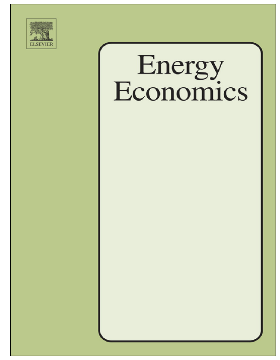

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PII: S0140-9883(18)30288-3
DOI: doi:10.1016/j.eneco.2018.08.001
Reference: ENEECO 4114

To appear in: *Energy Economics*

Received date: 11 September 2017
Revised date: 21 June 2018
Accepted date: 1 August 2018

Please cite this article as: Erdal Aydin, Piet Eichholtz, Erkan Yönder , The Economics of Residential Solar Water Heaters in Emerging Economies: The Case of Turkey. Eneeco (2018), doi:10.1016/j.eneco.2018.08.001

The Economics of Residential Solar Water Heaters in Emerging Economies: The Case of Turkey

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August 8, 2018

Abstract

In many emerging economies, household consumption of polluting solid fuels is still very high. We study the economics of one specific clean energy appliance that has been an important alternative for solid fuels in many developing countries: solar water heaters. Using a dataset including detailed information for around 23,000 Turkish households, 61 percent of which still use solid-fuel stoves, we first examine the determinants of the adoption of solar water heaters. We document that income, education, geographical location and the type of space heating system are important factors driving the adoption of solar water heaters. Analyzing the energy consumption of households, we find that total household energy consumption is reduced by around 13 percent when a solar water heater is present. Relating their presence to housing market outcomes, we document that the perceived value of owner-occupied homes increases by six percent, and find a three percent rent premium in the rental housing market.

JEL Codes: D12, Q51, R21

Keywords: Solar water heating, solid fuels, green energy, residential sector, house prices

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§We thank Siqi Zheng, whose invitation for the 2016 Green Cities in Asia workshop in Beijing was the catalyst for this paper. Furthermore, we thank Alpay Filiztekin, Pei Li and the attendees of the Green Cities in Asia workshop, as well as the Editor and the anonymous reviewers, for their helpful comments. Finally, we want to thank the Turkish Statistical Institute for graciously giving us access to the Turkish Household Budget Survey dataset.

1 Introduction

During the UN Climate Conference 2015 in Paris, countries agreed on international cooperation to lower greenhouse gas emissions, especially targeting developing economies. High-paced economic growth and increasing urbanization in these countries lead to worries about living environments, local air pollution and greenhouse gas emissions. In many of these countries, solid fuels are still the dominant primary energy source, which are relatively carbon intensive and produce local air pollution and smog.[1] For instance, in China, the share of coal in the primary energy mix is around 70 percent and coal is expected to remain the dominant energy source for the next decades.

One of the key objectives of the Sustainable Development Goals of the UN Climate Conference in 2015 is to lower the carbon intensity of energy. In order to reach these goals, the residential sector plays an important role. Around 30 percent of total energy is consumed in the house, and three billion people around the world still use wood, coal, charcoal or animal waste for cooking and heating. Reducing this dependency on solid fuels in the residential sector can have substantial environmental benefits.

In the residential sector, solar energy is considered to be among the most viable alternatives to fossil fuels. Farmer and Lafond (2016) predict that the share of solar panels in electricity generation will go up to 20 percent by 2027. However, the current adoption of solar panels is still far below that number. For instance, while Europe's average adoption of solar panels is the world's highest, these only produced 5 percent of Europe's total electricity consumption in 2014. Countries like India (0.34 percent), China (0.52 percent), and the United States (0.42 percent) follow far behind.[2] On the other hand, there is another form of residential solar energy technology that is growing rapidly and whose adoption is over 50 percent in some countries: solar water heaters. In this paper, we aim to explore the

[1]For example, international data from the US Energy Information Administration for the period 2010-2012 show that a given level of heat produced by coal created over 70 percent more CO2 emissions as compared to natural gas. These numbers mostly concern coal use for large electricity power plants, in which coal is at least burned in a relatively efficient way. Solid-fuel use in household settings is likely to be far less efficient and clean, thereby increasing air pollution problems besides the CO2 emissions.

[2]The statistics are obtained from US Energy Information Administration's international energy statistics. For further information, please visit http://www.eia.gov/cfapps/ipdbproject.

economics of these systems.[3]

Figure 1 presents data from the World Energy Council regarding adoption rates of residential solar water heaters globally and in selected regions. The graph shows that global solar water heater adoption per household has increased fourfold between 2005 and 2014, and that the global adoption rate is approaching six percent per household. China and Turkey are two countries in which the adoption of solar water heaters by households has outpaced the global average, and in these countries, the 2014 adoption rate per household stood at roughly 16 percent and 28 percent, respectively, showing quite rapid growth. However, the graph also shows that the developments in these two countries pale compared to the global leaders in this area: Cyprus and Israel, where 2014 adoption rates stood at roughly 73 percent and 58 percent, respectively. This dwarfs household adoption of photovoltaics, but it has not received much attention in the literature outside engineering. The fact that these appliances are gaining ground in emerging and developing economies is beneficial for global carbon emissions, since especially in these countries, the use of solid fuels by households still tends to be high. However, we also observe countries – often with similarly sunny climate conditions and comparable economic development – in which adoption rates of solar water heaters are very low. A deeper understanding of household-level adoption patterns and incentives is needed for a better understanding of these developments.

[Insert Figure 1 here]

In this study, we explore three main issues that affect the diffusion of residential solar water heating systems: we provide empirical evidence of the adoption patterns of solar water heating at the household level, of the effect of solar heating systems on household energy and water consumption, and of their effects on house values and rents.

So far, the literature on these topics has been limited to descriptive studies or to engineering studies based on assumptions regarding the adoption and use of solar water heaters by households.[4] The only exception is a recent paper by Qiu et al. (2017), which

[3]Mauthner and Weiss (2014) show that there is a significant potential reduction in carbon emissions by adopting solar water heaters globally. Denholm (2007) states that broad solar water heater adoption can lead to 50-70 million metric tons of carbon reduction.

[4]See, for example, Gillingham (2009), Sidiras and Koukios (2004) and Chang et al. (2008).

investigates the value premium associated with solar panels and solar water heaters for homes in Arizona. To our knowledge, ours is the first study to investigate the broader economic aspects of solar water heater adoption based on empirical analysis of household-level data. Our paper builds on the literature investigating clean energy adoption patterns. This literature is quite extensive for developed countries, and that also holds for the effects of sustainability and the use of clean energy on house prices (Bollinger and Gillingham, 2012; Balta-Ozkan et al., 2015; Brounen and Kok, 2011; Dastrup et al., 2012; Kahn and Kok, 2014). For emerging and developing nations, the available research is less extensive, and mainly concentrates on Singapore (Deng et al., 2012) and China (Zheng et al., 2012). None of these studies concern residential solar water heaters.

We use a large dataset of around 23,000 households in Turkey. This dataset is rich in information concerning the characteristics of households and the dwellings they live in, allowing us to control for the relevant covariates in a proper way. First, we investigate solar water heater adoption patterns, and document that households whose main energy source is electricity are most likely to install a solar heater. Those using wood and coal are also relatively likely to make that switch, but households who mainly use natural gas are very unlikely to do so. We also document that the likelihood of residential solar water heater adoption is significantly higher in rural areas. We attribute this finding to the presence of natural gas networks in Turkey, which are almost exclusively limited to cities. Finally, we show that as income and education levels increase, households are more likely to install solar water heating systems.

Examining the impact of solar water heating systems on actual household energy consumption, we document that the presence of a solar water heater in a dwelling reduces the annual energy bill by around ten percent for the average homeowner. Our estimation results also show that households whose main energy source is a solid fuel realize a higher reduction in energy expenditure. This creates a strong incentive to install a solar water heater, and it is likely to be a main cause of the recent growth in solar water heater adoption in Turkey. We find no effects of solar water heaters on water consumption.

Considering the effect of solar water heaters on perceived house values, we document consistent premiums of around six percent. When we estimate the effect of solar water heater presence on actual rents, we document a rent premium of 3.4 percent. In monetary terms, this rental premium is almost equivalent to the estimated household savings on energy costs, and provides an incentive for landlords to invest in solar water heating systems.

In the remainder of this paper, we first present and discuss the data on which our empirical analysis is based. We subsequently provide our estimation methods and results, and the paper ends with a short summary of our main findings and conclusions.

2 Data

To study the adoption of residential solar water heaters and their effects on household energy expenditure and home values, we employ a large household-level dataset provided by the Turkish Statistical Institute. Since 2003, the Turkish Statistical Institute has been conducting Household Expenditure Surveys covering samples of around 10,000 households each year. We use the surveys that have been carried out from 2010 to 2014, as the solar water heater ownership data have been available from 2010 onwards. This leads to a total initial sample of around 50,000 households. The survey's household sample is selected to be representative for Turkey as a whole. In the survey, households are asked to report their average monthly energy expenditures on each energy item classified as electricity, solid fuel, liquid fuel and natural gas. Besides, households are also asked to report information on their demographic characteristics and the characteristics of their residence.

In the formal adoption analysis, we focus on the owner-occupied segment of the housing market. In the rental housing market, landlords rather than occupants typically decide whether to install these systems, and we do not have data on landlord characteristics. We also exclude the 2014 sample from the regression analyses, as information on geographical location, which turns out to be an important factor for the adoption of different heating systems, is not provided in the 2014 survey data. Finally, we exclude the observations with missing variables and the outliers based on the distribution of the expected value and size of the home, and household income, energy expenditure, and size (always discarding observations below the 5^{th} and above the 95^{th} quantiles). The final sample of owner-occupied homes for the adoption analysis consists of 23,224 households.

Table 1 documents average dwelling characteristics for the full sample and the homes with and without a solar water heating system separately. In the survey, homeowners are asked to declare their expectation regarding the market value of their homes. The statistics indicate that the average expected market value in the Turkish housing market was around €33,000 between 2010 and 2013. The average value of homes with a solar water heating system is significantly lower as compared to other homes. This can be partly explained by the concentration of these homes in rural areas. According to the sample statistics, more than half of the homes with a solar water heater are located in a rural area, while this share is only 37 percent for the other homes in the sample.

[Insert Table 1 here]

When we look at dwelling characteristics, we observe that the majority of homes with a solar water heater are single-family homes, while the homes without it are mostly apartments. The statistics indicate that the dwelling stock in Turkey is rather new – at least compared to developed countries – and is mostly constructed after the 1980s. This is quite common for the residential sector in developing and emerging countries, where increasing incomes and rapid urbanization have created strong demand for better-quality housing in the last decades.

The recent vintage of the dwelling would suggest relatively high energy-efficiency levels, but most of the space heating technology used at these homes is in fact rather old. In Turkey, the most common heating system is still solid-fuel stove heating with a share of 61 percent (81 and 55 percent for homes with and without solar water heaters, respectively). This is of importance, as a main contributing factor to global climate change and local air pollution is the ongoing use of solid fuels in residential heating and cooking. Therefore, although newly built homes can lead to energy savings through stricter building standards, the high use of carbon intensive and air polluting heating technologies is still an issue in Turkey, mainly because of the lack of proper infrastructure and more efficient local energy sources.

However, in the last few years, we observe a switch from stove heating to natural gas heating. Figure 2-Panel A documents that the share of stove heating decreased from 66 percent to 56 percent from 2010 to 2014, while the share of natural gas heating increased from 23 percent to 36 percent (see Figure 2-B). But the pace of this change is expected to decrease over time, as the natural gas network diffusion in urban areas is approaching a saturation point, while it is far more costly to invest in natural gas infrastructure in rural areas, due to Turkey's mountainous terrain and low population density outside the urban centers.

[Insert Figure 2 here]

Given the high share of stove heating, an important decision for these households is how to obtain domestic hot water. Table 1 shows that approximately 17 percent of Turkish households do not yet have a hot water system. For the households that do have a hot water system in their homes, Figure 2-C documents that the most common water heating systems are electricity, natural gas and solar heaters. The type of water heating technology depends strongly on the type of space heating system used in the home. Parallel to the diffusion of natural gas networks, we observe that the share of natural gas use for water heating has increased in the last few years. For the households that use solid-fuel stoves for space heating purposes, the options for water heating systems are electricity, solar and LPG-based heating systems. Figure 2-C indicates that the share of solar water heaters has increased from 20 to 24 percent between 2010 and 2014. Figure 3 documents that especially households using air conditioners or solid fuel stoves for space heating prefer to use solar energy for hot water.

[Insert Figure 3 here]

Household-related factors may be important in the adoption decision as well as dwelling characteristics. Table 2 provides the average characteristics of the households in our sample, reported separately for the full sample and the homes with and without solar water heaters. The statistics indicate that households adopting a solar water heating system are mostly married couples with a larger household size, including more children and female members. These households have been living in their current homes for relatively long periods. Another important difference is that the households adopting solar water heaters have higher income levels and consist of more working members as compared to other households.

[Insert Table 2 here]

Another important factor in the diffusion of solar water heating is local climate. Since there is significant variation in climate conditions in different regions of Turkey, we can also expect variations in the geographical distribution of solar water heaters. Figure 4-A presents the regional patterns of residential solar water heater adoption in Turkey. The most striking observation is the very strong variation in adoption rates, with 70-80 percent of households having a solar water heater in some regions in the South, against less than 10 percent in some other regions. Partly, these patterns are in line with regional differences in solar radiation levels. Figure 4-B provides a solar radiation map of Turkey, which shows that irradiation is indeed highest in the Southern regions. However, a further comparison between Figures 4-A and 4-B also shows regions with high radiation intensity yet low average adoption rates. This can partly be explained by the regional variation in the availability of natural gas networks, for example around Izmir in the West. But the landlocked Southern regions bordering Syria and Iraq, where solar radiation is very high, have low adoption rates, even if they do not have natural gas networks.

[Insert Figure 4 here]

To conclude, we observe that local climate and the availability of natural gas networks seem to be two main drivers of the regional distribution of residential solar water heaters, but that other factors are likely to play a role as well. We will subsequently explore this in a more formal manner.

3 Methods and Results

3.1 Determinants of Solar Water Heater Adoption

We first examine the factors driving residential solar water heater adoption, and estimate the following empirical model:

$$P(SWH_i) = \beta_0 + \beta_1 D_i + \beta_2 H_i + \beta_3 T_i + \varepsilon_i \tag{1}$$

where SWH_i is a dummy variable indicating whether households use a solar water heating system. D_i is a vector of dwelling characteristics, such as dwelling type, size, number of rooms, construction period, space heating type, main energy source, a dummy variable indicating whether the home is located in a rural area and dummy variables indicating the geographical region in order to capture the region-specific factors affecting solar water heater adoption. H_i is a vector of household characteristics including income, household size, number of children, elderly, female and working members, marriage status of responsible person, education level of responsible person, average working hours of household members, length of stay in the current house, and the eligibility for employer support for gas, electricity and water expenses. T_i is a vector of dummy variables indicating each survey year and month. ε_i is the idiosyncratic error term.

Table 3 provides the estimation results for the determinants of solar water heater adoption, based on the empirical specification described in equation (1). We estimate both a linear probability model (column 1) and a logit model (column 2). The signs and orders of magnitude of the coefficients are the same in both models. Considering the marginal effects calculated based on logit estimation results, we document that homeowners using air conditioners as space heating system are 41 percent more likely to also have a solar water heater compared to those who use individual boilers on natural gas. Household who use solid fuel stoves as their space heating system are also significantly more likely to adopt a solar water heater (20 percent). The results imply that households connected to natural gas networks are the least likely to install a solar water heater. This seems reasonable, as water heating with natural gas is cheaper and easier compared to other water heating systems. Another finding that shows the importance of monetary concerns in the adoption of solar water heaters is that if households are receiving a subsidy for electricity, gas and water expenses, they are less likely to install a solar water heater.

[Insert Table 3 here]

Regarding the relevance of other dwelling characteristics, we find that households living in single-family dwellings are significantly more likely to adopt a solar water heater than those living in an apartment. House size is also positively associated with solar water heater installation, and the more recently a house is built, the more likely is the presence of a solar water heater. Solar water heaters are getting slightly more popular during the sample period: using survey year 2010 as the base year, we document that the adoption probability has increased three percent by 2013.

Assessing the household-related drivers of solar water heater adoption, we observe that higher education and higher incomes are both associated with a higher probability of solar water heater installation. And the longer the owners have lived in their current home, the higher is the probability of having a solar water heater (0.1 percent per year). Using the average working hours of household members as a proxy for the daily time spent at home, we document that more working hours lead to lower adoption probability. Finally, we observe that households who live in rural areas are five percent more likely to adopt a solar water heating system.

Having documented the household and dwelling characteristics linked to solar water heater adoption, we will now turn to the analysis of economic outcomes that may provide adoption incentives to households. Specifically, we will first analyze the effects on household energy use – and therefore the household energy bill – and will then look at the effects on perceived house values and housing rents.

3.2 Impact of Solar Water Heaters on Household Energy Use

The energy expenditure statistics for our sample indicate that households who own their home have an annual energy bill of around €750. Given that the average household income level is €12,000 (see Table 2), we can say that Turkish households, on average, spend around six percent of their disposable income on energy.[5] Figure 5 documents monthly household energy expenditure for different space heating types, distinguishing between households that do and don't have a solar water heating system. The graph shows that energy expenditure is highest for households using a collective central space heating system. This is likely to be related to the payment structure of central heating expenses. Since all households in the same apartment building share the total cost of the building's heating bill, they hardly have an incentive to economize on energy use. Another reason might be the inefficiency of central heating systems compared to individual boilers. We also see that households using a stove

[5] This number is in line with relative energy expenditure in the world. The share in Turkey lies between the share in China (4 percent) and the European Union (8 percent) (Van der Hoeven, 2012).

for space heating have the lowest energy expenditure. This can be partly explained by the fact that these households generally install the stove in their living rooms, and do not heat the other rooms of the house. Thus, thermal comfort levels for these homes are significantly lower than for homes using more advanced heating systems.

[Insert Figure 5 here]

Figure 5 also indicates that the total energy bill is lower for households using solar water heating systems for almost all space heating types. This is to be expected, as these households do not need to pay for the energy used for water heating. However, the size of the observed gap may also be related to the high correlation between the use of solar water heating systems and the climate conditions that affect the expenditure on space heating. To disentangle these effects, we will now turn to the regression analysis, which enables us to control for regional climate differences.

We examine the effect of solar water heaters on the energy expenditure of households, employing the following empirical model:

$$Log(E_i) = \delta_0 + \delta_1 SWH_i + \delta_2 D_i + \delta_3 H_i + \delta_4 T_i + \epsilon_i \tag{2}$$

where $Log(E_i)$ represents the logarithm of households' annual total energy expenditure. SWH_i is a dummy variable indicating whether a household uses solar energy for water heating. We also control for other dwelling characteristics (denoted by the vector of D_i), such as dwelling type, size, number of rooms, construction period, space heating type, main energy source, main energy source used in the kitchen, and ownership of various household appliances, a dummy variable indicating whether the home is located in a rural area and dummy variables indicating the geographical region. H_i is a vector of household characteristics such as income, household size, number of children, elderly, female and working members, marriage status of the responsible person, education level of the responsible person, average working hours of household members, and the eligibility for employer support for gas, electricity and water expenses. In order to control for the over-time variation in climate conditions and energy prices, we include a vector of dummy variables (T_i) indicating each survey year and month. ϵ_i is the idiosyncratic error term.

Estimating the model specified in equation (2), we document that the presence of a solar water heater significantly reduces households' energy bills. The reduction is 10 percent for the average homeowner, and for the owners who use a stove for space heating, it is 12 percent (the difference is not statistically significant). These results imply an annual saving of around €75-€90. Given that installation of a typical solar water heating system costs around €700 in Turkey, our results imply an investment payback period of eight to nine years.

[Insert Table 4 here]

However, the OLS analysis may suffer from a selection bias as the adoption of a solar water heating system is significantly related to a number of housing and household-related characteristics (see Table 3). To check the validity of our OLS results, we apply a propensity score weighting approach. This creates a synthetic sample in which the solar water heater adoption is independent of the included covariates. The synthetic sample is the result of assigning to each household a weight that is proportional to the inverse of his expected probability of adopting a solar water heating system. This enables us to compare the energy expenditure for the homes with and without solar water heating that have otherwise similar observable characteristics. By applying this method, we rely on the assumption that conditional on observable characteristics, the adoption of a solar water heater is independent of the unobservable factors that determine energy consumption. In columns 2 and 4 of Table 4, we report the results of the propensity score weighting estimation. The key take-away is that the estimated effects of solar water heater adoption on energy expenditure are not significantly different from the OLS results.

We should also note that there might still be some unobserved factors that are correlated with the adoption of solar water heaters and with energy use. For instance, households who install solar water heating systems may consume less energy from other sources. They might be more likely to conserve energy or have more energy-efficient appliances in general. If that is the case, our estimation strategy will not be able to isolate the effect of having a solar water heater on energy expenditure, and the estimated effect of the presence of such a system on energy use will be over-estimated as it will also capture the effect of energy conservation behavior. In order to test whether solar water heater adoption is associated with the demand for other energy services, we examine the link between solar water heater adoption and the energy used for other purposes except water heating: if households that adopt solar water heaters consume less energy in general, this link should be significantly negative. To do that, we analyze the demand for each specific energy type separately. While analyzing each energy source, we exclude the households that use that specific energy source for water heating. The results provided in Appendix, Table A1 indicate that there is no significant relationship between solar water heater adoption and energy used for other purposes, confirming the validity of the results we report in Table 4.

Considering space heating characteristics, we document that stove heating is associated with the highest energy expenditure as compared to individual boilers and air conditioning. The coefficients for the presence of electronic appliances are in line with expectations. A wide range of electric appliances like freezers, refrigerators, dishwashers, and computers significantly increase the energy bill. The size of the house also affects the energy expenditure, as larger homes require more energy to heat and lighten the whole area. The effects of household characteristics are also in line with those found in the literature (Brounen et al., 2012). For example, higher-income households spend more on energy, and larger households do so as well. Even after controlling for income, households led by an educated person spend more on energy than those without a formal education. Interestingly, more children under 15 imply a somewhat lower energy bill, while more elderly people leads to higher energy costs.

We also examine the effect of solar water heater adoption on total energy consumption (measured in KWh) and on the associated carbon emissions. We converted households' expenditure on each energy item to an overall energy consumption variable based on the yearly prices of each energy item and their energy potential. Columns (1) and (2) of Table 5 indicate that the presence of a solar water heater leads to a reduction in energy consumption of around 13-14 percent. We then convert the energy consumption numbers of each energy item to its potential carbon emissions, and document that the presence of a solar water heater has a larger effect for the homes with stove space-heating (in columns (3) and (4)). This suggests that the environmental effects of residential solar water heaters can be especially beneficial in countries where the residential use of solid fuels is high.

[Insert Table 5 here]

Finally, we test whether the presence of solar water heating system leads to an increase in the household's water consumption, indicating a rebound effect in the use of hot water.[6] Since the cost of water heating is zero for the households who are using these systems, we might expect a rebound effect that leads to an increase in the use of domestic hot water, and so to an increase in total water consumption. In order to test this question, we estimate the empirical model in equation (2), this time using the household's water consumption as the dependent variable. Given the results provided in Table 6, we conclude that there is not a significant effect of solar water heaters on households' water consumption. In other words, we find no evidence for a rebound effect in households' consumption of domestic hot water.

[Insert Table 6 here]

3.3 House Values and Solar Water Heaters

Besides comfort and a lower energy bill, another possible incentive for homeowners to invest in solar water heating systems might be a potential value premium in the housing market. There is a growing literature showing that a dwelling's energy efficiency level is capitalized in the housing market.[7] In this study, we investigate whether this also applies for solar water

[6]The literature on energy saving technologies mainly relies on engineering studies, which are mostly based on simulation estimates to quantify impacts on energy consumption (Branker et al., 2011). These engineering models are typically based on the assumption of a zero rebound effect, which may be violated. Gillingham et al. (2013) assess the importance of rebound effects in energy consumption. The authors mention direct, indirect, and macroeconomic rebound effects. The direct effect comes from the increased demand for energy due to a decrease in energy costs. The indirect effect occurs because of more spending on less energy-efficient products due to increased savings from energy efficiency. Aydin et al. (2017) examine the size of the direct rebound effect for residential energy. Using different techniques, the authors test the relationship between the predicted gas consumption and the actual gas consumption for a large sample of Dutch homes. They document a direct rebound effect of 41 percent for tenants and 27 percent for owners.

[7]Brounen and Kok (2011) document that a green-labeled Dutch home is sold at a significant premium of 3.6 percent after extensively controlling for property characteristics. Kahn and Kok (2014) concentrate on single-family homes in California, and find that a certified dwelling has a 2.1 percent higher value compared to its non-labeled peers. Deng et al. (2012) demonstrate that the premium for a green label in Singaporean homes is around 4 percent. In a follow-up paper, Deng and Wu (2014) find that the premium for green labels in the Singaporean residential market is even larger during the resale stage with a premium of 10 percent. In developing economies, Zheng et al. (2012) study the phenomenon for Beijing. Their findings show a premium for sustainable house characteristics at the stage of presale but a discount at the reselling stage. Dastrup et al. (2012) test the direct economic impact of solar panel adoption on house values in California. The authors find a solar panel premium of 3.5 percent in house prices.

heating installations. This would make sense, since they lead to lower energy expenses for the households buying a home. For tenants, it is possible that they are willing to pay a higher rent because of this lower energy bill, which would provide an incentive for landlords to invest in residential solar water heaters. This section therefore also analyzes the rental segment of the housing market, as the actual rent information is available in the data set.

In order to test whether there is a market value premium associated with the presence of solar water heaters, we propose the following hedonic model:

$$Log(P_i) = \gamma_0 + \gamma_1 SWH_i + \gamma_2 D_i + \gamma_3 T_i + \sigma_i \tag{3}$$

where $Log(P_i)$ is the logarithm of homeowners' assessment of the current market value of their homes, or the logarithm of the actual rent for the rental dwellings. SWH_i is a dummy variable representing whether there is a solar water heating system in the house. We also control for a large set of home characteristics likely to be relevant for house values and rents, denoted by the vector of D_i. These characteristics are house type, size, number of rooms, construction period, space heating type, main energy source, floor type, presence of an air conditioner, an elevator and parking place, a dummy variable indicating whether the home is located in a rural area and dummy variables indicating the geographical region and finally the ease to access shopping facilities, health services, public transport and schools. In order to control for the over-time change in house price expectations and rents, we include a vector of dummy variables (T_i) indicating each survey year and month. σ_i is the idiosyncratic error term.

We first estimate the hedonic model for owner-occupied homes. Since we do not have information on actual house prices, we use the households' own assessment of the value of their home. This makes sense, since we are mainly interested in value effects as incentives for households to adopt solar water heaters. The results reported in Table 7 indicate that there is a perceived market premium of six to seven percent for solar water heaters in the housing market. This finding contrasts with Qiu et al. (2017) who find a 15-17 percent premium for homes with solar panels, but no significant value premium for homes with solar water heaters. Given that the average perceived value of an owner-occupied home is €33,000 in our sample, this implies a premium of around €2,000, which is larger than the average cost of a solar water heating installation in Turkey.

[Insert Table 7 here]

We also measure the value effect of the space heating type used in a home relative to stove heating, and find that central heating systems and individual boilers are associated with higher perceived house values. We also find that larger homes with more rooms are worth more. Elevators, air conditioners and parking places are associated with value premiums, and that also holds for location quality, as proxied by ease of access to shopping, public transport and health service centers. We do not find large value differences for houses built in different periods, except that all periods seem to be preferred over homes built before 1945. The results also indicate that apartments and urban areas are preferred by Turkish home buyers.

Finally, we focus on the rental segment of the housing market, so as to understand the incentives for landlords to invest in solar water heating systems. In the survey, households who live in a rental dwelling report their expenditure on monthly rents. The results in columns (3) and (4) of Table 8 indicate that there is around three percent actual rent premium for rental homes with a solar water heating system.[8] Given that the annual average rent in our sample is €1,880, this implies an annual rent premium of €64 for landlords, which is very close to the annual energy bill savings (€75) we found for households. This implies that the energy expenditure savings resulting from the installation of solar water heaters are almost fully reflected into rents, which illustrates the efficiency of the rental market in capturing the energy efficiency investments.

[Insert Table 8 here]

It is important to note that there might exist some unobserved home characteristics that are correlated with the adoption of solar water heating systems and that could also lead to a

[8]The propensity score weighting estimation results provided in column 2 of Table 8 indicate a two percent premium, which is not statistically significant. When we limit the sample to the homes with stove heating system, the propensity score weighting estimation result becomes significant, indicating a three percent rental premium, which is similar to our OLS findings.

higher home value and/or rent. This kind of endogeneity issue has been discussed in a couple of studies examining the energy efficiency and the solar premium in the housing market. For instance, examining the impact of solar panel adoption on house values in California, Dastrup et al. (2012) applies a repeated sales approach to eliminate the influence of unobserved home-specific characteristics. The authors document a solar premium of 3.5 percent, verified by both OLS and repeated sales analyses. In another study, using instrumental variable and repeated sales approaches, Aydin et al. (2017) show that the energy efficiency premium in the housing market still exist after controlling for unobservables. These studies confirm that energy conservation investments in the housing sector are significantly capitalized by the market, even after controlling for unobservables. Besides, in our case, considering that solar water heating is a relatively cheap technology and is a necessity for most of the households as the alternatives (electricity, wood, LPG) are not very feasible, we do not expect its adoption to be highly correlated with other home improvements.

4 Conclusions

This paper investigates the economics of solar water heating systems in a household setting. The global adoption of these systems by private households is increasing, and in some countries, it is more than 20 percent, which dwarfs the household adoption of photovoltaics in any country. In key emerging countries like China and Turkey, the use of highly polluting solid-fuel stoves is still prevalent for heating water, but the adoption of solar water heaters is rapidly increasing in these countries.

We employ a high-quality Turkish household panel dataset of around 23,000 households between 2010 and 2013, which allows us to control for an extensive set of housing and household characteristics. The paper aims to answer three main questions, the first of which concerns the identification of factors determining solar water heater adoption. Here, we find that the existing main space heating system in a home is a key determinant. Households that mainly use stove heating and air conditioners are most likely to also utilize a solar water heater, while households using natural gas are very unlikely to do so. Households that are highly educated are also more likely to adopt a solar water heater system.

The second research question is whether households using a solar water heating system save on their overall energy bill. We document that homeowners using a solar water heater have around 10 percent lower annual energy bills (€75-€90) than those who do not, implying a payback period of approximately 8-9 years given the average price of a solar water heater in Turkey. The corresponding reduction in energy consumption and carbon emission numbers are 13 percent and 8 percent respectively. The associated reduction in carbon emissions is most prominent for households using solid fuel stoves for space heating purposes.

The last research question concerns the association between the presence of a solar water heater and the market value of the home. For the owner-occupied homes in the sample we observe self-assessed values, while we know the actual rents paid by the tenants of rental homes. For the former, our results show that households perceive solar water heaters as value-adding: we find an average value premium of around 6 percent, which is approximately €2000 in monetary terms. Using the rental housing data, our findings indicate a rent premium of 3.4 percent. This suggests that the rental market adjusts quite efficiently to the energy savings resulting from solar water heaters, as the monetary value of the average rental premium (€64) is very close to the average savings on energy bills, so providing an incentive for landlords to install solar water heaters.

To conclude, this paper takes a first step towards a better understanding of the economics of solar water heaters in households. Given the relatively high current adoption rates of these systems in some countries, but the very low adoption in other countries that are comparable in climate and economic development, they seem to have good potential as a clean energy appliance, especially as emerging economies make the transition from solid fuels to cleaner energy sources. More research is clearly needed in this area.

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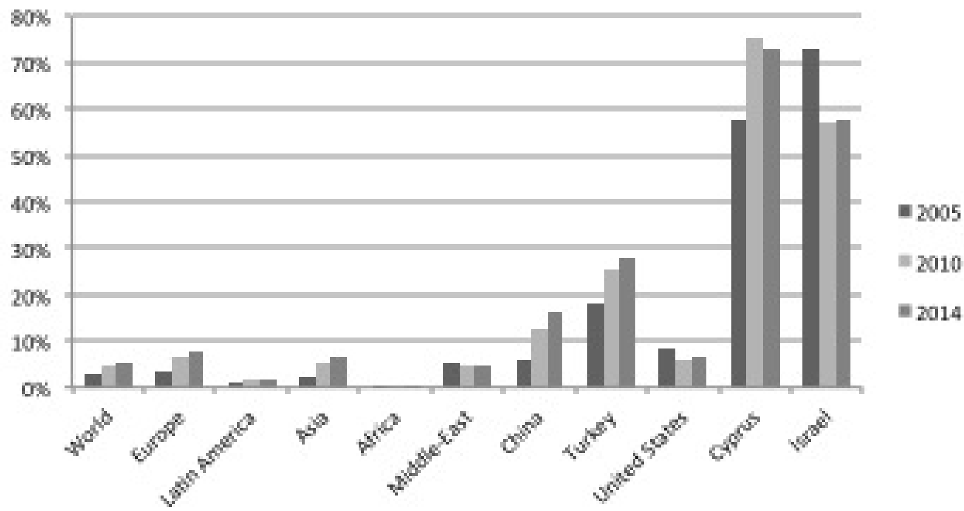
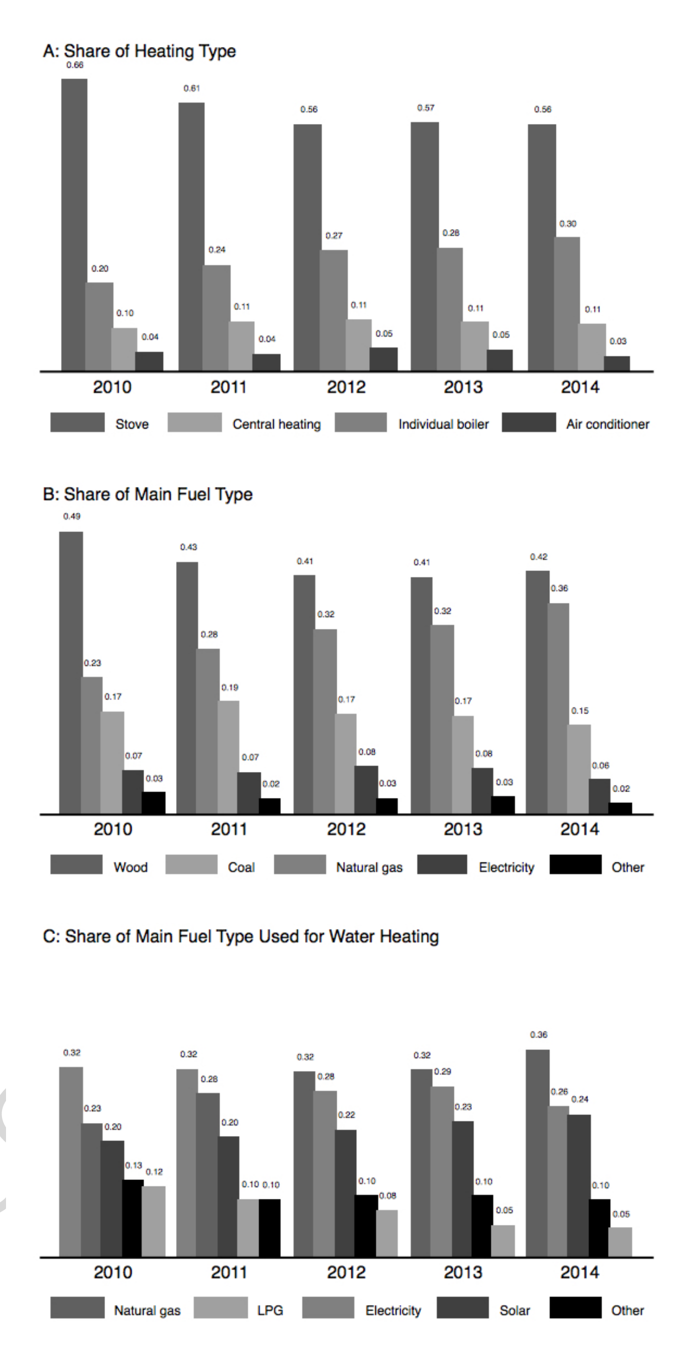
Figure 1: Solar Water Heater Adoption per Household in Different Regions of the World



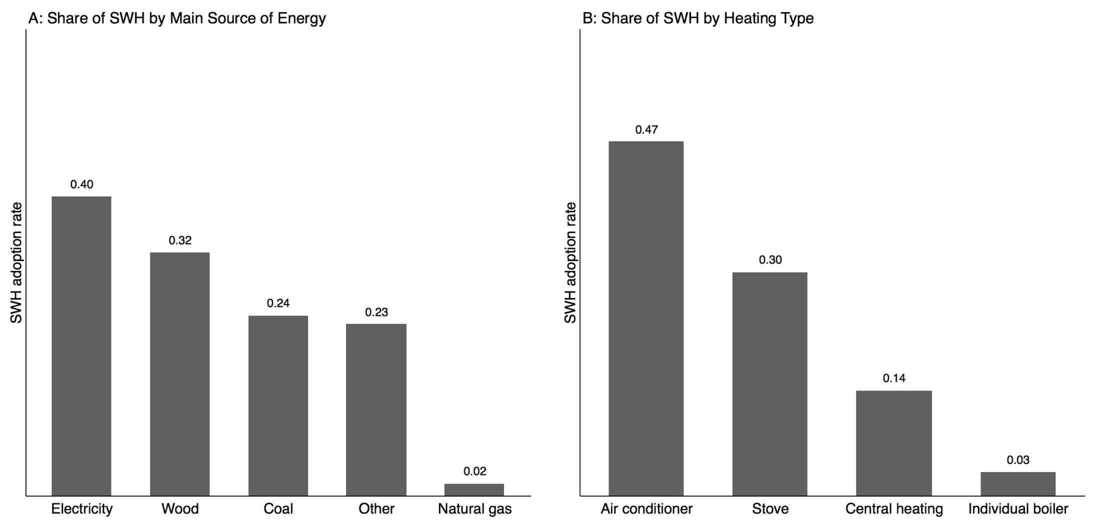
Notes: The statistics are calculated based on the data provided by Enerdata on the installed capacity (m^2) of solar water heaters per 1,000 inhabitants. We assume that the average collector area is 3 m^2 per installation. The data regarding average household size in different regions is collected from various sources. Source: Enerdata and own calculations. For more details, please visit https://www.wec-indicators.enerdata.eu.

Figure 2: Main Energy Use Characteristics of Turkish Households



Notes: Panel A presents the shares of dwellings with different heating systems. Panel B presents the shares of households that reported different fuel types as their main energy source. Panel C presents the shares of households that reported different fuel types as their main source of energy used for water heating purpose. All figures present the over-time changes in these statistics from 2010 to 2014. We exclude the year 2014 from the formal analysis, as regional variables are not available in the data set for that year.

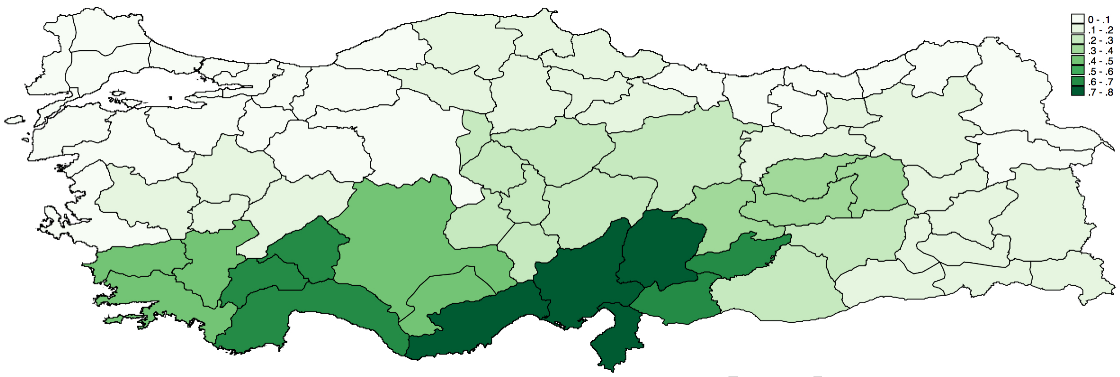
Figure 3: Solar Water Heating Adoption Rate by Different Space Heating Types



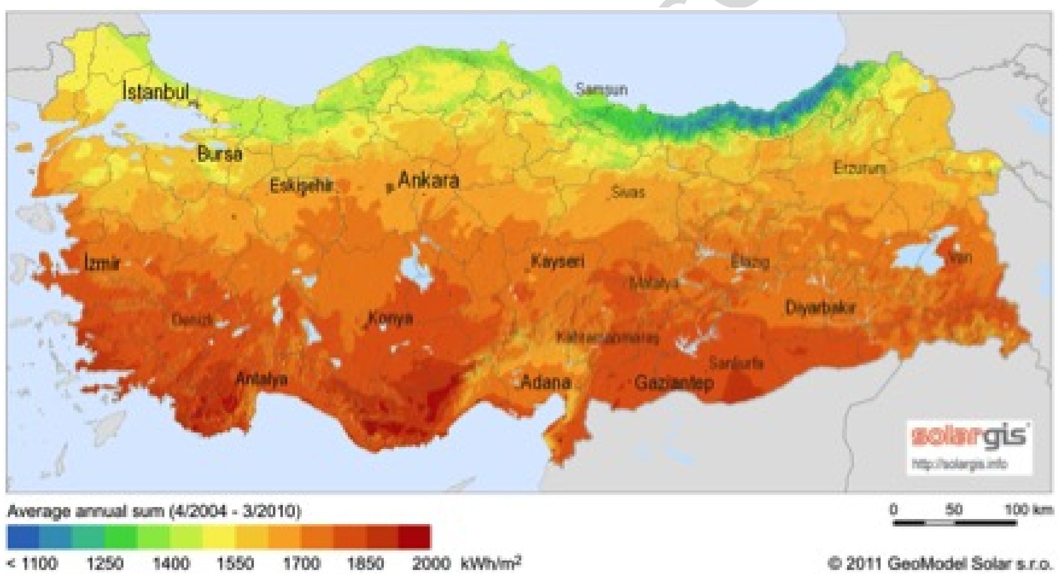
Notes: Panel A presents the adoption rate of solar water heating for households who reported different energy source types as their main energy source. Panel B presents the adoption rate of solar water heating for households who reported different space heating types. All figures present the average statistics for the time period between 2010 and 2014. We exclude the year 2014 from the formal analysis, as regional variables are not available in the data set for that year.

Figure 4: Geographical Information of Solar Water Heating Adoption and Solar Radiation

A: Residential Solar Water Heater Adoption by Region in Turkey

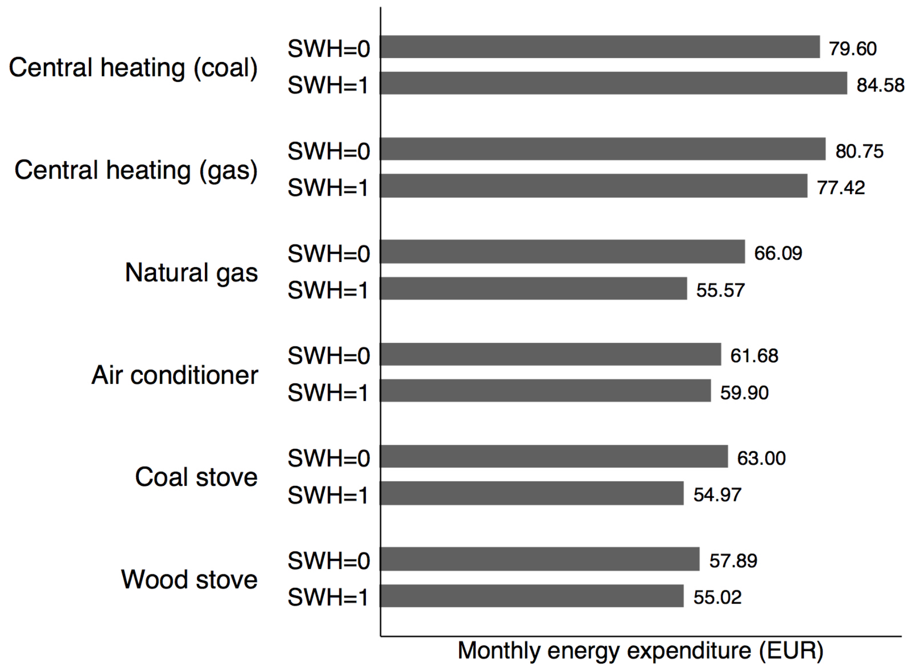


B: Global Horizontal Irradiation Map of Turkey



Notes: Figure 4-A presents the geographical distribution of the adoption rate of solar water heating in Turkey. The regions are described at NUTS-2 level. Each region covers 1 to 6 cities depending on the population of the cities. The adoption rate statistics are calculated for the time period between 2010 and 2013. Figure 4-B provides the global horizontal irradiation map of Turkey. This represents the total amount of shortwave solar radiation received by a surface horizontal to the ground. This value is important for the installation of solar water heating systems. Source: Solargis

Figure 5: Energy Expenditure by Space and Water Heating Types



Notes: Figure 5 presents the households' average monthly energy expenditure for different space heating types separately for homes with and without a solar water heating system. These numbers present the average statistics for the time period between 2010 and 2014. We exclude the year 2014 from the formal analysis, as regional variables are not available in the data set for that year.

Table 1: Descriptive Statistics for Dwelling Characteristics

	(1) All	(2) SWH==1	(3) SWH==0	(4) Diff.=(2)-(3)
Expected value of the dwelling (€1,000)	33.097	35.036	27.285	7.751***
	(26.89)	(28.66)	(19.56)	(19.18)
House Type==Detached	0.434	0.369	0.628	-0.259***
	(0.496)	(0.483)	(0.483)	(-35.43)
House Type==Semi-detached	0.086	0.085	0.089	-0.004
	(0.281)	(0.279)	(0.285)	(-0.899)
House Type==Apartment	0.480	0.546	0.283	0.263***
	(0.500)	(0.498)	(0.450)	(35.67)
House size	105.248	103.686	109.931	-6.245***
	(28.61)	(27.92)	(30.13)	(-14.47)
Number of rooms	3.552	3.546	3.569	-0.023*
	(0.764)	(0.763)	(0.767)	(-1.979)
Construction Period==1900-1945	0.027	0.029	0.020	0.009***
	(0.161)	(0.167)	(0.140)	(3.594)
Construction Period==1946-1960	0.051	0.053	0.047	0.006
	(0.220)	(0.223)	(0.212)	(1.698)
Construction Period==1961-1970	0.065	0.065	0.067	-0.002
	(0.247)	(0.246)	(0.250)	(-0.536)
Construction Period==1971-1980	0.144	0.143	0.147	-0.004
	(0.351)	(0.350)	(0.354)	(-0.784)
Construction Period==1981-1990	0.196	0.190	0.213	-0.023***
	(0.397)	(0.392)	(0.409)	(-3.751)
Construction Period==1991-2000	0.279	0.278	0.281	-0.003
	(0.449)	(0.448)	(0.450)	(-0.435)
Construction Period==2001-2005	0.114	0.111	0.121	-0.010*
	(0.318)	(0.314)	(0.327)	(-2.089)
Construction Period==2006-2014	0.124	0.131	0.104	0.027***
	(0.330)	(0.337)	(0.305)	(5.472)
Heating Type==Stove	0.614	0.548	0.812	-0.263***
	(0.487)	(0.498)	(0.391)	(-36.75)
Heating Type==Central heating	0.102	0.114	0.067	0.047***
	(0.302)	(0.317)	(0.250)	(10.19)
Heating Type==Individual boiler	0.241	0.310	0.035	0.274***
	(0.428)	(0.462)	(0.185)	(44.08)
Heating Type==Air conditioner	0.043	0.028	0.086	-0.058***
	(0.202)	(0.166)	(0.280)	(-18.94)
Main Energy Sorurce==Wood	0.457	0.394	0.646	-0.252***
	(0.498)	(0.489)	(0.478)	(-34.21)
Main Energy Sorurce==Coal	0.173	0.167	0.191	-0.025***
	(0.378)	(0.373)	(0.393)	(-4.302)
Main Energy Sorurce==Natural gas	0.273	0.358	0.018	0.340***
	(0.446)	(0.480)	(0.134)	(53.33)
Main Energy Sorurce==Electricity	0.063	0.045	0.116	-0.071***
	(0.243)	(0.208)	(0.320)	(-19.36)
Main Energy Sorurce==Other	0.034	0.036	0.029	0.007**
	(0.182)	(0.187)	(0.167)	(2.677)
Hot water system==1	0.827	0.774	0.986	-0.213***
	(0.378)	(0.418)	(0.116)	(-38.27)
Rural (population<20000)==1	0.368	0.322	0.504	-0.181***
	(0.482)	(0.467)	(0.500)	(-25.15)
Observations	23224	17414	5810	23224

Notes: Table 1 reports the descriptive statistics for dwelling characteristics for the full sample of owner-occupied homes (column 1), for the sample of owner-occupied homes without solar water heating system (column 2), for the sample of owner-occupied homes with a solar water heating system (column 3), and the differences between these homes (column 2 – column 3 = column 4). The statistics are calculated as the average of the years between 1010 and 2013. Standard deviation are reported in parentheses for columns (1), (2) and (3). The number in parenthesis in column (4) indicates the t statistics for the test of difference between columns (2) and (3). *** p<0.01, ** p<0.05, * p<0.1.

Table 2: Descriptive Statistics for Household Characteristics

	(1) All	(2) SWH==1	(3) SWH==0	(4) Diff.=(2)-(3)
The length of stay in the current house (Years)	16.984	16.604	18.123	-1.519***
	(14.03)	(14.16)	(13.58)	(-7.154)
Married==1	0.857	0.849	0.882	-0.033***
	(0.350)	(0.358)	(0.323)	(-6.219)
Number of household members	3.761	3.725	3.866	-0.141***
	(1.913)	(1.912)	(1.911)	(-4.859)
Household annual net income (€1,000)	12.078	12.342	11.286	1.056***
	(7.918)	(8.014)	(7.571)	(8.816)
Elderly (age>64)	0.209	0.214	0.197	0.017**
	(0.407)	(0.410)	(0.397)	(2.787)
No education==1	0.154	0.153	0.155	-0.002
	(0.361)	(0.360)	(0.362)	(-0.321)
Secondary education==1	0.591	0.578	0.632	-0.054***
	(0.492)	(0.494)	(0.482)	(-7.293)
High school==1	0.143	0.150	0.122	0.028***
	(0.350)	(0.357)	(0.327)	(5.365)
University==1	0.112	0.119	0.092	0.028***
	(0.316)	(0.324)	(0.288)	(5.773)
Working==1	0.623	0.609	0.665	-0.056***
	(0.485)	(0.488)	(0.472)	(-7.590)
Number of children (age<15)	0.870	0.856	0.912	-0.055**
	(1.243)	(1.246)	(1.233)	(-2.939)
Number of elderly (age>64)	0.383	0.385	0.375	0.010
	(0.656)	(0.657)	(0.656)	(1.010)
Number of working members	1.317	1.279	1.431	-0.153***
	(1.083)	(1.057)	(1.148)	(-9.331)
Number of female members	1.941	1.924	1.989	-0.065***
	(1.204)	(1.197)	(1.224)	(-3.543)
Observations	23224	17414	5810	23224

Notes: Table 2 reports the descriptive statistics for household characteristics for the full sample of owner-occupied homes (column 1), for the sample of owner-occupied homes without solar water heating system (column 2), for the sample of owner-occupied homes with a solar water heating system (column 3), and the differences between these homes (column 2 – column 3 = column 4). The statistics are calculated as the average of the years between 1010 and 2013. Standard deviation are reported in parentheses for columns (1), (2) and (3). The number in parenthesis in column (4) indicates the t statistics for the test of difference between columns (2) and (3). *** p<0.01, ** p<0.05, * p<0.1.

Table 3: Determinants of Solar Water Heating Adoption

VARIABLES	(1) Linear Probability Model	(2) Logit Model (Marginal Effects)
Heating Type==Stove	0.152***	0.197***
	(0.033)	(0.017)
Heating Type==Central heating	0.051**	0.178***
	(0.023)	(0.048)
Heating Type==Air conditioner	0.181***	0.411***
	(0.042)	(0.071)
Financial support for electricity/gas/water==1	-0.061**	-0.049***
	(0.026)	(0.016)
HouseType==Detached	0.103***	0.100***
	(0.014)	(0.011)
HouseType==Semi-detached	0.067**	0.085***
	(0.024)	(0.031)
Log of house size	0.130***	0.134***
	(0.023)	(0.014)
Construction Period==1946-1960	0.013	0.007
	(0.016)	(0.016)
Construction Period==1961-1970	0.059***	0.060***
	(0.017)	(0.018)
Construction Period==1971-1980	0.078***	0.082***
	(0.015)	(0.018)
Construction Period==1981-1990	0.100***	0.112***
	(0.022)	(0.027)
Construction Period==1991-2000	0.109***	0.121***
	(0.021)	(0.022)
Construction Period==2001-2005	0.113***	0.145***
	(0.019)	(0.029)
Construction Period==2006-2014	0.077***	0.088***
	(0.021)	(0.030)
Log of annual household net income	0.066***	0.064***
	(0.012)	(0.006)
Number of household members	-0.005	-0.002
	(0.004)	(0.003)
Married==1	0.021**	0.022***
	(0.008)	(0.008)
Secondary education==1	0.029***	0.021**
	(0.010)	(0.009)
High school==1	0.025**	0.024**
	(0.010)	(0.012)
University==1	-0.000	-0.001
	(0.008)	(0.012)
The length of stay in the current house (years)	0.001**	0.001**
	(0.000)	(0.000)
Number of children (age<15)	-0.006	-0.008**
	(0.004)	(0.004)
Number of elderly (age>64)	-0.004	-0.005
	(0.005)	(0.004)
Number of working members	0.008	0.005
	(0.007)	(0.005)
Number of female members	0.000	-0.001
	(0.004)	(0.004)
Average weekly working hours of members	-0.001***	-0.001***
	(0.000)	(0.000)
Year==2011	0.009	0.008
	(0.016)	(0.016)
Year==2012	0.025*	0.023
	(0.013)	(0.015)
Year==2013	0.032**	0.027*
	(0.014)	(0.015)
Rural (population<20000)==1	0.054**	0.046**
	(0.022)	(0.021)
Region fixed-effects	Yes	Yes
Year*month fixed-effects	Yes	Yes
Observations	23,224	23,224
R-squared	0.420	0.404

Notes: Dependent variable is the presence of solar water heating system. Base category for house type is apartment, for space heating system is individual boiler, for education is non-educated, for survey year is 2010, and for construction period is 1900-1945. Heteroskedasticity robust, clustered (region level) standard errors are reported in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Table 4: Energy Expenditure Analysis

	All Owner-occupied Homes		Owner-occupied Homes with Stove Heating	
	(1) (OLS)	(2) (PSW)	(3) (OLS)	(4) (PSW)
Solar water heating system==1	-0.097**	-0.114***	-0.117**	-0.119**
	(0.041)	(0.039)	(0.047)	(0.054)
House type = Semi-detached	-0.022	-0.072	-0.050	-0.126*
	(0.049)	(0.052)	(0.071)	(0.069)
House type = Appartment	-0.030	-0.023	0.037	0.039
	(0.038)	(0.034)	(0.044)	(0.051)
Log of house size	0.180***	0.167***	0.324***	0.300***
	(0.043)	(0.055)	(0.097)	(0.107)
Number of rooms	0.000	-0.010	-0.069*	-0.061*
	(0.017)	(0.020)	(0.037)	(0.037)
Type of heating system = Individual boiler	-0.206***	-0.214***		
	(0.053)	(0.035)		
Type of heating system = Air conditioner	-0.145***	-0.185***		
	(0.034)	(0.042)		
Presence of refrigerator	0.173**	0.140*	0.193	0.184
	(0.078)	(0.072)	(0.136)	(0.140)
Presence of freezer	0.063***	0.071***	0.073	0.097*
	(0.018)	(0.022)	(0.045)	(0.055)
Presence of dishwasher	0.083***	0.076***	0.052	0.032
	(0.017)	(0.023)	(0.042)	(0.037)
Presence of washing machine	0.188	0.156	0.234	0.113
	(0.122)	(0.111)	(0.137)	(0.126)
Presence of dryer	-0.022	-0.011	0.514***	
	(0.037)	(0.052)	(0.172)	
Presence of electricity generator==1	0.031	0.071	0.111	0.028
	(0.048)	(0.049)	(0.210)	(0.197)
Presence of computer	0.051***	0.024	0.041	0.029
	(0.014)	(0.018)	(0.034)	(0.041)
Presence of LCD televisions	0.011	0.014	0.033	0.045
	(0.015)	(0.016)	(0.056)	(0.053)
Rural (population¡20000)==1	0.058	0.059	-0.007	-0.051
	(0.057)	(0.042)	(0.049)	(0.043)
Log of annual household net income	0.230***	0.265***	0.318***	0.331***
	(0.021)	(0.026)	(0.045)	(0.046)
Number of household members	0.116***	0.136***	0.061	0.102**
	(0.023)	(0.027)	(0.052)	(0.047)
Number of household members^2	-0.007**	-0.009***	-0.004	-0.008**
	(0.003)	(0.002)	(0.004)	(0.004)
Married==1	-0.020	-0.029	-0.035	-0.091
	(0.028)	(0.033)	(0.061)	(0.066)
Secondary education==1	0.074**	0.068*	0.122**	0.145**
	(0.027)	(0.041)	(0.057)	(0.065)
High school==1	0.079**	0.090**	0.147	0.184**
	(0.034)	(0.045)	(0.093)	(0.085)
University==1	0.055	0.057	0.119	0.232**
	(0.041)	(0.048)	(0.089)	(0.109)
Length of stay in the current house (years)	0.002*	0.002	0.003*	0.004**
	(0.001)	(0.001)	(0.002)	(0.002)
Number of children (age<15)	-0.027**	-0.033**	-0.026	-0.037
	(0.010)	(0.013)	(0.024)	(0.026)
Number of elderly (age>64)	0.046***	0.048***	0.075*	0.058
	(0.013)	(0.016)	(0.038)	(0.038)
Number of working members	-0.000	0.025	0.007	0.044
	(0.023)	(0.022)	(0.036)	(0.043)
Number of female members	0.001	-0.005	0.014	0.010
	(0.008)	(0.013)	(0.015)	(0.028)
Average weekly working hours of members	-0.001	-0.003**	-0.002	-0.004
	(0.001)	(0.001)	(0.002)	(0.002)
Financial support for electricity, gas, water==1	-0.049	-0.065	-0.003	0.025
	(0.041)	(0.058)	(0.180)	(0.169)
Construction period	Yes	Yes	Yes	Yes
Year*month fixed-effects	Yes	Yes	Yes	Yes
Region fixed-effects	Yes	Yes	Yes	Yes
Constant	1.130***	0.794**	-0.552	-0.432
	(0.366)	(0.331)	(0.429)	(0.615)
Observations	7,613	7,503	1,560	1,619
R-squared	0.301	0.282	0.309	0.275

Notes: Dependent variable is the logarithm of monthly energy expenditure. Since wood might be freely available for some households, we exclude the households using wood as main heating energy source. We also exclude homes with central heating system as the energy expenditure is shared with other households. Base category for house type is detached house, for space-heating system is stove, for education is non-educated, for survey year is 2010. Heteroskedasticity robust, clustered (region level) standard errors are reported in parentheses. For the PSW analyses, we excluded the outliers in predicted propensity score weights (above 95th percentile). *** p<0.01, ** p<0.05, * p<0.1

Table 5: Effect of Solar Water Heater on Energy Consumption and Emissions

VARIABLES	(1) Log of energy consumption (KWh)	(2) Log of energy consumption (KWh) With stove heating	(3) Log of CO2 emission	(4) Log of CO2 emission With stove heating
Solar water heating system==1	-0.129**	-0.144*	-0.082*	-0.166*
	(0.060)	(0.080)	(0.045)	(0.085)
Dwelling characteristics	Yes	Yes	Yes	Yes
Household characteristics	Yes	Yes	Yes	Yes
Year*Month fixed-effects	Yes	Yes	Yes	Yes
Region fixed-effects	Yes	Yes	Yes	Yes
Observations	7,610	1,619	7,610	1,619
R-squared	0.261	0.185	0.400	0.191

Notes: In columns (1) and (2), the dependent variable is the logarithm of monthly energy consumption (KWh) and in columns (3) and (4) it is the logarithm of CO2 emissions that corresponds to the consumption of households use of different energy sources. The expenditure figures are converted to actual consumption based on prices of each energy source in different years. Since wood might be freely available for some households, we exclude the households that are using wood as main heating energy source. We also exclude the homes with central heating system as the energy expenditure is shared with other households and this creates different incentives. All control variables that are included in expenditure analysis are also included in these models. Heteroskedasticity robust, clustered (region) standard errors are in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 6: Effect of Solar Water Heating on Water Consumption

VARIABLES	(1) Owner-occupied Homes	(2) Owner-occupied Homes with Stove Heating
Solar water heating system==1	0.028	0.023
	(0.024)	(0.026)
Dwelling characteristics	Yes	Yes
Household characteristics	Yes	Yes
Year*Month fixed-effects	Yes	Yes
Region fixed-effects	Yes	Yes
Observations	15,351	7,552
R-squared	0.169	0.130

Notes: The dependent variable is the logarithm of monthly water consumption (m^3). The expenditure figures are converted to actual consumption based on unit price of water in different years. The reason for having different observation numbers as compared to the energy consumption analysis is that here we also include the homes with central heating and wood stove heating in the analysis. Heteroskedasticity robust, clustered (region) standard errors are in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 7: Effect of Solar Water Heater on Expected House Value

	All Owner-occupied Homes		Owner-occupied Homes with Stove Heating	
	(1) (OLS)	(2) (PSW)	(3) (OLS)	(4) (PSW)
Solar water heating system==1	0.059***	0.057***	0.070***	0.075***
	(0.019)	(0.011)	(0.022)	(0.013)
Type of heating system = Central heating	0.193***	0.171***		
	(0.040)	(0.016)		
Type of heating system = Individual boiler	0.131***	0.146***		
	(0.036)	(0.017)		
Type of heating system = Air conditioner	0.031	0.070***		
	(0.049)	(0.027)		
Air conditioner==1	0.112***	0.109***	0.096***	0.100***
	(0.021)	(0.013)	(0.025)	(0.019)
Rural (population<20000)==1	-0.210***	-0.214***	-0.225***	-0.227***
	(0.030)	(0.012)	(0.030)	(0.014)
House type = Semi-detached	0.032	0.027	0.033	0.026
	(0.022)	(0.019)	(0.026)	(0.021)
House type = Apartment	0.079***	0.067***	0.117***	0.106***
	(0.026)	(0.012)	(0.021)	(0.015)
Log of house size	0.538***	0.476***	0.473***	0.445***
	(0.036)	(0.023)	(0.041)	(0.029)
Number of rooms	0.034***	0.045***	0.029**	0.034***
	(0.011)	(0.008)	(0.012)	(0.010)
Construction period = 1946-1960	0.063	0.061*	0.053	0.073**
	(0.041)	(0.035)	(0.038)	(0.034)
Construction period = 1961-1970	0.142**	0.121***	0.108**	0.104***
	(0.051)	(0.034)	(0.046)	(0.034)
Construction period = 1971-1980	0.189***	0.174***	0.178***	0.177***
	(0.045)	(0.032)	(0.045)	(0.032)
Construction period = 1981-1990	0.173***	0.181***	0.171***	0.189***
	(0.045)	(0.031)	(0.045)	(0.032)
Construction period = 1991-2000	0.199***	0.209***	0.224***	0.237***
	(0.051)	(0.031)	(0.048)	(0.032)
Construction period = 2001-2005	0.227***	0.231***	0.246***	0.262***
	(0.053)	(0.032)	(0.051)	(0.035)
Construction period = 2006-2014	0.252***	0.257***	0.305***	0.322***
	(0.048)	(0.032)	(0.041)	(0.035)
Easiness to access the shopping stores	0.031**	0.018*	0.018	0.008
	(0.013)	(0.010)	(0.016)	(0.013)
Easiness to access public transport	0.057***	0.066***	0.075***	0.086***
	(0.012)	(0.010)	(0.012)	(0.012)
Easiness to access health service centers	0.069***	0.067***	0.068***	0.060***
	(0.015)	(0.011)	(0.018)	(0.014)
Easiness to access schools (1=v.dif., 4=v.easy)	-0.020	-0.009	-0.018	-0.010
	(0.016)	(0.010)	(0.020)	(0.012)
Elevator==1	0.139***	0.136***	0.074**	0.065***
	(0.023)	(0.010)	(0.033)	(0.023)
Parking place==1	0.100***	0.107***	0.106***	0.125***
	(0.025)	(0.016)	(0.028)	(0.025)
Main energy source type	Yes	Yes	Yes	Yes
Floor type	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes
Month fixed effects	Yes	Yes	Yes	Yes
Region fixed effects	Yes	Yes	Yes	Yes
Constant	8.074***	8.316***	8.371***	10.687***
	(0.163)	(0.098)	(0.169)	(0.192)
Observations	21,996	21,755	13,228	13,062
R-squared	0.645	0.620	0.493	0.462

Notes: In models (1) and (2), the dependent variable is the logarithm of expected home value and in models (3) and (4) it is the logarithm of actual monthly rent. In the regressions, base category for house type is detached house, for space-heating system is stove, for construction period it is "1900-1945". Easiness to access variables take value of 1 if access is very difficult, and take 4 if it is very easy. Heteroskedasticity robust, clustered (region level) standard errors are reported in parentheses. For the PSW analyses, we excluded the outliers in predicted propensity score weights (above 95th percentile) *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 8: Effect of Solar Water Heater on House Rent

	All Rental Homes		Rental Homes with Stove Heating	
	(1) (OLS)	(2) (PSW)	(3) (OLS)	(4) (PSW)
Solar water heating system==1	0.034**	0.020	0.032**	0.031*
	(0.014)	(0.014)	(0.015)	(0.017)
Type of heating system = Central heating	0.201***	0.181***		
	(0.028)	(0.015)		
Type of heating system = Individual boiler	0.110***	0.097***		
	(0.030)	(0.015)		
Type of heating system = Air conditioner	-0.030	-0.018		
	(0.020)	(0.022)		
Air conditioner==1	0.122***	0.119***	0.126***	0.136***
	(0.015)	(0.012)	(0.011)	(0.015)
Rural (population<20000)==1	-0.111***	-0.113***	-0.105***	-0.107***
	(0.029)	(0.014)	(0.031)	(0.018)
House type = Semi-detached	0.034	0.024	0.043*	0.042**
	(0.026)	(0.019)	(0.025)	(0.019)
House type = Apartment	0.140***	0.131***	0.147***	0.137***
	(0.020)	(0.012)	(0.019)	(0.014)
Log of house size	0.286***	0.294***	0.223***	0.232***
	(0.032)	(0.024)	(0.034)	(0.032)
Number of rooms	0.054***	0.049***	0.068***	0.054***
	(0.012)	(0.009)	(0.013)	(0.012)
Construction period = 1946-1960	0.003	0.004	0.014	0.018
	(0.039)	(0.049)	(0.043)	(0.059)
Construction period = 1961-1970	0.018	0.026	0.007	-0.011
	(0.035)	(0.042)	(0.040)	(0.051)
Construction period = 1971-1980	0.063*	0.086**	0.078**	0.065
	(0.032)	(0.040)	(0.028)	(0.049)
Construction period = 1981-1990	0.028	0.053	0.065**	0.060
	(0.037)	(0.039)	(0.028)	(0.049)
Construction period = 1991-2000	0.025	0.051	0.073**	0.071
	(0.040)	(0.040)	(0.030)	(0.050)
Construction period = 2001-2005	0.018	0.045	0.085***	0.101**
	(0.040)	(0.040)	(0.025)	(0.051)
Construction period = 2006-2014	0.008	0.057	0.075**	0.089*
	(0.047)	(0.041)	(0.036)	(0.053)
Easiness to access the shopping stores	0.040***	0.046***	0.029**	0.035***
	(0.011)	(0.010)	(0.012)	(0.013)
Easiness to access public transport	0.036***	0.035***	0.052***	0.052***
	(0.011)	(0.010)	(0.012)	(0.013)
Easiness to access health service centers	0.029**	0.026**	0.009	0.009
	(0.012)	(0.011)	(0.011)	(0.014)
Easiness to access schools	-0.018*	-0.016	-0.012	-0.006
	(0.011)	(0.011)	(0.012)	(0.014)
Elevator==1	0.096***	0.099***	0.076***	0.072***
	(0.016)	(0.010)	(0.022)	(0.020)
Parking place==1	0.056***	0.076***	0.005	0.038
	(0.015)	(0.019)	(0.026)	(0.032)
Main energy source type	Yes	Yes	Yes	Yes
Floor type	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes
Month fixed effects	Yes	Yes	Yes	Yes
Region fixed effects	Yes	Yes	Yes	Yes
Constant	4.026***	3.984***	4.229***	4.219***
	(0.111)	(0.102)	(0.119)	(0.132)
Observations	8,484	8,114	4,726	4,128
R-squared	0.661	0.668	0.590	0.590

Notes: In models (1) and (2), the dependent variable is the logarithm of expected home value and in models (3) and (4) it is the logarithm of actual monthly rent. In the regressions, base category for house type is detached house, for space-heating system is stove, for construction period it is "1900-1945". Easiness to access variables take value of 1 if access is very difficult, and take 4 if it is very easy. Heteroskedasticity robust, clustered (region level) standard errors are reported in parentheses. For the PSW analyses, we excluded the outliers in predicted propensity score weights (above 95th percentile) *** p<0.01, ** p<0.05, * p<0.1

Appendix

Table A1: Effect of SWH Adoption on the Demand for Other Energy Services

	(1) Electricity	(2) LPG	(3) Coal/Wood
Solar water heating system==1	-0.016	0.009	-0.045
	(0.032)	(0.047)	(0.096)
Dwelling characteristics	Yes	Yes	Yes
Household characteristics	Yes	Yes	Yes
Year/Month fixed-effects	Yes	Yes	Yes
Region fixed-effects	Yes	Yes	Yes
Constant	0.961***	1.600***	0.080
	(0.199)	(0.546)	(1.018)
Observations	6,281	1,150	1,731
R-squared	0.313	0.335	0.660

Notes: Since wood might be freely available for some households, which means that it is not captured by expenditure variable, we exclude the households that are using wood as main heating energy source. We also exclude the homes with central heating system as the energy expenditure is shared with other households and this creates different incentives for individual households. In Column (1), dependent variable is the logarithm of monthly electricity expenditure. For electricity analysis, we exclude the homes using electrical water heating systems. In Column (2), dependent variable is the logarithm of monthly LPG expenditure. For LPG analysis, we exclude the homes using LPG based water heating systems. In Column (3), dependent variable is the logarithm of monthly coal and wood expenditure. For coal/wood analysis, we exclude the homes that are using wood/coal based water heating systems. We don't provide the results for natural gas expenditure analysis as only 72 households in our sample use natural gas for other services while they declare that natural gas is not their main energy source for water heating. Standard errors are in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Highlights

- Solar water heaters are very common in some countries, yet hardly installed in others.
- Higher income and education lead to more solar water heaters adoption.
- Households with a solar water heater consume 13 percent less energy.
- Solar water heaters increase house rents and values.