction

variables have fixed coefficients. All coefficients are assumed to be normally distributed. 500 Halton draws are used for the simulation.

2.6 Experimental Results

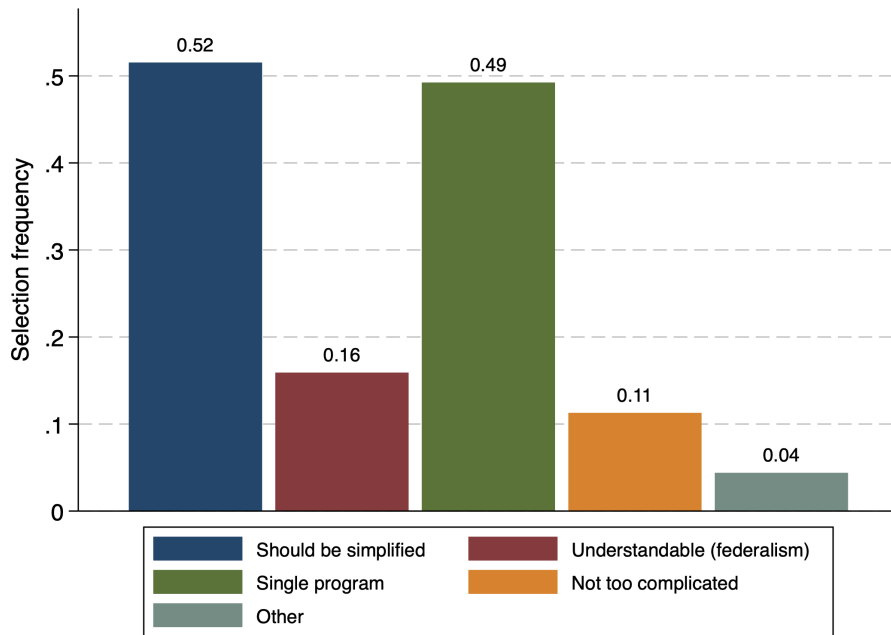
In the upcoming parts, both descriptive statistics and estimation results are presented to identify how previous investments and experience with the subsidy application process are perceived, what are their preferences, and which factors play a role in investment decisions.

2.6.1 Descriptive statistics

One focus of this research is to find out whether the subsidy application process is considered complex, which may be a barrier for subsidies and, as a result, ultimately for energy investments. This provides insights into whether simplifications can be beneficial. To get a better understanding of their perception, all respondents receive information about the current subsidy procedure to make sure that even those who have no experience with subsidies understand how the system works. Thereafter, they are asked what describes this system best. Their responses can be seen in Figure 2.2. For this question, several answers could be chosen. The shares in the figure refer to all answers given. As is can be seen, the most popular answers are that the current approach should be simplified (39%) and integrated in a single program (37%)⁸.

⁸In order to determine whether there are differences between those who have already received subsidies and those who have not, a detailed analysis for each group is also carried out. Respective Figures can be found in Appendix 2.8.3. However, there are no major differences in the responses, which is why Figure 2.2 is presented here for all respondents together.

Figure 2.2: Impression of the subsidy system

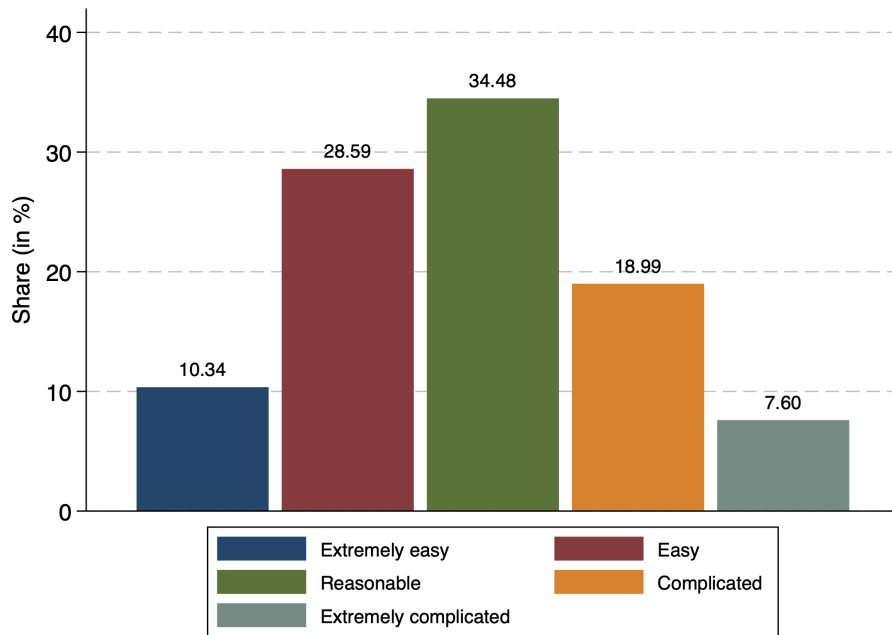


This figure is based on responses of all respondents who answered this question (2,872 respondents).

To get a better picture of the complexity of the subsidy application process, recipients are asked how they experienced the process. By design, these questions could only be answered by respondents from Sample 2 (2,072 individuals) because Sample 1 only consists of owners who have not yet received subsidies. Consequently, they cannot have experience with the subsidy application process.

Through this, we seek to get a better idea of whether the complexity of the subsidy application can be a significant barrier. As data in Figures 2.3 suggest, most respondents do not consider the subsidy application process as overly complicated. Only roughly 8% state that the process was extremely complicated. On the other hand, 73% think that is easy or at least reasonable. Thus, the current situation does not appear to hinder applications.

Figure 2.3: Perception of the subsidy application



This figure only refers to responses from Sample 2 (2,072 respondents), as Sample 1 does not contain any respondents with experience with subsidies

Those who reported that they preferred changes in the subsidy application process and have obtained subsidies for previous energy investments (1,148 respondents) are asked how their personal experience with the subsidy application process were. The most popular results of this question are displayed in Table 2.4. Respondents are allowed to choose multiple out of these options. 23% of all responses indicate that a substantial share had their subsidy tasks handled by an expert. 20% of all responses show that many had support when filling out their applications. So although they stated that the current system is too complicated and should be simplified, not all of them took care of the application on their own. This may indicate that they have either involved an expert because of complexity, or that they have no experience of the process and their statement about complexity is based on pure conjecture.

Others indicate that the process is complex and effort is required to handle all application tasks.

Table 2.4: Personal experience in applying for subsidies

	Percent of responses
Someone else made the subsidy application for me (planner, installer, craftsman)	23.29
Asked for help in filling in the application form (planner, installer, craftsman)	19.57
Knew in advance about subsidies	18.24
Time-consuming to obtain the necessary information	10.52
Administrative process of applying for subsidies seemed very complicated	7.88
Had to fill in the same information more than once	4.87

These responses come from 1,148 respondents who have already received subsidies and indicated that they would appreciate simplifications

These descriptive insights do already give first indications about their perception of the subsidy process. A large share have experience with energy investments. In our samples, hardly anybody invested in PV without subsidy support. Even though the majority does not think that the subsidy application process is too complex, a large share would appreciate simplifications. How this experience affects their preferences in the choice experiment will be one of the insights obtained by the upcoming econometric analysis.

2.6.2 Results and Discussion

Due to their dissimilarities, but also in order to identify possible differences between those who have experience with subsidies and those who do not, the analysis is carried out separately for both samples. The mixed logit results are reported in Table 2.5⁹. The coefficients for each sample are always reported in the first column, and the respective standard deviations (SD) for variables with random coefficients in the second column.

⁹Latent class model estimation results can be found in Appendix 2.8.4.

Table 2.5: Estimation results

	Sample 1		Sample 2		
	Mean	SD	Mean	SD	
Investments (base: no energy investment):					
Envelope reinstatement	0.314 (0.33)	2.429*** (0.56)	-0.931** (0.36)	2.247*** (0.38)	
Insulation	3.066*** (0.69)	4.667*** (1.06)	2.606*** (0.34)	3.356*** (0.54)	
Heating reinstatement	1.679*** (0.28)	2.822*** (0.48)	-0.303 (0.30)	2.822*** (0.38)	
Insulation and heating reinstatement	2.985*** (0.62)	2.815*** (0.73)	1.594*** (0.44)	3.755*** (0.49)	
Renewable heating	3.056*** (0.42)	1.877*** (0.66)	2.923*** (0.25)	1.433*** (0.25)	
PV	3.690*** (0.45)	3.950*** (0.62)	3.633*** (0.26)	1.888*** (0.27)	
PV and renewable heating	4.604*** (0.54)	3.108*** (0.56)	4.696*** (0.37)	2.465*** (0.31)	
Insulation and renewable heating	4.424*** (0.72)	3.732*** (0.58)	4.081*** (0.43)	2.947*** (0.30)	
Net costs (in 1,000 CHF):					
		-0.046*** (0.01)		-0.028*** (0.00)	
Subsidies (in %):					
		0.021** (0.01)		0.026*** (0.01)	
Energy savings (in %):					
		0.024*** (0.00)	0.062*** (0.01)	0.021*** (0.00)	0.046*** (0.00)
OSS treatment (interacted with subsidies):					
		0.011 (0.01)		-0.001 (0.01)	

Significance levels * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Standard errors in parentheses.

Sample 1: 818 respondents with no experience with subsidies;

Sample 2: 2,072 respondents who have already received subsidies

Looking first at the effects of the various investment options, it is noticeable that the options that lead to substantial benefits are the most valued. PV and renewable heat, but also comprehensive renovations of insulation in combination with renewable heating, have the

strongest effects. Compared to this, insulation alone has a smaller effect. This indicates a greater appreciation of renewable energy, which also speaks for a trend towards prosumption. The magnitude of the coefficients is similar for most investment options in the two samples. However, respondents from Sample 2 seem to have less appreciation for simple reinstatements. Also, insulation is less appreciated in this sample.

Costs and benefits are often identified as being crucial for investment decisions (see e.g., Alberini et al., 2018; Gillingham et al., 2009). This is supported by our results, as they show a negative cost effect and a valuation of benefits in form of savings of conventional energy and CO₂ emission. Interestingly, there is a positive subsidy effect, even though net costs are considered in the analysis. Consequently, the subsidy effect should be zero for rational individuals. The positive effect, on the other hand, shows that subsidies are valued beyond pure cost saving. This is in line with findings by Alberini et al. (2013) and underlines the importance of subsidies to promote energy investments on residential buildings. Interestingly, the cost coefficient is lower for Sample 2, whereas the subsidy effect is larger. As Sample 2 consists of individuals who already obtained subsidies, this could indicate that non-monetary factors are less decisive for those who know about subsidies. Conversely, such costs seem to play a role for inexperienced individuals. For them in particular, simplifications that reduce such non-monetary costs could be beneficial¹⁰.

However, the results do not show any significant effect of the OSS scenario introduced before the choice experiment for either sample. As already discussed in the descriptive statistics, the complexity of the subsidy application process does not seem to be perceived as negative by the majority of householders. The results support that by showing no significant

¹⁰We tried different specifications of the model. A variant with net costs and subsidies converted to CHF showed similar results, as it can be seen in Appendix 2.8.5. More so, we included an experience dummy for Sample 1 to see whether those who have already invested have different preferences to those without any experience. Yet, the results were not significant. Also, we tried different specifications to examine whether the valuation of subsidies differs for the different investment options. However, the results were also not significant, which is why we excluded these variables from the presented results.

effect of the OSS treatment on either experienced or inexperienced owners. Thus, such a version of an OSS that simplifies the subsidy application does not seem to be appreciated. As seen in Table 2.4, homeowners at least partially receive help with the subsidy application from others, for example from experts and craftsmen. Thus, an OSS would not really affect them, which can also explain the lack of appreciation of such concept. Other studies have also shown that an OSS that take care of all investment-related decisions and implementations are rather appreciated (Biere-Arenas et al., 2021). Accordingly, such “all-inclusive” models may be better suited to promote investment, which might be examined in upcoming studies.

Anyhow, the fact that subsidy-related tasks are regularly done by experts shows that there is already a market solution available, that decreases the subsidy-application-related burden for residents interested in energy investment. This does not only decrease the complexity for investors, but it also leads to scale advantages. It also means that investors do not have to bear transaction costs for their own efforts for subsidy-related tasks. Instead, the expert is remunerated for the working time required for subsidy-related work, among other tasks. However, as it can be assumed that the expert has a comparative advantage because she is involved in such tasks more often than regular homeowners, this is likely to result in efficiency gains and scale advantages if the experts handles such tasks for multiple owners. This in turn means that the need for provision of an OSS solution is not necessarily given, and that there may be no need for further simplifications in order to decrease the burden for residents if the market already provides a solution. It also means that the risk of attracting free riders through simplifications is not necessarily an issue if they can benefit from the experts’ services anyway. Analysing the extent to which costs and benefits are shared between investors and experts is an exciting prospect for future research. Results can show whether the market solution is efficient and who benefits to which extent.

The estimated standard deviations (SD) indicate that there are at least partially substantial differences in taste between homeowners. Relatively large standard deviations point

out that preferences are heterogeneous. They show that whilst a certain investment may be highly appreciated by one individual, this is not necessarily the case for another respondent. Even energy savings are not always appreciated to the same extent. This shows that tastes differ between homeowners. When comparing Sample 1 and Sample 2, the SD for PV show that preferences of respondents from Sample 1 are very heterogeneous, with some having no appreciation for such installations at all. On the other hand, preferences of respondents from Sample 2 are less heterogeneous and despite the fact that they still differ, there appears to be at least a basic valuation of such investment. This suggests a certain satisfaction with this investment, as all respondents from Sample 2 have already invested in PV.

Heterogeneity is also reflected in their choice patterns. Table 2.6 presents choice patterns in the DCE. It shows shares of respondents who always, sometimes, or never chose the available options. This shows whether the respondents' preferences are heterogeneous and, if so, whether the heterogeneity is comparable for all investment options or whether there are visible differences.

Because not all energy investments were equally often offered, the total number of respondents who received the option is also reported. As a reminder: retrofits were only offered, if the building is older than 30 years and has not been retrofitted in the past 30 years. As a result, such a building would benefit from, for instance, replacement of the windows to increase energy efficiency, whereas this is not the case for new buildings. This is done to make sure that the offered alternatives are of interest to the respective respondent.

Status-quo was always selected by 3% of respondents. This shows a general interest in the proposed energy investments. When it comes to investments, envelope reinstatement and heating overhaul do not seem to be appreciated, as they were never selected by a large share of respondents who received this option. Insulation is also not appreciated by a significant share of respondents, even though there are also around 30% of respondents who always

selected this option. On the contrary, PV and renewable heating enjoy greater popularity as they were always selected by the majority of respondents whenever they were offered. But also for these investment options, there are more than 20% of respondents who never chose these options. Overall, it can be said that preferences are rather heterogeneous and renewable energy appears to be more valued in general.

Table 2.6: Choice patterns

	Status-quo	Envelope reinstatement	Insulation	Heating overhaul	Insulation Heating overhaul	Renewable heating	PV	PV & Renewable heating	Insulation & Renewable heating
Never	76.96	86.46	67.15	75.22	69.87	27.23	24.20	22.02	42.31
Sometimes	19.97	6.08	4.11	7.32	17.62	15.51	12.10	10.31	27.63
Always	3.08	7.45	28.74	17.46	12.51	57.26	63.70	67.67	30.06
Total number of respondents who received the respective option:									
	2,890	2,120	1,169	1,913	1,175	2,398	1,628	2,416	1,567

Shares of all respondents who received the respective option in %.

Never: never chosen if available, sometimes: at least once but not always chosen if available, always: chosen whenever available

Investment options offered were tailored based on the respective housing situation

Even though PV coefficients in this analysis are still greater than for insulation, the results are not as clear as in Chapter 1. This may have different reasons, but these cannot be verified. However, Covid-19 may have had an effect on energy-related behaviour (Swiss Federal Office of Energy, 2023b; Todeschi et al., 2022). While the experiment for Chapter 1 was conducted after the first Covid-19 wave, the respondents of Chapter 2 experienced more time at home due to Covid-19. They had to work more from home due to the restrictions and had to spend more time at home due to limited opportunities. On the one hand, energy consumption increased during this time in Switzerland (Swiss Federal Office of Energy, 2023b; Todeschi et al., 2022). Resulting higher costs can be a factor in favour of energy efficiency measures. But comfort can also play a role (Banfi et al., 2012). With the increased time spent at home, it can be assumed that energy efficiency issues, such as old windows, have become more significant, which may also have increased interest in upgrades. However, the exact reasons and whether this is a short-term or long-term effect cannot be clarified within the scope of this study.

My study may be subject to limitations due to its experimental design. With DCEs, it is difficult to find the right balance between clear and concise choice tasks and understandable explanations. The respondents must not be overwhelmed, but at the same time receive enough information to make an informed choice. Therefore, attributes and investments are rather briefly explained. If necessary, additional information is provided via hover text. However, it is not possible to say for sure whether this is correctly understood and utilised. This may lead to confusion. As in the other experiments, it is primarily the benefit attribute that is not necessarily clear, especially for inexperienced respondents. The difficulty here is that no monetary values are given, only percentage savings. It cannot always be assumed that respondents are aware of their energy consumption and the associated costs (see e.g. Blasch et al., 2018; Brounen et al., 2013). Thus, our benefit attribute may not have been understood correctly. On the other hand, it is difficult to show realistic cost savings for the respective respondent because the individual consumption and costs are not always available. Incorrect information would in turn distort the results. So even if we decided in favour of the chosen path for a reason, it may well be a limitation. The same is true for subsidies, which are also displayed as percentage of costs covered. Therefore, respondents have to find out for themselves what these figures mean in monetary terms. It is impossible to say, whether this ultimately makes a difference. Follow-up questions might have been helpful here. For example, respondents could have been asked what a corresponding saving or subsidy would mean for them in monetary terms. The results of this could provide information as to whether the attributes were understood. On the other hand, this would also make the experiment longer and increase the respondents' burden due to the calculation. This could have negative effects and lead to a higher drop-out rate. It is difficult to weigh up the advantages and disadvantages in advance. Nevertheless, these potential limitations must be recognised when evaluating the results.

2.7 Conclusion

In this study, we analyse data from 2,890 Swiss homeowners to investigate the role of subsidies for energy investment decisions. We find a positive effect for subsidies, that even goes beyond the pure cost advantage. This means that the marginal valuation of subsidies exceeds the marginal benefit to the recipient. This again shows behavioural aspects of such measures, which make them a reasonable tool for promoting energy investments. That almost all PV installations of respondents have been supported by subsidies shows that these policies are appreciated, and bureaucratic barriers do not seem to hinder their uptake. This is also supported by the fact that most respondents state that the subsidy process is not very complex. This is also reflected in the estimation results, as our simplified OSS treatment shows no statistically significant effect. As the process is considered appropriate, the policy approach as it stands seems adequate to encourage energy investment. Because further simplification can lead to potential free rider problems, the advantages, and disadvantages of this need to be examined. However, there seems to be no urgent need to simplify the process further. The fact that subsidy-related tasks are regularly done by experts, such as installers, shows that the market already provides a solution that decreases complexity and workload for investors.

We also find that SFH owners are most interested in PV and renewable heating investments in our DCE. Yet, insulation is also appreciated. Simple reinstatements, on the other hand, have less or no effect. This picture is even more pronounced for homeowners who are experienced. When it comes to real energy investments, the tendency is largely similar for experienced and inexperienced owners. Thus, experience with subsidies, and as a result, also experience with energy investments does not seem to affect preferences in general.

2.8 Appendix

2.8.1 DCE

The idea for the experiment came about together with the Swiss Federal Office of Energy. The aim was to investigate the role of subsidies and the necessary process for energy investments. The DCE design was created based on the lessons learned from the previous experiments for Chapters 1 and 3 and adapted to the needs of investigating these topics. Because there were no problems with the previous experimental design, we decided to create a similar design for the experiment. Thus, we chose a similar range of investments, even though we solely focussed on investments in the own building and not collective investment options. Because costs and benefits are amongst the most influential factors when it comes to investment, we included both for all choice tasks. The attribute levels were provided by engineers from TEP Energy to have realistic values. To be able to answer which role subsidies play for investment, we included subsidies as an attribute whenever it was relevant for the respective investment. We tried to make the experiment and the choice as realistic as possible by matching the energy options available to the living conditions and offering a range of different relevant investments. These could represent an actual decision by the respondents.

The experiment and its design was tested in an internal pretest with other researchers involved in the 2021 SHEDS wave. We kept the design because there were no issues identified, and we did not receive negative feedback. Thus, the same design was used for SHEDS, the survey in Zürich and the Pronovo survey. No problems occurred for either survey.

Prior to the actual choice tasks, respondents are asked about their living situation to adjust the choice tasks according to it. This makes the choice tasks as relevant as possible to respondents and helps to get unbiased responses. By asking them about previous energy investments, we are able to use this information in our analysis. So we ask them about

PV, insulation and renewable heat investments to see whether such experience affects choice behaviour. Then we ask whether they received subsidies for their investments and how they experienced the process. This information is used in the analysis to see whether choices of experienced owners differ from those who have never applied for subsidies. We also ask who took the investment decision in order to see how familiar respondents actually are with the investment and subsidy process.

After this part, we state that they should choose as if they could decide again on previous investments when choosing the energy investments in our choice experiment. This is done to avoid possible bias. Otherwise, respondents may not choose a particular energy investment because they have already made a particular investment. This is followed by a description of potential energy upgrades on residential buildings and the resulting benefits. After a description of the current subsidy process, the OSS treatment is introduced to the treatment group. Because the previous experiments with within intervention to present the policy scenarios appeared to be complicated, we opt for a simpler approach in this DCE. No policy scenarios have to be remembered. This part is concluded with questions about the opinion of the current system and the experiences made with it in order to be able to assess the perception.

Thereafter, respondents receive additional information about the experiment, as well as the energy investments and their attributes. Implications of all energy investments are explained. This should allow respondents to make informed choices. To foster truthful responses, we tell respondents that the results of this study will be provided to policymakers, who may use them to adapt future policies. This is to make respondents realise that sharing honest preferences can benefit them later when their real interests are represented. By reminding them that they should answer according to their financial means, realistic answers should be obtained.

In order to avoid a bias due to the arrangement of the energy investment options, this is randomised for each choice tasks. Additionally, to the two energy investment options, we always offer the status-quo option. By selecting this option, respondents could choose a different alternative that is not energy-related if the offered energy options are of no interest to them. Whilst the status-quo remains the same, the energy options and their respective attribute levels change for each choice task. This makes it possible to analyse the resulting effect.

The total number of choice tasks is reduced to 4 compared to 6 in previous experiments for Chapters 1 and 3. These adaptations aims to reduce the burden of the experiment. In each of the four choice tasks, respondents are asked to select the options they preferred. Additional information that may be decisive for the selection is displayed via hover text if an attribute or its implications are unclear. The respondents are also informed about this possibility above the choice task. The choice always includes two energy investments, tailored to the building situation of the respective respondent, and the status-quo option. For the first choice of the latter, a follow-up question is asked. The purpose of this is to find out more about the respondents' preferences if they do not like any of the energy investment options. It is only asked on the first time selecting the status-quo option, so as not to discourage respondents from choosing this option by asking the same question repeatedly. This is to avoid biasing the responses. The corresponding answers can be found in Table 2.7.

The most frequent answers to this question indicate a preference for saving, either for retirement or without a specific purpose, and to use it for different renovations of their building. The latter in particular shows that respondents are interested in projects on their own building, be it energy investments or other renovations in and around the building.

Furthermore, after the experiment, we ask respondents which attribute they considered how important in their decision-making. The aim of this question is to get a better picture

Table 2.7: Alternative usage of money

	Selection
Invest	85 (9.05)
Save for retirement	209 (22.26)
New car	18 (1.92)
Vacation	26 (2.77)
Save	93 (9.90)
Other	217 (23.11)
Other renovation	291 (30.99)
Total	939 (100.00)

Shares in % in parentheses.

of how energy investment attributes are perceived. Their responses can be seen in Table 2.8. This shows that investing in energy upgrades in particular, but also factors such as benefits, play a very important role. Subsidies and costs are rated as very important, but comparatively fewer respondents rate them as extremely important. This question is posed to get more information about their motivation for their decision-making.

Table 2.8: Importance of aspects for selection

	Not at all important	Not important	Moderately important	Very important	Extremely important
Costs	1.76	4.88	40.80	42.73	9.83
Benefits	0.69	1.80	14.88	62.15	20.48
Subsidies	3.36	9.38	49.55	30.59	7.13
Investment in renewables	1.73	3.11	18.34	48.37	28.44
Investment in energy efficiency	1.21	2.08	21.25	53.32	22.15

Sample: 2,890 respondents

2.8.2 OSS treatment

The OSS treatment, that is presented to the treatment group before the choice tasks, can be seen in Figure 2.4. It contains information about this concept as well as information about the further procedure. It is also pointed out that the concept should be considered in the selection process as if it was really in place. Thereby, it should be analysed whether such an OSS could be promoting interest in subsidies and ultimately also interest in energy investment.

Figure 2.4: OSS treatment

mistee_treatment. The current situation regarding subsidies is quite complicated. Assume that a considerable simplification is implemented: like in a **"one-stop shop"** you can settle all subsidy requests at once.



For you as a homeowner, this means:

- All subsidies are organized within a single program.
- There will be one simplified request form for all types of investments (building and energy-related renovations and heating and PV systems). This means that the administrative burden is noticeably reduced ("less paper work").
- Tax deductions are still attributed at the cantonal level (as they are now).

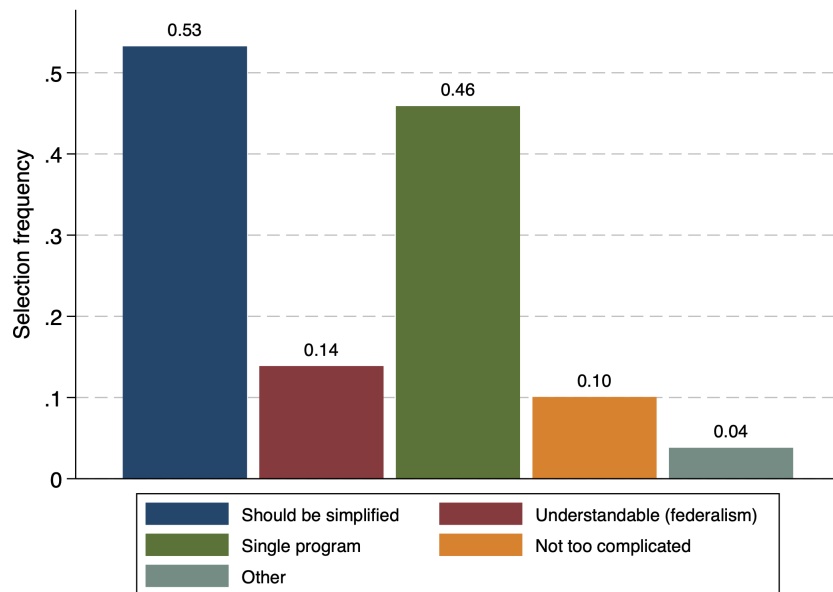
You will now be asked **four questions where you can choose between two energy investment alternatives or none of the two.**

If you have already implemented some of the offered investments, please still select your preference assuming that you could go back in time and decide again. Your experience is important for us. **Please select your preference keeping in mind the above simplification of the subsidy landscape ("one-stop shop").**

2.8.3 Impression of the current subsidy system

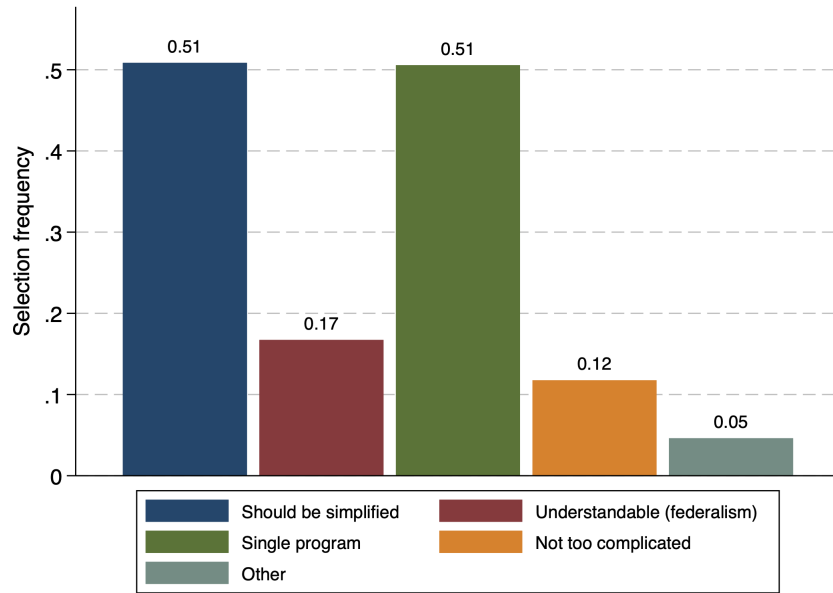
To see whether the impression of the subsidy system differs between those who have no experience with subsidies and those who have already received subsidies, their responses are detailed in Figure 2.5 and Figure 2.6 respectively. As it can be seen, the answers are similar. It has to be mentioned, that multiple responses could be made, which explains why the sum of shares is greater than 1.

Figure 2.5: How inexperienced respondents feel about the current subsidy system



This figure is based on the answers of all respondents who are not experienced with subsidies (815 respondents).

Figure 2.6: How experienced respondents feel about the current subsidy system



This figure is based on the answers of all respondents who are experienced with subsidies (2,057 respondents).

2.8.4 Latent class estimation results

I also attempted latent class analysis but due to convergence problems with greater number of classes I decided to report mixed logit results in this chapter. Yet, the latent class results give further insights into their preferences and corresponding heterogeneity¹¹.

Table 2.9: BIC and CAIC

Classes	BIC	CAIC
2	16422.42	16448.42
3	16000.23	16040.23

¹¹For a detailed description and comparison of latent class and mixed logit see also (Greene and Hensher, 2003).

Table 2.9 presents the BIC and CIAC figures that are used to identify the best model by repeatedly fitting the same model with increasing amount of classes. Both key figures show the advantages of the model with three classes. Raising the number of classes further leads to numerical convergence problems.

The estimation results for the latent class model with three classes are reported in Table 2.10. As it can be seen, Class 1 and 3 show appreciation of energy investments, predominantly for investment in renewable energy. Insulation is also valued, even though to a smaller extent, in Class 3. In contrast, Class 3 shows appreciation for envelope reinstatement, which is disliked by respondents in Class 1. Class 3's greater appreciation for simple overhauls may be due to the relatively low cost of options, such as envelope reinstatement or heating overhaul, as Class 3 is more cost sensitive. Unlike the other two classes, respondents in Class 2 show no appreciation for energy investments in general. Compared to the other classes, Class 1 is the least cost sensitive. Yet, they show the highest valuation of subsidies. Class 1 is also the class whose members are more likely to have experience with subsidies. For the other characteristics, its members do not differ significantly from those in Class 3. People who have experience with subsidies therefore seem to value them more, which indicates a positive experience. Class 2, whose members appear to have no interest in energy investments, is the smallest class. Classes 3 and 1 account for a larger proportion of respondents.

Table 2.10: Latent class estimation results

	Class 1	Class 2	Class 3
Investments (base: no energy investment):			
Envelope reinstatement	-1.106** (0.48)	-1.335*** (0.31)	1.546*** (0.17)
Insulation	2.952*** (0.24)	-0.051 (0.57)	2.589*** (0.29)
Heating overhaul	0.507** (0.21)	-0.866*** (0.25)	2.151*** (0.17)
Insulation and heating overhaul	2.774*** (0.25)	-0.664 (0.74)	1.988*** (0.32)
Renewable heating	2.534*** (0.18)	-0.853* (0.46)	2.945*** (0.23)
PV	2.878*** (0.17)	-0.493 (0.35)	3.173*** (0.21)
PV and renewable heating	3.656*** (0.23)	-0.115 (0.55)	3.401*** (0.26)
Insulation and renewable heating	3.564*** (0.31)	0.761 (0.71)	2.810*** (0.35)
Netcosts after subtracting subsidies (in 1,000 CHF):			
	-0.006*** (0.00)	-0.033*** (0.01)	-0.033*** (0.00)
Subsidies (in %):			
	0.021*** (0.00)	0.016 (0.01)	0.011** (0.01)
Energy savings (in %):			
	0.007*** (0.00)	0.000 (0.00)	0.007*** (0.00)
OSS treatment (interacted with subsidies):			
	0.006 (0.01)	-0.020** (0.01)	0.003 (0.01)

– continued from previous page

	Class 1	Class 2	Class 3
Class membership model parameters : Class 3 = Reference class:			
Experience with PV	0.277 (0.18)	−0.020 (0.28)	0 0
Experience with subsidies	0.410*** (0.09)	−0.115 (0.17)	0 0
Building age (>30 years)	−0.070 (0.14)	−0.027 (0.18)	0 0
Retired (respondent age >65)	−0.047 (0.14)	0.450** (0.19)	0 0
Constant	−0.173 (0.16)	−1.424*** (0.19)	0 0
Class share	0.554	0.088	0.358

Significance levels * p < 0.1, ** p < 0.05, *** p < 0.01.

Standard errors in parentheses. Sample: 2,890 respondents.

2.8.5 Alternative estimation results

To confirm the estimation results presented in Table 2.5, we also tried different specifications. In Table 2.11, instead of using subsidies as percentage of investment costs, we used subsidies translated in monetary values to see whether this confirms the higher valuation of subsidies compared to costs. Indeed, the significant positive subsidy effect shows that subsidies are valued more than an equally high reduction of costs.

Furthermore, we included a variety of characteristics such as experience indicators, to see whether these affect choices. Anyhow, the results showed no significant effect. Thus, these variables were dropped from the analysis. Also, we checked whether subsidies are perceived differently for PV, but the results showed no significant effect.

Table 2.11: Alternative estimation results

	Sample 1		Sample 2	
	Mean	SD	Mean	SD
Investments (base: no energy investment):				
Envelope reinstatement	0.244 (0.35)	2.615*** (0.61)	-0.888** (0.37)	2.299*** (0.38)
Insulation	3.123*** (0.83)	5.163*** (1.29)	3.087*** (0.32)	3.335*** (0.54)
Heating reinstatement	1.611*** (0.35)	2.774*** (0.48)	-0.250 (0.30)	2.793*** (0.38)
Insulation and heating reinstatement	3.282*** (0.62)	2.749*** (0.77)	2.019*** (0.43)	3.775*** (0.49)
Renewable heating	3.273*** (0.50)	1.260 (1.59)	3.348*** (0.23)	1.380*** (0.25)
PV	4.014*** (0.45)	3.745*** (0.59)	3.993*** (0.25)	1.855*** (0.27)
PV and renewable heating	5.003*** (0.58)	3.246*** (0.59)	5.155*** (0.36)	2.495*** (0.32)
Insulation and renewable heating	4.732*** (0.79)	3.744*** (0.60)	4.545*** (0.42)	2.920*** (0.30)
Costs after subtracting subsidies (in 1,000 CHF):				
	-0.050*** (0.01)		-0.033*** (0.00)	
Subsidies (in 1,000 CHF):				
	0.019* (0.01)		0.019*** (0.01)	
Energy savings (in %):				
	0.025*** (0.00)	0.061*** (0.01)	0.021*** (0.00)	0.046*** (0.00)
OSS treatment (interacted with subsidies):				
	1.118 (1.15)		0.494 (0.63)	

Significance levels * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Standard errors in parentheses.

Sample 1: 818 respondents with no experience with subsidies;

Sample 2: 2,072 respondents who have already received subsidies

Chapter 3

Empowerment of Tenants for a Greener Future

The case of collective investments and smart technologies

This chapter is based on a working paper co-authored by Mehdi Farsi (University of Neuchâtel, Institute of economic research), Sylvain Weber (University of Applied Sciences and Arts Western Switzerland (HES-SO), Haute école de gestion de Genève (HEG)) and Martin Jakob (TEP Energy). This paper has been published as part of the IRENE Working Paper Series (WP 22-08).

3.1 Introduction

Rental dwellings account for a large share of residential buildings in Switzerland (Federal Statistical Office, 2021). Given the buildings' significant fraction of CO₂ emissions (Swiss Federal Office of Energy, 2022a; European Commission, 2020), tenants could play an important role for achieving the goal of sustainable energy demand (see e.g., Swiss Federal Office of Energy, 2020; European Commission, 2018). At times, however, it is not entirely clear exactly what this role involves.

While there is evidence for an energy efficiency gap in buildings in general, empirical studies single out the case of rental buildings as a significant example of underinvestment. The investment gap between owned and rental dwellings is associated to the split incentive problem that occurs in rental buildings (Davis, 2023). The split incentives problem refers to underinvestment in energy efficiency measures due to asymmetric information and non-alignment of interests between landlords and tenants (Melvin, 2018). Furthermore, transaction costs might hinder the optimal sharing of costs and benefits of energy investments. This misalignment of incentives can lead to inefficiently low energy investment levels, resulting in lower energy efficiency and higher energy costs (Petrov and Ryan, 2021; Melvin, 2018).

This misalignment can be solved if both tenants and landlords coordinate their actions. This can happen, for example, when tenants indicate their willingness to contribute to costs. In that case, investment costs through rent increases can also be more attractive for the landlord (Lambin et al., 2023; Carroll et al., 2016). In the Swiss context, studies like Farsi (2010) show that tenants have a willingness to pay for energy efficiency measures. Yet, a variety of potential energy investments is feasible and preferences within this broader picture remain unclear. However, recent developments show that whilst energy efficiency investment rates remain at low levels, prosumption is on the rise (IEA, 2021; Inderberg et al., 2018). Thus, the situation may be changing towards prosumer preferences, also because new opportunities

are emerging. To the best of our knowledge, this has not yet been sufficiently investigated for tenants. The focus of the split incentives problem is also more on efficiency measures (Gillingham et al., 2012). However, in order to achieve the climate goals, the presumption of renewable energies is also required (Swiss Federal Office of Energy, 2020). We fill this research gap by investigating tenants' preferences when it comes to energy investments. We also calculate WTP, as this is an important signal that can help solve the split incentives problem (Lambin et al., 2023; Carroll et al., 2016).

A more comprehensive investigation of the current state is also necessary because investing has changed in recent years. While split incentives and a lack of tenants' decision-making power used to lead to limited opportunities, more and more collective investment projects have emerged in recent years (Moret and Pinson, 2018; Bonzanini et al., 2016). These enable people to invest regardless of their housing situation. Technological advances also favour presumption, as they make presumption more flexible and cheaper (Kostková et al., 2013). As a result, tenants now have new opportunities to invest themselves irrespective of the landlord and, therewith, contribute to more sustainable energy consumption. How these new opportunities are perceived by tenants and whether they may even empower them to overcome underinvestment is largely unexplored. It is therefore the main focus of this study. Estimating the WTP for energy improvements on the rental building can show whether investing is worthwhile for landlords (Carroll et al., 2016). Furthermore, we investigate how investment decisions are influenced by different policy scenarios that are relevant in the Swiss context.

We pose the following research questions: (i) Are tenants in general interested in energy investments, and is a preference for presumption observable? (ii) Are there signs that collective investment options can drive a possible preference for renewable energy compared to energy efficiency investments? (iii) Which role do smart technologies play for investment decisions? (iv) Are their investment preferences affected by hypothetical policies?

To answer these research questions, we conduct a discrete choice experiment (DCE) in which tenants are asked to choose between multiple relevant energy investment options and a status-quo alternative. The obtained data from a sample of 543 Swiss tenants is analysed with a mixed logit approach and a mixed logit model in the WTP space.

Our results show that purchasing green electricity and PV are the most appreciated investment options, followed by energy efficiency upgrades. Thus, even though there appears to be a slight preference for renewable energy, energy efficiency is valued and shows that there is no clear trend towards renewables. Collective investment options do not appear to be a game changer that make the investments of the landlords superfluous. In fact, tenants show a preference for contributing to the landlord's investments in their own residential building. However, there is also some interest in collective investment opportunities that offer more options to tenants. Tenants also show that they value storage, which can come with prosumption installations and makes consumption more flexible. Our hypothetical policy situations do not show any significant effect on investment decisions. This may be, for instance, due to the hypothetical nature of the experiment or the limited importance for them because tenants are not necessarily directly affected. The generally high standard deviations show a substantial heterogeneity between tenants, indicating that preferences differ and policies may have to target specific groups in order to be most effective.

The remainder of the paper is structured as follows. The upcoming Section 3.2 outlines the literature, Section 3.3 addresses the experiment, followed by the methodology in Section 3.4. Section 3.5 presents and discusses the results, and Section 3.6 concludes and provides policy implications.

3.2 Literature review

Real world developments show that energy efficiency retrofit rates remain low, whereas renewable energy investment rates, for instance for PV, are rising (IEA, 2021; Swiss Federal Office of Energy, 2021b; Weber and Wolff, 2018). Yet, the literature on the split incentive problem focuses largely on energy efficiency investments (see e.g., Davis, 2023; Melvin, 2018; Gillingham et al., 2012). It is argued that a low WTP can be a reason for split incentive problems (Carroll et al., 2016). It can be difficult for tenants to understand the current energy efficiency level or which systems are operating, which can lower acceptance of rent increases necessary for making energy investments (Lambin et al., 2023). Anyhow, several studies show that Swiss tenants are indeed willing to pay a premium in order for more efficient heating systems or other devices, which can even exceed the actual costs of such upgrades (Lang and Lanz, 2021; Farsi, 2010; Banfi et al., 2008).

In this context, the focus on energy efficiency upgrades neglects the potential preference for renewable energy. However, such investments can also lead to more sustainable consumption and are more relevant than ever in light of current concerns about rising energy prices and the threat of shortages. A study that examines tenants' attitude towards and WTP for solar panels and storage for the produced renewable electricity is conducted by Fleischhacker et al. (2018). They use different models and find a positive WTP for solar panels and storage. The tenants' WTP for the installation of shared PV and energy storage systems is influenced by factors such as the perceived environmental benefits, the level of autonomy over the energy use and the perceived fairness of the allocation and pricing scheme.

Upcoming collective investment projects concerned with production of renewable energy have potential to fundamentally change the energy investment situation (Moret and Pinson, 2018; Bonzanini et al., 2016). Microgeneration on one or multiple residential buildings, or even independent of the residency, can decrease costs and come with environmental and

personal benefits, which can help to enhance the penetration with renewable energy (Stadler et al., 2016). Increasingly emerging self-consumption communities and crowd investment projects can be a way to invest in energy independent of the landlord and are favourable for those who might otherwise not be able to invest in sustainable energy on their own (Viardot, 2013). This can correct potential under-investment in prosumption systems on residential buildings and enriches the tenants' possibilities (Moret and Pinson, 2018).

Battery storage installed with a PV system can make prosumption more flexible. On the other hand, load management decreases the flexibility, but provides another possibility to optimise electricity consumption and save costs (Kostková et al., 2013). Yet, acceptance of such optimisation depends on the exact design (Soland et al., 2018). In general, however, both battery storage and load management can be beneficial for the consumer and also make collective prosumption more efficient. Yet, for tenants it can be more difficult to benefit from battery storage due to the limited capacity and rivalry in consumption, when the storage can be used by all tenants of the rental building or even all participants of the prosumer community. Thus, uncertainty and risk may play a role, which can limit the attractiveness of such technologies.

Purchasing “green” instead of conventional electricity can be an easy way to enhance sustainable energy consumption. In their literature review, Gillingham et al. (2009) examine the factors that influence consumer preferences and WTP for green electricity. It reveals that consumer preferences and the respective WTP are influenced by a variety of factors, including the price and environmental attitude. The review also finds that consumers are willing to pay a premium for green electricity, but the size of the premium varies depending on the specific context. Similar findings are presented by Hansla et al. (2008); Yoo and Kwak (2009).

Policies have been found to impact energy investment decisions, for instance, by lowering financial hurdles (Mundaca and Samahita, 2020; IEA, 2010; Gillingham et al., 2009). Subsidies and netmetering aim to lower costs and make such investments more worthwhile (Heiskanen and Matschoss, 2017; Alberini et al., 2013). On the other hand, CO₂ taxes can be used to incentivise residents to lower their energy consumption by making it more expensive (Köppl and Schratzenstaller, 2022). Effectiveness of such taxes is not always given, for instance, due to relatively insignificant energy expenditures or low financial literacy when it comes to energy cost (Blasch et al., 2018; Brounen et al., 2013). However, there is little evidence on how such policies affect tenants, probably because they are not the ones making investment decisions and deal with subsidies as part of it. Yet, they may value such policies and this may also affect their willingness to contribute.

3.3 Experiment

Both stated and revealed preference approaches can be used to study energy investment preferences (see e.g. Newell and Siikamäki, 2014). We apply a discrete choice experiment to get information about tenants' preferences (Louviere et al., 2000). These preferences are not always detectable by revealed data, as the tenants are usually not in charge when it comes to investment decisions. The stated preference approach comes with different up- and downsides. For our study, the chosen approach is useful to analyse investment preferences. In the context of this paper, especially innovative collective investment projects and technologies that potentially change the market make the stated preference approach better suited than revealed preferences. This is also the case because such changes limit the significance of past actions for future developments (Golden, 1992). Also, controlling provided information and attributes, as well as respective levels, allows investigating how these determinants affect decision-making, which is often not possible when using revealed preferences (Bidwell, 2013).

Before the actual choice sequence, respondents are primed by providing information to promote accurate and truthful responses. Therefore, we displayed reminders that the results of our research projects are consolidated for policy purposes and that for this reason it would be best for them to choose according to their real preferences and under consideration of their budget constraints (Newell and Siikamäki, 2014; Johnston et al., 2017). Additionally, participants receive information about the energy investments and resulting effects. Furthermore, they are asked to provide information about their building to ensure relevance of the displayed options by tailoring the energy investments accordingly.



The actual choice experiment consists of three sections: (i) 2 choice tasks presented to participants before any information treatment is provided. Participants are randomly assigned to one of the treatment groups, or the control group. Afterwards, the treatment is introduced, and four additional choice tasks are presented, of which the last two may come with smart technologies not featured in the first four choice tasks. An example of the choice task design can be seen in Figure 3.1.

In all six choice tasks, they have the choice between two energy investment options and a status-quo (SQ). When the latter is selected for the first time, respondents are asked to indicate their preferred alternative way of spending, investing or saving the money not spent in an energy-related investment. Offered options are spending it on vacation, purchasing a new car, saving it or investing it on the financial market. The energy investment options are tailored to the building age, technological standard and operated system, so that only relevant options are displayed. The order of the energy options, and the investments themselves, are randomized to avoid a potential bias.

All energy investment options are displayed in Table 3.1. Both energy efficiency and renewable energy investments are included to find out whether there is a prosumer preference or if split incentives appear to rise interest in efficiency upgrades. Furthermore, by including

Figure 3.1: Example of a choice task

Additional information will be displayed by placing the mouse over the elements of the table below.

	Option 1	Option 2
	Renewable heating system 	Photovoltaic installation 
Costs	CHF 70 per month	CHF 120 per month
Benefits: Reduction of non-renewable energy and CO₂ emissions	40%	70%
Financing	Provider (invests in the heating system of your building)	Crowdfunding (of a project outside your building)
Storage in batteries	None	Yes

Your choice: Option 1 Option 2 None of the two

collective investment projects, we can infer if they can help to circumvent the split incentive problem.

These attributes are chosen according to findings in the literature and are adapted to our research questions. All energy investment options come with five different attributes, whereas the smart technology attribute is just available for the last two choice tasks to prevent respondents from being overwhelmed and at the same time to see to what extent such opportunities are perceived. The attributes are: (I) type of energy investment option; (II) corresponding costs; (III) the benefits expressed as saving of otherwise (conventionally produced) consumed energy and resulting CO₂ emission. This also implies that they save a

Table 3.1: Energy investments, attributes, levels

Investment	Description	Collective investment possible
Envelope reinstatement	Renewal of the facade without efficiency gains (e.g. painting)	no
Insulation	Insulating the building's envelope with efficiency gains (e.g. replacement of windows and/or insulation of façade)	no
Heating reinstatement	Reinstatement of the existing fossil fuel powered heating system	no
Insulation and heating reinstatement	Insulation and heating reinstatement	no
Renewable heating	Switch from a fossil fuel powered to a renewable heating (e.g. heat pump)	yes
Insulation and renewable heating	Insulation of the building and switch to renewable heating	no
PV	Photovoltaic installation	yes
- with storage		yes
- with load management		yes
- with storage and load management		yes
PV and renewable heating	Photovoltaic installation and switch to renewable heating	yes
Green electricity	Purchase of renewable electricity from the utility	no

certain amount of their current expenses due to the investment; (IV) financing options. The choice was between contributing to investment cost paid by the landlord, or participating in a self-consumption community (SCC) or crowd investment project. Collective investments were only available for PV and renewable heating systems, as these are the only ones of the available investment options that can also be carried out at another location away from one's own building; and (V) whether there is any form of storage in batteries and load management involved.

Cost and energy saving levels are presented in Table 3.2. The corresponding levels do not differ between investments in the own building and collective investments. All levels are chosen according to expert suggestions. Compared to house owners, tenants usually do not have to pay upfront investment costs but rather a monthly rent premium or their contribution to collective investments. While the investments lead to savings, the green electricity costs are only a premium for consuming renewable energy instead of conventionally generated energy. This does not result in any savings. To make costs comparable, we have converted the green electricity costs into the respective amount of costs for the corresponding share of energy. For instance, if the offered option comes with 50% benefits, this means that respondents pay the premium for 50% of their consumption, and costs used in the analysis include not only the premium for this share, but also costs for the usual consumption of this 50%. All costs are presented as monthly costs. Benefits mean that the respective share is saved and/or produced by renewable energy, which leads to savings of previously consumed energy. This is also accompanied by CO₂ savings.

Furthermore, we also identify how tenants' preferences change under different policy scenarios. The offered information describe hypothetical, but realistic policy changes that have already been discussed in Switzerland. These are (i) an increase in CO₂ taxes, which will lead to higher energy costs if fossil fuels are utilised. A first increase in CO₂ taxes already took place in Switzerland in 2022 and the population is aware of the possibility of further

Table 3.2: Cost and benefit levels

	Costs in CHF/month	Benefits in %
Envelope reinstatement	40; 60 ; 70; 80	0
Heating reinstatement	10; 20	5; 10; 15; 25
Renewable heating	70; 90; 110; 130	20; 40; 60; 100
PV	30; 40; 70; 90	15; 25; 40; 60
- with storage	40; 60; 90; 120	20; 30; 50; 70
- with load management	60; 90; 110	20; 30; 70
- with storage and load management	60; 80; 110; 130	20; 40; 60; 80
- with renewable heating	100; 130; 180; 220	20; 70; 100
- and storage	110; 150; 200; 260	40; 70; 100
- and load-management	110; 150; 200; 240	20; 40; 70; 100
- and storage and load-management	130; 170; 220; 270	20; 40; 70; 100
Insulation	90; 130; 180; 220	15; 25; 40; 60
- with heating reinstatement	40; 110; 170; 220	15; 25; 40; 60
- with renewable heating	170; 220; 270; 330	20; 40; 60; 100
Purchasing renewable electricity	3; 7; 11; 15	15; 25; 40; 60

increases (Federal Office for the Environment, 2021a); (ii) netmetering, which has been in place in Switzerland from 2008 to 2022, but which were recently replaced by subsidies (Swiss Federal Office of Energy, 2019). Netmetering has been identified to affect energy choices, see e.g. Castaneda et al. (2020); (iii) information about subsidies, which will cover 30% of all investments costs. Subsidies have been identified to promote investment decisions (see e.g., Mundaca and Samahita, 2020) by lowering otherwise high investment costs (see e.g., Heiskanen et al., 2012). Even though one may assume that it is rather the owner for whom reduced upfront costs play a role, tenants may appreciate the associated benefits and the lower costs that are passed on to them. All three treatments are based on hypothetical scenarios described in scripts that are similar in length¹.

¹For exact treatment texts, see Appendix 3.7.

The last two choice tasks can come with storage and load management to identify whether such optimisation options affect choice behaviour. Because even though storage that accompanies PV can increase flexibility of prosumption, it is not necessarily economically sensible, and load management is not always appreciated (Riveros et al., 2019; Fell et al., 2015). Especially for tenants, it remains to be seen how they perceive such options that can potentially foster the attractiveness of prosumption. Also with respect to load management, it is still not clear whether tenants appreciate such optimisation, that can be important to consume energy more sustainably (Kostková et al., 2013).

The experimental design is made with the software *Ngene*. The actual choice experiment is created with *Qualtrics* (Weber, 2021). Our experiment was part of the “Swiss Household Energy Demand Survey (SHEDS)” (see Weber et al., 2017) which was launched in 2020. SHEDS was conducted in all Swiss cantons except Ticino between 20 May and 27 June 2020. Participants are subscribers from Intervista, which is a company that manages a large panel of potential participants in Switzerland. A random selection of tenants from the representative SHEDS sample was assigned to our experiment. 543 Swiss tenants serve as the sample for the econometric analysis.

Characteristics of the respondents are shown in Table 3.3 in comparison to the Swiss population. As can be seen, our sample tends to include younger respondents. This is probably because younger people are more likely to be renters, while homeowners are more likely to be older (see also Table 1.3). In terms of gender distribution, our sample is comparable with the Swiss population. Also with respect to education, our sample is close to the Swiss average, even though those with compulsory school are underrepresented. Also, there are relatively few respondents with very low household income (below CHF 3,000), whereas higher earning households are overrepresented.

Table 3.3: Respondent characteristics

	Respondents	Switzerland
Age		
18-34	179 (32.97)	(25.31)
35-54	214 (39.41)	(34.41)
55-64	76 (14.00)	(16.90)
65 +	74 (13.63)	(23.39)
Sex		
Male	272 (50.09)	(49.31)
Female	271 (49.91)	(50.69)
Education (highest qualification)		
Compulsory school	16 (02.95)	(13.90)
High school or vocational school	268 (49.45)	(41.40)
University (of Applied Sciences)	258 (47.60)	(44.70)
Household gross income		
Less than 3,000	28 (6.09)	(18.1)
3,001-6,000	153 (33.26)	(34.6)
6,001-9,000	140 (30.43)	(28.9)
9,001-12,000	90 (19.57)	(10.0)
More than 12,000	49 (10.65)	(7.5)

Shares in parentheses (in %). Data for the Swiss population relates to persons of legal age.

Data sources: age and sex: Federal Statistical Office (2023e) (Year 2022);

education: Federal Statistical Office (2023b) (Year 2022);

income: information provided by the Federal Statistical Office; only for this dissertation, not publicly available (Year 2020).

Table 3.4 displays information about the living situation of respondents in comparison to the Swiss population. In Switzerland, more flats are occupied by a single person than in our sample. In our sample, the majority of respondents live in a two-person household. Most of the respondents in our sample (70%) live in newer houses that do not necessarily require energy renovation, whereas the majority of the Swiss population (73%) live in buildings that are over 30 years old. With respect to PV and renewable heating, our sample is close to the Swiss population.

Table 3.4: Building characteristics

	Respondents	Switzerland
Household size		
1 person	192 (35.42)	(45.31)
2 persons	217 (40.04)	(28.79)
3 persons	69 (12.73)	(12.18)
4 persons and more	64 (11.81)	(13.72)
Building age		
Built until 1990	160 (29.47)	(73.06)
Built between 1991 and 2020	383 (70.53)	(26.94)
Building with PV		
No	494 (90.98)	(>89.00)
Yes	49 (9.02)	(<11.00)
Building with renewable heating		
No	330 (60.77)	(57.50)
Yes	213 (39.23)	(42.51)

Shares in parentheses (in %).

Data sources: household size: Federal Statistical Office (2023a) (Year 2020, tenants only);

building age: Federal Statistical Office (2023d) (Year 2020, all residential buildings);

buildings with PV: Swiss Federal Office of Energy (2023c) (Year 2023; these numbers are estimates based on the total number of PV installations and the amount of residential buildings in Switzerland. Yet, the number of PV systems refers not only to residential buildings. It is probably lower for residential buildings);

buildings with renewable heating: Federal Statistical Office (2023c) (Year 2022; refers not only to tenants).

3.4 Methodology

The econometric framework builds upon the Random Utility Theory by McFadden (1974). It states that individual utility depends on characteristics or attributes and not only on the object itself. Respondents are assumed to consider all offered alternatives and respective attributes in each choice situation and choose the alternative that maximises the own utility (Louviere et al., 2010).

For the econometric analysis, we use a mixed logit model. This approach is regularly used in this context in the literature and allows avoiding critical assumptions about the independence from irrelevant alternatives (IIA) (Train, 2009). In the mixed logit model, some coefficients enter as fixed, whereas others are random. In our approach, the investment variables and benefits come with random coefficients. All other variables come with fixed coefficients. It is assumed that coefficients are normally distributed. This is motivated by the fact that not too many assumptions have to be made about variables and distribution.

Having a fixed cost coefficient comes with an advantage. It allows estimating the WTP by simply dividing the estimated coefficients by the cost coefficient (Hole and Kolstad, 2012; Train and Weeks, 2004). Another way is to calculate the mixed logit in the WTP space. For that, a log-normal cost coefficient is assumed and costs are used for scaling the other parameters (Hole and Kolstad, 2012). The WTP for tenants' energy contributions is calculated in CHF per month, as they usually have to pay a rent premium for such investments made by the landlord. On the other hand, they could also pay a certain amount for participating in collective projects or to purchase green electricity. It also ensures that the results are comparable.

3.5 Results and Discussion

The result section presents the estimation results of the econometric analysis in Table 3.5. These results are used to answer the research questions and shed light on whether we can identify a potential preference for prosumption, and if so, whether this is driven by collective investment options and smart technologies.

The coefficients of PV and purchasing renewable electricity show the greatest valuation. However, insulation together with heating renewal is not far off. Even if insulation and heating renewal alone do not have quite as great an effect, it is still positive and shows an appreciation of such investments. Therefore, while it can be said that prosumption is definitely appreciated, a clear trend towards it cannot be clearly identified. The appreciation of energy efficiency measures also points to split incentives problems or underinvestment in such measures in the rental buildings. This also indicates that there is still potential for improvement with regard to such efficiency measures. These findings are also reflected by the estimated WTP in Table 3.6 and 3.7 ².

If the WTP is considered in Table 3.6, for which the investment coefficients are divided by the fixed cost coefficient, it can be seen that the highest WTP of CHF 202 and CHF 219 per month is for photovoltaics and the purchase of green electricity, respectively. This is even higher than the actual costs and indicates, that investment in PV can be worthwhile, both for tenants and landlords. Even though the WTP for energy efficiency upgrades hint an energy efficiency gap for rental buildings, as pointed out for instance by Davis (2023), the respective WTP is not necessarily large enough to facilitate substantive upgrades, especially when it comes to insulation.

The results show that collective investments are less valued compared to investments in one's own home. This may be due, for example, to concerns about coordination problems

²At the time of the experiment: 1 CHF \approx EUR 0.93 \approx USD 1.07

Table 3.5: Estimation results

	Mean	SD
Investments (base: no energy investment):		
Insulation	1.142*** (0.35)	2.373*** (0.26)
Heating reinstatement	1.097*** (0.26)	2.087*** (0.31)
Insulation & Heating reinstatement	2.023*** (0.51)	2.103*** (0.67)
Insulation & Renewable heating	0.289 (1.15)	4.660*** (1.73)
Renewable heating		
- landlord contribution	1.448*** (0.28)	0.153 (0.28)
- SCC	1.295*** (0.35)	1.664*** (0.47)
- crowd	0.101 (0.44)	1.197 (0.84)
PV		
- landlord contribution	2.092*** (0.24)	1.616*** (0.30)
- SCC	1.508*** (0.25)	1.449*** (0.32)
- crowd	1.126*** (0.25)	1.084** (0.48)
PV & Renewable heating	0.388 (0.57)	3.388*** (0.87)
Green electricity	2.264*** (0.29)	2.518*** (0.41)
Benefits (% of conventional energy saved):		
Benefits	0.044*** (0.00)	0.053*** (0.00)
Costs (in CHF/month):		
Cost	-0.010*** (0.00)	
Storage (base: no battery or load-management):		
Battery	0.466** (0.18)	
Load management	-0.377 (0.37)	
Battery and load management	0.153 (0.30)	
Treatment effect (base: control group; interacted with relevant investments):		
CO ₂ Tax × Renewable Heating	0.050 (0.34)	
Subsidy × PV	-0.090 (0.23)	
Netmetering × PV	-0.012 (0.24)	

Sample: 543 respondents

Significance levels * p < 0.1, ** p < 0.05, *** p < 0.01. Standard errors in parentheses

Table 3.6: Willingness to pay (in CHF per month)

	Average willingness to pay	Lower limit	Upper limit
Insulation	110.21	59.46	160.96
Heating reinstatement	105.79	47.41	164.17
Insulation & Heating reinstatement	195.20	100.99	289.41
Insulation & Renewable heating	27.85	-187.72	243.42
Renewable heat			
- landlord contribution	139.69	91.53	187.84
- SCC	124.92	62.60	187.25
- crowd	9.73	-73.19	92.66
PV:			
- landlord contribution	201.84	136.26	267.41
- SCC	145.46	86.13	204.79
- crowd	108.66	57.95	159.36
PV & Renewable heating	37.41	-67.36	142.19
Green electricity	218.45	130.71	306.18

Sample: 543 respondents

or the general uncertainty associated with them. Furthermore, the results show that the willingness to pay is largely high enough to cover the realistic costs, or even higher. However, in the case of crowd investment in renewable heating, it can also be seen that the willingness to pay is on average not sufficient.

The mixed logit in the WTP displayed in Table 3.7 show a similar picture as the simple WTP figures in Table 3.6. Only crowd investment in renewable heating and the combination of insulation and renewable heating are not significant. A comparison shows that WTP is at a similar level, but slightly higher for renewable options. Since switching from a conventional heating system to, for example, a heat pump is more cost-intensive than simply reinstating the conventional heating system, this difference may be too small to make a switch worthwhile. In general, however, it also shows that tenants are interested in investing in improved heating systems, which reflects a certain dissatisfaction with the current situation. This may be an indication of split incentive problems. The results also show a positive WTP for storage that accompanies PV installations to make prosumption more flexible. Thus, despite the fact

Table 3.7: Mixed logit in the WTP space

	Mean	SD
Investments (base: no energy investment):		
Insulation	109.668*** (22.25)	212.456*** (34.94)
Heating reinstatement	107.305*** (29.74)	167.956*** (48.62)
Insulation & Heating reinstatement	172.398*** (43.10)	185.972*** (51.42)
Insulation & Renewable heating	8.034 (191.01)	443.804 (394.73)
Renewable heating		
- landlord contribution	132.041*** (22.22)	28.844 (21.50)
- SCC	117.886*** (35.14)	165.225*** (29.24)
- crowd	37.903 (24.02)	67.682*** (17.62)
PV		
- landlord contribution	189.984*** (31.20)	142.910*** (39.01)
- SCC	127.373*** (29.98)	106.523*** (31.85)
- crowd	98.329*** (21.87)	38.487 (32.12)
PV & RH	81.013** (40.31)	230.492*** (56.21)
Green electricity	209.437*** (37.50)	200.204*** (44.09)
Benefits (% of conventional energy saved):		
Benefits	4.199*** (0.69)	4.588*** (0.72)
Costs (in CHF/month):		
Costs	-0.022** (0.01)	0.026 (0.20)
Storage (base: no battery or load-management):		
Battery	50.502*** (14.29)	
Load management	-29.123 (30.32)	
Battery and load management	4.545 (25.78)	
Treatment effect (base: control group; interacted with relevant investments):		
CO ₂ Tax × Renewable Heating	3.591 (28.21)	
Subsidy × PV	-12.768 (16.11)	
Net-metering × PV	14.522 (22.33)	

Sample: 543 respondents

Significance levels * p < 0.1, ** p < 0.05, *** p < 0.01. Standard errors in parentheses

that storage is not always economically worthwhile, the resulting flexibility appears to be appreciated by tenants.

To summarise the findings regarding our first research question: in general, our results show a positive attitude towards energy investments. Furthermore, the WTP for most offered investments is sufficiently high to make investing worthwhile. The slightly larger valuation of renewable energy can be interpreted as an indication of a prosumer trend. Yet, the valuation of energy efficiency upgrades also shows that there is also room for improvement, probably due to split incentive problems. Especially the large effect for insulation and heating indicate that there are energy efficiency issues.

The second objective is to find out whether such a potential prosumer preference may be driven by collective investment options, as these enrich the tenants' opportunities and lower some other downsides of traditional energy investments on the own building, such as limited flexibility. This can be especially important for tenants who are usually less tied to their building and may move more often (Black et al., 1985). The results for the collective investment options show that tenants have the highest appreciation for participating in the investments made by the landlord in the rental building. Self-consumption communities and crowd investment show through their positive effect that tenants are also interested in them. However, the smaller effect compared to a simple contribution to an investment in the own building indicates that tenants value investment by the landlord more. This is also reflected in the WTP figures in Tables 3.6 and 3.7, which show that whilst the willingness to contribute is often even exceeding realistic costs, the WTP for collective investment may be insufficiently large. Potential explanations for this can be that tenants are probably not familiar with collective investment options and uncertain about how they work out. Furthermore, collective investment projects in our choice experiment are neighbourhood projects, which require collective decision-making and action. Resulting transaction costs and risks can lead to a lower WTP or reduce interest in such projects (Matschoss et al., 2013; Heiska-

nen et al., 2012). These factors may lead to these results, reflecting a higher valuation of investments on the own building. Still, these non-building-related projects actually open up more opportunities for them, as it is no longer the landlord but the tenants themselves who can make investment decisions. This can therefore correct the under-investment by landlords. Tenants may be more willing to invest in projects supported by institutions such as utilities, as this could reduce the associated risk and transaction costs. Even though the coefficients and WTP for collective investment is lower compared to contributions to upgrade the own building, the figures are still positive. Lower costs and a high degree of flexibility may motivate some tenants to invest in such projects. Thus, these opportunities may correct potential under-investment and may be a driver of the transition towards sustainable energy usage in the future.

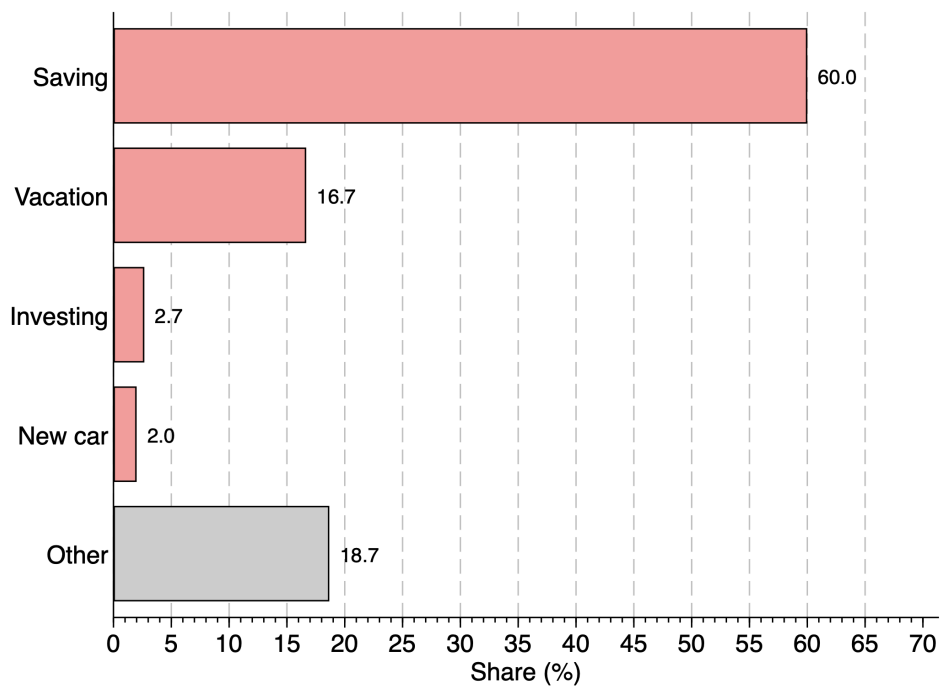
Thirdly, it is important to answer whether smart technologies and optimisation play a role in tenants' decisions. Storage comes with a positive effect, and tenants are willing to pay a premium in order to benefit from the more flexible prosumption allowed by storage. Load management on the other hand shows no significant effect. These results can reflect a valuation of greater flexibility, which is ensured by means of storage and limited by load management.

Finally, we need to answer whether our hypothetical policy scenarios have an effect on respondents' energy investment choices and, if so, which policy seems to be most effective in increasing tenants' interest in investing. Yet, none of our treatments show a significant effect on investment decisions. The lack of significant effects of a potential CO₂ tax increase may be explained by the lack of importance of energy expenditures or low price elasticity when it comes to energy prices (Labandeira et al., 2017; Ürge-Vorsatz et al., 2007). Moreover, the effect of these policies, which is passed on to the tenants by the landlord, is rather small, which is why such policies hardly play a role for tenants. Also, tenants may lack knowledge or feel like it is not affecting them, which can explain the lack of subsidy and netmetering

effects. The hypothetical nature of our experiment and the treatments may also explain the lack of significant effects.

We also want to understand the reasons for not choosing energy investment options. Therefore, the first time respondents choose the status quo option, they are asked what they would like to use the money for instead of the energy investment. The results can be seen in Figure 3.2. The majority of tenants (60%) state that they would prefer to save the money. This is more or less in line with their intended usage of an unexpected tax refund, reported in Appendix 3.7.

Figure 3.2: Responses to status-quo follow-up question



Both in the mixed logit coefficients and in the mixed logit in the WTP space estimates, the generally large standard deviation underlines that there is a certain heterogeneity among the respondents. It shows that respondents react differently to the offered information and preferences vary. Some of them may have a very high valuation for specific investments,

whilst others do not appreciate these options at all. This is also visible in the choice patterns. These choice patterns, that are presented in Table 3.8, show which share of respondents chose always, sometimes or never a certain option whenever it is offered. Total gives the number of respondents who received the respective option at least once.

Table 3.8: Choice patterns

	Status- quo	Envelope reinstatement	Heating overhaul	Renewable heating	PV	Insulation	Green electricity
Always	3.13	12.99	12.31	22.22	23.02	7.69	60.43
Sometimes	24.49	9.09	53.08	53.42	62.25	48.08	15.72
Never	72.38	77.92	34.62	24.36	14.73	44.23	23.85
Total number of respondents who received the respective option:							
	543	231	130	234	543	364	369

Always, sometimes and never: shares (%) of respondents who received the specific option.

Only a small fraction of 3% of all respondents always chose the non-energy option. On the other hand, a large share of 72% never chose this option, indicating a certain interest in energy investments and our experiment. Certain patterns emerge in the energy investment contributions, as some options were sometimes chosen, probably depending on the alternative and attributes, while for other options a clearer preference for or against is seen. Green electricity was always chosen by more than 60% of respondents whenever it was offered. This may be, for instance, due to the comparably low displayed costs. In addition, tenants do not necessarily have a close connection to the building and, unlike owners, do not benefit from the increase in value that a building receives as a result of energy investments. On the other hand, there is a significant proportion of over 44% of all respondents who have never chosen to insulate the building, even though this would be appropriate for their building. Thus, whilst there is a general interest in insulation by the majority of respondents who received this option, a significant fraction shows no valuation of such investment. This is even more pronounced with facade reinstatement, with 72% of respondents never choosing this option. This could be, for instance, due to the less intensive association with the building compared to owners (Black et al., 1985). The majority of respondents showed a less pronounced

preference for heating investments and PV, as the majority sometimes chose these options. However, even for these options it can be seen that preferences are not evenly distributed, with some respondents always selecting certain investments, while others never select them. This illustrates the heterogeneity of preferences. In general, the selection tendencies suggest that although tenants are willing to invest in more sustainable energy consumption, they do not necessarily have a valuation for an increase in the value of the building.

This is also reflected in the WTP figures. Comparing the WTP of respondents from Chapter 1 and 3, whose data were collected as part of SHEDS in 2020, provides insights into similarities and differences in their preferences. This is interesting for various reasons. On the one hand, the literature often talks about split incentive problems and the resulting underinvestment in energy efficiency measures in rental buildings. Accordingly, the interest of tenants in such measures should be high. In my studies, this is also reflected in their WTP for insulation (in Table 3.6), which is higher than that of SFH owners (see Table 1.6). On the other hand, SFH owners should have a higher willingness to pay for investments that increase the value of their building (Black et al., 1985). This should play less of a role for tenants due to their lower attachment to the building. It should primarily be the case for investments in their own building, rather than collective investments, as these are not necessarily done on the own property. A comparison of the WTP for the same period shows that this is the case for PV. For such an investment, homeowners have a significantly higher WTP of CHF 139,300 compared to CHF 68,394 for tenants (total WTP for a lifetime of 30 years). The lack of significant results for the investment in a renewable heating system by SFH owners means that the WTP calculated on the basis of the regression coefficients has only limited significance. Even if my studies do not allow me to identify the proportion of SFH owners' WTP for the upgrading of their building, there seems to be a certain willingness to pay for it. The fact that SFH owners are more interested in upgrading their own building, while this is less important for tenants, can be deduced from the WTP for PV and green energy. Both

options lead to renewable energy being consumed instead of conventional energy. However, SFH owners have a much higher WTP for PV, while tenants are more willing to pay for green energy from the utility.

Our research design may be subject to limitations that may affect the results. Even though we try to describe all concepts and attributes as clearly as possible, respondents may have difficulty understanding everything. Especially benefits as we present them can be difficult to grasp. Presenting benefits as savings in conventional energy consumption and CO₂ emission may be difficult to translate into meaningful numbers for respondents. The impact on energy expenditures may also not be easy for everyone to understand. This can also be the case because energy costs are often not entirely clear to residents anyway (Brounen et al., 2013). This could mean that benefits are seen as more or less important than they actually would be. This can be a potential explanation for the respective standard deviation in the regression results. A different type of presentation, for example a monetary saving, could be easier to understand. However, translating these savings into precise cost reductions for each respondent, which depend on the building, consumption and other factors, is difficult.

The complexity of the experiment can also be a challenge. Especially considering the policy scenarios, that are introduced within the experiment, may be difficult for tenants as they might not even be aware of such policies and their implications. This could possibly be checked with comprehension questions. However, we do not ask such questions in order to keep the experiment as short as possible, to minimise the burden on respondents, which otherwise could affect the results and drop-out rate. Also, it is not clear whether the advantages or negative effects of such additional questions would have prevailed. With respect to the policy scenarios, another approach may be better suited. For instance, it could be feasible to simply tell them about a certain policy and ask them whether, and if so, how this would affect their choices. Yet, then it would not be possible to analyse the policy effects the way we planned. Even though we tried to keep the experiment and its design as sim-

ple as possible, the amount of questions and concepts can be exhausting. This is especially the case for tenants who do not necessarily deal with energy investments for buildings on a day-to-day basis, as it is not them but the landlord who has to make such decisions (Davis, 2023). However, we check whether respondents tend to choose the status quo option more often with the length of the experiment. This could indicate fatigue. However, we find no such signs.

3.6 Conclusion

By their numbers alone, tenants are influential in terms of energy usage and climate change. Energy investments on rental buildings can make their energy consumption more sustainable and decrease the resulting footprint. However, what influences their decisions on energy investments and their willingness to take action has not been extensively studied, especially in the context of recent developments and under consideration of innovations that may change the energy investment situation. This is especially relevant because new options allow them not only to passively support the landlord's investment decisions, but also to invest themselves independently of the landlord through upcoming collective investment projects. This and smart technologies can make prosumption comparably more attractive than energy efficiency upgrades. Yet, potential split incentives problems and possibly resulting underinvestment in efficiency measures may lead to a valuation for such investments. Collective investment options can help to empower tenants and to circumvent underinvestment by the landlord. This could make the role of tenants in the energy transition ever greater.

To analyse the situation, we conduct a discrete choice experiment and gather data from 543 Swiss tenants, which allows us to investigate their energy investment preferences. A

mixed logit model and the estimated WTP are used to identify preferences, influential factors and potential implications.

Our results show that tenants value prosumption, but also energy efficiency upgrades. This means that there is no clear indication for a prosumption preference. Even though collective investment projects add to the opportunities for tenants and allow investing independently of the landlord, they prefer to contribute to investments carried out by the landlord. Again, this does not indicate that a general change is ongoing. Their WTP and valuation of collective investment can help to reduce the negative effects of split incentives by making investments worthwhile for both sides or circumventing under-investment on the rental building. In general, the WTP for most energy investments is sufficiently large or even exceeding realistic values. The lower willingness to pay for collective investments may be due to transaction costs and uncertainty. It can be seen that this positive effect and respective WTP is diminishing with the number of co-investors. Their general appreciation shows that such projects but also their contributions for investments on rental buildings may play a role for the energy transition in the future.

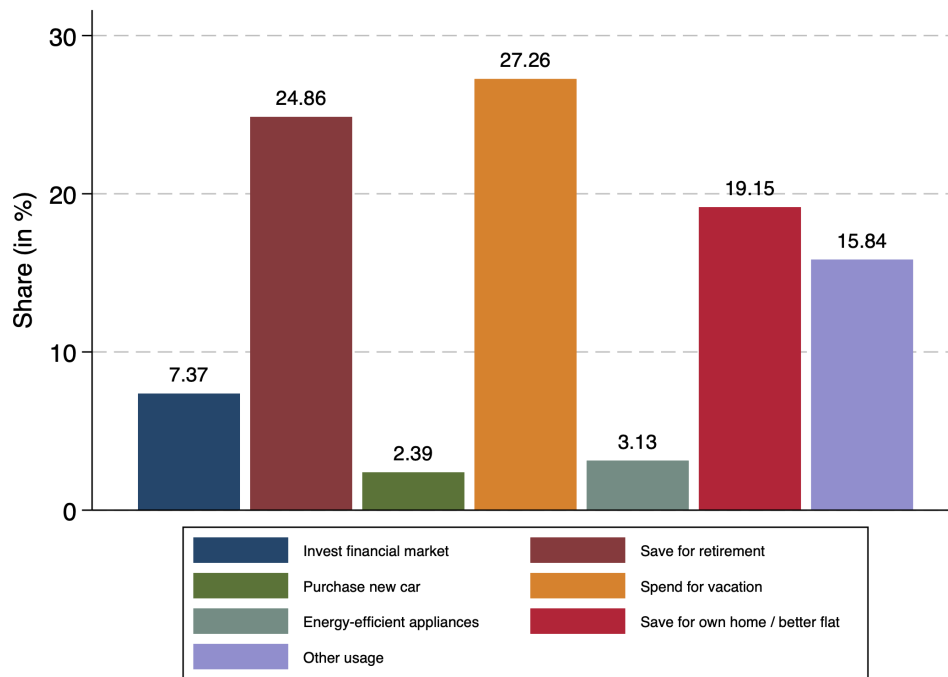
Flexibility also seems to be important to tenants. Storage is valued, while load management has no significant positive effect. Even though policies like CO₂ taxes, subsidies and netmetering potentially also affect tenants, the policy scenarios do not lead to a significant change in their investment choices. This may be due to the hypothetical nature of the treatments, a lack of knowledge, or the relative low importance of energy costs.

Large standard deviations of the estimation results show that there is a substantial heterogeneity between tenants, and their preferences vary a lot. This also has policy implications. It can be inferred that policies have to target specific groups or investments in order to be effective. But then, tenants can also play an important role in the shift towards more sustainable energy use.

3.7 Appendix

The general DCE design is fairly similar to the one for owners, as described in Appendix 1.7.1, because they were simultaneously launched. We also ask tenants how they would spend an unexpected tax return amounting to CHF 5,000 to get a first idea about their preferences. Responses to this question are presented in Figure 3.3. As it can be seen, spending it on vacation and saving it for retirement are the most popular options, followed by saving the money for a new home. Compared to the SFH owners, tenants are rather willing to spend the money, whereas SFH owners would rather invest it in their building, as it can be seen in Figure 1.2 in Appendix 1.7.1. This shows that the relationship to the building is different for owners and tenants, which can also help to understand the estimation and WTP results discussed in Section 3.5.

Figure 3.3: Usage of unexpected tax return



Yet, there are some differences in the experimental design. Due to their situation, tenants are not offered to invest themselves in their building. Instead, they can choose to contribute to investments made by the landlord. Also, the treatments are adapted. For them, the following policy scenarios were introduced between the second and third choice tasks. A single treatment was randomly displayed to each respondent. Each treatment group contains a similar share of all respondents. The control group received no treatment and jumped directly from the second to the third choice task. The treatments were formulated exactly as follows:

Treatment 1: Policy – CO₂-tax increase

Today, fossil fuels are taxed at CHF 96 per ton of CO₂. In order to reduce CO₂ emissions, the Swiss government is expected to increase this tax to CHF 200. If your heating runs on heating oil or gas, your energy costs will increase. If the owner invests in your building, your energy costs go down, but your rent will probably increase.

Treatment 2: Policy – Subsidies

The Swiss government is planning to substantially increase subsidies for building retrofits and producing renewable electricity (PV). New federal and cantonal contributions will cover about 30% of homeowners' investment costs. That means, if your owner makes some investments, you benefit from these subsidies.

Treatment 3: Electricity tariff system – Net metering

Netmetering and higher tariffs make investing in PV more attractive for owners. Imagine that these measures are increased by the state and the house owner wants to invest such system. This might lead to a higher rent for you, but you might also benefit from lower costs for energy.

Conclusion

In this PhD thesis, I study energy investments in residential buildings in Switzerland. Residents represent a large part of the energy demand and, as a result, are liable for a significant share of CO₂ emission. This makes them an important group for policymakers. Investments in improved energy efficiency and consumption of renewable energy can play an important role in the transition to a more sustainable energy use in the future. Policymakers in many countries are choosing subsidies and other policies to encourage residents to make such investments. However, investment rates are still low, and the determinants of residents' investment decisions are not yet fully understood.

This is especially important in a dynamic market, which has been changing in recent years. Innovative opportunities allow residents to invest as a collective. In addition to new financing options, smart technologies allow for optimisation of consumption. Such changes can lead to a general shift from traditional energy efficiency upgrades on the own building to prosumption. Prosumption can also take place independently of the residential building. Self-consumption communities and crowd investment can be game changers.

However, it is still not sufficiently investigated whether such a shift can be identified in investors' preferences and which are influential factors and whether innovative possibilities have the expected effect. In addition, there is uncertainty whether the current approaches of policymakers can be improved, for instance because policies may be too complex. Resulting transaction costs could deter potential investors, as especially subsidies often seem essential for energy investments.

In this thesis, I investigate energy investment decisions of residents in multiple choice experiments to get more information about their preferences and influential factors. The

focus is on trade-offs between energy efficiency and renewable energy investments. Several discrete choice experiments were conducted in 2020 and 2021 and different resident groups were studied. In a nutshell, the results show differences between residents. For owners, there seems to be a preference for renewable energy as opposed to energy efficiency. On the other hand, such a pattern cannot be detected for tenants, which may be resulting from split incentive problems. Collective investment opportunities seem to be only a limited driver for a potential trend towards renewable energy, as all resident groups value the modernisation of their own building more. Among a number of relevant measures, subsidies appears to be a reasonable instrument to increase investment rates, for example for PV. The need to simplify the current system in Switzerland by means of an OSS is not apparent.

In Chapter 1, I provide empirical evidence on SFH owners' preferences when it comes to energy investments. In this context, a large variety of energy investments are considered. New collective forms of investment and optimisation are also considered. By doing so, I provide new insight into preferences for energy investments. Results show that indeed there seems to be a preference for prosumption rather than for energy efficiency upgrades. However, innovative solutions do not necessarily drive this tendency. Rather, a preference for investing on the own building is visible. Amongst a range of policy scenarios, only a positive effect for net metering is detectable. Preferences, as well as the willingness to pay for energy investment options, are heterogenous amongst respondents.

On a similar note, SFH owners are also the observed group in Chapter 2. In contrast to Chapter 1, the aim was to find out more about the role of subsidies and the corresponding application process. Thus, I investigate the importance of subsidies and whether the current application process is considered too complex and if simplification in the form of an OSS are appreciated. The analysis shows the importance of subsidies, which are valued more than a similar cost reduction. The current application process is not considered too complicated by the majority of respondents. Consequently, it is not surprising that the OSS scenario

has no significant impact. Subsidies also prove to be particularly important for PV, as in contrast to insulation and renewable heat, almost all PV investments have been supported with subsidies.

In Chapter 3, I focussed on tenants' energy investment preferences. They differ from owners because of their situation, as they are often not free to decide on investments, a situation that could change by means of collective investment projects. These can help to circumvent potential underinvestment in rental buildings. The results do not show a clear preference for renewable energy, but also a valuation of efficiency upgrades. This may hint to the persistence of split incentive problems. Even though collective investment projects can empower them, they prefer to contribute to investments in their own buildings. Yet, their positive attitude towards collective investment suggests that these may be feasible options if the landlord does not invest.

In general, these studies show that preferences are heterogenous amongst residents. For SFH owner, preferences for renewable energy can be detected. Energy efficiency upgrades are not valued to the same extent. Although it is conceivable that prosumption could be promoted by collective investment projects and optimisation opportunities that can mitigate some disadvantages of investments in the own building, this can only be concluded to a limited extent in the studies. Even though collective investments are at least partly appreciated, the results show a higher appreciation of own investment in residential buildings. In contrast to owners, tenants do not show a clear preference for renewable energy production. Rather, they show a stronger interest in energy efficiency measures, which may indicate the energy efficiency gap in rental buildings discussed in the literature. Financial incentives, such as subsidies, seem to be a driver for energy investment. The fact that the other policy scenarios did not deliver meaningful results does not necessarily mean that they are not effective. Rather, it may also be due to the policy presentation in the experiments. The fact that most

subsidy recipients categorise the process as not too complex and that there are apparently already market solutions for it shows that there is probably no urgent need for simplifications.

When comparing the estimation results from Chapter 1 and 2, a similar preference for prosumption can be observed. A greater preference for PV compared to insulation is still present in Chapter 2, however it is not as pronounced as in Chapter 1. This greater appreciation of insulation retrofits in Chapter 2 may have various reasons that cannot be precisely identified. However, as the experiment for Chapter 1 was conducted in 2020 and the Chapter 2 experiment in 2021, Covid-19 may have played a greater role in the second experiment (see e.g. Todeschi et al., 2022). For example, it is possible that respondents show a greater appreciation for insulation due to a year with increased time at home due to Covid-19. During this time, energy consumption and corresponding expenditures increased (Swiss Federal Office of Energy, 2023b). In this context, another potential explanation for a greater valuation of insulation may be a more intense experience of a lack of comfort due to insufficient energy efficiency levels. After all, many residential buildings are still inadequately insulated, as discussed in the Introduction. Yet, it is not possible for me to identify the exact reasons for the greater valuation of energy efficiency upgrades. Studying the development and potential reasons for it may be an interesting topic for future research in the years to come.

However, my research is also not free of limitations. Possible limitations may result from the DCE design. Even though care was taken to provide enough information for informed choices, for example with the help of hover texts, some respondents may not have understood certain attributes correctly. Benefits, for example, were described as savings in conventional energy and CO₂ emission. Nevertheless, it is possible that the respondents did not read the hover text correctly, or did not have a general understanding of such savings and the resulting implications. The fact that Chapter 2 subsidies were presented as percentage and not as monetary savings could also have led to comprehension problems. It might be better to present savings in monetary terms, or in both ways. However, specifying attributes in

monetary values also leads to the challenge of having to calculate them for each specific choice situation and respondent. The exact values can depend on a number of factors, such as the living condition. In addition, when it comes to energy expenditures, financial literacy is not always given. This means that respondents may not be able to put the savings into perspective. A clear advantage in favour of one approach is not readily apparent. Follow-up questions to ask for understanding of the attributes and concepts presented could be informative. On the other hand, this would further increase the complexity of the DCE, which could lead to fatigue and lower response rates. In order to better answer the individual research questions in all chapters, more precise explanations of concepts, such as the OSS or collective investment, could be helpful. But here, too, the trade-off is that more information makes the experiment longer and more complex, which in turn can have negative effects. However, maximum emphasis should be placed on ensuring that all concepts and attributes are most likely understood correctly in order to get meaningful results.

In Chapter 2, further questions on the investments and subsidy applications already made could have provided better information on the type of experience gained. This would have made it easier to filter out those who had made the entire subsidy application on their own. Then it could have made sense to treat these respondents, others who received help and those who had no experience with energy investments and corresponding subsidies differently. This could have provided better insight into the extent to which the help already offered is accepted and whether an OSS is considered interesting at all. Perhaps an alternative to the OSS concept could have been relevant. For example, we could have offered the often already practised support of an expert to see whether the market has already provided a solution here that makes the OSS obsolete. In addition, a more precise breakdown of the sample would have allowed more meaningful insights to be gained into the complexity of the subsidy process. The opinion of those who did not have to do anything themselves to receive the subsidies is only of limited value, which can affect the significance of the results.

The fact that the political scenarios presented in Chapters 1 and 3 should be regarded as existing for the purpose of answering the following questions may also have influenced their effect. The way we presented them may mean that they were not seriously considered in the selection. This may also have been due to cognitive limits. However, this does not mean that a lack of meaningful results shows that these policies cannot influence investment decisions in real life. This is something that should perhaps be looked at again differently. This can be done in future research projects and provide interesting insights with high policy relevance.

The OSS concept presented in Chapter 2 was also limited. As the analysis has shown, complexity in relation to subsidies does not seem to be a major obstacle. This may also be due to the fact that subsidy concerns are often taken over by experts. However, this does not mean that the advantage of an OSS has been fully captured. Whether such an OSS would not prove itself in real life cannot be said on the basis of the results. Moreover, other specifications of such an OSS may be more effective. There are indications that residents see the investment process itself as complex. Especially in the light of many innovative solutions that are on the rise, an OSS that takes care of the entire investment decision could be well received. Such an OSS may well be a mean to increase energy investment rates. This can be investigated in future studies.

It will also be interesting to see how these innovative solutions penetrate the market and if different approaches, such as collective investment in a utility-backed project, are more or less valued. Such institutional projects can reduce uncertainty and risk for potential investors and, thus, people may be rather willing to contribute to such projects. This could also decrease some issues of decentralised presumption. This, too, would be an exciting topic for future research.

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