Home Improvement, Wealth Inequality, and the Energy-Efficiency Paradox*

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Abstract

This article examines the rate at which different households go green and how this affects the distribution of both wealth and CO2 benefits. Using a unique dataset from the Netherlands, we find that lower-income households are less likely to make their homes more energy efficient. At the same time, higher-income households sort themselves into homes that are already more energy efficient to begin with. Over a 15-year horizon, the combined effect on energy savings accumulates to 17% of median net wealth, with ex ante sorting explaining 65% of this effect. Although a policy that encourages lower-income households to own energy-efficient homes reduces wealth inequality and poverty, it leaves 83% of the potential CO2 benefits unrealized because the brownest households are in the upper part of the income distribution. Thus, our results indicate that there is a policy trade-off between protecting low-income households against high energy expenditures on the one hand and effectively reducing CO2 emissions on the other.

Keywords — Energy efficiency, home improvement, wealth inequality, CO2 emissions.

JEL codes — D31, Q41, Q43, Q54, R31.

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1. Introduction

Given climate goals and greenhouse gas emissions from households, making the housing stock energy efficient is a major focus for policymakers.[1] Although there is growing literature on the effectiveness of government-led home improvement programs (Fowlie et al., 2018) and stricter building codes (e.g. Aroonruengsawat et al., 2012; Jacobsen and Kotchen, 2013), the capitalization of energy labels in house prices (e.g. Brounen and Kok, 2011; Fuerst et al., 2016; Kahn and Kok, 2014) and the returns on home improvements (e.g. Kattenberg et al., 2023; Metcalf and Hassett, 1999), much less is known about the extent to which households actually go green and what the distributional effects of such differences are. In particular, are those with sufficient income and wealth the ones who shelter themselves against high energy costs, and how do policies aimed at making the housing stock green affect the accumulation and distribution of wealth on the one hand and CO2 emissions on the other?

This article shows two important findings. First, we show that differences in income and wealth affect households' ability to invest in energy efficiency, leading to a difference in the rate at which they become green. We consider home improvements (*intensive margin*), as well as the degree to which households sort themselves into energy-efficient housing (*extensive margin*). We do so for all housing sectors: owner-occupied, rental, and social housing. Many policies these days focus on the intensive margin, and many research papers on either the intensive or extensive margin, and typically for only one of the housing sectors. However, poor households tend to live in social housing while rich households live in rental or owner-occupied housing, the incentives to become green are also different in those sectors, and the intensive margin captures only part of households' efforts to go green. So, to understand the extent to which households go green and get a proper estimate of the distribution of energy expenditures and CO2 emissions, it is important to examine both the intensive and the extensive margin across the entire income distribution (all housing sectors).

Second, we examine how differences in becoming green affect the accumulation and distribution of wealth, on the one hand, and the distribution of CO2 benefits, on the other. That is, if we adopt policies that protect low-income households from high energy costs, as many

[1] For example, in the US, 80% of greenhouse gas emissions are due to households and about 35% of that is directly related to housing, see https://www.pbs.org/newshour/science/5-charts-show-how-your-household-drives-up-global-greenhouse-gas-emissions.

policies do, how would this impact our progress toward achieving climate goals related to CO2 reduction? We show that reducing poverty and inequality does not necessarily correspond to reducing CO2 more effectively, since those who are poor are typically not the ones who emit the most CO2.

We use a unique dataset from the Netherlands that contains information on energy efficiency, all types of home improvements, energy expenditures, disposable household income and (net) wealth. In particular, the data are based on two waves (2006 and 2018) of the Dutch Housing Demand Survey (WoON), each containing about 65,000 households and covering owner-occupied, freehold, and social rented housing.

Based on the 2006 wave, we find that a standard deviation increase in disposable household income relative to mean income increases the probability of making home improvements by 1.7 percentage points - an economically significant effect given the average probability of 15.2%. This effect is largest in the owner-occupied market segment, as households in the other sectors do not own their own homes. The same increase in income also increases the probability of residing in an energy-efficient home (measured by the presence of double glass) by 2.1 percentage points.

For 2018, the effect on home improvement is 3.8 percentage points and the likelihood of living in a house with an A- or B-energy label increases by 3.1 percentage points. The average annual reduction in utility expenditures resulting from home improvements and living in an energy-efficient home amounts to 26% of the average total utility expenditures and the present value of the expected savings amounts to 17% of the median net wealth. Furthermore, sorting into energy-efficient housing explains 65% of these savings. We find that these savings *decrease* the net wealth Gini coefficient by 1.2%, and the poverty index (Atkinson index) by 2.9%.[2]

Crucially, we observe that energy savings are 36% of median net wealth for households in the first quartile of income and only 7% for households in the upper quartile. Instead, households in the upper quantile emit 1.5 times more CO2, and the remaining potential to reduce CO2 emissions is nearly half of the total across income quartiles. This leads to a policy trade-off between reducing poverty and inequality versus effectively reducing CO2 emissions. A policy that makes the home of below-median income households green would reduce the Atkinson poverty index by an additional 1.3 percentage points, but this would leave 63% of potential

[2]While high-income households nominally benefit the most from improving the energy-efficiency from their home and are more likely to own or make their homes more energy efficient, wealth at the bottom of the income distribution is so low that households in that part of the distribution stand to gain the most in relative terms.

CO_2 benefits unrealized. Focusing solely on the first quartile of households leaves 83% of the potential CO_2 benefits unrealized. Paradoxically, achieving our climate goals would require incentivizing those households that emit the most CO_2, which are high-income households, rather than focusing on those that are economically hurt the most from high energy costs.

Our paper contributes to a growing body of literature on energy efficiency investments. Fowlie et al. (2018) estimate the returns on investments in energy efficiency based on the Michigan weatherization program. They find that the returns on these investments are negative. Fowlie et al. (2018) show that this cannot be attributed to an increase in energy demand due to improved efficiency (i.e., a "rebound effect") and show that returns remain negative when broader societal benefits are taken into account. The experience in the Netherlands has been different, with some reporting a positive return on home insulation (Kattenberg et al., 2023). There have also been large subsidy programs in the Netherlands, which we show positively affects home improvement next to the effect of income. In addition, 21% of households indicated that if they were to make future home improvements, they would not need to fully recoup their investment through lower energy bills. So, climate preferences are also important.

Several other studies are also closely related to our article. Kattenberg et al. (2023) use Dutch data to estimate the reduction in gas bills resulting from investments in home insulation. They find that home insulation reduces gas consumption by approximately 20%, on average, for both owner-occupied and rental homes, and they find no evidence of a rebound effect. In contrast, Aydin et al. (2017) do find a rebound effect based on energy performance certificates (EPC) and using a Dutch household panel dataset. Hancevic and Sandoval (2022) also study the effect of housing investments on energy consumption, documenting that such investments reduce electricity use, but have no effect on natural gas use. Instead, using data from Gainesville, Florida, Jacobsen and Kotchen (2013) show that building codes are effective in reducing both electricity and natural gas consumption.

Our paper is also related to Roberdel et al. (2023), who examine low-income households in the social housing sector and use a quasi-experimental design to show that the effect of a Dutch policy aimed at improving the energy efficiency of houses leads to a significantly smaller reduction in energy use for those in the very left tail of the income distribution. Also, Ossokina et al. (2021) show that public housing tenants in the Netherlands require 30% return on the retrofit of their home and are more likely to do home improvements if they get the right information. Moreover, using Danish inheritance data Berg et al. (2024) find that wealth has a positive effect on installing green heating. The effect is larger for the lower part of the wealth distribution.[3]

The key contribution of this article compared to the aforementioned studies is that we examine the distribution of home improvement and energy efficiency and how this affects the distribution of wealth and CO2 emissions. Although there is a long line of research on wealth inequality (for an overview, see Benhabib et al., 2019) that focuses on the decomposition of inequality based on savings and income, less research has been done on the impact of the green energy transition on the accumulation and distribution of wealth.[4]

Fried (2024) assesses the distributional impacts of higher temperatures in the US, by quantifying a macro heterogeneous-agent model in which households are heterogeneous in terms of their income, as well as their ability to specialize in different types of heating equipment. She finds that the welfare effects of climate change vary considerably by income and region. Kuhn and Schlattmann (2024) built a life-cycle model with heterogeneous adoption rates of clean goods by income to quantify carbon reductions as a result of different (carbon) taxes and subsidies. Such policies will accelerate the reduction of carbon emissions but will mainly incentivize high-income households as they emit the most carbon and thus lead to redistributional effects (net transfers from low to high income). Instead, our paper empirically shows that high-income households acquire more energy-efficient housing and that this leads to redistributional effects (poverty, inequality) through energy savings. We show that this is *because* of the distribution of energy savings throughout the wealth distribution. So, although the argument of who emits the most carbon is similar to that in our paper, the focus of our paper and the trade-off we discuss are fundamentally different.

The remainder of this paper is structured as follows. In Section 2, we show a household-level conceptual framework that highlights key choices and trade-offs of energy efficiency. In Section 4, we introduce the data and Section 5 describes the methodology. The results are presented in Section 6 and 7. Section 8 concludes.

[3] Our paper further relates to Potepan (1989), who argues that homeowners do more home improvements instead of moving when interest rates are higher or when there are less technological constraints. They find evidence of these effects based on the panel study of income dynamics for 1979. However, the paper of Potepan (1989), although also examining the extensive and intensive margin, does not focus on energy efficiency.

[4] Our paper is also related to the theoretical work of Van der Straten (2024), who shows that low-income households have a disincentive to adapt to climate change, as this only benefits them in the future, and highlights the implications this has on the distribution of wealth.

2. Conceptual framework

The purpose of this section is to highlight the energy-efficiency choice (intensive and extensive margin) and to discuss how this affects CO2 emissions and energy savings. Households live for two periods. In the first period, households spend their income to purchase housing capital (H_t with a relative price p) and invest in energy efficiency, and save any remaining income. In the second period, households purchase energy (e_{t+1} per unit of housing capital, with a relative price q) and spend any remaining resources, including the resale value of their housing capital, on the purchase of a consumption good (c_{t+1}, with a price normalized to 1). Household preferences over housing, energy, and the consumption good are characterized by the following utility function:

$$U\left(c_{i,t+1}, e_{i,t+1}, H_{i,t}\right) = c_{i,t+1}^{\alpha} H_{i,t}^{\beta} e_{i,t+1}^{1-\alpha-\beta} \tag{1}$$

where $\alpha > \beta, \alpha \in (0, 0.5]$ and $\beta > \frac{1-\alpha}{2}, \beta \in (0, 0.5)$.[5]

Household i invests in energy efficiency, $x_{i,t}$, at time t when purchasing their housing capital, with $x_{i,t} \in [0, 1)$ (cf. Van der Straten (2024)). The investment in energy efficiency can be viewed as (i) the premium paid to purchase of a more energy efficient home (extensive margin), or as (ii) the investment required for making home improvements (intensive margin). To capture both, denote $\mathbf{x}_{i,t} = [x_{i,t}^1, x_{i,t}^2]$, where $x_{i,t}^1$ denotes the increase in energy efficiency of purchasing a more energy-efficient home and $x_{i,t}^2$ denotes the increase in energy efficiency of home improvements. By investing in energy efficiency, the amount of energy, $e_{i,t+1}$, consumed per unit of housing capital, $H_{i,t}$, decreases by a fraction, $\mathbf{x}_{i,t}$. This reduces energy costs:

$$C_{i,t+1}^{e}(e_{i,t+1}, H_{i,t}, \mathbf{x}_{i,t}) = (1 - \underbrace{\mathbf{x}_{i,t}) \cdot e_{i,t+1} \cdot H_{i,t} \cdot q}_{S_{i,t+1}} \tag{2}$$

where $S_{i,t+1}$ denote the savings in energy costs of household i in period $t+1$. However, investing in energy efficiency is costly. The costs of reaching a higher level of energy efficiency rise at an accelerating rate as energy efficiency increases. Furthermore, the costs of acquiring energy efficiency increase in the units of housing owned, as the costs of, for example, insulation rise in

[5]The consumption of housing and energy are thus complementary, indicating that households do not obtain any utility from consuming housing without consuming energy.

the size (in m^2) of the home:

$$C^x_{i,t}(H_{i,t}, \mathbf{x}_{i,t}) = \frac{\theta}{2} H_{i,t} \cdot (\mathbf{x}_{i,t})^2 \tag{3}$$

where θ reflects the ease of improving the energy efficiency of ones' home.[6]

Households have heterogeneous (and exogenous) income and wealth profiles. The income of household i in period t is denoted by $y_{i,t}$ and household i is endowed with an initial wealth of $A_{i,0} = v(y_{i,t})$ where $v' > 0, v'' > 0$. Households only earn income in the first period, but can save part of their income (and wealth) for future consumption. On these savings, households earn a rate of return of r, which is exogenously given. Define $A^{net}_{i,t}$ as the net savings of a household i in period t:

$$A^{net}_{i,t}(H_{i,t}, \mathbf{x}_{i,t}) = (y_i + A_{i,0}) - \left(p + \frac{\theta}{2}\mathbf{x}^2_{i,t}\right) \cdot H_{i,t} \tag{4}$$

The solution to the household utility optimization problem can be found in Appendix A. The model illustrates the two key points that are explored in this paper in Panel A and, respectively, Panel B, depicted in Figure 1. Panel A illustrates that households with higher incomes invest more in improving the energy efficiency of their homes, both at the intensive and the extensive margin. However, this does not lead to a reduction in energy consumption, as the demand for energy increases with income. We define the $CO2$ emission index as the $CO2$ associated with the consumption of e_{t+1} units of energy, $f(e_{t+1})$ with $f' > 0, f'' > 0$.[7] Accordingly, Panel B shows that the $CO2$ emission index increases with income. Panel B also shows that energy savings relative to wealth decrease as income rises. This is due to wealth increasing faster than the savings in energy costs. Although higher-income households demand more energy efficiency, the energy savings associated with energy efficiency improvements are therefore of greater significance for low-income households relative to their wealth. Instead, the potential reduction in CO2 emissions is greater for high-income households, as they emit the most CO2. Differences in acquiring an energy-efficient home based on income (Panel A) and the effect

[6]We assume that the ease of sorting in a more energy efficient home, and the ease of undertaking energy efficiency enhancing home improvements are equal, i.e. $\theta^1 = \theta^2 = \theta$. For a discussion of the general trade-off between moving or doing home improvement, see Potepan (1989).

[7]For simplicity, we assume that the consumption of housing and the consumption good do not generate emissions on their own.

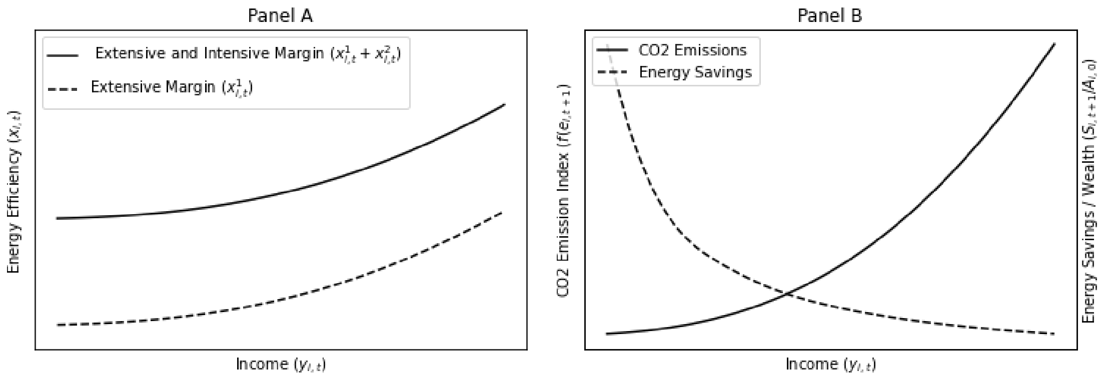

Figure 1 – Intensive, extensive margin and trade-off emissions and savings

Note: Panel A shows the optimal choice of energy-efficiency (x_t), both on the intensive and extensive margin. Panel B shows the optimal demand for energy (e_{t+1}) scaled to represent emissions, and the energy costs savings relative to initial wealth (S_{t+1}/A_0).

on energy savings (wealth accumulation) versus CO2 benefits (Panel B) are explored in the remainder of this paper.

3. Institutional context

Households in the Netherlands accounted for 21 percent of greenhouse gas emissions in 2018 (CBS (2018)). While this is much lower than the contribution of households on the global level, reducing greenhouse gas emissions of households, and particularly those directly related to the consumption of energy in their house, has been one of the focal points of Dutch climate policy. The Netherlands is a member state of the European Union. The Dutch institutional context regarding energy efficiency in housing is thus primarily shaped by European directives, which are accompanied by national policies and local initiatives.

In 2009, the European Union issued the Renewable Energy Directive. This directive stipulated that the renewable energy part of energy consumption had to increase to 20% by 2020. The European Union leaves it up to its member states how to achieve this goal (European Commission, 2013). The Netherlands aimed at increasing the share of renewable energy to 14% (European Commission, 2013) and this goal was formalized in a widely supported agreement (Energy Agreement) that was reached in 2013.

In 2010, the Energy Performance of Buildings Directive (EPBD), which was adopted by the European Union in 2002, was recasted. The EPBD recast mandated energy performance certificates to be included in advertisements when buildings are sold or rented. It further mandated measures to improve the energy performance of buildings and set minimum energy performance standards for new buildings, or buildings subject to major renovation, as well as for the replacement or retrofit of building elements. The EPBD recast also mandated all new buildings to be nearly zero energy buildings by 31 December 2020. The Netherlands has translated these requirements into national law and, in anticipation of the EPBD recast, the Netherlands introduced a national energy labeling system for homes, where labels range from A (most efficient) to G (least efficient).

In 2013, the Dutch government reached an energy agreement with many central stakeholders in the Dutch society (i.e. labor unions, environmental organizations, financial institutions) to reduce CO2 emissions by 2020–2023. In 2019, the Netherlands extended this ambition as the National Climate Agreement was reached to reduce CO2 emissions by 49% in 2030 compared to 1990, and by 95 percent in 2050. Housing plays a significant role in achieving this goal. The agreement outlines specific measures to enhance energy efficiency and proposed large-scale energy renovations of existing buildings, aiming to retrofit 1.5 million homes by 2030. This includes improving insulation, upgrading heating systems, and integrating renewable energy sources. To achieve this goal, a large-scale subsidy program was operationalized in operation.

The Dutch government offers a range of financial incentives and subsidies to encourage investments in energy efficiency. The Investeringssubsidie Duurzame Energie (ISDE), introduced in 2016, is a subsidy program providing financial support to homeowners for installing renewable heating systems, such as heat pumps, solar water heaters, and biomass boilers.[8] For landlords there is the Stimuleringsregeling aardgasvrije huurwoningen (SAH), which incentivizes making rental properties natural gas-free by connecting them to a heating network. Solar panel installation has been heavily subsidized in the Netherlands. Since 2004, homeowners can supply self-generated solar energy back to the grid through the netting arrangement, allowing them to offset their annual electricity consumption with generated electricity, free of taxes. Additionally, households that installed solar panels after mid-2013 were eligible for a retroactive VAT refund. As of 2023, the VAT on solar panels has been reduced to zero.

Homeowners are also encouraged to obtain an energy savings loan, a low-interest loan program

[8]The subsidy programme was prior know as the Subsidie Energiebesparing Eigen Huis (SEEH).

designed to finance energy efficiency improvements. These loans have been available since 2020 through the National Heat Fund, which is publicly and privately financed and offers terms of up to 20 years. Initially, the interest rate on a 20-year loan was 2.2 percent, with lower rates for shorter terms. Since mid-2021, the program has expanded to provide financing to homeowners who lack borrowing space or do not qualify due to age.

4. Data and descriptive statistics

Our main data source is the Dutch Housing Demand Survey (WoON), which has been conducted on behalf of the Dutch government for more than 40 years. The survey supports the policy making of the Dutch government. We use the Housing Market module of the WoON-survey (other modules are, e.g., recording residential environment, home improvement and home maintenance, energy and security, livability, consumer behavior and affordability, housing and care, structural home inspection). The Housing Market module takes place once every three years and surveys roughly 40,000 individuals. To improve the provision of reliable information at the local level, municipalities are given the opportunity to have additional interviews conducted in their work area. We use both the 2006 and 2018 waves of the survey. The 2006 dataset is particularly useful to analyze, as it contains detailed information about location (zip code) and contains both household income and energy expenditures from administrative sources. It was the last wave that had such detailed location information in the public use file. It also contains proxies for home improvement and energy efficiency of the home. Instead, the 2018 wave contains more information on the exact type of home improvement done and the exact energy efficiency (energy labels were introduced in 2009) of the house. It also includes administrative information on (net) wealth. By analyzing both datasets, we can see whether our results are consistent over time.[9]

4.1. WoON-Survey (2006)

For our main analysis, we use the WoON 2006 survey, in which there are 64,005 respondents. Households were surveyed between August 2005 - March 2006. We focus on the respondents

[9] A later wave, which includes proxies for home improvements and energy efficiency, was collected during the COVID-19 pandemic that began in the Netherlands in February 2020. Due to a major lockdown, the sampling period was split into two parts and the response rate was lower. Moreover, households faced other challenges during this period, making home improvements or purchasing energy-efficient housing less of a priority. As a result, 2021 is not the most representative year for examining this topic. Therefore, we will not use the 2021 sample in our main analysis, but we will include it in robustness checks.

for whom all variables of interest are available, which gives us a sample of 54,173 respondents. Table 1 provides summary statistics. The cross-sectional dataset consists of households living in owner-occupied housing (55.4%) as well as rental housing, where we distinguish between the free rental sector (6.0%) and social housing (38.6%).

Our main variables of interest are whether a household has done energy-efficiency home improvements and the energy efficiency of their home. The *home improvements*-variable is a binary variable that indicates whether a household has done insulation or energy saving facilities (also by order of the landlord) such as double glazing, roller shutters, floor insulation, the installation of an HR boiler or water saving measures in the past 12 months. The *energy efficiency*-variable is a binary variable that indicates whether the house has double glazing (a more general measure of energy efficiency, energy labels, is explored using the extended WoON 2018 dataset).

Most of the households in our sample live in energy-efficient homes (90.3%) and there is little variation between the percentage of households with double glazing in owner-occupied housing (92.6%) and social housing (90.2%). On the contrary, relatively fewer households in the free rental sector have energy-efficient homes (74.3%). Only 15.2% of households in our sample have made improvements in energy efficiency at home 12 months prior to the survey. There is some heterogeneity based on whether households are homeowners or renters. Within our sample, 18.8% of all homeowners made home improvements, while only 10.4% of renters in the free rental sector did and 10.7% of renters in social housing.

Additionally, to assess whether energy efficiency-enhancing home improvements reduce energy expenditures, we also utilize information from the utility operator (Statistics Netherlands) on households' annual gas and electricity expenditures, as well as households' annual utility expenditures, which are measured as their annual energy expenditures plus water bills. Households spend about 8% of their income on utilities. Most of energy expenditures, about 4.4%, are spend on natural gas. The distribution of energy expenditures is reported in Figure 2.

The main independent variable of interest is households' disposable income, which comes from tax registry data (merged by Statistics Netherlands). Household disposable income is measured as gross income including social benefits and net of paid income transfers, insurance premiums, and taxes on income and capital. We exclude households whose income is negative

Table 1 – Home improvement, energy efficiency, and energy expenditures (2006).

Variable	Mean	SD	Min	Max
Energy efficiency & home improvements				
Energy efficiency (double glass, living room)	0.903	0.297		
Home improvement (insulation, last 12 months)	0.152	0.359		
Household Characteristics				
Spendable household inc.(euros)	31,140	27,458	142	1,757,024
Age	51	17	18	103
Young child	0.476	0.265		
Female	0.549	0.498		
Higher education	0.263	0.440		
House Characteristics				
House size (sq. mtr.)	123	78	6	935
Construction < 1945	0.183	0.387		
Construction 1945-1959	0.121	0.326		
Construction 1960-1969	0.147	0.355		
Construction 1970-1979	0.194	0.396		
Construction 1980-1989	0.156	0.362		
Construction 1990-1999	0.137	0.344		
Construction > 1999	0.062	0.241		
Single-standing	0.134	0.340		
Two under one roof	0.115	0.318		
Corner	0.115	0.318		
Row	0.191	0.357		
Flat/apartment 1990-1999	0.312	0.168		
Other	0.095	0.105		
Sector				
Social housing	0.386	0.482		
Free-rental sector	0.060	0.271		
Owner-occupied	0.554	0.497		
Energy Expenditures				
Annual gas expenditures (euros)	1,054	517	138	5,084
as part of income	0.044	0.039	0.002	1.866
Annual electricity expenditures (euros)	745	399	83	3,484
as part of income	0.029	0.026	0.001	1.513
Annual water expenditures (euros)	176	55	69	709
as part of income	0.007	0.009	0.001	1.732
Utility expenditures (euros)	1,976	770	324	8,470
as part of income	0.080	0.565	0.008	1.962
Heating: own boiler	0.805	0.396		
Heating: block/district/city	0.111	0.315		
Heating: heater	0.072	0.259		
Heating: other	0.011	0.103		
Number of persons in hh	2.959	1.321	1	27
Robustness				
Partner	0.628	0.483		
Instrumental variables				
Divorce	0.009	0.093		
Marriage	0.021	0.144		

Note: Based on 54,173 observations, from the WoON-survey (2006). We restrict all types of energy expenditures as a share of income to be at most equal to two.

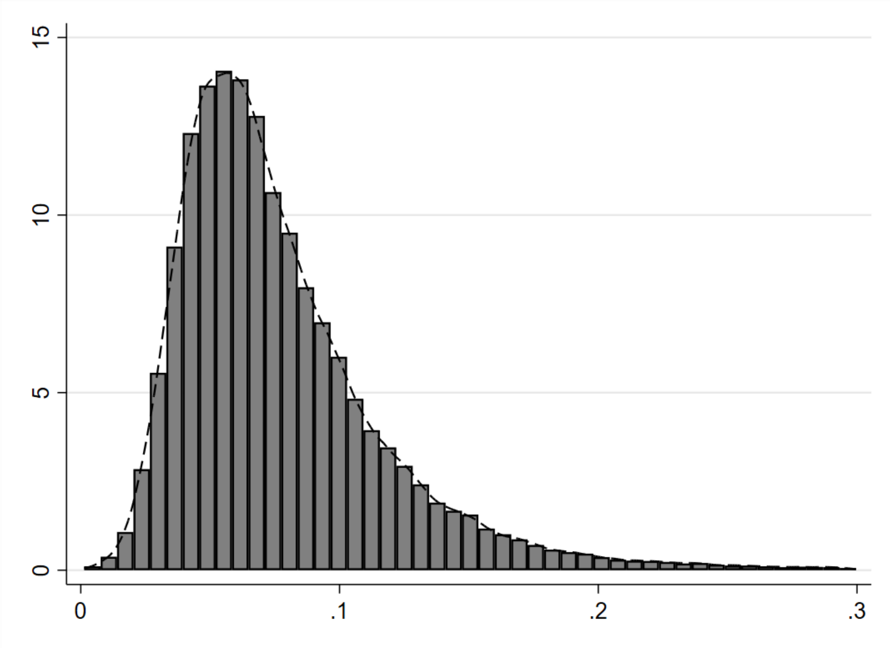

Figure 2 – Utility expenditures as a share of income (2006)

Note: The distribution of utility expenditures as a share of income in our sample for 2006. Utilities expenditures are measured as annual energy expenditures plus water bills. For this histogram, we only include respondents for which the utility expenditures as a share of income are at most 30%.

(0.18% of all respondents) and households with an income higher than 2,500,000 euros (less than 0.01% of all respondents). The mean household income is equal to 31,140 euros, and the median is 27,116 euros.

We include a set of household characteristics and home characteristics as control variables. The household characteristics that we consider are age, gender, and education. To control for education, we include a dummy indicating whether the respondent has a university degree or finished higher professional education. To proxy for household structure, we obtain information on the number of persons in the household (which is particularly useful for modeling energy expenditures) and include a dummy variable indicating whether the respondent has children under the age of 2 (in the robustness section, we also include a dummy indicating whether a respondent has a partner).[10] The home characteristics we consider are the type of house (single-standing, two under one roof, corner, in between two other homes, flat/apartment, other), house size (measured in square meters), the type of heating system (boiler, block, district or city heating, heating by heaters, other), and the year of construction.

[10]The survey contains information on the household structure, this variable is only available for approximately 17.000 respondents. Therefore, we use the presence of a young child as a proxy for household structure.

4.2. WoOn-Survey (2018)

The number of respondents in the 2018 sample is 67,523 and they were surveyed from August 2017-March 2018. We focus on the respondents for whom all variables of interest are available, giving us a sample of 56,283 respondents. Summary statistics for the 2018 sample can be found in Appendix B. Compared to the 2006 sample, a higher number of respondents live in owner-occupied housing (66.2%) and in the free rental sector (9.1%). The number of respondents in social housing has declined (24.7%).

The 2018 survey provides a set of binary variables indicating whether a household has obtained (i) double glazing, (ii) roof, wall or floor insulation, (iii) the installation of solar panels, (iv) or the installation of a boiler panels (v) or other energy saving facilities in the past 5 years. We define our *home improvements*-variable as a binary variable that is equal to 1 if a household has undertaken at least one of these measures and zero otherwise. Our *energy efficiency*-variable is a binary variable based on the energy label of the house, which is provided by the Dutch government (RVO). The variable is equal to 1 if a household lives in a house with an A or B energy label, and zero otherwise. Energy labels range from A to G, with A being the most energy efficient and G the least efficient. We define houses with an energy label of A or B as energy efficient and houses with another label as energy inefficient.

Table B2 provides summary statistics for energy efficiency and home improvement. Using the 2018 definition of energy efficiency (rather than the presence of double glazing in the 2006 sample), only 24.3% of households in our sample live in energy-efficient homes (compared to 90.3% in the 2006 sample). The fraction of households in the 2018 sample that did improve home energy efficiency is 56.8%. This is much larger than in the 2006 sample (15.2%), which can be explained in part by the fact that we look at home improvements for the last 5 years instead of last year. Most households improve their home by taking a more efficient boiler (34.6%) or installing double glass (26.3%).[11]

Our main other variables of interest are households' disposable income and wealth. The average income in the 2018 sample is equal to 43,490 euros. We consider total wealth (defined

[11] We also examined the geographical distribution of home improvements. In the urban core of the Netherlands (in Dutch: the Randstad), 54.1% of households did a home improvement. This is less than in the periphery, where 58.3% of households did a home improvement. Regarding energy efficiency, 23.8% of households have an energy-efficient home in the Randstad. This is again less than in the periphery, where 24.6% of households have an energy-efficient home. For the potential urban economic implications of energy efficiency see Glaeser and Gyourko (2005) and Kahn and Kok (2014).

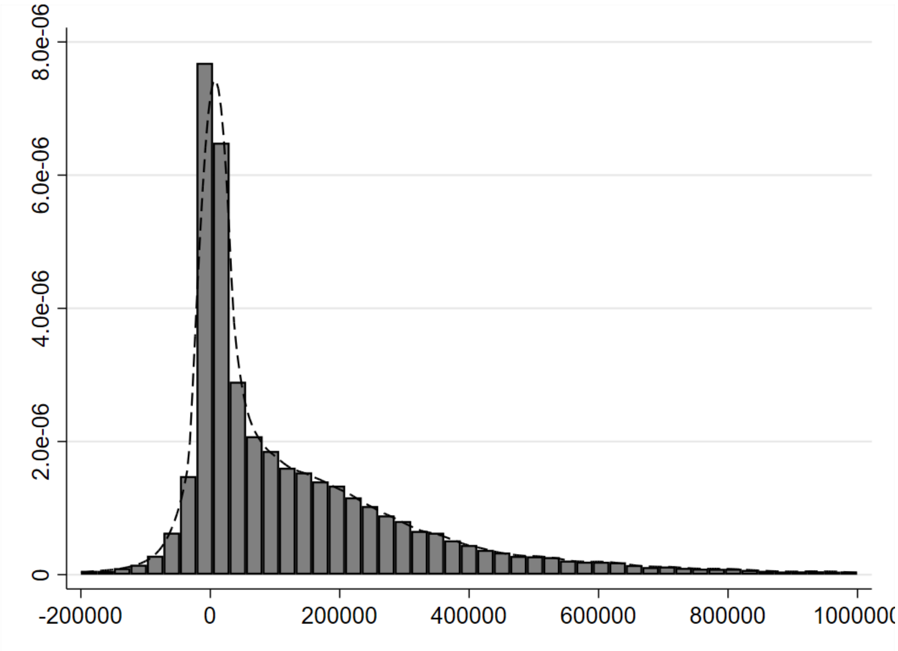

Figure 3 – The distribution of net wealth (2018)

Note: The distribution of net wealth within our sample. Information on wealth, which is defined as the total value of assets minus debt, comes from tax registry data. We exclude households with wealth below -200,000, and households with wealth higher than 1,000,000 euros for this histogram.

as the total value of assets, including savings, stocks and bonds, and housing) as well as net wealth (wealth minus debt, including mortgage debt). Information about both wealth variables comes from tax registry data (Statistics Netherlands) as well. We again exclude households whose income is negative and households with an income greater than 2,500,000 euros. We also exclude households with negative total wealth and households with a total wealth value greater than 2,000,000 euros. Finally, we exclude households with net wealth lower than - 200,000 euros and households with net wealth higher than 2,000,000 euros.

The average total wealth in the resulting sample is 264,771 euros (with a median of 217,972), its distribution is shown in Figure 3, and the average net wealth is equal to 152,846 euros (with a median of 56,652). Controlling for the composition of the Dutch society using household weights reduces average (net) wealth. Specifically, once we incorporate household weights, the weighted average of total wealth is 241,678 euros (with a median of 191,668) and the weighted average of net wealth is given by 134,977 euros (with a median of 35,576). In the remainder of this paper, we are particularly interested in how home improvement and/or buying an energy-efficient house affect the accumulation and distribution of wealth.

5. Methodology

We start our analysis with the WoON 2006 dataset and show how income affects home improvement (intensive margin) and sorting into energy-efficient homes (extensive margin). Heterogeneity in the results, including the effect of subsidies that were given, the role of income versus wealth, the effect on energy consumption, wealth inequality, and CO2 emissions are discussed when analyzing the WoON 2018 dataset.

Based on the 2006 data, we first model the probability that the household has improved the energy efficiency of the home in the last 12 months:

$$\text{Home improvement}_i = \beta \log \text{Inc}_i + \theta X_i + \delta h_i + \alpha_j + \eta_i, \tag{5}$$

where $\log \text{Inc}_i$ is the natural logarithm of the income of household i, X_i are housing characteristics (house size, type of house, construction year dummies), h_i are household characteristics (age, presence of young children, gender, and education), α_j are zip code fixed effects, and η_i is the error term. We also estimate the relationship using COROP region (work-living areas, NUTS2 classification) and municipality level (NUTS3 classification) as a robustness exercise. This is useful, as for the 2018 data we only have the COROP region. We will examine the probabilities of different types of home improvement using the WoON 2018 dataset.

Next, we model the probability that a household lives in an energy efficient house (as proxied by the presence of double glass):

$$\text{Energy efficiency}_i = \beta \log \text{Inc}_i + \theta X_i + \delta h_i + \alpha_j + \varepsilon_i, \tag{6}$$

where all variables are defined as before and ε_i is the error term. A more general measure of energy efficiency (energy labels, energy index) is explored using the WoON 2018 dataset.

We estimate Eq. (5) and (6) using OLS and cluster standard errors at the municipality level. We explore whether the type of ownership influences the results by re-estimating the equations for social rental, free rental, or owner-occupied housing. Furthermore, we show robustness using an instrumental variable approach, controlling for household structure, estimating the relationship for a sample of recent movers, and respondents surveyed during the winter, adding an additional control for unobserved housing characteristics, and including sampling weights. We also explore logit, multinomial logit, and nested logit as households might first decide on the extensive margin, Eq. (5), and then on the intensive margin, Eq. (6).

6. Results based on WoON 2006

6.1. Energy efficiency, home improvement, and the effect of income

Table 2, columns 1-5, reports the results on the probability that a household has improved the energy efficiency of the house in the last 12 months, as specified in Eq. (5). The results in column 1 suggest that the effect of income is positive and statistically significant at the one percent significance level. The effect is also economically sizeable against the average home improvement rate of 0.15. In particular, a standard deviation increase in income (27,458 euros) relative to mean income (31,140 euros) increases the probability of undertaking energy efficiency-enhancing home improvements by 1.7 percentage points.[12] The effect decreases by more than half when we control for the type of ownership, see column (2), since income and the type of ownership chosen by a household are strongly correlated. Both social and free rental sector houses are less likely to experience home improvements. A potential explanation for this is that these households must rely on the owner of the house to make home improvements, while the energy savings are for the households themselves, as they typically pay the energy bill. These households do not benefit in terms of house value and it is also difficult for the owner to capitalize on their investment. This split incentive problem is well established and reduces the likelihood of implementing energy efficiency measures (e.g., see Bird and Hernández, 2012).

We re-estimate Eq. (5) for the sub-sample of owners and each type of renter. The results, which are reported in columns 3-5, confirm that the effect of income on home improvements is entirely driven by the owner-occupied market segment. The results thus imply that regulations (subsidies) to make it more financially attractive for a household to, for example, insulate the house are most likely mainly effective for the owner-occupied housing sector.

Table 2, columns 6-10, reports the estimates using the indicator of whether the home is energy efficient (measured by the presence of double glass) as dependent variable, see Eq. (6). The results in column 6 suggest that the effect of income is positive and statistically significant at the

[12] This effect is calculated as $[\ln(1 + (27,458/31,140)).] \cdot 0.0268 \cdot 100 = 1.7$ percentage points.

one percent significance level. A standard deviation increase in income relative to mean income increases the probability of residing in an energy-efficient home by 2.1 percentage points. The effect remains comparable once we control for the type of ownership, see column (7). Interestingly, houses in the free rental sector are much less likely (by about 10%) to be energy efficient. Social rental sector housing has, ceteris paribus, the same share of houses with double glass as the owner-occupier housing sector. This suggests that housing corporations that are owners of the social housing at least seem to shelter (poor) households against not having double glass (and hence against high energy expenditures). Like before, we re-estimate Eq. (6) for the subsample of owners and each type of renters. The results are reported in columns 8-10 and confirm that having a higher income increases the probability of living in an energy-efficient home. The relationship appears present, but somewhat weaker, for households in the free rental sector.[13] [14]

6.2. Robustness checks

This section summarizes several robustness checks on the baseline home improvement and energy efficiency regressions reported in Table 2. The regression results are reported in Appendix C.

First, to alleviate potential concerns about the exogeneity of our income variable, we estimate our model using instrumental variables. While we are not concerned about reverse causality and/or simultaneity bias (since our main independent variable is spendable household income), the results could potentially suffer from omitted variable bias. There are a number of household characteristics (e.g. occupation, ability) and house characteristics (e.g. monument status) which are correlated with income and both our outcome variables, and for which we cannot control. To mitigate these concerns, we use plausibly exogenous shocks to income as instrumental variables. In particular, households who moved into their home at most two years before the survey was conducted (between 2003-2006) were asked about the reason for moving. We identify respondents for whom the reason for moving was a divorce or marriage.[15] The idea is that divorce or marriage has a large effect on income and, as such, affects the choice to buy an energy-efficient home or

[13]The full results of the baseline regressions are reported in Table C1, Appendix C. Households with young children are more likely to live in an energy-efficient home and to make home improvements. Older people also live in energy-efficient housing, but are less likely to do home improvement. Newer houses are more likely to be energy efficient and it is less likely that home improvements are made.

[14]We also verify that the results remain valid when the estimation is carried out using fixed effects at the municipality and COROP level (see Table C3).

[15]Note that these outcomes are not perfectly collinear, as this variable does not indicate whether a respondent has been/is married or divorced, but rather whether a divorce or marriage was the reason for moving.

Table 2 – Home Improvements and Energy Efficiency - Baseline Estimates (2006)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Home Improvement					Energy Efficiency				
	Baseline	Sector	Social rent	Free rent	Owner-Occupied	Baseline	Sector	Social rent	Free rent	Owner-Occupied
Income (log)	0.0268***	0.0117**	0.0084	0.0116	0.0160**	0.0331***	0.0303***	0.0191***	0.0379*	0.0345***
	(0.004)	(0.005)	(0.006)	(0.017)	(0.006)	(0.004)	(0.004)	(0.006)	(0.020)	(0.005)
Social rent		-0.0552***					0.0046			
		(0.007)					(0.006)			
Free rent		-0.0664***					-0.1020***			
		(0.008)					(0.009)			
Household Char.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
House Char.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Location FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	54,173	54,173	19,831	4,338	30,004	54,173	54,173	19,831	4,338	30,004
Adjusted R-squared	0.048	0.052	0.047	0.093	0.057	0.120	0.128	0.090	0.191	0.121

Note: Estimation results for Eq. (5) (columns 1 - 5) and Eq. (6) (columns 6 - 7), based on the WoON-survey (2006). We estimate both equations with OLS, and include ZIP-code fixed effects and time fixed effects. Standard errors are clustered at the municipality-level, *** p<0.01, ** p<0.05, * p<0.1.

make home improvements in the new home. Since we have overidentifying restrictions, we can test for the exogeneity of these instruments.

The results of the first stage are reported in Table C2, column 1. The F-statistic of 194 indicates that the instruments are highly relevant. The effect of divorce on income is negative and statistically significant at the one percent significance level. Respondents who moved to their current homes as a result of a divorce have $[\exp(-0.1938) - 1] * 100 = -17.6\%$ less income on average. On the contrary, the effect of marriage on income is positive and statistically significant at the one percent significance level. Respondents who moved to their current homes as a result of a marriage have 22.8% more income on average.

The results of the second stage are reported in columns 2-3. The effect of income on the probability of making home improvements and on the likelihood of living in an energy-efficient home is much larger than suggested by our baseline results. A standard deviation increase in income increases the probability of undertaking energy efficiency enhancing home improvements by 5.8 percentage points (compared to 1.7 percentage points in the baseline), and increases the probability that a respondents' house is energy efficient by 4.9 percentage points (compared to 2.1 percentage points in the baseline). However, the results of the baseline are within the confidence intervals for both outcome variables. The effect of instrumented income remains statistically significant, although the significance level decreases. While the two instrumental variables might still be correlated with unobserved house and household characteristics, the Hansen-J test statistic suggests that our instruments are valid (i.e., we cannot reject the null hypothesis of instrumental exogeneity).

Second, in Table C4 we explore logit, multinomital logit, and nested logit results. It is well known that controlling for detailed location fixed effects is difficult within these models. That is, the estimation easily becomes computationally infeasible or the model does not converge. To overcome this, we use municipality fixed effects for the logit results, region (COROP) fixed effects in the multinomial logit model, and province fixed effects for the nested logit model. In addition, the interpretation becomes different as it considers the odds ratios, rather than probabilities. We rescale the coefficient to reflect a standard deviation change in income evaluated at mean income. We find that a standard deviation change in income has a positive effect of 24% on the odds ratio of making home improvements and 15% on the odds ratio of living in an energy-efficient house. Therefore, with somewhat less detailed fixed effects, we find a similar direction of the effects to those of our baseline estimates.

We also estimate a multinomial logit and nested logit model. Doing home improvement and sorting into an energy-efficient home are not independent of each other. In particular, 8.7% of households did not make home improvements or do not live in an energy-efficient house, 14.1% have done home improvements and live in an energy-efficient house, 76.2% live in an energy-efficient house but did not make home improvements, and only 1.1% did home improvements while not living in an energy-efficient house. The multinomial logit model estimates the effect of income on all responses jointly. Using not making home improvements and not living in an energy-efficient home as a base category, the results in Table C4 show that a standard deviation change in income mainly increases the odds ratio to sort into an energy-efficient home and doing (40% effect) or not doing (23% effect) home improvements. Just making home improvements while not living in an energy-efficient home appears to be less affected by income (12% effect). The nested logit model assumes that households choose to sort themselves (first nest) and then also decide whether or not to do home improvement (second nest, decision tree). In comparison to the multinomial logit model, it allows for cross-correlations in the error term within (but not across) nests. The results confirm the findings of the multinomial logit model, but the effect becomes more pronounced (about 3 times larger) for the "having an energy-efficient home and doing home improvement" category, although the standard error is much larger also. In addition, the size of the effect should be interpreted with caution, as the model does not adequately control for location. Also, the Pseudo-R-Squared is much lower for the nested logit model. However, in general, these results confirm that income plays a crucial role in both extensive and intensive margins together.

Third, in Table C5 we report several other robustness tests. In particular, in columns 1-2 we add whether a respondent has a partner (according to the survey 87% of the respondents) as a control. Although our dependent variables are related to the head of the household, income is measured at the household level. Consequently, respondents with a partner are more likely to have a higher disposable income. This is confirmed by the results. The effect of income becomes lower but remains significant at the one percent significance level. Having a partner increases the probability of undertaking energy efficiency-enhancing home improvements by approximately

1.7 percentage points and increases the probability of living in an energy-efficient home with approximately 2.4 percentage points.

We also assess whether households are more likely to do home improvement when they have just settled in their home, and whether recent movers are more likely to reside in energy-efficient houses. We re-estimate Eq. (5) and (6) for a subsample of recent movers, which we define as respondents who moved into their current home in 2004. The results are reported in columns 3-4. The effect of income is stronger for respondents who recently moved, both when considering home improvements and energy efficiency as the outcome variable. A standard deviation increase in income increases the probability of undertaking energy efficiency-enhancing home improvements by 2.8 percentage points (compared to 1.7 percentage points in the baseline), and increases the probability that the house is energy efficient by 3.0 percentage points (compared to 2.1 percentage points in the baseline). Although both effects increase in size, the statistical significance is lower. The effect of income on the probability of undertaking energy efficiency-enhancing home improvements is only statistically significant at the 10 percent significance level. The effect of income on the likelihood of living in an energy-efficient house is statistically significant at the 5 percent significance level.[16]

In addition, we assess whether attention influences the effect of income on home improvement and buying an energy-efficient home. In particular, we re-estimate Eq. (5) and (6) for the subsample of respondents surveyed during winter (December 2005 - January 2006). The results are reported in columns 5-6. The results indicate that the effect on income is somewhat stronger for the respondents surveyed during the winter months, both when considering home improvements and energy efficiency as the outcome variable. A standard deviation increase in income increases the probability of undertaking energy efficiency-enhancing home improvements by 1.8 percentage points (compared to 1.7 percentage points in the baseline) and increases the probability that the house is more energy efficient by 2.3 percentage points (compared to 2.1 percentage points in the baseline). Both effects remain statistically significant at the one percent significance level.

[16] To ensure that the coefficient on energy efficiency really picks up sorting effects, we re-estimate Eq. (5) for the sub-sample of recent movers (defined as respondents who moved into their current home in 2004) that did not conduct any home improvements. The effect of income on the likelihood of living in an energy-efficient home remains statistically significant at the 5 percent significance level, with a standard deviation increase in income raising the probability that the house is energy-efficient by 3.0 percentage points. Hence, the result is similar to the estimate based on the entire subsample of recent movers.

We also verify the robustness of our results when controlling for unobserved house characteristics. We proxy for unobserved house characteristics using the most recent assessed value of the property (used for tax purposes). This variable is only available for respondents who are home owners, and we exclude observations for which the assessed property value is less than 50.000 euros or greater than 1.5 million euros. The results are reported in columns 8-9. The effect of income becomes smaller when controlling for unobserved house characteristics. A standard deviation increase in income increases the probability of undertaking energy efficiency-enhancing home improvements by 0.9 percentage points (compared to 1.7 percentage points in the baseline). The effect on the probability of living in an energy-efficient house is roughly equivalent to the baseline result. A one percent increase in income increases the probability that the house is energy efficient by 2.0 percentage points. Importantly, the effect of unobserved house characteristics is statistically insignificant on both the probability of undertaking energy efficiency improvements and the likelihood of sorting into a more energy-efficient home.

Next, we verify the robustness of our results against the inclusion of sampling weights. The results are reported in columns 9-10. Incorporating household weights does not affect our main results. Both the probability of making home improvements and the likelihood of living in an energy-efficient home remain roughly the same. Finally, in Table C3 we look at fixed effects using different spatial scales and find that the results using COROP or municipality fixed effects are similar.

7. Heterogeneity in the Results: Survey of 2018

7.1. Replication of the 2006 results

We expand our analysis using the 2018 survey to verify that our previous results hold in this wave and to explore the heterogeneity of the results. We first replicate our baseline estimates from Table 2 (i.e., Eq. (5) and (6)) using the 2018 sample. The results are reported in Appendix D.

The effect of income on the probability of undertaking improvements in energy efficiency in the home becomes more than two times greater than in the 2006 sample, with a standard deviation increase in income increasing the probability of undertaking improvements in energy efficiency in the home by 3.8 percentage points.[17] This could be due to either a decrease in costs

[17]This effect is calculated as $[\ln(1 + (31,203/43,490)).] \cdot 0.0698 \cdot 100 = 3.8$ percentage points.

of energy efficiency enhancing measures or as individuals value energy efficiency more as a result of an increase in climate change awareness, but we are unable to disentangle these effects in our data. Again, houses in the social and free rental sector are less likely to experience home improvements.[18]

The effect of income on the likelihood of living in an energy-efficient home is about one and a half times greater than in the 2006 sample. A standard deviation increase in income increases the probability that the house is more energy efficient by 3.1 percentage points. Houses in the free rental sector are still less likely to be energy efficient. Similarly to the 2006 results, the effect of income on the likelihood of living in an energy-efficient home is also present in the subsample of respondents who live in rental houses.

7.2. *Types of home improvement, reasons, and the role of subsidies*

We estimate the propensity to carry out energy efficiency-enhancing home improvements as a result of increases in income, as specified in Eq. (5). We estimate this relationship using our home improvement variable as well as for the different types of home improvement. In particular, we estimate the relationship separately for home improvements in the form of(i) double glazing, (ii) roof, wall or floor insulation, (iii) the installation of solar panels, (iv) or the installation of a boiler (v) or other energy saving facilities. The results are reported in Table 3. A standard deviation increase in income leads to the largest increase in the probability of installing a boiler. This probability increases by 2.3 percentage points. The effect is smallest for the propensity to install solar panels. This probability increases with 1.3 percentage points. This implies that, as income increases, households are most likely to first get a better boiler and only eventually end up placing solar panels.

Subsidies can play an important role in home improvement. Our measure of income does not account for that. Although we do not know the exact level and type of subsidies, we can control whether a household received a subsidy. About 6.8% of the sample received a subsidy. This is 14.2% of those who do home improvement. We re-estimate the results of Table 3 and add this additional control variable. The results are reported in Appendix E. Households who have received a subsidy are 43% more likely to have done home improvement. The effect is

[18]The effect of income on the probability of making home improvements is also statistically significant for the subsample of respondents who live in rental houses. However, once we control for unobservables using our IV strategy (divorce, marriage), the effect becomes statistically insignificant.

Table 3 – Different types of home improvements (2018)

VARIABLES	(1) Home Improv.	(2) Double Glass	(3) Insulation	(4) Solar	(5) Boiler	(6) Other
Income (log)	0.0698***	0.0330***	0.0404***	0.0241***	0.0428***	0.0264***
	(0.005)	(0.004)	(0.003)	(0.002)	(0.005)	(0.003)
Household Characteristics	Yes	Yes	Yes	Yes	Yes	Yes
House Characteristics	Yes	Yes	Yes	Yes	Yes	Yes
Location FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	56,283	56,283	56,283	56,283	56,283	56,283
Adjusted R-squared	0.091	0.064	0.097	0.044	0.055	0.014

Note: Estimation results for Eq. (5) for various types of home improvement, based on the WoON-survey (2018). We estimate the equation with OLS, and include COROP-code fixed effects and time fixed effects. Standard errors are clustered at the COROP-level, *** p<0.01, ** p<0.05, * p<0.1.

larger for households that have added solar panels and lower for those who installed a heating boiler. This is not surprising, as solar panels have been highly subsized in recent years. About 50% of the sample indicates that they have had subsidies against only 11% in case of a boiler. In general, the marginal effect of income also becomes much greater. A standard deviation increase in income leads to an increase in the probability of making home improvements by 7.7 percentage points. This is twice as large as our baseline estimate for 2018. Importantly, while the results do reveal a positive association between subsidies and the propensity to undertake energy efficiency-enhancing home improvements, the main insight brought forward in this analysis is that the effect of income remains significant once we control for subsidies.

Lastly, we also evaluated other reasons why households made improvements to their home that improved energy efficiency. The results are reported in Appendix F. Table F1 reveals that the most common reason for making home improvements is the need for maintenance (43%). Additionally, many households believe that the investment pays off or makes the house more pleasant (24%). Table F1 indicates that the most common reason to not make home improvements is because the house is already energy efficient (38%). Furthermore, investment is out of budget for 16.7% of respondents who did not make home improvements.

Table F2 shows how the probability of each reason for implementing home improvements changes with income. We find that an increase in income makes it more likely that households undertake home improvements in order to make their home more pleasant or because of environmental considerations, while an increase in income makes it less likely that home improvements are necessary due to maintenance. Table F3 shows how the probability of each reason not to make home improvements also changes in income. An increase in income raises the likelihood that the home is already efficient, as well as the probability that respondents did not get to making home improvements yet and plan to move. An increase in income reduces the likelihood that households have an investment that is out of budget.

7.3. Sorting based on energy labels

We re-estimate the probability of moving to a more energy-efficient home for an increase in income, as specified in Eq. (6), but using data on energy labels and the energy index of the house. The results are reported in Table 4. We first use temporary labels as a dependent variable, as we have data available on temporary labels for all respondents in our sample, since all homes in the Netherlands were assigned a temporary energy label in 2015. The effect of an increase in income on the likelihood of living in an energy-efficient home becomes insignificant. This occurs because part of the temporary labels were assigned according to the year of house construction. Consequently, there is a strong negative correlation (-0.9) between the year of construction and the energy label. We account for this by excluding the construction year from our control variables in the estimation. The effect of income on the likelihood of sorting into a more energy-efficient home becomes statistically significant at the one percent significance level, as shown in column 2 of Table 4. A standard deviation increase in income leads to an increase in the likelihood of living in a house with a high energy label by 3.1 percentage points.[19]

As temporary energy labels do not take into account any measures to improve energy efficiency in the home, homeowners can request a final energy label. We have data on the final energy label of roughly half of the respondents within our sample, and we redo the estimation with final energy labels as dependent variable. Columns 3 and 4 report the results (with and without incorporating the construction year as a control variable). The effect of income on the likelihood of sorting into a more energy-efficient home is significant at the one percent level when we exclude the construction year from our control variables. An increase in income by a standard deviation increases the likelihood of living in a home with a high energy label by 2.2 percentage points - an effect which is roughly comparable to the estimate obtained when using temporary labels as outcome variable. The effect when adding construction year dummies as controls is quite somewhat smaller, but still statistically significant.

Lastly, we re-estimate Eq. (6) using the (log) energy index as the outcome variable in columns 5-6. The energy index is a numerical measure of the energy performance of a home. An energy label of $A++$ corresponds to an energy index below 0.6, while an energy label of G corresponds to an energy index greater than 2.7. This means that a *lower* energy index reflects higher energy performance. Accordingly, the effect of income on the energy index is negative and statistically significant at the one percent level. According to column 6 (estimated as log-log model), an increase in income by a standard deviation is associated with a decrease in the energy index by

[19]We also estimated a multinomial logit model using the different energy labels. The results are in line with our main findings. A unit increase in log income (100%) increases the relative risk ratio for energy label A or B versus G by a factor of 1.5 while increasing the ratio by 1.07 for energy label F. Therefore, as income increases, households are more likely to eventually have an A or B energy label.

Table 4 – Energy Efficiency: Energy Label and Energy Index (2018)

VARIABLES	(1) Energy Label (temp.)	(2) Energy Label (temp.)	(3) Energy Label (fin.)	(4) Energy Label (fin.)	(5) Energy Index	(6) Energy Index
Income (log)	0.0016	0.0581***	0.0072*	0.0409***	-0.0114***	-0.0300***
	(0.003)	(0.008)	(0.004)	(0.007)	(0.004)	(0.007)
Household Characteristics	Yes	Yes	Yes	Yes	Yes	Yes
House Characteristics	Yes	Yes	Yes	Yes	Yes	Yes
Construction Year	Yes	No	Yes	No	Yes	No
Location FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	54,170	54,170	22,789	22,789	16,855	16,855
Adjusted R-squared	0.672	0.064	0.478	0.039	0.393	0.039

Note: Estimation results for Eq. (6), based on the WoON-survey (2018). We use (i) temporary energy labels (columns 1-2), (ii) final energy labels (columns 3-4) and (iii) the energy index (columns 5-6) as a proxy for energy efficiency. We estimate the relation with and without the inclusion of construction year as the control variable (first, respectively, second column). We estimate the equation with OLS, and include COROP-code fixed effects and time fixed effects. Standard errors are clustered at the COROP-level, *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

2.2%.[20]

7.4. *Wealth or income?*

We assess whether home improvement or sorting into a more energy-efficient home is affected more by wealth or income. We include the total value of the assets of the respondents in addition to the income in the estimation of Eq. (5) and (6). The results are reported in columns 1-2 of Table 5. The effects of both income and total assets are positive and statistically significant at the one percent significance level. A standard deviation increase in income increases the probability of undertaking energy efficiency-enhancing home improvements by 3.2 percentage points, while a standard deviation increase in wealth only increases the probability of undertaking energy efficiency-enhancing home improvements by 0.7 percentage points.[21] This indicates that the income of the respondents matters more to the likelihood of making improvements in energy efficiency in the home than the wealth of the respondents. A similar pattern is observed for the likelihood of living in a more energy-efficient home. The effect of a standard deviation increase in income on the probability of living in a more energy-efficient home is 2.3 percentage points, while a standard deviation increase in wealth increases the probability of living in a more energy-efficient home by 0.8 percentage points.

Although the total value of a respondents' assets serves as a proxy of wealth, this variable does not account for an effect of debt on the propensity to invest in energy efficiency out of wealth. That is, households can attract debt to finance investments in energy efficiency. Many Dutch households, particularly low-income ones, indicate that it is difficult to find adequate financing to do home improvement (**?**). Although we do not know the exact amount that households borrow to finance home improvement, about 8% of households indicated that they borrowed to invest in home improvements. Of these households, 64 percent used a mortgage. To determine the effect of debt on our estimation results, we re-estimate Eq. (5) and (6) using net wealth. The results are reported in columns 3-4. An increase in wealth by one standard deviation increases the probability of undertaking energy efficiency-enhancing home improvements by 0.8 percentage points. This is roughly equal to the effect based on the total value of assets, indicating that debt plays a negligible role in determining the likelihood of making home improvements, at least

[20]This effect is calculated as $[\exp((31,203/43,490) * 0.03)) - 1] \cdot 100 = 2.2\%$.

[21]This estimated effect is calculated as $\ln(1 + (299400/264771)) \cdot 0.0094 \cdot 100 = 0.7$ percentage points.

Table 5 – Effect of Income vs Wealth (2018)

VARIABLES	(1) Home Improv.	(2) Energy Eff.	(3) Home Improv.	(4) Energy Eff.
Income (log)	0.0595***	0.0420***	0.0711***	0.0543***
	(0.006)	(0.006)	(0.006)	(0.007)
Total Assets	0.0094***	0.0109***		
	(0.001)	(0.002)		
Net Wealth			0.0144***	0.0252**
			(0.005)	(0.009)
Household Characteristics	Yes	Yes	Yes	Yes
House Characteristics	Yes	Yes	Yes	Yes
Location FE	Yes	Yes	Yes	Yes
Observations	55,619	53,528	55,418	53,378
Adjusted R-squared	0.093	0.068	0.091	0.065

Note: Estimation results for Eq. (5) and Eq. (6), based on the WoON-survey (2018). We include wealth as an explanatory variable, using total assets (columns 1-2) and net wealth (column 3-4) as proxy. Results for Eq. (5) are reported in columns 1 and 3, and for Eq. (6) in columns 2 and 4. We estimate the equation with OLS, and include COROP-code fixed effects and time fixed effects. Standard errors are clustered at the COROP-level, *** p<0.01, ** p<0.05, * p<0.1.

in this particular sample. However, when it comes to energy efficiency, a standard deviation increase in net wealth increases the probability of living in a more energy-efficient home by 1.3 percentage points. This is a stronger effect than when we consider the total value of assets, suggesting that equity plays an important role in financing the purchase of a more energy-efficient home.

7.5. Climate preferences

Why do households make home improvements if the returns are potentially negative? According to our sample, 21% of households that plan to undertake further home improvements in the future would do so even if the net present value of the investment is negative. Additionally, around 19% of households are willing to pay a premium for an energy-efficient house, even if lower energy bills will not fully offset the higher purchase price. This indicates that climate preferences play a significant role in the Netherlands.

However, climate preferences may be linked to income. To investigate whether our findings are driven by households' climate preferences, we interact income with a variable that equals 1 for households with strong climate preferences. We define strong climate preferences as those

Table 6 – Effect of Climate Preferences (2018)

VARIABLES	(1) Home Improv.	(2) Energy Eff.
Income (log)	0.0644***	0.0655***
	(0.006)	(0.008)
High Climate Preference	0.4364***	0.3030***
	(0.152)	(0.156)
High Climate Preference x Income (log)	-0.0283**	-0.0356***
	(0.014)	(0.014)
Household Characteristics	Yes	Yes
House Characteristics	Yes	Yes
Location FE	Yes	Yes
Observations	56,283	54,170
Adjusted R-squared	0.096	0.067

Note: Estimation results for Eq. (5) and Eq. (6), based on the WoON-survey (2018). We include high climate preferences based on whether household indicated that they would consider doing future home improvement without earning back the investment via a lower energy bill. We estimate the equation with OLS, and include location fixed effects based on COROP regions. Standard errors are clustered at the COROP-level, *** p<0.01, ** p<0.05, * p<0.1.

households willing to make additional home improvements despite a negative net present value. The results, presented in Table 6 show a strong correlation between climate preferences, home improvements, and energy efficiency.

7.6. The effect of the COVID-19 pandemic

We use the WoON 2021 database, a sample period which coincides with the COVID-19-pandemic in the Netherlands, to see if the effects were different during the COVID-19 pandemic.The descriptive statistics and regression results for home improvement and energy efficiency are in Appendix G.

We observe that households were slightly less likely to do home improvement on average, as 53% of the households did home improvements while this was 57% of households in the 2018 sample. The share of energy-efficient housing increased from 24% to 45%. This is in part due to the fact that the 2018 statistics are based on preliminary energy labels, while the 2021 statistics are based on the actual labels.[22] Apart from this, the Dutch Climate Agreement between companies and (government) organizations that came into effect in 2019 has also stimulated

[22] In the 2018 statistics, actual energy labels are only available for 30% of the sample.

substantial investments in energy efficiency, for example by introducing large subsidies. Moreover, energy prices have also become higher. Households have spend 6.2% of their income on utilities which is much less than in 2018 (6.8%). The key takeaway from the regression results is that the marginal effect of income is somewhat lower in the 2021 sample than in the 2018 sample. In particular, the regression coefficient in 2021 (2018) for home improvements is 0.051 (0.070). For sorting into energy-efficient housing, the regression coefficient is 0.034 (0.058).

7.7. Energy expenditures and energy savings

To explore how energy efficiency affects wealth distribution on the one hand and CO2 gains on the other, we examine how improvement of the home and sorting into energy-efficient housing affects energy consumption both in euros and in physical quantities (e.g., KWh, m^3). In particular, we estimate households' energy consumption as a fraction of income:

$$\begin{aligned}\text{Energy consumption}_i(\%) &= \gamma_1 \text{Home improvement}_i + \gamma_2 \text{Energy efficiency}_i \\ &\quad + \phi_1 \text{Number of persons}_i + \phi_2 \text{Heating type}_i + \theta X_i + \delta h_i + \alpha_j + \omega_i,\end{aligned} \tag{7}$$

where Number of persons$_i$ captures the number of persons in the household and Heating type$_i$ are dummy variables for the type of heating system being utilized. Again, X_i are housing characteristics, h_i household characteristics, α_j location fixed effects, and ω_i is the error term. As a dependent variable, we will use the general costs of utilities, but we also provide estimates for gas, electricity, and water separately.

A potential reason for caution in the estimation of Eq. (7) is that it could be affected by a rebound effect. That is, as soon as a household does home improvement or owns an energy-efficient home, this can lead to a higher energy consumption. As such, we would underestimate the true effect of energy efficiency on energy consumption. In addition to the fact that there is mixed evidence on the rebound effect, as some find such an effect (Aydin et al., 2017) while others do not (Kattenberg et al., 2023; Fowlie et al., 2018), the fact that the effect we estimate possibly includes a rebound effect would suggest that we underestimate the returns to energy efficiency (which is not the focus of our study). However, we would effectively capture the actual energy expenditure (including any behavioral considerations) and its implications for wealth

Table 7 – The Effect on Energy Consumption (2018)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Gas/Income		Electricity/Income		Water/Income		Utility/Income
	in euros	usage (in m^3)	in euros	usage (in KWh)	in euros	usage (in m^3)	in euros
Home Improvements	-0.0023***	-0.0028***	-0.0021***	-0.0070***	-0.0003***	-0.0002***	-0.0047***
	(0.0005)	(0.0006)	(0.0004)	(0.0012)	(0.0001)	(0.0001)	(0.0005)
Energy Efficiency	-0.0076***	-0.0113***	-0.0010**	-0.0031***	-0.0003*	-0.0002***	-0.0088***
	(0.0006)	(0.0007)	(0.0005)	(0.0017)	(0.0001)	(0.0001)	(0.0008)
Household Characteristics	Yes	Yes	Yes	Yes	Yes	Yes	Yes
House Characteristics	Yes	Yes	Yes	Yes	Yes	Yes	Yes
ZIP-code FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	53,805	53,805	53,809	53,809	53,821	53,821	53,782
Adjusted R-squared	0.082	0.079	0.048	0.028	0.028	0.018	0.108

Note: Estimation results for Eq. (7) for various types of energy expenditures, based on the WoON-survey (2018). We estimate the equation with OLS, and include COROP-code fixed effects and time fixed effects. Standard errors are clustered at the COROP-level, *** p<0.01, ** p<0.05, * p<0.1.

accumulation and CO2 reduction benefits.

The estimation results of Eq. (7) are reported in Table 7. The reduction in expenditures is largely driven by a decrease in the gas bill, which explains 48.9% (i.e., $-0.0023/-0.0047*100\%$) of the overall reduction in utility expenses for home improvements. In case of sorting into energy-efficient homes, it is 86.6%. We find evidence that home improvements reduce utility expenditures as a share of income by -0.5 percentage points. This is a reduction of approximately 6.4% of the average annual utility expenditures as a percentage of income (which are equal to 7.8%, see Table B1). Utility expenditures as a share of income of respondents living in a house with an A- or B-energy label are on average -0.9 percentage points lower. This leads to a reduction in the average annual utility expenditure as a percentage of income by 11.5%. Interestingly, the marginal effect of sorting into an energy-efficient home is larger in terms of actual usage than in euros for gas and electricity consumption. This implies that the energy price that is being paid is lower in the case of sorting. One possible explanation is that households who sort themselves into more energy-efficient housing get a more advantageous energy contract. However, we do not have information on energy contracts to investigate this further.

We also run several robustness checks on the utility expenditure regression. These are reported in Appendix H, Table H3. First, we re-estimated the utility expenditure regression using data from 2021. We find that the marginal effect of home improvement is -0.0018, which is about 2.5 times lower than our baseline estimate. The coefficient on living in an energy-efficient home is -0.0079, which is slightly lower than our baseline estimate as well, but still falls within the 95 percent confidence interval. An explanation for the reduced impact of home improvement could be that the type of home improvement undertaken changed between 2018 and 2021. Specifically, the percentage of households that improved their homes by installing double glass, a new boiler, heat pump, or insulation decreased. Importantly, these types of home improvement are typically the first to be undertaken and have a strong effect on energy savings. Instead, the number of households that installed solar panels increased from 8.5% to 15.3% in the 2021 data (see Table B2 and Table G2).

Second, we re-estimated the effect for the 95th percentile of energy expenditure to income in 2018 (quantile regression). This corresponds to the average energy expenditure to income of households in the lowest income quartile. The effect of home improvement and energy efficiency become about twice as large, as the first home improvement that a household does is typically the most beneficial in terms of the energy savings generated.

Third, we interaction energy efficiency and home improvement to assess whether the effects of home improvements on energy consumption are lower when the home is more energy efficient. However, the interaction effect is not statistically significant. An interesting alternative issue is given by Adelino and Robinson (2023). They argue that home improvements typically coincide with other changes in the home, which effectively reduce the benefits of energy savings. In our dataset, inside and outside changes are negatively correlated with home improvement, indicating that households do not tend to carry these out simultaneously. While other changes, like adding a sun room, or a dormer, a new kitchen, or changing the house plan increase energy expenditures, our main results remain quantitatively similar.

Fourth, we again use a three-step IV strategy using on divorce and marriage (as reason for moving) as income shock. In line with the 2006 results, getting a divorce decreases income by 18% and getting married increases income by 10%. Using these income shocks to instrument our home improvement and energy efficiency variables leads to a doubling of the effect of energy efficiency. The effect of home improvements becomes four times as large. This seems to suggest that our estimated energy savings are quite conservative, although the standard errors are also much larger.

Finally, we evaluate the heterogeneity of the effects of various types of home improvement on utility expenditures. The results, which are reported in Appendix H, Table H4, indicate that solar panel installation leads to the largest reduction in utility expenditures as a share of income, while double glass installation does not appear to lead to a statistically significant reduction in utility expenditures. We also explore the heterogeneity in the effect of distinct energy labels on utility expenditures. The results reveal that utility expenditures are significantly lower for houses with an A-, B-, or C-energy label. Additionally, households living in a house with an D-, E- of F-label also have significantly lower utility expenditures compared to households who live in a house with a G-label.

Based on our baseline estimates, reported in Table 7, the average annual reduction in utility expenditures resulting from home improvements (0.5% of income) and living an energy-efficient home (0.9% of income) amounts to 587 euros, which constitutes 25.9% of the average total utility

TABLE 8 – PRESENT VALUE OF AVERAGE ENERGY SAVINGS (2018)

Investment horizon		$\rho = 0.02$	$\rho = 0.05$	$\rho = 0.08$
10-year horizon	in euros	5,273	4,533	3,939
	as % of median wealth	2.8	2.4	2.1
	as % of median net wealth	14.8	12.7	11.1
15-year horizon	in euros	7,543	6,093	5,024
	as % of median wealth	3.9	3.2	2.6
	as % of median net wealth	21.2	17.1	14.1
20-year horizon	in euros	9,598	7,315	5,763
	as % of median wealth	5.0	3.8	3.0
	as % of median net wealth	27.0	20.6	16.2

Note: Based the WoON-survey (2018). The real interest rate is based on a nominal interest rate of 4, 7 and 10% respectively, and an inflation rate of 2%.

expenditures. We determine the present value of the average savings, which is given in Table 8. Based on an investment horizon of 15 years and a real interest rate rate ρ, of 5%, the present value of savings is 6,093 euros.[23] These savings amount to 3.2% of median wealth, 17.1% of median net wealth (ignoring installation costs), 16.0% of median disposable household income, or 2.1% of the average house price in the Netherlands in 2018. According to our regression estimates, sorting explains about 65% of these savings.[24]

Although the costs for making home improvements can vary substantially across suppliers, time, and type of home improvement, the costs associated with the installation of double glass range from 2,000-3,000 euros for a standard row house, and the costs of solar panels are 3,000-4,000 euros. Buying an energy label A house instead of an energy label D house costs about 5,000 euros extra (Aydin and Brounen, 2016). So taking our baseline energy savings and a 3,000 (9,000) euros investment cost (for both sorting and some home improvement) suggests an annualized return of 4.8% (-2.6%). As mentioned, this is most likely an underestimate but it does suggest that, in line with Fowlie et al. (2018), these investments might not always be worthwhile.[25]

[23] In comparison, Fowlie et al. (2018) report an average life-span of home improvements of 16 years and use a 3%-7% discount rate.

[24] We conduct a similar exercise using the 2006 data (see Appendix H). In 2006, energy savings amount to 12.3% (4,058 euros) of the median net wealth based on aggregate wealth data from Statistics Netherlands. Sorting explains 80% of these savings. Sorting also explains 80% in 2021 and the present value of energy savings is 12.2% (5,074 euros) of net wealth in this year.

[25] The investment horizon of certain home improvement may be longer, so it might well be a more favorable investment opportunity in some cases (see for example the returns to insulation as estimated by Kattenberg et al., 2023).

Why do households still make home improvements if the returns are potentially negative? The descriptives in our sample suggest that of those who would consider doing additional home improvement in the future, 21% would do such an improvement even if they would not earn back the investment through a lower energy bill. About 19% of households are willing to pay a higher house price for an energy-efficient house even if it would not be covered by a lower energy bill. This suggests that climate preferences also play an important role in the Netherlands.

7.8. Wealth inequality, CO emissions, and public policy scenarios

In this section, we consider the effects of savings related to energy efficiency on the distribution of wealth and CO2 benefits. Panel A reports the current footprint per quartile of income (1^{st} Quartile <€25k, 2^{nd} Quartile €25k-38k, 3^{rd} Quartile €38k-55k, 4^{th} Quartile >€55k). Households in the first quartile spend much more on utilities (11.4%) than households in the upper quartile (3.8%). They also have relatively high gas expenditures. In terms of actual energy usage, households in the upper quartile use 1.5 times more gas, almost 2 times more electricity, and more than 2 times more water, than households in the lower quartile.

Using a m^3 gas to MMBTU conversion factor of 0,0366, a KWh electricity to MMBTU conversion factor of 0,003404, a MMBTU to CO2 conversion factor of 53,07kg, and 0.4kg CO2 per cubic meter of water, we can calculate the CO2 emissions associated with the energy usage.[26] Fowlie et al. (2018) report an abatement cost per ton of CO2 of 201 to 285 dollars for home improvements. The preferred estimate of Rennert et al. (2022) is 185 dollars. Kikstra et al. (2021) report social costs of CO2 of 185-200 dollars based on the SSP1-1.9 en SSP1-2.6 climate scenarios, which are in line with the Paris Climate Agreement and incorporate climate feedback and economic forces. Based on these estimates, we use a CO2 cost of 200 dollars (*0.92 = 185 euros) per ton of CO2. Then, our findings indicate that households in the upper quartile of income emit about 7,500 euros of CO2 over a period of 15 years which is about 1.5 more than household in the lowest quantile.

We use a similar approach to examine what the energy savings and CO2 gains are as the results of the current distribution of home improvement and sorting and using the estimates in Table 7. The results are reported in Panel B. The key finding is that although low-income

[26] For the gas and electricity conversion factors, we use a Dutch source (www.energieconsultant.nl) but the numbers are similar if we look at the U.S. Energy Information Administration (EIA). The MMBTU to CO2 conversion factor comes from the EIA. The CO2 per cubic meter is 0.34 - 0.46 kg according to www.brightest.io.

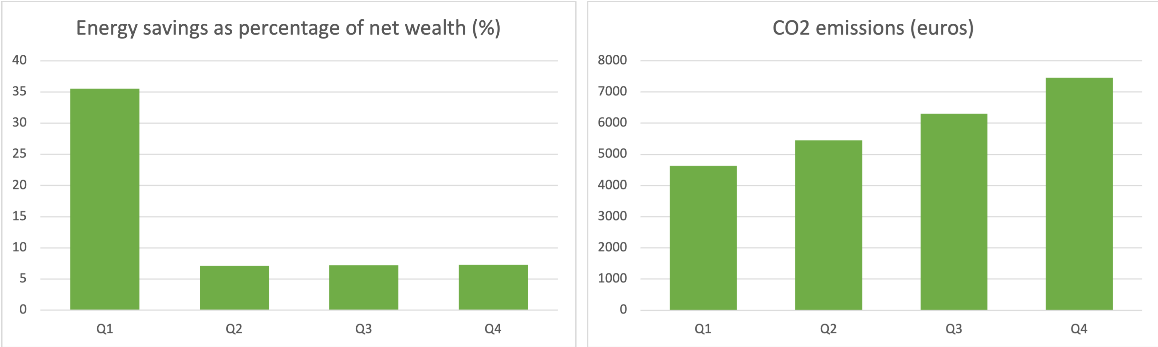

Figure 4 – The energy-efficiency paradox (2018)

Note: The left panel displays energy savings in euros as a percentage of net wealth, by income quartile. The right panel displays the current carbon footprint of households by income quartile, as measured by the CO2 emissions associated with their energy consumption. For more details, see Table 9.

households may be less likely to make home improvements and, when they do, the nominal PV of energy savings is relatively low, the amount they save relative to their wealth is particularly high. For the lowest quartile of income, the energy savings are 35.5% of net wealth while it is only 7.3% for the upper quartile. Instead, we find the opposite for CO2 savings. Households in the upper quartile save about 4 times more (4,000 euros versus 1,000 euros) given their current state of energy efficiency (sorting + home improvement) and their total savings (2.7 billion euros) represent 49.5% of the overall savings within a time frame of 15 years. Additionally, the remaining CO2 benefits in the upper quartile based on houses that are not yet energy efficient represent 38.0% (3.9 billion euros) of the overall remaining CO2 benefits and 90.5% of those benefits come from the owner-occupied housing sector. The difference in the distribution in energy savings relative to wealth, on the one hand, and CO2 emissions (savings), on the other — as summarized in Figure 4, also see Figure 1, Panel B — underlies the policy trade-off which we turn to next.[27]

Panel C reports the current level of (net) wealth inequality (Gini coefficient) and a welfare equivalent that weights in poverty more heavily (Atkinson index). To be more precise, the Atkinson index includes the inequality aversion parameter e. A low level of aversion is when $e = 0.5$, and a relatively high one when $e = 1.0$. Even higher aversion parameters tend to give results close to perfect inequality (i.e., index value of 1). Both indices are between 0 and 1 but we rescaled them to be between 0 and 100. The post (15 years) column indicates the

[27] This trade-off is also present in the 2021 data, see Figure H1. The difference in energy savings has become stronger as poor households were more negatively affected in terms of wealth during the Corona pandemic. Wealthy household have reduced their CO2 emissions most, but remain more brown than poor households.

Table 9 – Distribution of Wealth, Energy Savings, and CO2 benefits (2018)

Panel A: Current footprint per quartile of income				
	1^{st} Quartile	2^{nd} Quartile	3^{rd} Quartile	4^{th} Quartile
Mean Income (euros)	18,810	31,359	45,856	78,184
Utility costs (as % of income)	11.4	6.8	5.3	3.8
Gas costs (as % of utility costs)	52.4	51.5	50.4	50.5
Electricity costs (as % of utility costs)	39.5	40.2	41.1	41.2
Water costs (as % of utility costs)	8.1	8.3	8.4	8.3
CO2 emissions (euros, 15 years)	4,629	5,449	6,300	7,453
Gas (m^3/year)	1,131	1,313	1,487	1,754
Electricity (kWh/year)	2,118	2,683	3,314	3,984
Water (m^3/year)	71	96	120	143
Panel B: Savings per quartile of income				
PV of energy savings (euros, 15 years)	2,637	4,396	6,428	10,960
as % of median wealth	26.9	2.4	2.6	3.0
as % of median net wealth	35.5	7.1	7.2	7.3
PV of CO2 savings (euros, 15 years)	972	1,612	2,358	4,020
Total PV CO2 (mil. euros, 15 years)	582	839	1,297	2,705
as % of overall PV	10.7	15.4	23.7	49.5
Remaining CO2 savings (mil. euros, 15 years)	1,764	2,060	2,614	3,944
as % of overall remaining PV	17.0	19.8	25.2	38.0
in owner-occupied housing (%)	17.2	58.0	80.0	90.5
in social housing (%)	57.8	27.3	11.5	3.9

Panel C: Policy scenarios

Policy 1: The first quartile of income gets an energy-efficient house and home improvement.
Policy 2: Below median income gets an energy-efficient house and home improvement.
Policy 3: Everyone has the same energy-efficient house and the same level of home improvement.

	Post (15 years)	Policy 1	Policy 2	Policy 3
Inequality & Poverty				
Wealth Gini (current: 57.6)	57.3 (-0.5%)	57.4 (-0.3%)	57.2 (-0.7%)	56.7 (-1.6%)
Net Wealth Gini (current: 77.0)	76.1 (-1.2%)	76.6 (-0.5%)	76.2 (-1.0%)	74.4 (-3.4%)
Wealth Atkinson($e = 0.5$, current: 33.7)	33.3 (-1.2%)	33.2 (-1.5%)	32.8 (-2.7%)	31.9 (-5.3%)
Net Wealth Atkinson($e = 0.5$, current: 38.7)	38.5 (-0.5%)	38.6 (-0.3%)	38.5 (-0.5%)	37.8 (-2.3%)
Wealth Atkinson($e = 1.0$, current: 74.8)	71.7 (-4.1%)	70.5 (-5.7%)	68.6 (-8.3%)	65.5 (-12.4%)
Net Wealth Atkinson($e = 1.0$, current: 74.2)	72.6 (-2.9%)	71.7 (-3.4%)	70.9 (-4.4%)	69.0 (-7.0%)
Climate				
CO2 savings (mil. euros, 15 years)	8,962	+1,764	+3,824	+10,382
as % of all potential savings (Policy 3)	-	17.0	36.8	100.0
Costs				
100% funding (costs in bil. euros)		14.1	24.2	41.7
Low costs (3,000 euros per house)		7.1	12.1	20.9
High costs (9,000 euros per house)		21.2	36.4	62.6

Note: Based on the WoON-survey (2018). In panel A, we used a m^3 gas to MMBTU conversion factor of 0.0366, a KWh electricity to MMBTU conversion factor of 0.003404, and a MMBTU to CO2 conversion factor of 53.07kg. We assume 0.4kg CO2 per cubic meter of water and a social cost per ton of CO2 of 200 dollars (185 euros). In panels B and C, we use a 15-year investment horizon and a 5% discount rate. In panel B, the total and remaining savings, and in panel C, the inequality indices, CO2 savings, and funding costs are calculated using sampling weights. The calculations in panels B and C are based on the estimates shown in Table 7. The costs in panel C are based on 6,000 euros per household, where 9,000 is used as an upper bound and 3,000 euros as a lower bound.

level of inequality based on the current level of sorting into energy-efficient homes and home improvements. Surprisingly, both the net and overall wealth Gini-coefficients are expected to decrease over a 15-year, forward-looking, horizon. For example, the net wealth Gini-coefficient decreases from 77.0 in 2018 based on the actual wealth distribution to 76.1 (about -1.2%) based on the expected accumulated savings over a 15-year horizon.[28] Even though households in the higher quartiles are more likely to make home improvements and the CO2 benefits are nominally the highest, this is outweighed by the fact that households in the lowest quartile gain relatively more from having an energy-efficient house. This is even more salient when we look at the Atkinson indices. Next, we determine the implications of various policy scenarios given our estimation results. Policy 1 provides households within the lowest quartile that do not have an energy-efficient house and/or have done home improvements recently (i.e., Home improvement$_{i,t}$ and/or Energy efficiency$_{i,t}$ equals zero in Eq. (7)) an energy-efficient house. Policy 2 does the same for households below the median income. Policy 3 provides an energy-efficient house to all households. That is, after the policy, there is no difference in the level and adjustment rate of energy efficiency between households.

Policy 1 reduces inequality only slightly (compared to the status quo), but does lead to a significant reduction in poverty (Atkinson indices). Importantly, this policy only captures 17% of the overall potential CO2 benefits, leaving 83% unrealized (which are predominantly concentrated in the owner-occupied sector, see Panel B). Under Policy 2 the inequality-reducing effects become stronger, but 63% of the CO2 benefits remain unrealized, as these benefits stem from the upper part of the income distribution. Policy 3 performs best in terms of inequality and poverty reduction and captures the most CO2 benefits.[29] Paradoxically, if the objective is to achieve climate goals effectively, our results suggest that policymakers should also incentivize households with above-median incomes. This does not necessarily imply that we should *subsidize* wealthy households. Rather, our results indicate that we need to consider how to *incentivize* wealthy households as well (for example, through taxes or higher prices), as high-income households are also typically brown households.

Although the costs of such policies are difficult to estimate, Panel C also provides some

[28]This is based on the assumption that all energy savings feed into savings. Therefore, the estimated impact on the wealth distribution should be regarded as the effect on 'consumption equivalent' wealth.

[29]Inequality and poverty decline since there are many households in the lower part of the upper quartile of the income distribution who did not improve the energy-efficient of their home yet. As a result, this policy scenario reduces inequality within the upper quartile, and hence leads to the largest reduction in inequality overall.

indication about the costs. For our baseline, we assume that obtaining an energy-efficient house (through sorting or home improvements or a combination of both) costs 6,000 euros. We use a lower bound of 3,000 euros and upper bound of 9,000 euros.[30] For our baseline calculation, the cost ranges between 14 and 42 billion euros which is about 2.2% to 5.5% of GDP (764 billion euros). First, it is important to note that in all policies, the costs substantially outweigh the CO2 savings. This implies that changes in economic conditions and technological progress (leading to lower costs) or higher social costs of CO2 can make some of these policies worthwhile if the focus lies only on CO2 benefits (i.e., not factoring in poverty or inequality considerations), but these policies may currently not be very cost efficient, which is consistent with Fowlie et al. (2018).

Second, if we look at the highest impact on poverty (relative to the status quo), which is captured by the Atkinson of wealth, and examine the effects per billion euros invested, Policy 1 leads to 0.11% reduction in the Atkinson index and 0.13 billion euros CO2 savings, Policy 2 leads to 0.17% reduction in the Atkinson index and 0.16 billion euros CO2 savings, and Policy 3 leads to 0.20% reduction in the Atkinson index and 0.25 billion euros CO2 savings. Hence, our conclusions are unchanged when considering the effecr per (billion) euros invested.

Finally, we calculate by how large the social cost of carbon must be to ensure that the benefits of each policy equal the associated costs. specifically, we determine the break-even point based on the monetary value of CO2 savings. To break-even, the social cost of carbon must be 1,479 euros (1,608 dollars) per ton of CO2 for Policy 1. For Policy 2, the social cost of carbon must be 1,171 euros (1,273 dollars) per ton of CO2, and for Policy 3 they mus be 743 euros (808 dollars) per ton of CO2.[31] Although there is much uncertainty about the exact social costs of carbon, there are some projection om the evolution of those costs (in a business as usual scenario), see Lin and Van Wijnbergen (2023). These projections suggest that the break-even point is reached around 2090 for Policy 1, in 2080 for Policy 2, and in 2060 for Policy 3. If the frequency of climate disasters increases more than expected, this would lead to a steeper increase in the social cost of carbon and the break-even level will be reached sooner.

[30] Fowlie et al. (2018) report a retrofit cost of 4,585 dollars. Aydin and Brounen (2016) find that house prices in the Netherlands are 5,000 euros higher for an energy label A versus D. So it seems reasonable to assume that a combination of sorting and home improvement costs between 3,000 and 9,000 euros on average.

[31] Some estimates of the current social costs of CO2 are already around this range (1,056 dollars per ton of CO2, see Bilal and Känzig, 2024), while others suggest a more gradual increase which is in line with (uncertainty in) future economic growth (Van den Bremer and Van der Ploeg, 2021).

8. Conclusion

The transition to a green economy requires fundamental changes in the way in which firms produce, but also in the way in which households live. This paper sheds light on the critical intersection between household income, housing, and the transition to a green economy. Our results reveal that high-income households are more likely to make energy-efficient home improvements and tend to sort into energy-efficient homes. Both of these effects accumulate to 17% of median net wealth over a 15-year horizon. Most of this effect, about 65%, is not due to actively improving the energy efficiency of the existing home, but by presorting into energy-efficient homes. Hence, buying energy-efficient housing appears to be a key channel through which households become green. Although many policies focus on the intensive margin, there is real potential to help the energy transition through the extensive (supply side) margin as well via, for example, stricter building codes.

While high-income households contribute to a more sustainable living environment, the rate at which households become green is not equally distributed throughout society. Yet, unexpectedly, we find that wealth inequality will most likely decrease as a result. Although the level of wealth benefits for households at the bottom of the wealth distribution is lower and they are less likely to realize these benefits, the benefits they do receive by living in an energy-efficient home are disproportionately high relative to their wealth. However, we find that wealth inequality could be even lower if *all* households become green at the same pace. Moreover, if we try to alleviate poverty and shelter households below the median income against climate risk, it comes at the cost of less effectively reducing CO2 because 63% of the potential CO2 benefits are in the above median income group. This is even 83% when policy only focuses on the lowest quartile of income.

Although our study emphasizes the economic relevance of sustainable living choices, it also underscores the importance of recognizing the unequal distribution of efforts toward sustainability and the subsequent impact on the accumulation and distribution of wealth. As societies make efforts to mitigate climate change, it becomes imperative to design policies that not only promote ecological responsibility but also ensure an equitable transition to a green economy.

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Appendix A. Household Optimization Problem

Households maximize lifetime utility subject to their budget constraints. In the first period, households spend their income on purchasing housing capital and investing in energy efficiency, and save any remaining income. In the second period, households purchase energy and spend the remainder of their savings, including the resale value of their housing capital, on the purchase of the non-durable consumption good.

$$\max_{c_{i,t+1},e_{i,t+1},\mathbf{x}_{i,t},H_{i,t},S_{i,t}} U(c_{i,t+1}, e_{i,t+1}, H_{i,t}) = c_{i,t+1}^{\alpha} H_{i,t}^{\beta} e_{i,t+1}^{1-\alpha-\beta} \tag{A1}$$

$$s.t. \quad (y_i + A_{i,t}) \leq \left(p + \frac{\theta}{2}\mathbf{x}_{i,t}^2\right) H_{i,t} + S_{i,t}$$

$$c_{i,t+1} \leq (1+r)S_{i,t} + (p - (1-\mathbf{x}_{i,t})q \cdot e_{i,t+1}) \cdot H_{i,t}$$

$$c_{i,t+1}, e_{i,t+1}, \mathbf{x}_{i,t}, H_{i,t} \geq 0$$

The equilibrium is characterized by a system of equations. Specifically, the optimal investment in energy efficiency for a given household i in period t is given by

$$\mathbf{x}_{i,t}^{*} = \frac{q \cdot e_{i,t+1}^{*}}{\theta \cdot (1+r)}, \tag{A2}$$

which increases in the price of energy, q, as well as the amount of energy consumed, $e_{i,t+1}$. The optimal demand for energy is given by

$$e_{i,t+1}^{*} = \frac{(1-\alpha-\beta) \cdot c_{i,t+1}^{*}}{\alpha(1-\mathbf{x}_{i,t}^{*}) \cdot q \cdot H_{i,t}^{*}}, \tag{A3}$$

and the optimal demand housing is given by

$$H_{i,t}^{*} = \frac{\beta \cdot c_{i,t+1}^{*}}{\alpha\left[(1+r)\left(p + \frac{\theta}{2}\mathbf{x}_{i,t}^{*2}\right) - (p - (1-\mathbf{x}_{i,t}^{*})qe_{i,t+1}^{*})\right]}, \tag{A4}$$

The demand for the consumption good follows from the time $t+1$-spending constraint:

$$c_{i,t}^{*} = (1+r)\left((y_i + A_{i,t}) - \left(p + \frac{\theta}{2}\mathbf{x}_{i,t}^{*2}\right) H_{i,t}^{*}\right) + \left(p - (1-\mathbf{x}_{i,t}^{*})q \cdot e_{i,t+1}^{*}\right) \cdot H_{i,t}^{*}. \tag{A5}$$

Appendix B. Descriptive Statistics, WoON (2018)

Table B1 – Household, house characteristics, and energy expenditures (2018).

Variable	Mean	SD	Min	Max
Household Characteristics				
Spendable household inc.(euros)	43,490	31,203	11	1,274,501
Total wealth	264,771	299,400	0	2,498,334
Net wealth	152,846	250,575	-199,918	1,994,929
Age 17-24	0.023	0.149		
Age 25-34	0.133	0.340		
Age 35-44	0.146	0.353		
Age 45-54	0.193	0.395		
Age 55-64	0.202	0.401		
Age 65-74	0.180	0.384		
Age 75+	0.123	0.328		
Young child	0.086	0.281		
Partner	0.613	0.487		
Higher education	0.338	0.473		
House Characteristics				
House size (sq. mtr)	123.925	68.824	14.000	1,000.000
Construction < 1945	0.171	0.376		
Construction 1945-1959	0.090	0.286		
Construction 1960-1969	0.135	0.341		
Construction 1970 - 1979	0.179	0.383		
Construction 1980 - 1989	0.154	0.361		
Construction 1990 - 1999	0.123	0.329		
Construction 2000 - 2009	0.096	0.295		
Construction > 2010	0.052	0.223		
Single-standing	0.160	0.367		
Two under one roof	0.144	0.351		
Corner	0.130	0.336		
Row and other	0.295	0.456		
Flat	0.272	0.445		
Sector				
Social	0.247	0.431		
Rent	0.091	0.288		
Occupied	0.662	0.473		
Energy expenditures				
Annual gas expenditures (euros)	1,156	513	227	6,276
as part of income	0.036	0.047	0.001	1.935
Annual electricity expenditures (euros)	924	345	291	2,660
as part of income	0.028	0.039	0.001	1.955
Annual water expenditures (euros)	188	56	96	597
as part of income	0.006	0.008	0.000	0.486
Utility expenditures (euros)	2,268	748	624	8,822
as part of income	0.068	0.065	0.002	1.961
Heating type	1.777	1.789	1.000	8.000
Number of persons in hh	2.230	1.173	1.000	5.000

Note: Based on 56,283 observations from the WoON-survey (2018). For for net wealth, we have 55,418 observations. We restrict all energy expenditures as a share of income to be at most equal to two. We have 8 dummies for the different heating types (central heating boiler, wood-burning heating device, pellet stove, gas heater, heat pump, block/district heating, city heating, other). In our sample, 88% of respondents have a central heating boiler. The variable 'heating type' displays the average heating type.

Table B2 – Energy efficiency and home improvements (2018)

Variable	Energy Eff.	A-Label	B-Label	C-Label	D-Label	E-Label	F-Label	G-Label
Mean (Overall)	0.243	0.089	0.155	0.310	0.076	0.130	0.113	0.128
Social	0.198	0.090	0.108	0.365	0.048	0.265	0.077	0.047
Rent	0.198	0.085	0.114	0.226	0.030	0.192	0.070	0.283
Owner-occupied	0.266	0.089	0.177	0.300	0.092	0.071	0.132	0.140

Variable	Home Improv.	Glass	Insulation	Solar	Boiler	Other
Mean (Overall	0.568	0.263	0.196	0.085	0.346	0.089
Social	0.497	0.248	0.144	0.054	0.308	0.048
Rent	0.383	0.186	0.091	0.024	0.228	0.043
Owner-occupied	0.620	0.279	0.232	0.105	0.376	0.111

Note: Based on 56,283 observations from WoON-survey (2018). *Home improvements*-variable is a binary variable equal to 1 if a household has undertaken at least one type of home improvement measure in the last 5 years (double glazing, roof, wall or floor insulation, the installation of solar panels, or the installation of boiler panels, or other energy-saving facilities), and zero otherwise. *Energy efficiency*-variable is a binary variable based on the energy label of the house and equal to 1 if a household lives in a house with an A or B energy label, and zero otherwise. Energy labels range from A to G, with A being the most energy-efficient, G the least efficient.

Appendix C. Robustness: Effect of Income, WoON (2006)

Table C1 – Full Baseline Regression Results (2006)

	(1) Home Improv	(2) Energy Efficiency
Income	0.0268***	0.0331***
	(0.004)	(0.004)
Age	-0.0052***	0.0039***
	(0.001)	(0.001)
Age^2	0.0000***	-0.0000***
	(0.000)	(0.000)
Child	0.0190**	0.0164***
	(0.008)	(0.005)
Education	0.0024	-0.0073**
	(0.004)	(0.004)
Size	0.0200***	0.0075*
	(0.004)	(0.004)
Two under one roof	0.0185**	0.0226***
	(0.008)	(0.004)
Corner	0.0141*	0.0240***
	(0.008)	(0.005)
Row	0.0040	0.0144***
	(0.007)	(0.005)
Flat/apartment 1990-1999	0.0247	-0.0192
	(0.020)	(0.014)
Other House Type	-0.0254***	-0.0135*
	(0.008)	(0.007)
Construction 1945-1959	-0.0477***	0.0758***
	(0.007)	(0.008)
Construction 1960-1969	-0.0313***	0.1187***
	(0.007)	(0.007)
Construction 1970-1979	-0.0178**	0.1342***
	(0.007)	(0.007)
Construction 1980-1989	-0.0360***	0.1800***
	(0.008)	(0.007)
Construction 1989-1999	-0.1249***	0.1970***
	(0.009)	(0.008)
Construction > 1999	-0.1491***	0.2024***
	(0.009)	(0.008)
Observations	54,173	54,173
Adjusted R-squared	0.048	0.120

Note: This Table shows the full estimation results of Eq. (5) and Eq. (6). Standard errors are clustered at the municipality-level, *** p<0.01, ** p<0.05, * p<0.1.

Table C2 – Instrumental Variables Regression (2006)

	First Stage	Second Stage	
VARIABLES	Income (log)	Home Improv.	Energy Eff.
Divorce	-0.1938***		
	(0.0206)		
Marriage	0.2054***		
	(0.0151)		
Income (log)		0.0924*	0.0778*
		(0.0500)	(0.0416)
Weak Instruments (F-statistic)	194		
Hansen J (χ^2)		1.367	0.699
p-value		0.242	0.403
Household Characteristics	Yes	Yes	Yes
House Characteristics	Yes	Yes	Yes
Location FE	Yes	Yes	Yes
Observations	53,717	53,717	53,717
Adjusted R-squared	0.395	0.023	0.045

Note: Based on the WoON-survey (2006). The second-stage estimation results for Eq. (5) and Eq. (6) are reported in columns (2) and (3). We instrument income based on whether the reason for moving was a divorce or marriage (column 1). Standard errors are clustered at the municipality-level, *** p<0.01, ** p<0.05, * p<0.1.

Table C3 – Different Spatial Scale of Fixed Effects (2006)

	(1)	(2)	(3)	(4)	(5)	(6)
	Home Improvements			Energy Efficiency		
Spatial Scale	COROP	MUNICIP.	ZIPCODE	COROP	MUNICIP.	ZIPCODE
Income (log)	0.0288***	0.0285***	0.0268***	0.0285***	0.0279***	0.0331***
	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)
Household Characteristics	Yes	Yes	Yes	Yes	Yes	Yes
House Characteristics	Yes	Yes	Yes	Yes	Yes	Yes
Location FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	54,173	54,173	54,173	54,173	54,173	54,173
Adjusted R-squared	0.037	0.039	0.048	0.101	0.104	0.120

Note: Estimation results for Eq. (5) (columns 1-3) and Eq. (6) (columns 4-6), based on the WoON-survey (2006). We estimate the equations with OLS using (i) COROP, (ii) municipality and (iii) ZIP-code level fixed effects. Standard errors are clustered at the municipality-level, *** p<0.01, ** p<0.05, * p<0.1.

Table C4 – Logit, Multinomial Logit, and Nested Logit (2006)

	Logit	Logit	Multinomial Logit				Nested Logit			
	Home Imp.	Energy Eff.	En. Eff. (N) H. Imp. (N)	En. Eff. (N) H. Imp. (Y)	En. Eff. (Y) H. Imp. (N)	En. Eff. (Y) H. Imp. (Y)	En. Eff. (N) H. Imp. (N)	En. Eff. (N) H. Imp. (Y)	En. Eff. (Y) H. Imp. (N)	En. Eff. (Y) H. Imp. (Y)
Income (log)	0.2157***	0.1406***	-	0.1136**	0.2039***	0.3365***	-	0.1942	0.0583*	0.8518***
	(0.039)	(0.021)		(0.052)	(0.040)	(0.043)		(1.737)	(0.033)	(0.151)
Household Char.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
House Char.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Municipality FE	Yes	Yes	No	No	No	No	No	No	No	No
COROP FE	No	No	Yes	Yes	Yes	Yes	No	No	No	No
Province FE	No	No	No	No	No	No	Yes	Yes	Yes	Yes
Observations	52,786	54,088	54,173				54,173			
Pseudo R-squared	0.178	0.060	0.101				0.013			

Note: Logit, multinomial logit, and nested logit results for Eq. (5) and (6), based on the WoON-survey (2006). We estimate the equations with maximum likelihood. We report the log odds ratio effect of a standard deviation change in income (evaluated at the mean). The logit models include municipality fixed effects, the multinomial logit model region (COROP) fixed effects and the nested logit model province fixed effect. Standard errors are clustered at the COROP level, *** p<0.01, ** p<0.05, * p<0.1.

Table C5 – Other Robustness Checks (2006)

	Family Structure		Recent Movers		Winter		Unobserved House Char.		Sampling Weights	
VARIABLES	Home Imp.	Energy Eff.	Home Imp.	Energy Eff.	Home Imp.	Energy Eff.	Home Imp.	Energy Eff.	Home Imp.	Energy Eff.
Income (log)	0.0187***	0.0216***	0.044*	0.048**	0.0277***	0.0364***	0.015*	0.032***	0.0252***	0.0313***
	(0.005)	(0.004)	(0.025)	(0.023)	(0.006)	(0.006)	(0.008)	(0.006)	(0.005)	(0.005)
Partner	0.0166***	0.0236***								
	(0.004)	(0.004)								
Unobserved House Char.							0.003	0.012		
							(0.012)	(0.008)		
Household Char.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
House Char.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
ZIP code FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	54,173	54,173	3,443	3,443	26,551	26,551	21,472	21,472	54,173	54,173
Adjusted R-squared	0.049	0.121	0.194	0.108	0.044	0.119	0.057	0.120	0.082	0.160

Note: Robustness tests for Eq. (5) and (6), based on the WoON-survey (2006). We verify the robustness of our results against (i) controlling for family structure, (ii) focusing a sub-sample of recent movers, (iii) focusing on a sub-sample of households surveyed during the Winter, (iv) controlling for unobserved house characteristics, and (v) including sampling weights. Results for Eq. (5) are reported in the first column and for Eq. (6) in the second column, respectively. We estimate both equations with OLS, and include ZIP-code fixed effects and time fixed effects. Standard errors are clustered at the municipality-level, *** p<0.01, ** p<0.05, * p<0.1.

Appendix D. Replication of Baseline Regressions, WoON (2018)

TABLE D1 – REPLICATION BASELINE RESULTS

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Home Improvements					Energy Efficiency				
	Baseline	Sector	Social rent	Free rent	Owner-Occupied	Baseline	Sector	Social rent	Free rent	Owner-Occupied
Income (log)	0.0698***	0.0523***	0.0388***	0.0248**	0.0598***	0.0581***	0.0531***	0.0348***	0.0281***	0.0601***
	(0.005)	(0.005)	(0.013)	(0.010)	(0.006)	(0.008)	(0.007)	(0.009)	(0.009)	(0.007)
Social		-0.0560***					-0.0097			
		(0.008)					(0.013)			
Rent		-0.1385***					-0.0583***			
		(0.008)					(0.007)			
Household Characteristics	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
House Characteristics	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
ZIP-code FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	56,283	56,283	13,885	5,131	37,267	54,170	54,170	13,572	4,832	35,766
Adjusted R-squared	0.091	0.096	0.073	0.050	0.083	0.064	0.066	0.056	0.033	0.076

Note: Estimation results for Eq. (5) (columns 1 - 5) and Eq. (6) (columns 6 - 7), based on the WoON-survey (2018). We estimate both equations with OLS, and include COROP-code fixed effects and time fixed effects. Standard errors are clustered at the COROP-level, *** p<0.01, ** p<0.05, * p<0.1.

Appendix E. Home Improvement and Subsidies, WoON (2018)

Table E1 – Home improvement and Subsidies (2018)

VARIABLES	(1) Home Improv.	(2) Double Glass	(3) Insulation	(4) Solar	(5) Boiler	(6) Other
Income (log)	0.1420***	0.0670***	0.0545***	0.0221***	0.0942***	0.0308***
	(0.007)	(0.004)	(0.004)	(0.002)	(0.005)	(0.002)
Subsidy (yes/no)	0.4316***	0.2031***	0.2714***	0.5155***	0.1124***	0.1011***
	(0.008)	(0.012)	(0.026)	(0.025)	(0.008)	(0.007)
Household Characteristics	Yes	Yes	Yes	Yes	Yes	Yes
House Characteristics	Yes	Yes	Yes	Yes	Yes	Yes
ZIP-code FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	46,466	46,466	46,466	46,466	46,466	46,466
Adjusted R-squared	0.235	0.110	0.158	0.277	0.100	0.032

Note: Estimation results for Eq. (5) for various types of home improvement, based on the WoON-survey (2018). We estimate the equation with OLS, and include COROP-code fixed effects and time fixed effects. Standard errors are clustered at the COROP-level, *** p<0.01, ** p<0.05, * p<0.1.

Appendix F. Reasons for Home Improvement, WoON (2018)

Table F1 – Reasons for Doing and not Doing Home Improvements

VARIABLES	Observations	Mean	Std. Dev.
Necessary due to maintenance (1A)	23,485	0.426	0.494
Investment pays off (1B)	23,485	0.242	0.428
Make the home more pleasant (1C)	23,485	0.204	0.403
Environmental considerations (1D)	23,485	0.064	0.244
Agreed in homeowner's association (1E)	23,485	0.012	0.110
Enhance marketability of the home (1F)	23,485	0.011	0.106
Other reasons (1G)	23,485	0.0401	0.197

Panel A. Reasons for undertaking energy efficiency-enhancing home improvements.
Note: Based on Dutch survey data (WoON-survey) from 2018.

VARIABLES	Observations	Mean	Std. Dev.
Home is already energy efficient (2A)	11,310	0.384	0.486
Outside of my budget (2B)	11,310	0.167	0.373
Savings are insufficient (2C)	11,310	0.124	0.329
Don't know what the possibilities are (2D)	11,310	0.055	0.227
Don't want to renovate (2E)	11,310	0.069	0.253
Homeowner's association doesn't want this (2F)	11,310	0.020	0.141
Didn't get to it yet (2G)	11,310	0.224	0.417
Planning to move (2H)	11,310	0.060	0.238
Others (2I)	11,310	0.131	0.338

Panel B. Reasons for not undertaking energy efficiency-enhancing home improvements.
Note: Based on the WoON-survey (2018).

Table F2 – Reasons for Undertaking Home Improvements (regression results)

VARIABLES	(1) 1A	(2) 1B	(3) 1C	(4) 1D	(5) 1E	(6) 1F	(7) 1G
Income (log)	-0.0451***	0.0012	0.0212***	0.0266***	0.0026*	-0.0018	-0.0048
	(0.011)	(0.008)	(0.006)	(0.004)	(0.001)	(0.002)	(0.004)
Household Characteristics	Yes	Yes	Yes	Yes	Yes	Yes	Yes
House Characteristics	Yes	Yes	Yes	Yes	Yes	Yes	Yes
ZIP-code FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	23,104	23,104	23,104	23,104	23,104	23,104	23,104
Adjusted R-squared	0.039	0.028	0.033	0.032	0.109	0.002	0.034

Panel A. Reasons for undertaking energy efficiency enhancing home improvements.

Note: Estimation results for the various reasons to undertake home improvements, based on the WoON-survey (2018). We estimate the equation with OLS, and include COROP-code fixed effects and time fixed effects. Standard errors are clustered at the COROP-level, *** p<0.01, ** p<0.05, * p<0.1.

Table F3 – Reasons for Not Undertaking Home Improvements (regressions results)

VARIABLES	(1) 2A	(2) 2B	(3) 2C	(4) 2D	(5) 2E	(6) 2F	(7) 2G	(8) 2H	(9) 2I
Income (log)	0.0340***	-0.0980***	0.0176***	-0.0008	-0.0024	0.0013	0.0346***	0.0118***	0.0006
	(0.009)	(0.008)	(0.006)	(0.005)	(0.005)	(0.003)	(0.008)	(0.004)	(0.007)
Household Characteristics	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
House Characteristics	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
ZIP-code FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	11,109	11,109	11,109	11,109	11,109	11,109	11,109	11,109	11,109
Adjusted R-squared	0.134	0.059	0.021	0.012	0.020	0.110	0.059	0.006	0.017

Panel B. Reasons for not undertaking energy efficiency enhancing home improvements.

Note: Estimation results for the various reasons not to undertake home improvements, based on the WoON-survey (2018). We estimate the equation with OLS, and include COROP-code fixed effects and time fixed effects. Standard errors are clustered at the COROP-level, *** p<0.01, ** p<0.05, * p<0.1.

Appendix G. The COVID-19 Pandemic, WoON (2021)

Table G1 – Household, house characteristics, and energy expenditures (2021)

Variable	Mean	SD	Min	Max
Household Characteristics				
Spendable household inc.(euros)	50,438	48,038	32	1,306,182
Total wealth	321,770	343,135	0	2,497,365
Net wealth	206,457	285,328	-198,084	1,997,481
Age 17-24	0.025	0.155		
Age 25-34	0.138	0.345		
Age 35-44	0.147	0.354		
Age 45-54	0.176	0.381		
Age 55-64	0.198	0.399		
Age 65-74	0.184	0.388		
Age 75+	0.132	0.338		
Young child	0.081	0.272		
Partner	0.606	0.489		
Higher education	0.378	0.485		
House Characteristics				
House size (sq. mtr)	125.079	84.789	10.000	2,700.000
Construction < 1945	0.184	0.387		
Construction 1945-1959	0.079	0.270		
Construction 1960-1969	0.120	0.325		
Construction 1970 - 1979	0.161	0.368		
Construction 1980 - 1989	0.145	0.352		
Construction 1990 - 1999	0.126	0.332		
Construction 2000 - 2009	0.101	0.301		
Construction > 2010	0.084	0.277		
Single-standing	0.160	0.367		
Two under one roof	0.138	0.345		
Corner	0.126	0.332		
Row and other	0.281	0.449		
Flat	0.295	0.456		
Sector				
Social	0.229	0.421		
Rent	0.108	0.311		
Occupied	0.662	0.473		
Energy expenditures				
Annual gas expenditures (euros)	1,143	547	233	6,331
as part of income	0.0317	0.0450	0.002	1.916
Annual electricity expenditures (euros)	951	335	309	2,820
as part of income	0.026	0.037	0.001	1.988
Annual water expenditures (euros)	188	57	99	666
as part of income	0.005	0.008	0.000	0.488
Utility expenditures (euros)	2,282	780	713	8,427
as part of income	0.062	0.064	0.0014	1.942
Heating type	1.855	1.653	1.000	8.000
Number of persons in hh	2.221	1.174	1.000	5.000

Note: Based on 38,814 observations from the WoON-survey (2021). For for net wealth, we have 38,050 observations. We restrict all energy expenditures as a share of income to be at most equal to two. We have 8 dummies for the different heating types (central heating boiler, wood-burning heating device, pellet stove, gas heater, heat pump, block/district heating, city heating, other). In our sample, 86% of respondents have a central heating boiler. The variable 'heating type' displays the average heating type.

Table G2 – Energy efficiency and home improvements (2021)

Variable	Energy Eff.	A-Label	B-Label	C-Label	D-Label	E-Label	F-Label	G-Label
Mean (Overall)	0.448	0.277	0.171	0.264	0.134	0.072	0.047	0.036
Social	0.455	0.263	0.115	0.296	0.150	0.058	0.026	0.014
Rent	0.413	0.275	0.138	0.223	0.138	0.094	0.066	0.067
Owner-occupied	0.451	0.288	0.163	0.251	0.121	0.076	0.058	0.044
Variable	Home Improv.	Glass	Insulation	Solar	Boiler	Heat. Pump	Other	
Mean (Overall	0.526	0.173	0.143	0.153	0.288	0.011	0.087	
Social	0.474	0.199	0.146	0.115	0.270	0.008	0.048	
Rent	0.329	0.101	0.053	0.042	0.210	0.007	0.041	
Owner-occupied	0.576	0.176	0.157	0.185	0.308	0.013	0.108	

Note: Based on 38,814 observations from WoON-survey (2021). *Home improvements*-variable is a binary variable equal to 1 if a household has undertaken at least one type of home improvement measure in the last 5 years (double glazing, roof, wall or floor insulation, the installation of solar panels, or the installation of boiler panels, or other energy-saving facilities), and zero otherwise. *Energy efficiency*-variable is a binary variable based on the energy label of the house and equal to 1 if a household lives in a house with an A or B energy label, and zero otherwise. Energy labels range from A to G, with A being the most energy-efficient, G the least efficient.

Table G3 – Replication Baseline Results (2021)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Home Improvements					Energy Efficiency				
	Baseline	Sector	Social rent	Free rent	Owner-Occupied	Baseline	Sector	Social rent	Free rent	Owner-Occupied
Income (log)	0.0514***	0.0448***	0.0261**	-0.0013	0.0547***	0.0351***	0.0545***	0.0422***	0.0913***	0.0453***
	(0.005)	(0.006)	(0.012)	(0.012)	(0.006)	(0.009)	(0.008)	(0.010)	(0.014)	(0.015)
Social		-0.0092					0.0779***			
		(0.009)					(0.016)			
Rent		-0.1271***					0.0124			
		(0.008)					(0.016)			
Household Characteristics	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
House Characteristics	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
ZIP-code FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	38,814	38,814	8,907	4,208	25,699	22,862	22,862	8,551	2,790	11,521
Adjusted R-squared	0.083	0.088	0.074	0.022	0.075	0.030	0.033	0.034	0.056	0.058

Note: Estimation results for Eq. (5) (columns 1 - 5) and Eq. (6) (columns 6 - 7), based on the WoON-survey (2021). We estimate both equations with OLS, and include COROP-code fixed effects and time fixed effects. Standard errors are clustered at the COROP-level, *** p<0.01, ** p<0.05, * p<0.1.

Appendix H. Energy Expenditure Regressions, WoON (2006, 2018, 2021)

Table H1 – Energy expenditure regressions (2006)

VARIABLES	(1) Gas/Income	(2) Electricity/Income	(3) Water/Income	(4) Utility/Income
Home improvements	-0.0012***	-0.0011***	-0.0002***	-0.0026***
	(0.0004)	(0.0003)	(0.0001)	(0.0007)
Energy efficiency	-0.0070***	-0.0027***	-0.0005***	-0.0100***
	(0.0009)	(0.0006)	(0.0001)	(0.0013)
Household Characteristics	Yes	Yes	Yes	Yes
House Characteristics	Yes	Yes	Yes	Yes
Location FE	Yes	Yes	Yes	Yes
Observations	54,169	54,169	54,169	54,169
Adjusted R-squared	0.174	0.107	0.707	0.152

Note: Estimation results for Eq. (7) for various types of energy expenditure, based on the WoON-survey (2006). We estimate the equation with OLS, and include ZIP-code fixed effects and time fixed effects. Standard errors are clustered at the municipality-level, *** p<0.01, ** p<0.05, * p<0.1.

Table H2 – Present value of average savings (2006)

Investment horizon		$\rho = 0.02$	$\rho = 0.05$	$\rho = 0.08$
10-year horizon	in euros	3,512	3,019	2,624
	as % of median net wealth	10.6	9.1	7.9
15-year horizon	in euros	5,024	4,058	3,347
	as % of median net wealth	15.2	12.3	10.1
20-year horizon	in euros	6,393	4,873	3,839
	as % of median net wealth	19.3	14.7	11.6

Note: Based on the WoON-survey (2006). We use median net wealth (which includes any private residence) as reported by CBS in 2006, which is 33.100 euros. The real interest rate is based on a nominal interest rate of 4, 7 and 10% respectively, and an inflation rate of 2%. With a nominal interest rate of 7%, the payback period is 10 years.

Table H3 – Robustness: Energy expenditure regressions (2018,2021)

VARIABLES	(1) WoOn-2021	(2) Quantile	(3) Interaction	(4) Other home impr.	(5) IV income	(6) Final eq.
Home improvements	-0.0018***	-0.0087***	-0.0052***	-0.0040***		-0.0228***
	(0.0005)	(0.0010)	(0.0007)	(0.0005)		0.0050
Energy efficiency	-0.0079***	-0.0178***	-0.0097***	-0.0091***		-0.0204***
	(0.0006)	(0.0009)	(0.0010)	(0.0008)		(0.0016)
Home impr.x Energy eff.			0.0018			
			(0.0012)			
Dormer or roof structure				0.0022**		
				(0.0010)		
Extension or sun-room				0.0034***		
				(0.0009)		
Kitchen or bathroom				0.0022***		
				(0.0007)		
Adjusted house plan				0.0032***		
				(0.0009)		
Divorce					-0.1749***	
					(0.0160)	
Marriage					0.1010***	
					(0.0128)	
Household Characteristics	Yes	Yes	Yes	Yes	Yes	Yes
House Characteristics	Yes	Yes	Yes	Yes	Yes	Yes
Location FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	22,723	53,782	53,782	53,782	53,782	53,782
Adjusted R-squared	0.115	0.143	0.108	0.109	0.392	0.025

Note: Robustness tests for Eq. (7). We include COROP-code fixed effects and time fixed effects. In column 2 we look at the 95% quantile for utility expenditures relative to income. Columns 5 and 6 are based on the estimation of a system of equations, in which income, home improvements, energy efficiency and utility expenditures are used as dependent variables. For the quantile regression, we report the Pseudo-R^2. For the IV estimation, we report the R^2. Standard errors are clustered at the COROP level, *** p<0.01, ** p<0.05, * p<0.1.

Table H4 – Heterogeneity: Energy expenditure regressions (2018)

VARIABLES	(1) Utility/Income	(2) Utility/Income	(3) Utility/Income	(4) Utility/Income
Home improvements	-0.0047***		-0.0049***	
	(0.001)		(0.001)	
Double Glass		-0.0004		-0.0005
		(0.001)		(0.001)
Insulation		-0.0022***		-0.0031***
		(0.001)		(0.001)
Solar		-0.0071***		-0.0066***
		(0.001)		(0.001)
Heating		-0.0017***		-0.0016***
		(0.001)		(0.001)
Other		-0.0031***		-0.0031***
		(0.001)		(0.001)
Energy Efficiency	-0.0088***	-0.0086***		
	(0.001)	(0.001)		
A-Label			-0.0161***	-0.0156***
			(0.002)	(0.002)
B-Label			-0.0141***	-0.0143***
			(0.002)	(0.002)
C-Label			-0.0100***	-0.0101***
			(0.001)	(0.002)
D-Label			-0.0042***	-0.0040***
			(0.001)	(0.001)
E-Label			-0.0050*	-0.0050*
			(0.003)	(0.003)
F-Label			-0.0047***	-0.0047***
			(0.002)	(0.002)
Household Characteristics	Yes	Yes	Yes	Yes
House Characteristics	Yes	Yes	Yes	Yes
Location FE	Yes	Yes	Yes	Yes
Observations	53,822	53,822	53,822	53,822
Adjusted R-squared	0.002	0.001	0.002	0.001

Note: Estimation results for Eq. (7) for various types of energy expenditure, based on the WoON-survey (2018). We estimate the equation with OLS, and include COROP-code fixed effects and time fixed effects. Energy label F is the reference category for energy labels. The home improvements are not mutually exclusive and thus do not have a reference category. Standard errors are clustered at the COROP-level, *** p<0.01, ** p<0.05, * p<0.1.

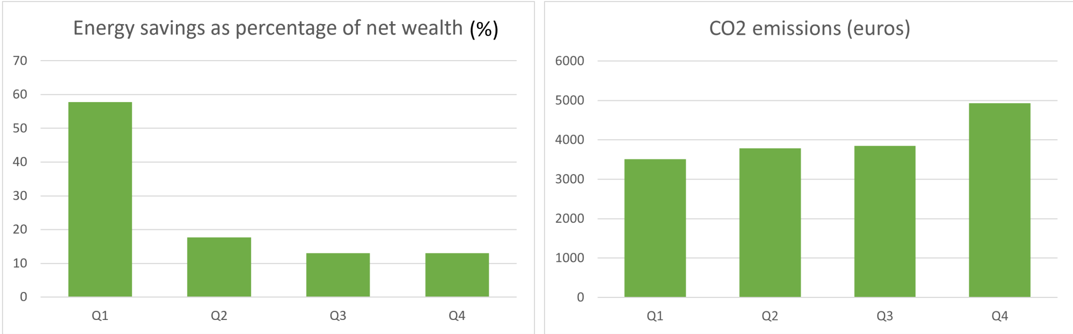

Figure H1 – The energy-efficiency paradox (2021)

Note: The left panel displays energy savings in euros as a percentage of net wealth, by income quartile. The right panel displays the current carbon footprint of households by income quartile, as measured by the CO2 emissions associated with their energy consumption.