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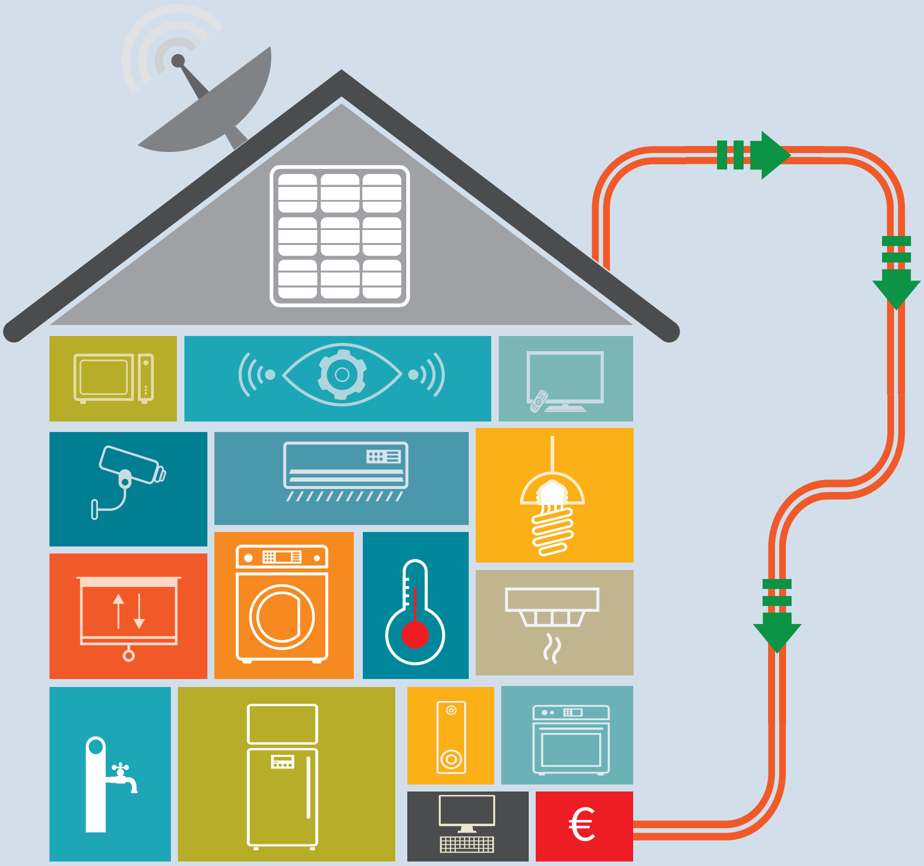

Energy Poverty in Europe

How Energy Efficiency and Renewables Can Help

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The study is printed in this form to communicate the result of an analytical work with the objective of generating further discussions on the issue.

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This study was drafted by Edo Omic (Economist) under the supervision of Jérôme Halb (Director of Corporate Responsibility & Studies Department, Deputy Director for European Cooperation & Strategy).

March 2019

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Overview of Key Findings

Energy poverty is an enduring issue that disproportionately affects the most vulnerable households in Europe. The term 'energy poverty' has no universal definition, but typically means that households spend an unreasonably high proportion of their income on energy or that households are unable to afford to meet basic energy needs. The causes of energy poverty can be multidimensional, stemming from low incomes, poor quality homes, and energy inefficient appliances.

An estimated 30 million people live in energy poverty[1]. While energy poverty rates are highest in Southern and Central-Eastern European countries, the problem is European-wide. High rates of energy poverty correlate with higher at-risk-of-poverty rates, food poverty (i.e. inability to afford basic food staples) and, at times, with higher rates of self-reported health issues.

Energy prices and income levels influence energy consumption to different degrees of magnitude and in different directions. In the short run, changes in prices of energy (be it electricity or gas) or in household income levels have a small impact on household energy consumption. However, in the long run, household demand for electricity tends to be price-inelastic (i.e. a 1% change in price does not equate to a proportional change in consumption) unlike the demand for gas which is price elastic (i.e. the % change in consumption is higher than a 1% change in price). Increases in prices therefore either force households to spend more money for a similar level of consumption (electricity) or even to forgo using the source of energy (gas). On the other hand, a rise in income in the long term is associated with an increase in the consumption of either electricity or gas and should thus help reduce energy poverty rates.

Governments across Europe are working to implement more policies to promote energy efficiency in homes. In the last 20 years, energy efficiency has gained increased importance and the number of related policies has ballooned. While many governments still employ housing and energy subsidies to help, in part, to combat energy poverty issues in the short run, the long-term trend towards energy efficiency contributes to improving the quality of homes and to reducing the energy cost burden to low-income households – and the need for subsidies.

The push for renewable energy will be a crucial driver to combat energy poverty when accompanied by household energy efficiency improvements. Renewable energy has become more common as a household energy source. As renewable energy technology develops and capacity increases, the marginal cost of renewables will continue to fall, making them affordable alternatives to conventional energy sources.

The study's empirical analysis shows that energy efficiency improvements and related regulatory policies contribute to decreases in household energy consumption and energy poverty rates. The econometric results find that household energy spending can decrease by 0.24% to 0.71% after a one-point (approx. 1%) increase in the household energy efficiency score. Moreover, several years after governments undertake and implement policies that set minimum regulatory standards on household energy efficiency, household energy consumption may drop by 0.22% (for one low-impact policy, but the effect increases with high-impact policies). Energy poverty rates also tend to drop by 0.21% when energy efficiency index scores increase by one point, thus showing the direct effect of energy efficiency in helping reduce energy-related economic vulnerability.

[1] Here defined as the inability to keep a home warm.

Chapter 1 – Energy Poverty and Energy Markets in Europe

Introduction

Energy poverty remains a systemic problem throughout Europe as low-income households are forced to make the hard decision of cutting energy spending (specifically heating) so that they may be able to afford other necessities.

There are multiple causes for energy poverty, ranging from low incomes, poor quality houses, and energy inefficient appliances. The highest rates of energy poverty are concentrated in Southern and Central-Eastern European countries, but even in Western Europe, millions of people remain energy poor. This energy poverty translates into lower standards of living and poor health outcomes.

Energy markets have, at times, been volatile and, on occasions, this has translated into changes in household consumption patterns. However, on average, household energy consumption in Europe appears to be weakly sensitive to price changes (and even to household income changes), thereby underlining its role as a necessary good. This is worrying given that, in the majority of European states, energy prices have been growing faster than the real incomes of those at the bottom of the income distribution.

This chapter presents a brief summary of a complex and well-researched topic. We aim to give the reader a snapshot of what energy poverty has looked like in recent years, how energy markets have affected the poor, and what kind of continued efforts will be needed to tackle the issue.

30 million Europeans live in energy poverty: the estimated number of those who cannot keep their homes warm.

18 countries have seen incomes of the bottom 20% grow more slowly than increases in energy price levels since 2007/08.

At-risk-of-poverty rates tend to be higher in countries with high rates of energy poverty.

The State of Energy Poverty

The fundamental cause of energy poverty is a combination of household income, access to affordable energy, and quality of the home (Bouzarovski 2014, Thomson, Snell and Liddell 2016). As Thomson et al (2016) put it, households that are energy poor either spend a disproportionately high amount of income on energy (at the cost of other needs such as adequate food) or simply limit spending on energy and accept a lower standard of living (i.e. not heating their homes during colder periods), and households are often forced to do both.

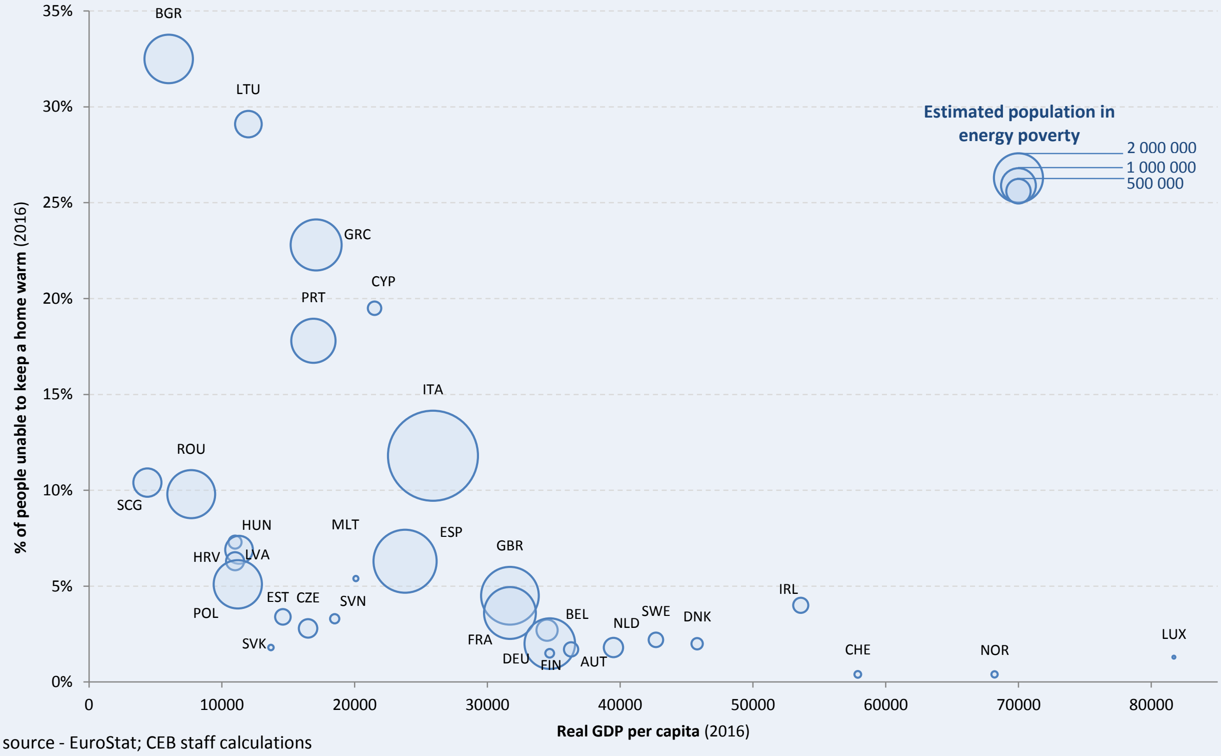
The highest rates of energy poverty are most pronounced in those European countries below mean and medium European GDP (see figure 1.1). High levels of energy poverty are concentrated in Southern and Central-Eastern Europe, where energy poverty is often the result of lower quality homes, tenure status, infrastructure access and the privatisation of energy markets (Bouzarovski 2014, Dheret and Giuli 2017). In Western Europe, energy poverty is driven by low incomes and energy-inefficient homes. Although energy poverty rates are relatively lower in Western Europe, in a number of countries such as France and Germany the gross numbers of energy-poor households are very high.

Info Box 1 - **What is energy poverty?**

There is no universally accepted definition of energy poverty and between European countries various definitions exist. The energy poverty definitions that do exist (approx. for a third of countries in Europe) can generally be divided into two categories: (1) one that focuses on the disproportionately high share of household income spent on energy; (2) one that focuses on households that do not spend enough on energy (Rademaekers, et al. 2016). However, these general categories represent a highly abridged explanation of what is, in fact, a multifaceted topic involving economic, social, behavioural, policy, spatial and temporal dynamics (Thomson, Bouzarovski and Snell 2017) .

In an effort to create more accessible data on the topic, Eurostat offers two main variables that try to measure energy poverty; (1) the % of the population that are unable to keep their homes adequately warm; (2) the share of the population with arrears on their utility bills. For the purposes of this paper we focus primarily on the first variable (1).

Figure 1.1 - GDP per capita correlated with energy poverty



source - EuroStat; CEB staff calculations

The countries with more low-quality housing tend to see higher levels of energy poverty. Often households that live in low-quality homes with poor insulation will spend a large share of their disposable income on heating such energy inefficient homes. Typically, the residents of these types of homes are highly vulnerable and already have limited/strained disposable incomes. As is shown in Figure 1.2, countries with a high share of the population living in deprived homes have a correlated high share of people who are unable to keep their homes warm.

There are an estimated 32 million people living in energy poverty in Europe. Nearly 85% of the total number of people in energy poverty can be found in 10 of 32 European states – Portugal, Romania, Poland, Bulgaria, Germany, Greece, France, the United Kingdom, Spain, and Italy. The problem of energy poverty is not just a rich or poor European country problem. Countries that have more than enough resources to combat energy poverty still face considerable energy poverty challenges.

Countries with high levels of energy poverty have higher at-risk-of-poverty rates. While a high at-risk-of-poverty rate is a combination of many factors (such as employment status, health of the economy, extent of public support, etc.), the high cost of trying to keep a home warm can be a considerable contributor (especially for low-income families). Typically, when national energy poverty rates are below 5%, the at-risk-of-poverty rate is at or below 25% (or vice-versa, as either can affect the other); thereafter the rates tend to jump up substantially (see figure 1.3).

Figure 1.2 - Low-quality dwellings correlated with energy poverty

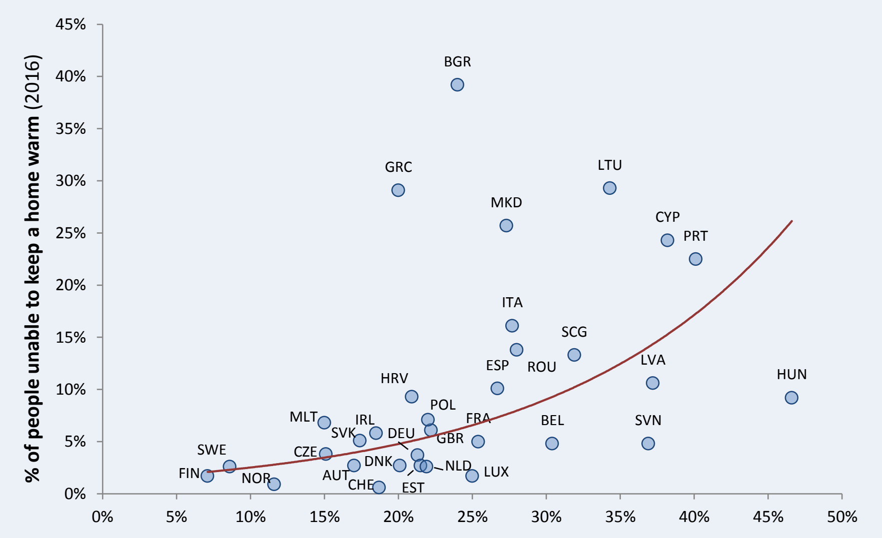


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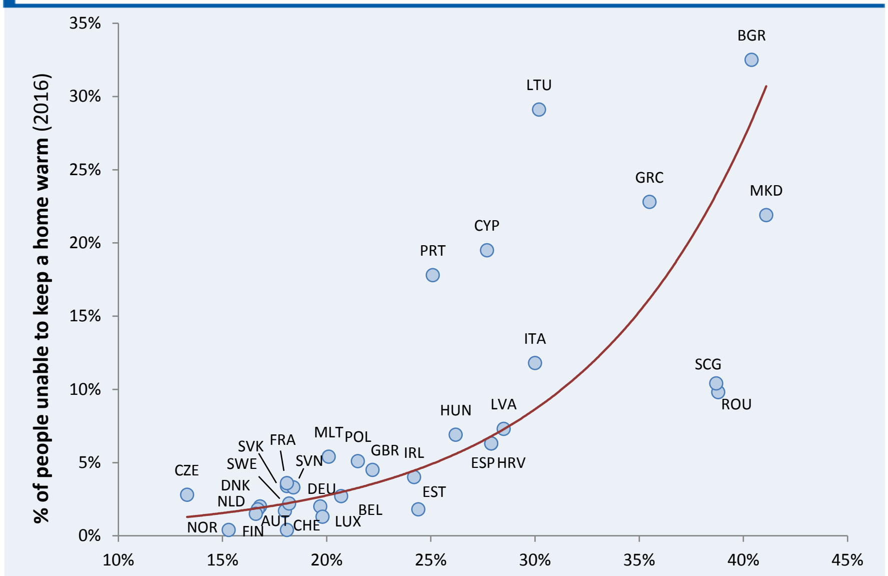
Figure 1.3 - At-risk-of poverty rate and energy poverty



source - EuroStat

Those in the bottom 20% of the income distribution have considerably higher rates of energy poverty than national averages. As can be seen in figure 1.4, in every country, the energy poverty rates of the bottom 20% are typically two to six times higher than the national averages. The differences are starkest in Southern and Eastern Europe. In the case of Lithuania, energy poverty is a nationwide problem that affects people in many income quintiles.

Figure 1.4 - Energy poverty of the bottom 20% vs. average population

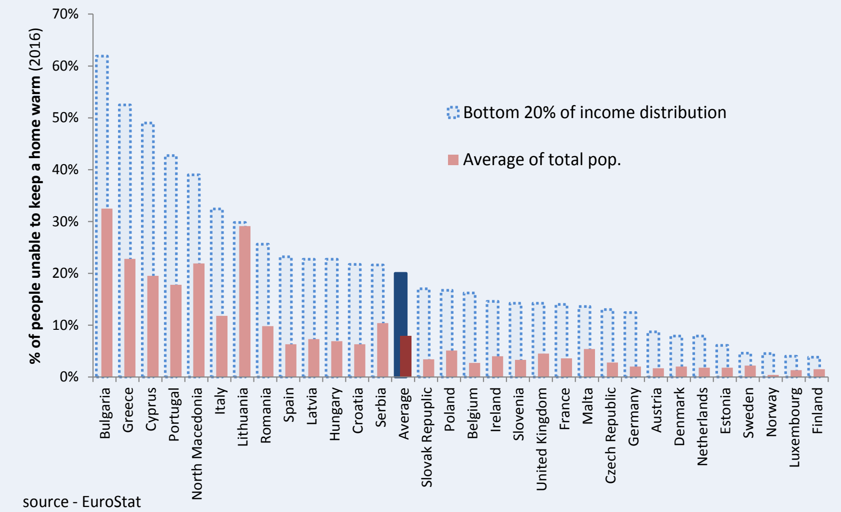


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Figure 1.5 - Food poverty and energy poverty

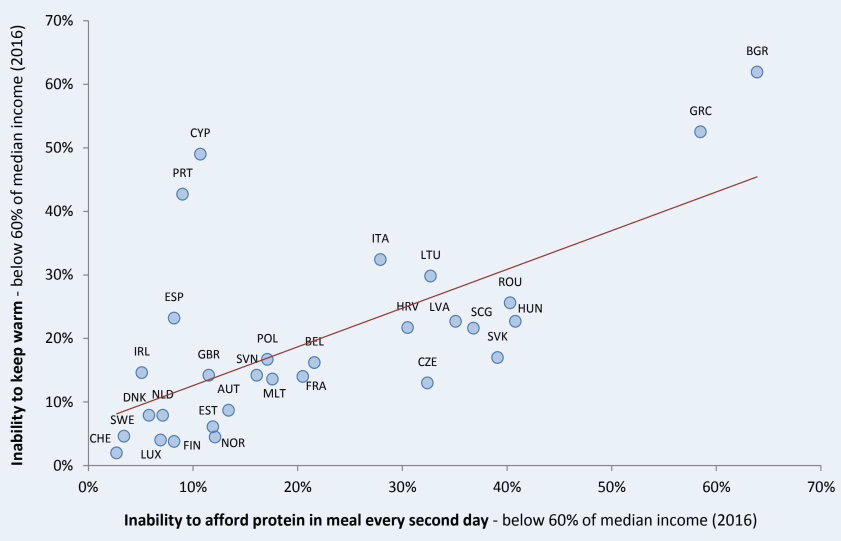

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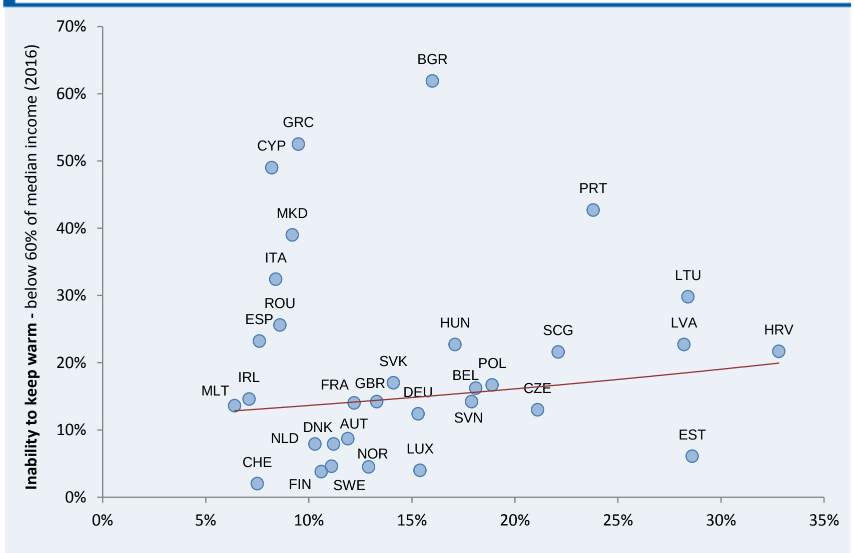
Figure 1.6 - Self-reported health and energy poverty



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High rates of energy poverty often coincide with food poverty. Energy-poor households are, at times, forced to "prioritise" between spending on energy and other daily necessities such as food (see figure 1.5). While this report analyses the inability to afford protein-based food, other studies have shown that, in comparison to non-fuel poor households, fuel poor ones often eat less fruit, vegetables and whole-grains, and are more likely to eat cheaper processed, sugary and fried foods (Healy 2004, Marmot Review 2010). Households that are forced to sacrifice one essential good over another risk increasing their material deprivation and may get into debt (or become further in debt) in order to afford all the necessary goods in the short term (EU 2016).

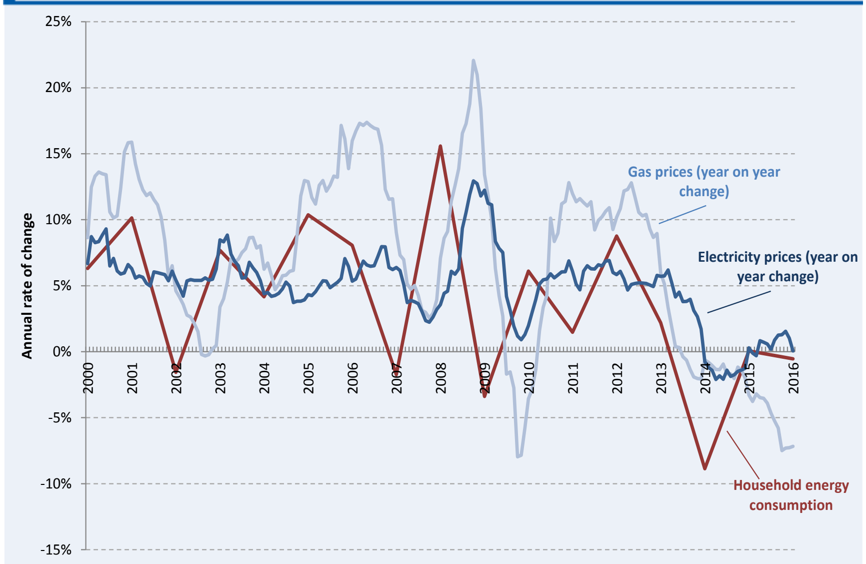
Poor health outcomes are reported in countries with high rates of energy poverty. As can be seen in figure 1.6, in a number of those countries, levels of bad or very bad self-reported health are relatively high. Admittedly, in a number of countries with high rates of energy poverty, poor health is not a major problem as health outcomes can be the result of a multitude of different factors (from life choices, availability and affordability of medical services, etc.). However, in general, fuel poor households live in colder homes and are potentially unable to afford other necessities (clothes and food), and maybe unable to afford medical services. All of this can exacerbate poor health and worsen long-term illnesses (Liddell and Morris 2010, Evans, et al. 2000). Studies have shown that fuel poor households are more likely to use medical services

(GPs, outpatient care, etc.) and children in such households are 30% more likely to visit a hospital or primary care physician (Lidell 2008, Thomson 2011).

Households and the Energy Market

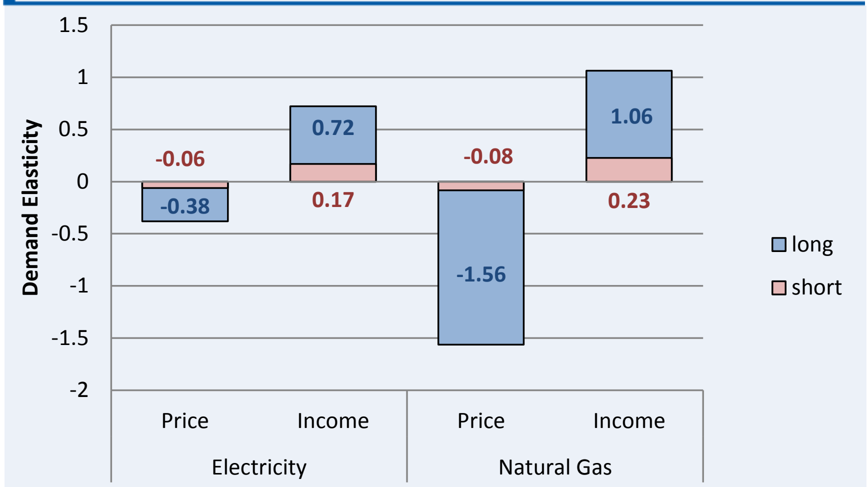
Household gas and electricity prices have historically had similar volatility patterns. However, as can be seen in figure 1.7, gas prices tend to be slightly more volatile than electricity prices and, since 2015, they have begun to diverge from one another.

Figure 1.7 - Energy price changes and consumption



source - EuroStat; CEB staff calculations

Figure 1.8 - Elasticity of demand – short- and long-term by energy



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For the most part, year-on-year changes in household energy consumption tend to respond positively to drops in energy prices; however, there is typically a one-year lag effect before consumption patterns change[1]. Figure 1.7 shows that households, especially those with low incomes, face higher costs to heat their homes when price changes happen suddenly (especially in an era of stagnate income growth – discussed in more detail below).

Household energy demand is relatively price- inelastic for electricity but elastic for natural gas, and has positive income-demand elasticity for both electricity and natural gas. As can be seen in figure 1.8, in the short term, a 1% increase in the price of electricity or gas will have a weak corresponding decrease of -0.06% and -0.08% in consumption – thus demand price is inelastic (i.e. only minor changes in consumption due to prices, as energy goods can be considered essential). In the long run, a 1% increase in prices will decrease household consumption of electricity by -0.38% – indicating that price elasticity of demand remains relatively low – but for gas it would fall by -1.56% – indicating natural gas is price elastic.

When household incomes increase by 1% in the short run, there is a slight uptick in consumption of electricity by 0.17% and gas by 0.23% - thus energy goods behave as necessity goods (i.e. normal goods that households will not reduce consuming even during difficult times). In the long run, the same increase in incomes corresponds to consumption increases of 0.72% for electricity and 1.06% for natural gas. While the consumption of both types of energy goods (gas and electricity) is sensitive to price and income

[1] This is, in part, a limitation of consumption data: while prices in the energy markets are available on a monthly time series, aggregate household consumption time-series data is often narrower (often on an annual basis).

changes, the degree of sensitivity is more pronounced for natural gas throughout the continent.

Households' long-term price elasticity of demand for electricity tends to be low throughout Europe. In figure 1.9, we correlate long-term price elasticity of demand for electricity with the percentage of the low-income population having difficulty in keeping their homes warm. Most countries with high levels of energy poverty tend to see household electricity consumption as relatively price inelastic. This indicates that, when prices fluctuate, households will not alter their consumption patterns proportionately. For poor households this means they will pay more for a nominally similar quantity of electricity, at the cost of reducing their consumption of other goods, including those that can help them combat their vulnerability (e.g. better education, etc.).

Growth in incomes is associated with higher energy consumption in some European countries. In nine of the twenty-one countries in our analysis, a 1% increase in household incomes is associated with an increase in electricity consumption of over 1% (see figure 1.10), indicating that here electricity is behaving as a superior good. However, for the remaining twelve countries, electricity demand does not rise disproportionately above income growth (i.e. behaves like a normal necessity good). In figure 1.10 income elasticity tends to be below one in countries with high and low energy poverty rates. A

Figure 1.9 - Energy price changes and consumption

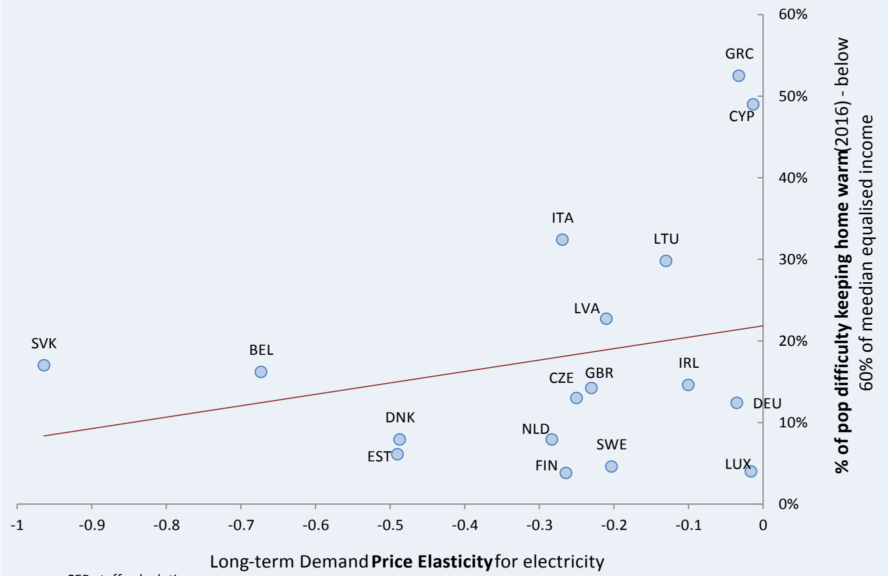

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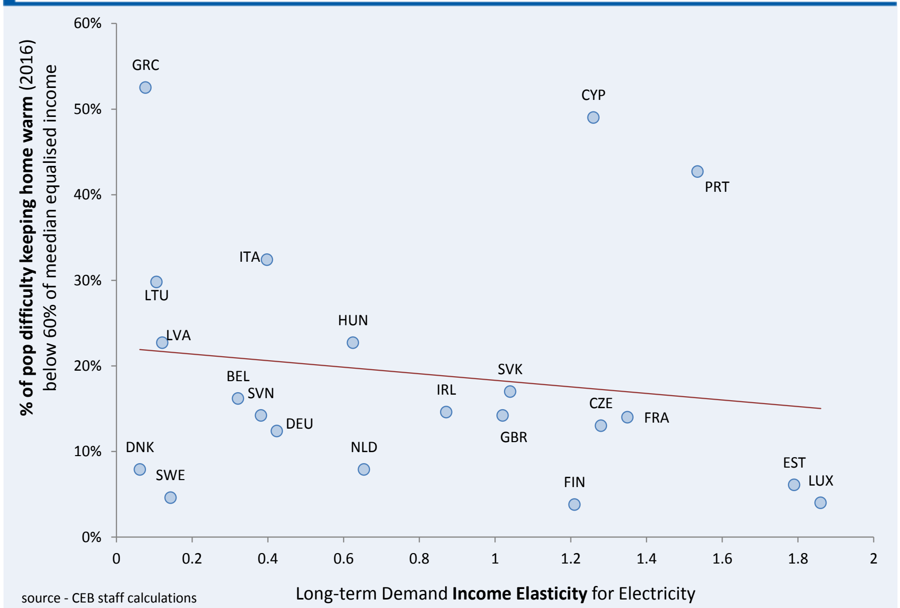
Figure 1.10 - Income changes and energy consumption



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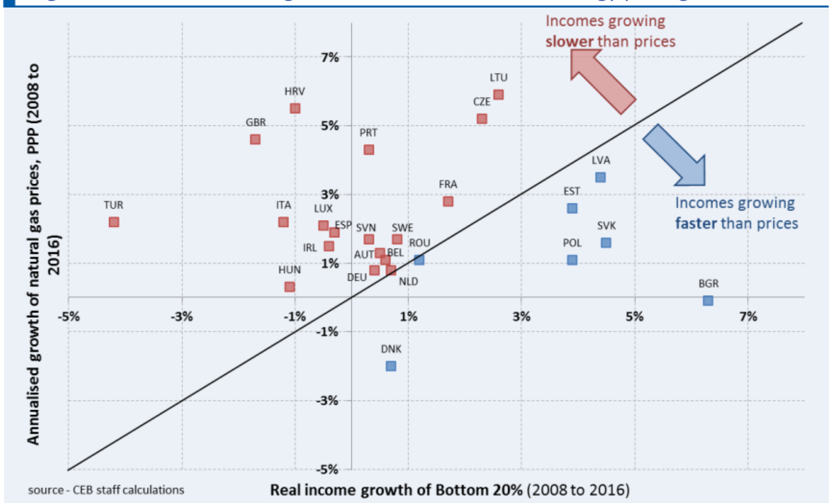
partial explanation may lay in the fact that some countries with low-energy poverty rates have already made considerable efforts towards transitioning to more energy efficient homes, thus dampening increased consumption. While for the countries with higher energy poverty rates the increases in incomes potentially being dedicated to other necessity goods.

Real income growth for those in the bottom 20% has been slower than energy prices since 2007/08. For those in the bottom 20% of the income distribution, real incomes have either stagnated (less than 1% annual growth) or, worse, contracted since 2008 (see figure 1.11). In 18 countries, energy prices are growing faster than real incomes for the bottom 20% (red boxes in figure 1.11 below). In almost all of these countries, energy-related goods are highly price inelastic. This means that, when prices increase, there will be no corresponding decrease in consumption because energy is a necessity good. Thus, as incomes shrink or stagnate, the price inelasticity may imply that poor households will spend a higher share of their disposable income on energy. This threatens to make their situation even more vulnerable as they may be forced to sacrifice spending on energy or other goods, thus lowering their overall standard of living.

Figure 1.11 - Real income growth of bottom 20% and energy price growth



Chapter 2 – Housing Policies and Energy Efficiency Regulations

Introduction

Energy poverty has multiple causes which often build upon each other: low incomes make it hard to pay energy bills, increasing prices compound those income constraints and, in turn, limit the funds available to live in energy efficient homes or upgrade to energy efficient appliances, resulting in wasteful use of costly energy, and thus perpetuating the cycle.

For many governments, it has become imperative to break this cycle through policies and subsidies to ensure that low-income households escape heightened vulnerability resulting from energy poverty. To this end, there is a wide array of different policy approaches that governments can and do undertake, but seldom do they all make the same policy choices.

This chapter presents a brief quantitative overview of the various energy subsidies and energy efficiency polices that European governments have undertaken to combat both immediate and future energy poverty issues. In the short term, many governments use energy subsidies to help low-income households meet the costs of energy bills, with richer countries naturally having more funds available to do this. In the long run, improving the energy efficiency of homes will reduce the overall number of people in energy poverty and simultaneously reduce the need for subsidies, thus increasing available public funds for other socially-needed investments.

0.6% of GDP is the average amount governments spend on housing and social exclusion subsidies.

451 energy efficiency policies
are currently active in Europe to help finance, improve standards, and inform about energy efficiency in homes.

9 million fewer people in energy poverty since 2005
(estimates) in a period of overall positive economic growth and increased energy subsidies and energy efficiency policies.

Social Assistance Policy

Governments across Europe are, or are becoming, more aware of energy affordability issues among their citizens, especially when they experience economic hardship or sharp spikes in energy prices. An immediate response to help tackle energy affordability is to provide subsidies to soften the blow of such circumstances. However, such polices are short-term in nature as they do not incentivise the development of energy efficiency measures and, if poorly designed, may have distortive price effects in the energy market.

Government social transfers

Those countries that are able to devote more of their budgets to help low-income households cover the costs of housing and social exclusion often tend to see lower rates of energy poverty (see figure 2.1). However, countries that are able to devote more funding often have the economic means to do so. That being said, relatively well-off Italy spends less than 0.2% of GDP on housing-related subsidies. In comparison, the average European level of public spending on housing and social exclusion currently stands at 0.6% of GDP.

Info Box 2 - **An imperfect measure for energy subsidies**

Due to the lack of any universal variable to measure energy subsidies to poor households, this paper uses as a proxy data on government spending on housing and social exclusion subsidies, from the Eurostat ESSPROS database. This is not ideal as such expenditure captures a wide range of social protection transfers that governments offer to low-income individuals to pay for housing-related expenses such as rent, to obtain social housing from public and non-profit housing providers, and to pay for fuel benefits. Spending can also include non-housing related transfers to prevent social exclusion, such as assistance in carrying out daily tasks, legal aid, food, clothing – essentially any government transfer not elsewhere specified in the ESSPROS database. Some governments identify fuel subsidies as a direct transfer to help cover costs while others classify them under the broader umbrella of overall housing transfers. Since it is hard to disaggregate these, this paper uses the above housing-related transfers. However, further research should be focused on this specific data problem.

In three out of five countries, the level of funding devoted to housing and social exclusion spending increased from 2000 to 2015 (see figure 2.2). Most of these increases occurred in Northern Europe, where spending levels were high to begin with (see figure 2.2). In Western Europe, average spending levels have stagnated since the 2008 financial crisis, but still remain well above the 0.6%-of-GDP average. In contrast, spending on housing and social exclusion has either fallen or remained below average levels in Southern, Central, and Eastern Europe (regions that include countries with the highest energy poverty rates).

Household Energy Efficiency

Fuel poverty is the result of an intersection between income poverty, high energy prices and poor energy efficiency homes (Bouzarovski 2014). European countries with high rates of fuel poverty often have high rates of low quality dwellings (i.e. poor insulation) as was shown in chapter 1. As the EU (2016) has emphasised, low-income households can become stuck in a "vicious cycle of energy poverty", since they are unable to afford energy efficient homes and home appliances, and this can result in increased consumption of costly energy that ends up being wasted.

Figure 2.1 - Spending on social housing and energy poverty

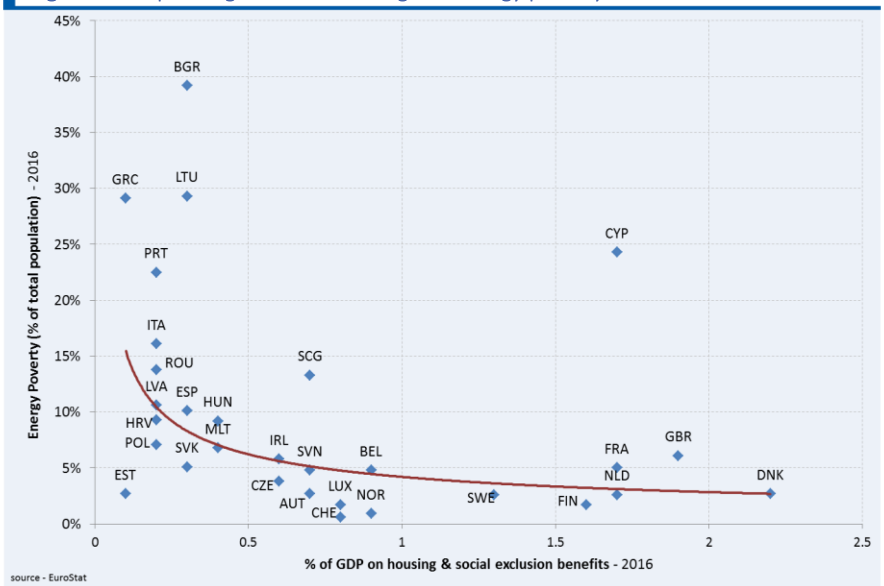


Figure 2.2 - Cumulative regional impact scores for household energy efficiency policies

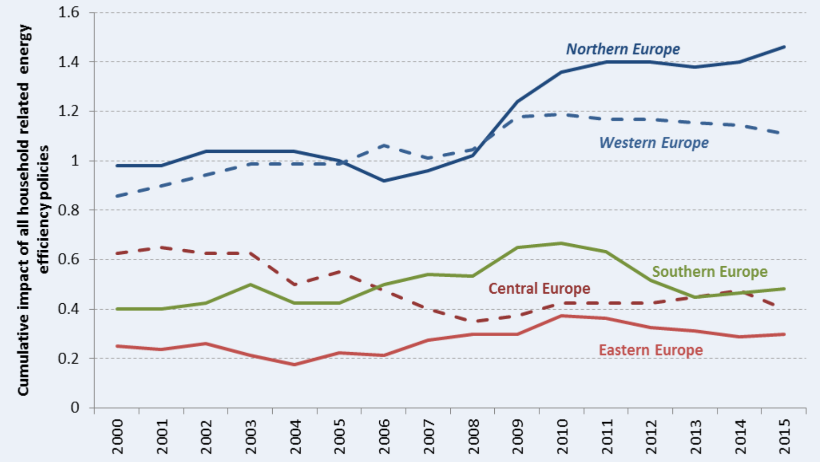


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Figure 2.3 - Public spending on social housing by country

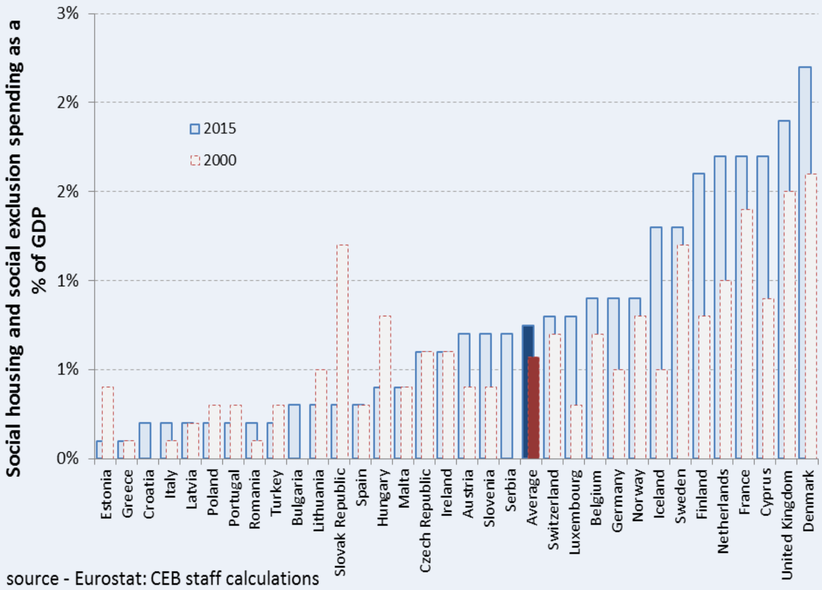

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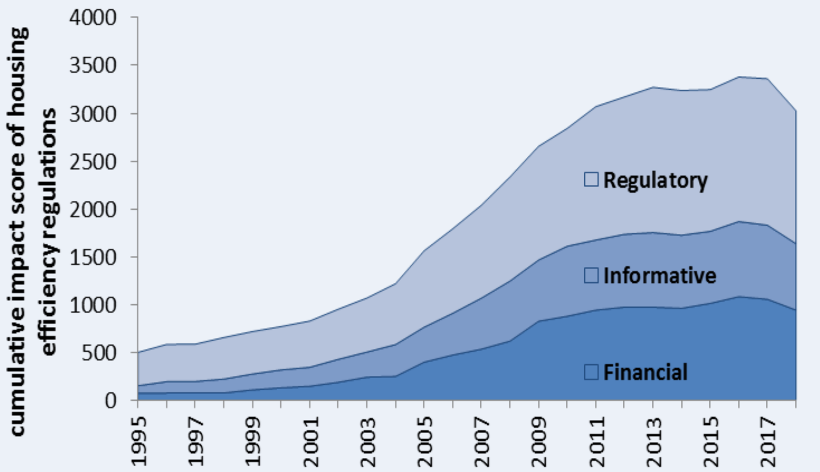
Figure 2.4 – Cumulative energy efficiency policy impact scores for Europe



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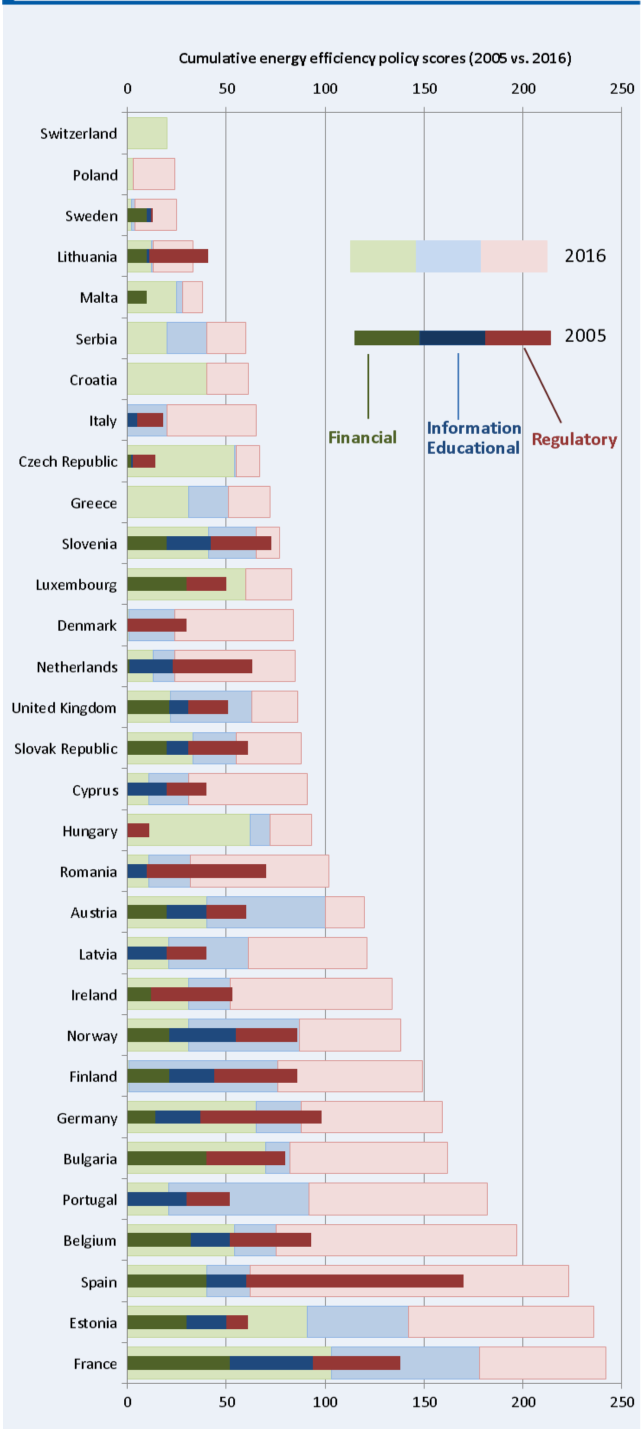
While subsidies are a short-term means to combat growing energy prices, the long-term priority should be to develop and implement energy efficiency policies. Such policies seek to promote efficient consumption choices, and to increase the quality and energy efficiency of housing construction (and retrofits) with financial subsidies and regulatory efficiency standards. European countries have been doing well in implementing various energy efficiency policies over the years. According to the MURE database, as of 2016, there were approximately 450 active housing energy efficiency policy measures in all European countries – a quarter of which are EU-related. The MURE database assigns an impact score for each policy (20 being the highest), In 1995, the cumulative score of all European policies was just below 500, while by 2016 the cumulative score had grown to nearly 3000. This cumulative impact score itself may not appear very meaningful, but its growth (see figure 2.4) is evidence of Europe's commitment to promoting energy efficiency in homes.

In a heterogeneous continent such as Europe, some countries have unsurprisingly placed more effort than others on implementing housing energy efficiency policies. For each EU country, Figure 2.5 compares the cumulative housing energy efficiency policy impact scores of all active policies for the years 2005 and 2016, based on three types of policies: (1) financial policies (green) which are often financial incentives, grants, vouchers, loan subsidies, and tax-incentives to help construct and retrofit homes to meet higher energy efficiency standards; (2) information policies (**blue**), which typically centre around appliance energy efficiency labelling, information campaigns, advanced "smart" metering systems, and energy consumption training programmes; (3) legislative and regulatory policies (**red**), which are centred around building codes, minimum standards for heating systems, and thermal/insulation ordinances.

Figure 2.5 - Energy efficiency scores by country and by policy for 2005 & 2016)



All countries have improved their total cumulative housing energy efficiency scores since 2005 (bar Lithuania, see figure 2.5). In most countries the largest score increase was the result of the implementation of new legislation and regulations. However, in a number of countries, information-related policy impact scores have increased substantially (in some cases they did not exist at all back in 2005). Additionally, unlike housing-related subsidies in the previous section, improvements in energy efficiency policy impact scores were not limited to rich European countries, and even some rich European states had relatively low scores. The efforts deployed by most European states to improve their respective energy efficiency policies reflect the increased importance given to such policies to generate wide-ranging positive social and economic benefits.

Improving the energy efficiency of homes has a multitude of general nation-wide benefits such as: reducing greenhouse gas emissions, reducing stress on energy grid systems (thus making them more stable), helping boost GDP and employment from energy efficiency home construction/retrofits (at least in the medium term), and increasing energy security (EU 2016). Importantly, energy efficiency can improve a country's fiscal position by reducing spending on energy-related subsidies/transfers, thereby freeing up funding space for other needed public investments.

At the household level, especially low-income households, energy efficiency helps reduce energy consumption and, in turn, spending on energy bills. Reduced spending on energy can generate a new source of savings that can help households not to have to choose between heating and food, or can be invested in educational opportunities and the consumption of other goods that increase standards of living. In some cases, a ***"rebound" effect*** occurs, when lower-income households redirect new-found savings from energy efficiency towards increased energy consumption, primarily to heat other areas of the home (poor households often cannot afford to heat more than one room) in order to improve the overall quality of their living environment. As households use the savings at their convenience, the rebound effect can be seen as generating positive well-being outcomes.

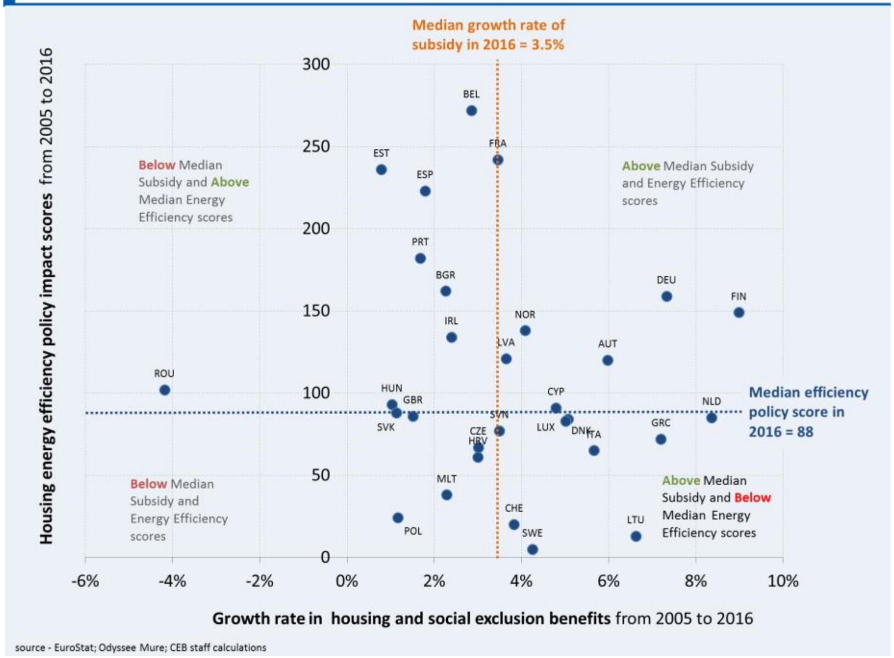
Energy efficiency can also help improve wellbeing by reducing the risk of developing health issues and cold-weather related mortality, by alleviating long-term health symptoms (cardiovascular, allergies, etc.) and by enhancing mental wellness. Improved energy efficiency can also increase employment and school place productivity, thereby increasing the overall quality of life. Moreover, for low-income households, having a more energy efficient home will reduce the cost of transition to renewable energy sources (EC-2016).

Energy Subsidy or Efficiency?

A country's choice to push policies to improve the energy efficiency of homes does not imply discounting subsidies entirely. In fact, energy subsidies can act as a short-term solution to help households cope with increases in energy prices or economic difficulties, while investments are being made to improve energy efficiency (thus reducing the need for energy subsidies in the future).

In a number of European countries, public authorities either invest more in improving energy efficiency or increase energy subsidies, but rarely do both. While there was positive growth in both energy subsidies and efficiency scores across Europe from 2005 to 2016 (bar Romania), there are some countries that either have energy efficiency scores above median levels or have increased the growth rate of housing-related subsidies (see Figure 2.6 below). In some countries, both policy measures are above median levels (namely Germany, Finland, Austria, Norway, Latvia, Cyprus, and France), while other countries are below median levels on both counts (Poland, Malta, Slovak Republic, Czech Republic, and the United Kingdom). However, the remaining countries highlight the continuing differences in the policy approaches that are being undertaken to combat energy related issues (including energy poverty).

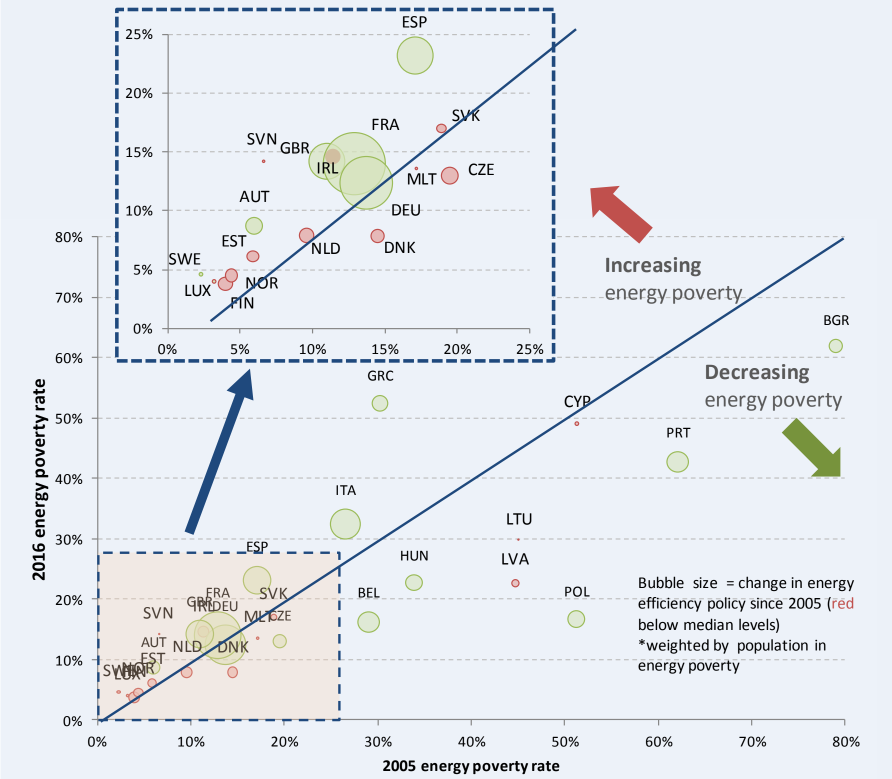
Figure 2.6 - Changes in subsidy and energy efficiency policy scores 2005-2016



In many cases, both policies have helped reduce energy poverty, but energy efficiency delivers slightly better results. However, overall economic/income growth is the largest contributor to reducing energy poverty rates. Since energy poverty is a complex topic with many intersecting causes that are hard to disentangle, it is difficult to ascertain if energy subsidies or energy efficiency is the more effective policy, especially considering that both often work together (although Chapter 4 of this study does attempt to undertake an empirical analysis of potential direct impacts). Both figures 2.7 and 2.8 below show the energy poverty rates in 2005 and 2016 on the x and y axes, respectively, with the bubble sizes indicating changes in energy efficiency scores weighted by the total population in energy poverty (figure 2.7) or growth in housing and social exclusion benefits (figure 2.8); the **red** and **green** colours indicate whether growth was above or below median levels.

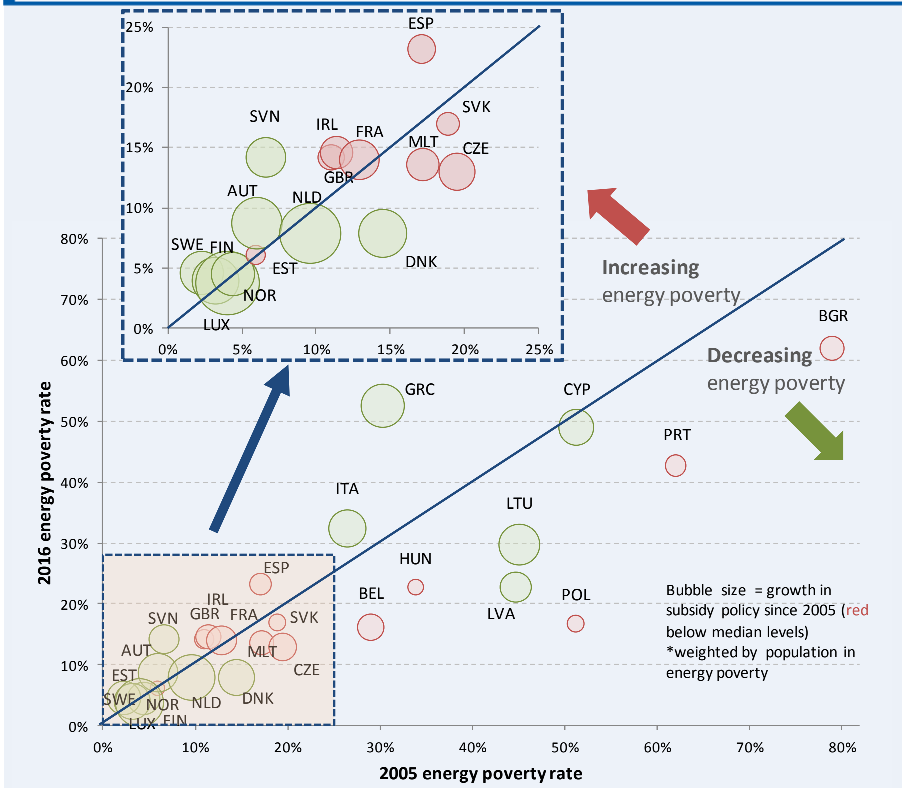
Countries with initially low levels of energy poverty are more likely to focus on energy subsidies. What is immediately evident from figures 2.7 and 2.8 is that those countries in the lower left-hand corner, with low levels of energy poverty (regardless of year) tended to see changes in energy efficiency policy scores below median levels (figure 2.7), while growth in subsidy levels was often well above median levels (figure 2.8). However, in those countries, there were only a limited number of cases in which energy poverty rates dropped and, on the contrary, most saw rates stagnate or even increase.

Figure 2.7 – Energy poverty and energy efficiency policy changes



source - EuroStat;Oydssee Mure; CEB staff calculations

Figure 2.8 - Energy poverty and government subsidy growth



source - EuroStat;Oydssee Mure; CEB staff calculations

In some of these countries, energy efficiency scores were already high to begin with (namely Norway, Finland, Estonia, Slovak Republic, and Ireland), but, in almost all of these countries, energy poverty rates stagnated.

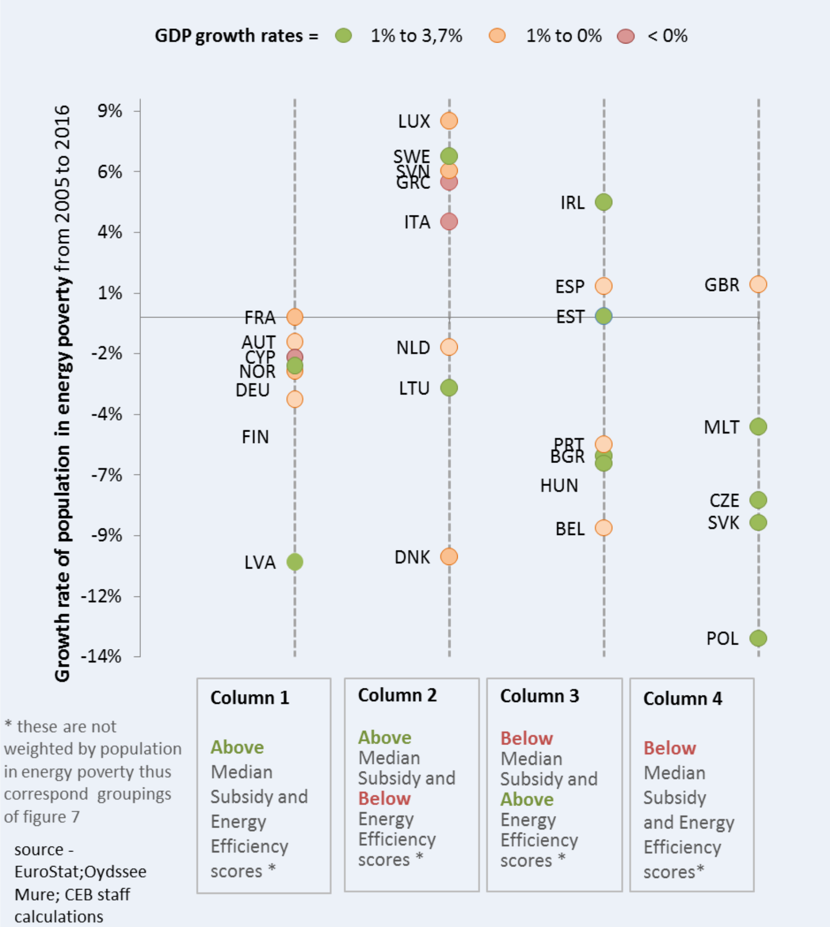
In countries with high levels of energy poverty, the policy choices were mixed, but in most cases energy poverty rates dropped. In most of these countries (primarily outside the boxes in figures 2.7 and 2.8), the high rates of energy poverty in 2005 dropped by 2016. Greece, and to a lesser extent Italy, were exceptions, showing energy poverty rates that were exacerbated by continuing economic hardship. The remaining countries that saw significant drops from initial high energy poverty rates had either above-median increases in energy efficiency scores (Bulgaria, Portugal, Poland, Hungary, and Belgium, as shown in figure 2.7) or above-median growth in subsidies (Lithuania, Cyprus, and Latvia, as seen in figure 2.8).

From Rates to Numbers

In total, over 9 million people on a net basis are estimated to have come out of energy poverty between 2005 and 2016. While, in total, an estimated 19.4 million people had dropped out of energy poverty since 2005, another estimated 10.4 million entered into it, thus depressing the net figure. Figure 2.9 shows the annualised growth rate for the total number of people in energy poverty between 2005 and 2016 for each country, with the colours representing different real GDP growth rates for the same time period, and each column representing the different policy choices (subsidy or efficiency) relative to respective median levels.

Countries in which spending on subsidies grew and energy efficiency policy scores were above median levels tended to see continuous annual drops in the population in energy poverty (column 1). Nearly 1.3 million people were lifted out of fuel poverty in the countries in column 1, while only representing less than 7% of the total number of people escaping energy poverty in Europe. These countries had varying macro-economic conditions, some with robust real GDP growth and others seeing GDP contractions, indicating that economic situations were perhaps not key drivers of the drops in the energy poor population.

Figure 2.9 – Growth in the energy poor population divided into energy efficiency policy, government subsidy, and GDP growth groups



The countries that saw above-median growth in subsidies but had energy efficiency policy scores below median levels for the most part experienced annual increases in energy poor individuals (column 2). Aside from the Netherlands, Lithuania, and Denmark, all other countries saw significant annual increases in the number of people in energy poverty. In some cases, such as in Greece and in Italy, the deep economic downturn played a significant role in the rise, as household incomes declined while governments were simply trying to use subsidies to stop the problem from getting worse. In total, an estimated 4.29 million people entered into energy poverty in the countries in column 2, representing about 50% of the total increases in Europe.

When countries increased energy efficiency policies to above-median levels, only some of them saw substantial annual drops in the number of energy poor (column 3). However, there were exceptions such as Ireland, Spain, and Estonia, which saw increases or stagnation in the energy poor population, indicating the possibility that both an increase in energy efficiency policies and limited (below-median growth but still positive) growth in subsidies were insufficient. For the remaining countries, the significant drop cannot be exclusively attributed to growth in energy efficiency policies, as a number of countries saw robust real GDP growth over the period. In total, an estimated 5.49 million people are no longer in energy poverty in the countries in column 3, representing about one third of the total European population exiting energy poverty.

In four of the five countries that saw below-median growth in subsidies and had energy efficiency policy scores below median levels, the growth in energy poor declined significantly (column 4). While all four countries (Malta, Czech Republic, Slovak Republic and Poland) did see only marginal increases in energy efficiency policies and subsidies, the robust economic growth since 2005 may have played a more important role in decreasing the energy poor population. In total, an estimated 10.6 million people are no longer in energy poverty since 2005, accounting for 55% of the total European Decline.

Info Box 3 – **The UN Sustainable Development Goals (SDGs) and Energy Poverty**

By tackling the issue of energy poverty, European countries will be able to contribute directly and indirectly to meeting several UN Sustainable Development Goals (SDGs). Following on from the Millennium Development Goals (MDGs), the 17 SDGs (and their associated 169 targets), as outlined in the UN 2030 Agenda for Sustainable Development adopted by all 193 UN member states in 2015, apply to all countries and aim to achieve the global ambition of sustainable economic, social, environmental and political development.

SDG 7 explicitly calls for countries to "Ensure access to affordable, reliable, sustainable and modern energy for all". The goal stipulates that countries should ensure affordable access to modern energy services, with an increased share originating from renewables and a doubling of the rate of energy efficiency improvements. The empirical analysis in this paper (chapter 4) demonstrates that energy efficiency reduces the overall household energy bill and reduces energy poverty rates, while also directly helping to meet the objectives set out in SDG 7.

Indirectly, a focus on reducing energy poverty via energy efficiency improvements and an increased focus on renewable energy sources will also contribute to meeting SDG 10 (Reduce inequality within and among countries), SDG 11 (Make cities and human settlements inclusive, safe, resilient and sustainable), and SDG 13 (Take urgent action to combat climate change and its impacts).

Chapter 3 – The Cost of Transition to Renewables in Households

Introduction

In 2009, the EU set a Europe-wide goal that 27% of final energy consumption should come from renewables by 2030 (later to be revised upwards to 32%). At national level, countries set their respective targets, all aimed at increasing the role of renewables. This shift will have profound effects on how Europeans source their energy, shoring up energy security and creating a more sustainable and environmentally friendly future.

But how does this transition translate to household consumption? When examining household energy consumption alone, we see that European households are well on their away to meeting any 32% goal[1]. Renewable energy sources increasingly account for a larger share of household energy consumption in most European states, with the exception of the largest European states, but even there renewables are on the rise.

The transition to increased use of renewables by households will have a significant impact on household (especially low-income) energy bills. In most countries, the cost of producing renewables is higher than the cost of conventional energy production. However, these costs have been declining for many renewable energy sources (e.g. solar) and, since renewable energies tend to have low marginal costs in the long term, this will ultimately translate into lower energy prices. This chapter outlines a number of scenarios that show that, in the short term, the transition to renewables will lead to a slight increase in household energy bills. However, in the long term, as renewable energy prices fall and energy efficiency standards continue to rise, low-income households should see their energy bills decrease, thereby reducing energy poverty rates.

26.5% renewables: the estimated share of renewables in all European household energy consumption.

Renewable prices falling: the costs of producing renewables are dropping as production capacity is increasing.

€ 210 per household: the estimated average annual savings households are expected to obtain as household energy shifts more towards renewables and energy efficiency standards increase.

[1] The 32% renewable energy target applies to all final consumption. Here we expand this target to apply to residential energy consumption, as there are no explicit residential renewable targets.

The increased role of renewables

Renewable energy in household consumption has been growing steadily since the 1990s. Natural gas still remains the chief input to most household energy consumption, followed by electricity energy, which can be generated by gas, nuclear or renewables – see figure 3.1 (these sources are disaggregated later in the chapter). On the other hand, solid fuels (coal, etc.), petroleum products, and other environmentally unfriendly sources of energy have seen their once significant roles decline over the last three decades. This is good news for a continent that aims to decrease the use of carbon-producing energy sources.

Over the years, the share of renewables has been increasing, but still remains below EU goals. In 1990, renewables accounted for just 10% of all household energy consumption, as of 2016, that figure stood at 26.5% (when we disaggregate the inputs of electric energy and derived heat[2] generation for household consumption). Conversely, solid and petroleum-related energy once constituted between 32% to 40% of all household energy consumption, but today that figure has dropped to less than 22% (see figure 3.3) and is continuing to decline (see figure 3.1 and 3.2). However, gas has historically played a significant role in household energy, typically hovering around 40% (again when derived heat and electricity generation inputs are disaggregated).

In 17 out of 40 countries, renewable energy sources constituted half of all household energy consumption in 2016 (see figure 3.4 below). Yet in the United Kingdom, France, and Germany, the largest overall consumers of energy, the share of renewables in household consumption stood at 10.6%, 18.6% and 25.2% respectively, all below the European 2016 average 26.5%. The ease of using renewables depends on a number of country characteristics such as relative size, number of households, availability of renewable energy resources, ability to use renewables while still maintaining national grid sustainability during peak demand cycles, and the of cost-effectiveness of modernising energy transmission systems. Many of these factors are constrained (or unavailable) for larger European states. Renewables such as wind or solar are classified as variable generation (VG), as they can only operate when the input is physically present (wind or sun). Thus, for many countries, renewables cannot be relied upon to meet base load (constant demand), or intermediate (daily variation demand) and peak (extreme-spike demand) demands at current supply and technology levels. However, renewables will play an increasingly important role as countries develop and invest in upgrading transmission systems that can connect with regions/countries with renewable energy production, increase the use of on-demand renewables (e.g. biomass, geothermal, etc.), and implement smart metering and grid systems (P. Lund 2011, Lund, et al. 2012, DOE 2014).

Figure 3.1 – Gross European household energy consumption by source

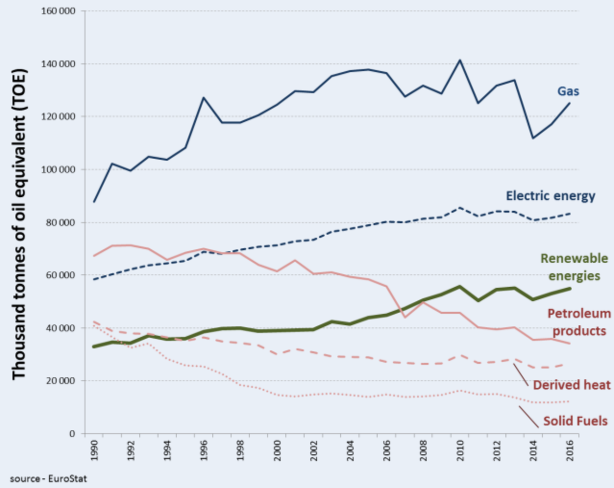
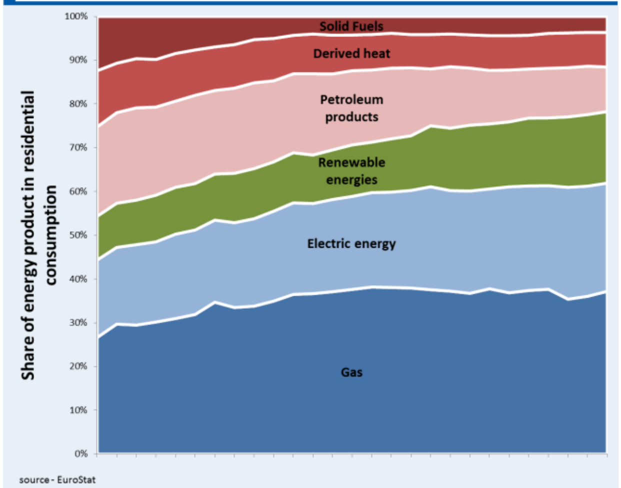
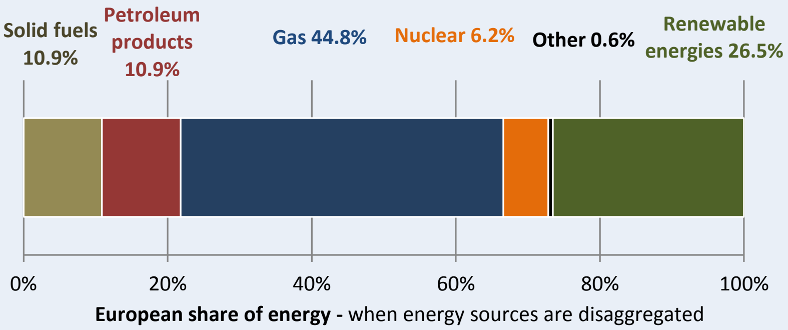


Figure 3.2 – Share of energy sources in total household consumption (non-disaggregated)



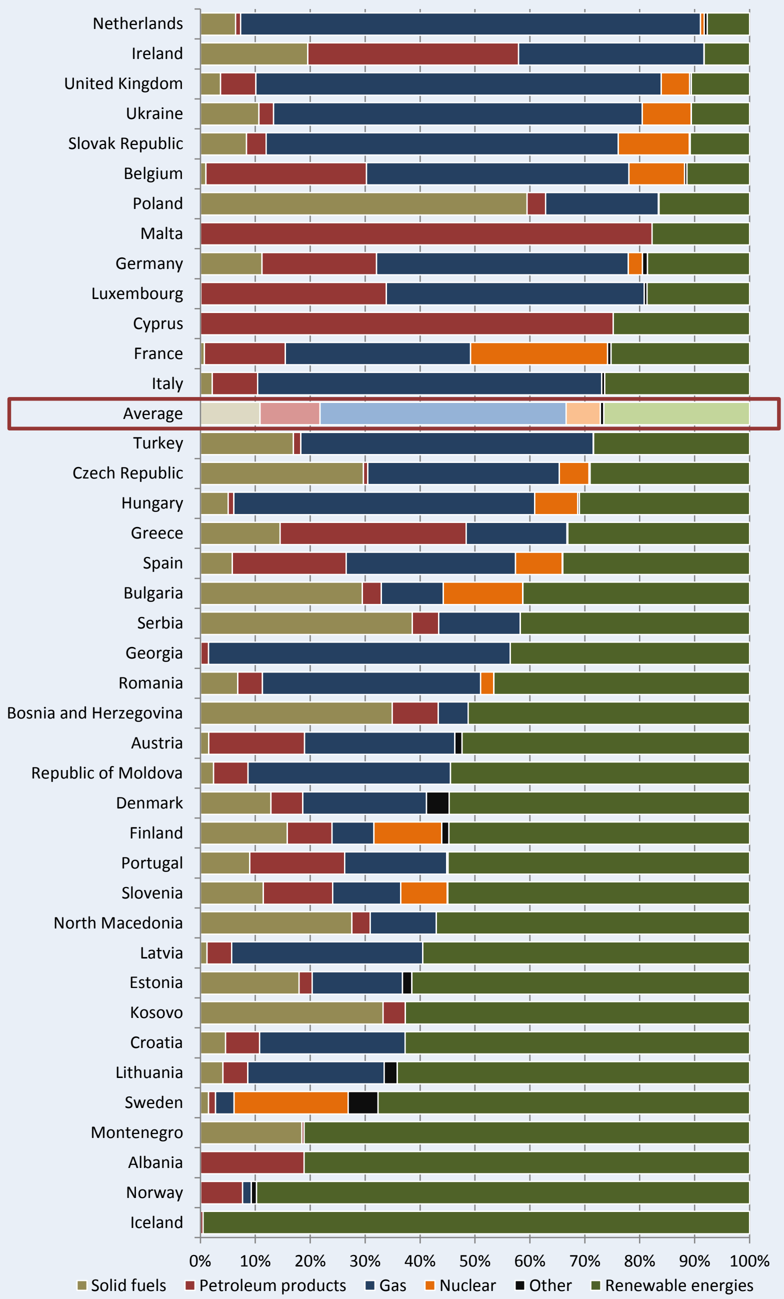
2 In both cases different inputs are used to generate energy – which include renewables and other traditional inputs

Figure 3.3 – Share of energy sources in total household consumption in 2016 (disaggregated by source)



source - EuroStat; CEB staff calculation

Figure 3.4 - Share of energy sources in total household consumption in 2016 by country (disaggregated by source)



source - EuroStat; CEB staff calculation

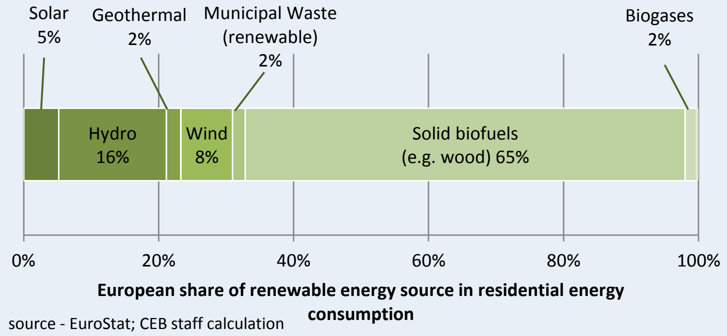
Renewable energy used by households often came from solid biofuels, followed by hydro and wind in 2016. An overwhelming 65% of all renewable energy generated for household consumption comes from solid biofuels such as wood (which still remains carbon-neutral) – see figure 3.5. In 31 out of 40 countries, solid biofuels represent 50% of all renewables (and in 15 countries over 75%) – see figure 3.6. In many small countries, solid biofuels are followed by hydro-related energy. Only in Ireland and Iceland do geothermal sources contribute to over 50% of household renewables. Solar power plays a minor role in household consumption in most countries (in nearly half of European countries, solar contributes to less than 1% of renewables sourced to households). The exceptions are Cyprus and Malta, where solar accounts for over 75% of household renewable energy.

The price of renewable energy

Energy prices and household consumption tend to be highly correlated. Figure 3.7 shows how European household energy consumption often tracks changes in energy price levels (a focus on price-elasticity can be found in chapter 1). Since about 2011, household consumption has begun to slowly increase as the corresponding price levels of both natural gas and electricity have been on a downward trend.

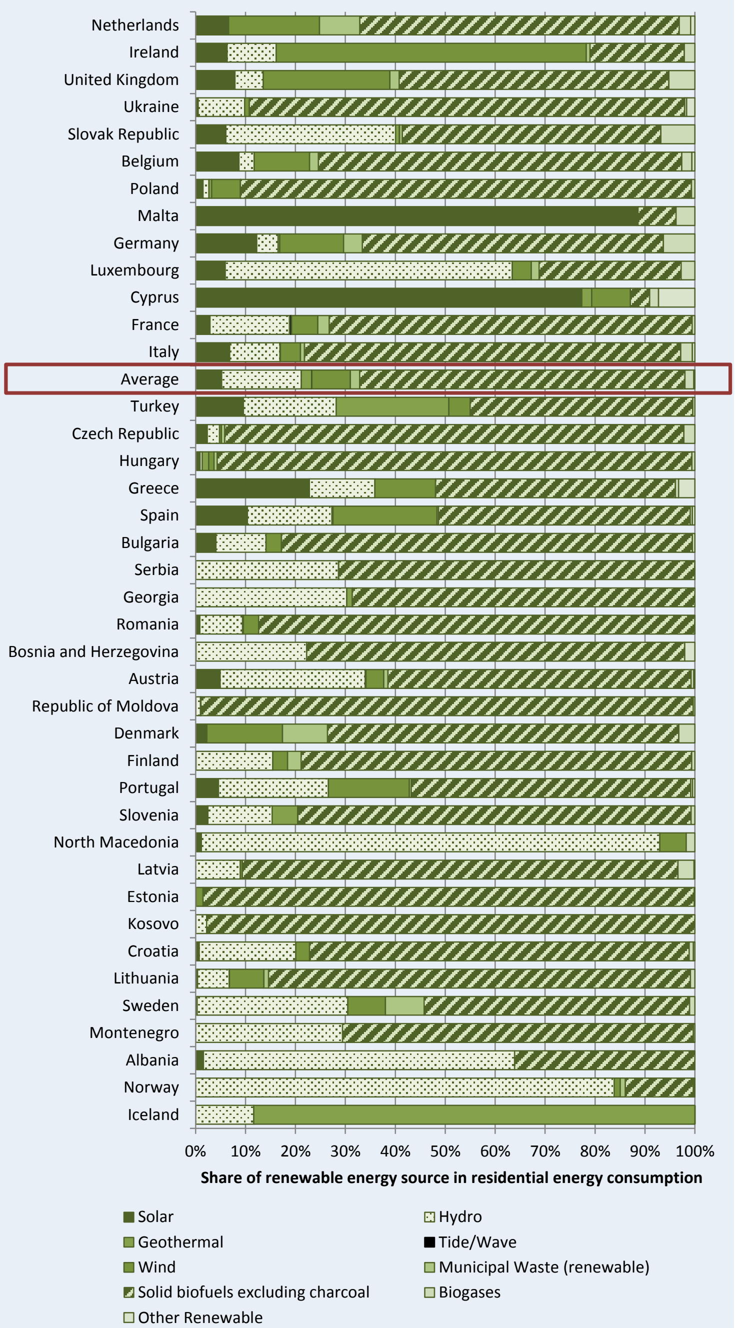
The price levels of most sources of renewables are nearing conventional energy prices. Figure 3.8 shows the average price of a specific energy source (with grey bars corresponding to the total distribution of all European country prices for a respective source).

Figure 3.6 – Share of renewable sources in total household renewable energy consumption in 2016



source - EuroStat; CEB staff calculation

Figure 3.6 - Share of renewable sources in total household renewable energy consumption



source - EuroStat; CEB staff calculation

While hydropower, onshore wind, and solid biomass average prices can potentially rival natural gas, their overall distribution of prices (the grey bars in figure 3.8) are still wide-ranging across Europe. For other forms of renewables such as CSP (concentrated solar power), photovoltaic solar, offshore wind and, to some degree, geothermal, prices in many places remain too high to be viable alternatives to traditional forms of energy (in most cases this is due to limited renewable energy capacity and thus the inability to generate economies of scale).

As renewable energy capacities increase, their associated costs are expected to decrease. For instance, studies have shown that as solar generation capacity increased in Germany, the associated costs dropped and even helped reduce energy costs during peak times (Haas, et al. 2013). Renewables will also likely impact future energy price markets; they have near zero marginal (operating) costs and may thus set lower market clearing prices (Haas, et al. 2013, Nielsen, Sorknaes and Ostergaard 2011). This will make it more difficult for fossil fuels and biomass plants to fully recover their higher fixed costs and energy costs (e.g. buying fuels). In turn, this may result in higher costs for fossil fuel/biomass, which may still need to be used during periods when renewables cannot be relied upon (Schaber, Steinke and Hamacher 2012). For the most part, renewable energy is becoming as cost-effective as conventional energy. Numerous studies have shown that renewable energies have, or will reach, cost parity with conventional energy as renewable technologies/ capacities develop (e.g. larger blades for wind turbines and more advanced solar photovoltaic designs (Popp, Hascic and Medhi 2009).

Prices have been affected by government renewable energy support schemes. European countries employ a host of different schemes to promote renewable energy development, ranging from fiscal-based incentives (government-backed grants and investments), quota obligations (a minimum share of electricity supply coming from renewables), financial incentives for biomass (e.g. generating electricity from carbon-neutral wood) and feed-in premiums (additional payments that producers receive for generating renewable energy) (Erbach 2016). A very popular method is to utilise feed-in tariff (FITs) [3] which pass on a tax to consumers, thus creating "policy costs" (Klessmann 2014, Moreno and Lopez 2011). In many countries, certain vulnerable groups are precluded from having to pay FITs (although this does not mean all low-income households).

As renewable energy deployment progresses, support schemes will change. FIT rates are being revised downwards as the production costs of many renewables have been dropping (IRENA 2014, Fruhmann and Turek 2014). In fact, most countries undertake regular reviews and adjustments of renewable support schemes as energy markets change and technologies develop (Erbach 2016). Optimistically, as nations increase their support for producing and thus using renewables, the final price will drop since variable costs for renewables are lower than for conventional energy production and their marginal costs are close to zero.

The cost of transitioning to renewables for households: simple scenario analysis

The transition to renewable energies is expected to have long-term environmental benefits, as well as eventually helping reduce household expenditure on energy consumption. However, this transition will not guarantee immediate economic benefits. As has been shown, renewable energies are not always cheaper relative to conventional sources and, depending on a country's dominant source of

Figure 3.7 - Electricity/Gas prices and household consumption

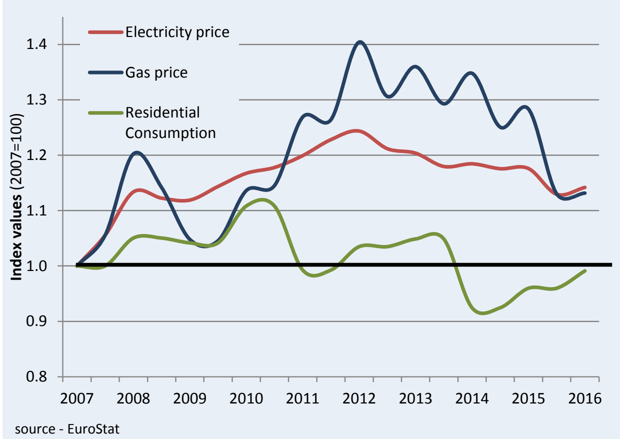
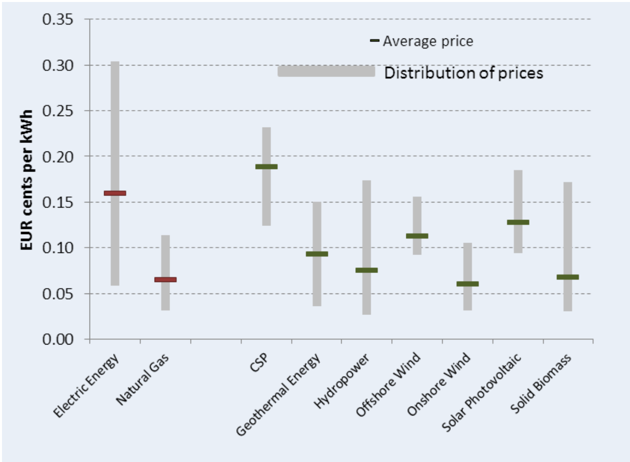


Figure 3.8 – Price levels of various energy sources



renewables, the transition may prove costly for households in the short term.

This chapter presents four scenarios for household energy consumption, the level of renewables in that consumption, the energy efficiency of homes, and price levels for all types of energy (including all forms of renewables shown in figures 3.5 and 3.6). We make a number of underlying assumptions (see detailed appendix methodology), for example, that any increase in the total use of renewable sources will result in a proportional increase in a country's current household renewable source profile (see figure 3.6); i.e. we do not assume that the distribution of the types of renewable sources will change.

[3] Feed-in tariffs are taxes that are placed on energy market participants (e.g. electricity suppliers and/or network operators) who then typically pass on the tax-related costs to consumers via higher prices.

We take into consideration that any future transition towards renewables will also require that residential energy efficiency increase (technological trends and efficiency indicators point in this direction (Odyssee 2017). We further assume, conservatively, that renewable energy prices will further decline, although not as dramatically as they have in recent years. We then calculate the share of a household's total expenditure on energy consumption for each source, for households in the bottom and top 20% or 25% (depending on data availability in quartiles or quintiles).

Table 3.1 – Share of household spending on energy in various renewable and energy efficiency scenarios (low-income vs. high-income households).

% of household expenditure		Current	Scenario 1	Scenario 2	Scenario 3
	Energy Mix	No change	32% minimum renewable electricity in residential consumption		
	Household consumption	No change	No change	Consumption reduced if energy efficiency increases to frontier country level(s)	
	Prices	No change	No change	No change	5% reduction in renewable costs
Country	**Income cohort**				
Slovak Republic	**Bottom 25%**	**14.60%**	**14.20%**	**12.57%**	**12.28%**
	Top 25%	8.50%	**8.20%**	**7.30%**	**7.10%**
Sweden	**Bottom 25%**	**9.10%**	**8.80%**	**8.01%**	**7.74%**
	Top 25%	5.90%	5.70%	5.20%	5.00%
Belgium	**Bottom 25%**	**7.50%**	**10.00%**	**8.51%**	**8.31%**
	Top 25%	4.20%	5.60%	4.80%	4.70%
Greece	**Bottom 25%**	**5.30%**	**5.20%**	**4.16%**	**4.05%**
	Top 25%	2.50%	2.50%	2.00%	2.00%
Spain	**Bottom 25%**	**5.00%**	**5.00%**	**4.19%**	**4.08%**
	Top 25%	3.00%	3.00%	2.50%	2.50%
Estonia	**Bottom 20%**	**19.10%**	**18.00%**	**13.51%**	**12.99%**
	Top 20%	6.00%	5.70%	4.20%	4.10%
Latvia	**Bottom 20%**	**16.60%**	**15.40%**	**10.41%**	**9.97%**
	Top 20%	11.80%	11.00%	7.40%	7.10%
Czech Republic	**Bottom 20%**	**16.10%**	**16.30%**	-	-
	Top 20%	11.90%	12.10%	-	-
Hungary	**Bottom 20%**	**14.70%**	**17.00%**	**13.64%**	**13.27%**
	Top 20%	9.60%	11.10%	8.90%	8.60%
Poland	**Bottom 20%**	**11.86%**	**11.58%**	**10.39%**	**10.22%**
	Top 20%	13.10%	12.80%	11.50%	11.30%
Bulgaria	**Bottom 20%**	**11.80%**	**11.10%**	**8.83%**	**8.60%**
	Top 20%	7.20%	6.70%	5.40%	5.20%
Croatia	**Bottom 20%**	**11.70%**	**14.10%**	**10.81%**	**10.34%**
	Top 20%	5.60%	6.80%	5.20%	5.00%
Slovenia	**Bottom 20%**	**9.50%**	**10.60%**	**8.27%**	**7.98%**
	Top 20%	10.21%	9.97%	8.94%	8.80%
Denmark	**Bottom 20%**	**8.90%**	**8.60%**	**3.74%**	**3.63%**
	Top 20%	7.10%	6.80%	3.00%	2.90%
Germany	**Bottom 20%**	**8.60%**	**8.40%**	**5.83%**	**5.69%**
	Top 20%	5.50%	5.30%	3.70%	3.60%
France	**Bottom 20%**	**8.30%**	**9.00%**	**7.70%**	**7.57%**
	Top 20%	4.40%	4.80%	4.10%	4.10%
Italy	**Bottom 20%**	**8.10%**	**8.80%**	**6.39%**	**6.27%**
	Top 20%	3.30%	3.60%	2.60%	2.60%
Ireland	**Bottom 20%**	**6.70%**	**5.30%**	-	-
	Top 20%	4.30%	3.40%	-	-
U.K	**Bottom 20%**	**5.80%**	**6.70%**	**5.40%**	**5.27%**
	Top 20%	1.60%	**1.80%**	**1.50%**	**1.40%**
Cyprus	**Bottom 20%**	**5.70%**	**3.30%**	**2.17%**	**2.06%**
	Top 20%	1.80%	1.00%	0.70%	0.60%
Austria	**Bottom 20%**	**5.00%**	**5.30%**	-	-
	Top 20%	5.00%	5.30%	-	-
Finland	**Bottom 20%**	**4.80%**	**4.30%**	**3.55%**	**3.43%**
	Top 20%	4.60%	4.10%	3.40%	3.30%
Portugal	**Bottom 20%**	**4.80%**	**4.70%**	**3.29%**	**3.17%**
	Top 20%	2.50%	2.50%	1.70%	1.70%
Netherlands	**Bottom 20%**	**4.80%**	**4.90%**	**4.39%**	**4.30%**
	Top 20%	4.10%	4.20%	3.80%	3.70%
Luxembourg	**Bottom 20%**	**2.90%**	**3.50%**	-	-
	Top 20%	2.30%	2.80%	-	-

Household expenditure change Decreasing Stagnate Increasing

CURRENT SCENARIO – this scenario (first column in table 1) calculates a household's share of energy-related expenditure if nothing changes as of 2016; the proportion of renewables in household consumption is exactly as seen in figure 3.6, renewable and conventional energy prices are unchanged, and the energy efficiency of homes remains at current levels.

For households in the bottom income quartile/quintile (henceforth "lower income households"), energy expenditure as a share of total household expenditure ranges from 2.9% (Luxembourg) to 19.1% (Estonia) and, on average, stood at 9% (or about 832 EUR annually). This is opposed to those in the top income groups, who, on average, spent just 5.6% on energy-related costs (about 1,609 EUR annually).

SCENARIO ONE – a minimum of 32% of household energy consumption comes from renewable[4] (second column in table 1). Under scenario 1, we assume that all countries will increase their renewable energy production capacities so that 32% of all energy consumed by households comes from renewables (or will increase renewable energy by another 10% if already at 32%). In this scenario, we make the strong assumption that renewable energy prices do not drop even as the capacity of renewables increases, which should theoretically decrease the marginal cost of generating additional units of renewable energy, especially in those countries with currently limited renewable energy capacities (although scenario 4, in part, does away with this assumption). Nonetheless, scenario 1 serves to showcase the costs that would be associated with switching towards renewables in the current price climate.

[4] a number of countries have already achieved the 32% level and, in such cases, we generated a hypothetical scenario of a 10% addition to current household use of renewables.

In 12 out of 25 countries, low-income households would see an increase in household expenditure; and in 11 countries, high income households would see the same. On average, low-income households would spend 9.1% (approx. 840 EUR annually) of their total expenditure on energy. Encouragingly, the maximum level of low-income spending would drop to 18% (this is in Estonia, down from 19.1% in the current scenario), showing that, for some countries, simply moving towards renewables is better than conventional energy sources. On the other hand, high-income households would, on average, spend 5.7% (approx. 1,668 EUR annually) on energy, representing an increase of 0.1%.

SCENARIO TWO – 32% of energy consumption comes from renewables and household energy efficiency levels increase. Under scenario two, we keep all the assumption of scenario one and reduce average household consumption by the gains that would be achieved if energy efficiency standards reached the frontier country level[5] (Sweden in our model).

Under scenario two, almost every country saw their share of household expenditure on energy drop, regardless of income bracket – see table 1. Low-income households, on average, will spend 7.3% (approx. 623 EUR annually) of their annual expenditure on energy, a drop of 1.7% from the current scenario. The country with the highest share, Estonia, stood at 13.5%, a drop of 5.3% under the current scenario. High-income households on average also saw their share of energy expenditure drop to 4.4% of total household expenditure (from 5.6% in the current scenario).

SCENARIO THREE – 32% from renewables, higher household energy efficiency, and a reduction of 5%. in renewable energy prices. In scenario three, we keep all previous assumptions and allow for a 5% reduction in energy prices for all types of renewables, since we assume that renewable energy prices will continue to drop in the coming years. We keep the drop at a relatively conservative level, but it is important to note that prices may drop further, thereby generating greater benefits.

[5] For those countries that are already near or at the frontier (Sweden), we allowed for an additional 10% reduction in household consumption due to assumed continued growth in household energy efficiency.

In scenario three, all households will see continued drops in the amount of spending they devote to energy consumption. On average, low-income households will spend 7.5% (approx. 606 EUR) of their total expenditure on energy. Hungary will still remain the country where low-income households spend the largest share, namely 13.3%. Richer households in all countries will continue to see gains, but in no case as dramatic as those seen by low-income households; high-income households will spend 4.17% of their expenditure on energy.

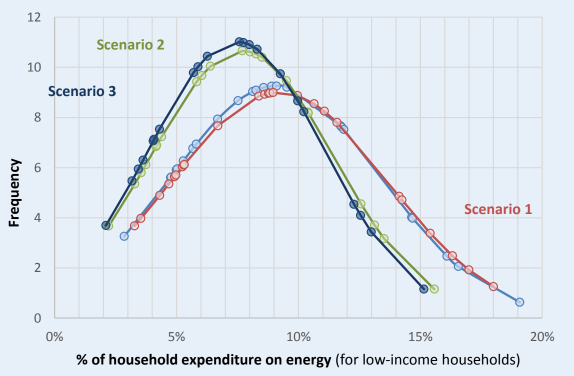
Distribution of household expenditure

The three scenarios are merely hypothetical in nature and serve to highlight the potential gains that low-income households may experience as governments push towards more renewables and energy efficiency. Figure 3.9 showcases the distribution of low-income household spending on energy under the different scenarios.

The current scenario shows a wide distribution of how much households will spend on energy, and scenario 1 actually slightly widens that distribution as the higher cost of renewables will marginally increase household energy costs.

However, the main takeaway from figure 3.9 is that it is only once countries invest in increasing household energy efficiency (scenario 2) in combination with decreased costs of renewables (scenario 3) that we can expect the distribution to skew towards the left (i.e. more countries concentrating at lower spending levels). Thus, only when energy efficiency standards increase will any transition to renewables perhaps start to ease the strain on low-income household energy bills.

Figure 3.9 – Distribution of household expenditure on energy under different scenarios



source - EuroStat; CEB staff calculation

Info Box 4 – The role of nuclear energy

An important component of the debate on how to effectively transition to non-CO2 electricity is the role nuclear energy might play. This study, and chapter 3 in particular, does not consider the role of nuclear energy in its scenario analysis due to the politically sensitive and somewhat controversial debate that is currently underway in Europe on the subject – as a result, the scenario analyses do not make any changes to the proportion of nuclear energy as a source of household energy (i.e. it is kept static at current levels of supply).

That being said, nuclear energy is a technology that can play a significant role in helping energy markets transition towards long-term sustainability. Renewables are intermittent in nature, and when their inputs are not around, they are unable to provide reliable energy for an electricity grid. Admittedly, new advances in energy storage systems are underway, that may store up energy produced by renewables that could be called upon later. However, in the long-run nuclear power can act as a complement to help shore up energy supply dips when renewables are inactive

Concerns about nuclear energy do exist and stem from fears of a meltdown disaster and actual worries that it generates too much nuclear waste. Advances in nuclear energy technology could help mitigate the concerns on both fronts. Scientists at the University of California are developing "fuel pebbles" of uranium enclosed in ceramic, instead of traditional fuel roads, which ensure that the uranium cannot melt and does not require water to cool (thus does not produce large quantities of waste), while using the uranium more efficiently. At the same time a number of engineering start-ups are working to design nuclear reactors that operate in atmospheric pressure without running the risk of an explosion (current reactors work at high pressures that increase the risk of a meltdown if a reactor system fails to cool the reactor down) and that use liquid uranium, again increasing efficiency of energy production. With these technological advances, nuclear power may become a vital player in a sustainable energy future.

Chapter 4 – Empirical Analysis of Energy Efficiency Policies on Household Consumption and Energy Poverty

Introduction

The last chapter of this report undertakes a quantitative empirical analysis of how energy efficiency improvements in European countries have translated into changes in consumption patterns and energy poverty rates. Utilising econometric techniques[1] enables us to statistically show how improvements in household energy efficiency and related policies can coincide with reduced household energy spending and help to lower energy poverty rates.

On the whole, in Europe, when energy efficiency measures increase by one point, household energy spending levels tend to drop by 0.24% to 0.71%. The effect is more pronounced in CEB target countries* where the same increase can be associated with a 1.15% decrease in spending levels.

When analysing government policies that promote energy efficiency in households, those policies that set minimum regulatory guidance (construction materials, boiler types, etc.) tend to have a statistically significant but delayed impact on reducing household energy spending. For instance, the implementation of a single low-impact regulation may, after five years, reduce household spending by 0.22%. Energy poverty rates, measured here by the percentage of people reporting to be unable to keep their homes warm, can see a statistically significant drop of 0.21% when energy efficiency increases by one point.

However, it is important to note that nearly all the models employed in this section found that the consistently most significant variable in reducing energy poverty were increases in income levels. Therefore, while energy efficiency improvements are a crucial component in reducing energy spending and energy poverty, they are only part of a large basket of needed economic and policy improvements.

Energy spending decreasing by 0.24% to 0.71%: the amount household energy spending may drop by, when the household energy efficiency index increases by one point.

Regulations towards energy efficiency: may be the most effective form of government policy in reducing energy spending, but take several years to become effective.

Energy poverty reduced by 0.21%: this number indicates the drop in the percentage of people reporting an inability to keep their home warm when household energy efficiency index increases by one-unit.

***Target countries** are the following: Albania, Bosnia and Herzegovina, Bulgaria, Croatia, Cyprus, Czech Republic, Estonia, Georgia, Hungary, Kosovo, Latvia, Lithuania, Malta, Republic of Moldova, Montenegro, Poland, Romania, Serbia, Slovak Republic, Slovenia and North Macedonia, Turkey.

[1] See methodological section for details on the econometric techniques employed for the analysis in annex 3.

Energy efficiency and household consumption

The paper begins by quantitatively analysing how energy efficiency gains between 2000 and 2015 affected residential energy consumption spending. Table 4.1 below presents the results of two econometric models[2] which analyse to what degree improvements in the Odyssee-MURE household energy efficiency index have reduced household annual energy consumption (measured as the total residential sector spending on energy divided by floor area[3]). Each model also includes other traditional variables that affect consumption decisions, such as energy prices for households, real disposable income, number of heating days in a year, and population growth.

In both models we examine the effect of improvements in the energy efficiency index not only for the reported year, but also with time delays (lags) to see if the effect either persists over time or is delayed.

Info Box 5 – **How to read the tables**

The econometric outputs in chapter 4 are relatively technical and for those not accustomed to reading such results the following fundamental explanations can hopefully serve as a guide.

Simply put, a regression in econometrics is to examine how an explanatory variable of interest (x) affects a dependent variable (y). An often-cited example is how much a person's wage (y) will change given the number of years of schooling (x).

In our outputs we have a number of different Xs that are mathematically altered. To simplify matters:

Explanatory variable (x)	Dependent variable (y) with **(log)**	Dependent variable (y) with **no (log)**
With **(log)**	Number in the table should be the % change in y if x increases by 1%	The number in the table shows a 1% increase in X, which should be divided by 100 to see by how much y changes
Has **no (log)**	Number in the table should be multiplied by 100 to see the % change in y	Number in the table represents how much y changes if x changes by 1

Table 4.1 – Energy efficiency effects on household energy spending – empirical results

Base model - Panel Fixed Effects Regression

Dependent - *Household energy consumption spending (log)*	All countries in sample				Target-countries				Non-Target countries			
	no lag	lag t-1	lag t-3	lag t-5	no lag	lag t-1	lag t-3	lag t-5	no lag	lag t-1	lag t-3	lag t-5
Household Energy Efficiency Index	-0.0071*** (0.0028)	-0.0066*** (0.0024)	-0.006*** (0.0021)	-0.0038 (0.0026)	-0.0115*** (0.0028)	-0.0111*** (0.0029)	-0.009** (0.003)	-0.0034 (0.003)	-0.0064* (0.0031)	-0.0058** (0.0027)	-0.0061** (0.0023)	-0.008** (0.0033)
Energy prices, household avg. (log)	-0.0177 (0.0373)	-0.0283 (0.0433)	-0.04 (0.0597)	-0.083 (0.0635)	-0.1521 (0.0816)	-0.1517* (0.0834)	-0.3633*** (0.026)	-0.2037*** (0.0572)	0.0271 (0.044)	0.011 (0.052)	0.0091 (0.057)	-0.040 (0.053)
Real disposable income (log)	0.339*** (0.0862)	0.386*** (0.0953)	0.460*** (0.108)	0.462*** (0.138)	0.3695** (0.1185)	0.4012** (0.1394)	0.380*** (0.1145)	-0.3213** (0.132)	0.421** (0.209)	0.467** (0.210)	0.603** (0.234)	0.680** (0.261)
Heating days (log)	0.0542 (0.0692)	0.039 (0.0681)	0.000001 (0.0838)	-0.021 (0.076)	0.0303 (0.046)	0.0257 (0.0560)	0.0077 (0.0460)	-0.12750* (0.0469)	0.110 (0.20)	0.074 (0.177)	0.086 (0.169)	0.095 (0.108)
Population (log)	0.302 (0.5364)	0.2 (0.529)	0.0262 (0.519)	0.250 (0.441)	-0.1538 (0.6303)	0.0027 (0.7050)	0.0387 (0.6786)	0.7336 (0.6027)	-0.449 (0.834)	-0.294 (0.808)	-0.222 (0.702)	-0.065 (0.542)
Observations	326	308	272	226	132	127	116	96	194	181	156	130
Countries	24	23	23	23	10	10	10	10	14	13	13	13

Model Two - LSDV Dynamic regression

Dependent - *Household energy consumption spending (log)*	All countries in sample				Target-countries				Non-Target countries			
	no lag	lag t-1	lag t-3	lag t-5	no lag	lag t-1	lag t-3	lag t-5	no lag	lag t-1	lag t-3	lag t-5
Household Energy Efficiency Index	-0.0024** (0.001)	-0.0019* (0.001)	-0.0012 (0.0011)	-0.0013 (0.0013)	-0.0037* (0.0022)	-0.0031 (0.0022)	-0.0026 (0.0019)	-0.0006 (0.0019)	-0.0030** (0.0013)	-0.0023* (0.0013)	-0.0021 (0.0014)	-0.0046** (0.0019)
Energy prices, household avg. (log)	-0.0187 (0.0181)	-0.0278 (0.0173)	-0.0239 (0.02)	-0.0483* (0.028)	-0.0780** (0.0321)	-0.0819** (0.0332)	-0.1968*** (0.0593)	-0.1404** (0.0586)	0.0131 (0.0245)	0.0058 (0.0229)	0.0088 (0.0225)	-0.0113 (0.0353)
Real disposable income (log)	0.1352*** (0.0435)	0.1545*** (0.0432)	0.1678*** (0.0484)	0.1762*** (0.0618)	0.1087* (0.0615)	0.1056** (0.0674)	0.1273* (0.0719)	0.1281 (0.132)	0.2117*** (0.0787)	0.2352*** (0.0756)	0.2752*** (0.0794)	0.3351*** (0.0973)
Heating days (log)	0.1942*** (0.065)	0.184*** (0.0621)	0.1879*** (0.0651)	0.1605** (0.0683)	0.0683 (0.0826)	0.0644 (0.0846)	0.0466 (0.0877)	-0.0506 (0.0851)	0.3618*** (0.112)	0.3132*** (0.1055)	0.4069*** (0.1022)	0.450*** (0.112)
Population (log)	-0.0964 (0.1293)	-0.0219 (0.1306)	0.077 (0.1434)	0.253 (0.1803)	-0.1067 (0.1992)	-0.1362 (0.2275)	-0.1044 (0.2538)	0.2334 (0.3196)	-0.2752 (0.2005)	-0.09 (0.2023)	-0.0516 (0.23)	-0.0920 (0.31)

Notes - *** indicates a 1% significance, ** indicates a 5% significance, and * indicates a 10% significance level

Interpreting this table - the models are a mix of log-level and log-log regressions. The household energy efficiency index variable should be interpreted as a log-level regression. Thus a one-point increase in the household energy efficiency index should be seen as affecting household energy spending by 100 * the household energy efficiency index value shown in the table (i.e. 100* β_{EF}). While the remaining variables should be interpreted as a log-log regression. Thus a 1% increase in any of the log variables (prices, disposable income, heating days, or population) is expected to see household energy consumption spending change by the value shown in the table.

[2] Full methodology of the model can be found in appendix 3

[3] Floor area is derived by taking the average floor area of a dwelling times the number of permanently occupied dwellings – all information is available on the MURE database and this method replicates the one employed by (O Broin, Nassen and Johnsson 2015).

Base model analysis

In the base model, for all CEB countries, we see that a one-point increase (equivalent to a 1% gain) in the household energy efficiency index with no lag results in a reduction in household energy spending of 0.71%. This effect is thus significant without a lag, but becomes slightly less so after one and three years, and turns statistically insignificant after five years. For instance, improvements in energy efficiency reduce consumption by -0.66% after a one-year delay and by -0.6% within three years.

On the other hand, in the same base model, for all CEB countries, growth in disposable income can be seen as a significant counterbalancing variable in increasing household consumption spending, regardless of how much the energy efficiency index is lagged – when energy efficiency is not lagged, a 1% increase in disposable income corresponds to a 0.34% increase in household energy consumption. According to table 4.1, the impact of disposable income increases over time as the lag effect of energy efficiency gains declines and become insignificant.

The base model also analysed data corresponding to CEB target and non-target countries. While reducing the sample size of the model, a number of interesting findings emerge.

In CEB target countries, the effect of energy efficiency on energy consumption spending is significant with no lag as well as with a one- and three-year lag. Interestingly, the magnitude of the effect is far greater compared to both the results found with all CEB countries (first column) and with non-target countries (third column) in the year of implementation. In the reported year (no-lag), a one-point increase in energy efficiency results in a -1.2% decrease in household energy consumption, and this contracting effect remains at around -1% after three years, after which the variable becomes insignificant.

However, in CEB non-target countries, the negative consumption effect of energy efficiency improvements, while overall much smaller than in CEB target countries, is significant up to five years after implementation. Furthermore, this effect increases over time. For instance, in the reporting year (no lag), a one-unit increase in energy efficiency corresponds to a -0.64% decrease in household energy consumption, but after five years the increase is associated with a -0.8% decrease in spending.

Model two analysis

The analysis runs a **second model**, known as a LSDVC dynamic regression, which in its simplest form (see methodological appendix for full details) examines the same variables, but adds a one-year lagged variable of household consumption as one of the determinants of current household consumption. The underlying logic is that consumption patterns observed in the previous year can strongly influence current levels (not reported in tables).

In the second model, many of the effects of energy efficiency on household energy consumption spending observed in the first model continue to hold, but their magnitude declines, with statistical significance levels tapering out over time. When examining all CEB countries, energy efficiency tends to have a negative impact on household consumption of -0.24% in the reported year, but remains significant for only one more year, when consumption is reduced by -0.2%. Conversely, increases in real disposable income, number of heating days and previous year consumption[4] all have a positive and significant impact on household energy consumption spending, regardless of how many years one delays implementation of energy efficiency improvements.

In **CEB target countries**, a one-point increase in the household energy efficiency index has a significant and negative effect on household energy consumption in the reported year (no-lag) of -0.37%, but the significance dissipates in later years. However, increases in energy prices also had a negative impact on consumption, which only increased as the lag on the energy efficiency index increased.

For **CEB non-target countries**, model two displays more or less the same results as in the base model, with improvements in energy efficiency having significant and negative, albeit lower, effects on household consumption. As in the base model, the magnitude of the impact of energy efficiency varies

[4] Not reported in tables

over time. In the reported year, a one-point increase in energy efficiency results in a -0.3% decline in consumption, with the effect reducing to -0.23% and -0.21%, one and three years later, respectively. However, the negative effect increases five years later, reducing household consumption by -0.46%. This jump may, in part, be explained by the fact that not all households are able to immediately take advantage of energy efficiency gains from new energy saving appliances due to high initial costs or limited savings. As in the base model, disposable income has a positive and significant effect, regardless of the lag on the energy efficiency index variable – as well as both the number of heating days and the previous year's consumption.

Policies promoting energy efficiency and household consumption

Additional influences on household energy consumption may come from the policies that are implemented to promote energy efficiency in the residential sector. Table 4.2 below follows the same econometric approach as table 4.1, but replaces the energy efficiency index score with three variables that quantitatively capture the impact of the financial, regulatory, and informative/educational policies that governments have undertaken to promote energy efficiency (the data are obtained from the Odyssee-MURE energy efficiency policy database). As in the previous section, we add lags (time-delays) for the respective policies, as it may take several years for a policy to take affe ct and alter consumption patterns (lags are set at one, three, five and six years).

Base model analysis

When examining the **base model** in table 4.2 for all the countries in the sample (column one), we see that **only the regulatory policies have a significant and negative effect on household energy consumption, five years after implementation**. Thus, a one-point increase in regulatory policies promoting energy efficiency (the equivalent of what is considered a "low-impact policy", see methodology in annex 3), results in a decrease in household energy consumption by -0.22% after five years, and by -0.21% after six years. However, the model does show that real disposable income remains the primary positive driver of household energy consumption, as shown by the significance values, regardless of the lags set on policy drivers.

When examining the base model for **CEB target countries** only (column 2), a more complex picture emerges. Energy prices and real disposable income remain, respectively, significant negative and positive drivers of household energy consumption, with increasing effects as lags are placed on policies. For instance, when examining the results in the year of a policy's implementation (no lag column), a 1% increase in energy prices drives down consumption by -0.37% and a 1% rise in real disposable income increases consumption by 0.42%. However, six years after the policies are implemented, the affects grow to -0.43% (for prices) and 1.24% (for income).

Concerning the impact of policies, the main issue at stake here, paradoxically, is a one-point increase in **financial policy** that promotes energy efficiency the year of implementation (with no lag) and after one year (lag t+1) has a significant effect in increasing household consumption by 0.3% and 0.36%. Similarly, a one-point increase in **information/ educational policy** is significant after three years of implementation and drives up household consumption by 0.98%. These unexpected results may stem from a few underlying reasons. First, it may happen that such policies were implemented during an era when levels of energy spending were growing, all else being equal, and those financial and information policies were not powerful enough to offset the increases.

Another potential mechanism driving an increase in energy spending is the "rebound effect" (explained in chapter 2) through the growing use of new subsidised energy efficient appliances, materials, etc. This may be valid in the context of some of the financial incentive policies implemented in CEB target countries, which helped households replace inefficient and outdated heating sources, boilers, etc. In some cases, this may have resulted in being able to heat more rooms in houses, requiring less input-work (feeding solid fuel into the system), and connecting systems to gas/electricity supplies. In all, this results in increased spending due to convenience/ease or the desire to improve household wellbeing (e.g. heating more rooms during winter).

Regulatory policies, on the other hand, tend to have a significant and negative effect on household energy spending six years after implementation (a result that is similar to the findings of other studies). Therefore, a one-point increase in regulatory policies on household energy efficiency has a rather significant impact in the year of implementation (no-lag), decreasing household consumption by -0.11%. After five years, that same effect remains significant and even bigger, reducing household consumption by -0.27%.

For **CEB non-target countries**, the base model shows that regulatory policies tend to have a significant effect five years after implementation, when a one-point increase in such policies results in household energy expenditure decreasing by -0.1%, and by -0.12% six years after implementation. Furthermore, information-related policies tend to be a significant driver in reducing energy spending after six years of implementation– perhaps indicating the time-lag it takes for behaviours to be changed by households and those constructing/designing homes and home heating systems. Financial-related policies tend to be significant after six years, with a one-point increase actually increasing household energy consumption by 0.06%.

Model two analysis

A Dynamic LSDV regression in table 4.2 (**model two**) was also run, utilising the same principles as in table 4.1. **For the most part, there are only a few changes in the significance values of the variables compared to those of the base model**. When examining all CEB countries, regulatory energy efficiency polices remain the only significant policies that reduce household energy spending. As in the base model, these policies only begin to generate a negative spending effect after five years, but the magnitude of the effect is smaller compared to that of the base model; a one-point increase in the regulatory policy is associated with a drop of just -0.08% in energy spending after five years, and of -0.09% after six.

In **CEB target countries** we do see a slight change. **Financial policies** remain significant and increase household energy spending in the year of implementation and one year later. However, after three years, they not only remain significant (a change from the base model) but they start to drive down

Table 4.2 – Government policies promoting energy efficiency effects on household energy spending – empirical results

Base model - Panel Fixed Effects Regression

Dependent - Household energy consumption spending (log)	All countries in sample					Target+countries					Non-Target countries				
	no-lag	lag t+1	lag t+3	lag t+5	lag t+6	no-lag	lag t+1	lag t+3	lag t+5	lag t+6	no-lag	lag t+1	lag t+3	lag t+5	lag t+6
Financial policy	-0.00009	0.00002	-0.0098	-0.0007	-0.0007	0.003*	0.0036**	-0.0008	-0.00007	-0.000005	-0.001	-0.0013	-0.0009	0.0007	0.0006*
	(0.0011)	(0.0012)	(0.0012)	(0.0006)	(0.0005)	(0.0014)	(0.0014)	(0.0017)	(0.0011)	(0.0011)	(0.001)	(0.0016)	(0.0012)	(0.0004)	(0.0003)
Regulatory policy	0.0007	0.0002	-0.0005	-0.0022**	-0.0021**	-0.001	-0.0015	0.0020	-0.0012	-0.004**	0.0012	0.0004	-0.0006	-0.0010*	-0.0012**
	(0.0008)	(0.0007)	(0.0009)	(0.0010)	(0.0008)	(0.0019)	(0.0023)	(0.0019)	(0.0013)	(0.001)	(0.0009)	(0.0008)	(0.001)	(0.0005)	(0.0004)
Information policy	0.0010	0.0006	0.0017	0.0005	0.0004	0.001	0.0024	0.0098***	-0.002	0.005	0.0004	-0.0002	0.0004	-0.00002	-0.0008**
	(0.0010)	(0.001)	(0.0011)	(0.0006)	(0.0009)	(0.0042)	(0.0047)	(0.0021)	(0.0012)	(0.003)	(0.0014)	(0.0012)	(0.0012)	(0.0004)	(0.0003)
Energy prices,	-0.172*	-0.104	-0.118	-0.229*	-0.229*	-0.367**	-0.281**	-0.285**	-0.425**	-0.434*	-0.058	-0.032	-0.126	-0.308***	-0.446***
household avg. (log)	(0.079)	(0.079)	(0.119)	(0.110)	(0.133)	(0.127)	(0.109)	(0.099)	(0.178)	(0.206)	(0.159)	(0.141)	(0.156)	(0.084)	(0.093)
Real disposable	0.489***	0.449***	0.414**	0.783*	0.768**	0.416**	0.402**	0.706***	1.262**	1.243**	0.564**	0.378	0.140	0.025	0.258
income (log)	(0.105)	(0.123)	(0.195)	(0.379)	(0.347)	(0.138)	(0.159)	(0.207)	(0.481)	(0.429)	(0.234)	(0.217)	(0.139)	(0.173)	(0.235)
Heating days (log)	0.055	0.078	0.060	0.037**	0.024	0.028	0.058	0.049	0.014**	-0.028	0.004	0.053	-0.083	0.155	0.240***
	(0.084)	(0.082)	(0.067)	(0.048)	(0.49)	(0.052)	(0.056)	(0.077)	(0.049)	(0.045)	(0.324)	(0.302)	(0.284)	(0.166)	(0.063)
Population (log)	-0.264	-0.216	-0.556	0.313	0.437	-0.420	-0.323	-0.204	1.388	1.682	0.432	0.301	-0.401	-0.897	-0.773**
	(0.522)	(0.639)	(0.935)	(1.965)	(1.28)	(0.462)	(0.580)	(0.736)	(1.505)	(1.855)	(1.131)	(1.150)	(1.000)	(1.233)	(0.278)
Observations	205	186	147	109	91	96	98	71	53	45	109	98	76	56	46
Countries	20	20	19	19	19	9	9	9	9	9	11	11	10	10	10

Model Two - LSDV Dynamic regression

Dependent - Household energy consumption spending (log)	All countries in sample					Target+countries					Non-Target countries				
	no-lag	lag t+1	lag t+3	lag t+5	lag t+6	no-lag	lag t+1	lag t+3	lag t+5	lag t+6	no-lag	lag t+1	lag t+3	lag t+5	lag t+6
Financial policy	-0.000013	0.00001	-0.0006	-0.00015	0.0006	0.0018***	0.0016*	-0.0018**	-0.00002	-0.0009	-0.0011*	-0.0008	0.00001	0.0005	0.0005
	(0.0552)	(0.0004)	(0.0004)	(0.0004)	(0.0004)	(0.0007)	(0.0008)	(0.0009)	(0.00087)	(0.0008)	(0.0006)	(0.0005)	(0.0005)	(0.0004)	(0.0004)
Regulatory policy	-0.00017	0.0004	0.00004	-0.0008**	-0.0009**	-0.0011*	-0.0012*	0.0003	-0.0002	-0.0027***	0.00006	-0.0005	-0.00012	-0.0009**	-0.0006
	(0.0003)	(0.0003)	(0.0004)	(0.0004)	(0.0004)	(0.0006)	(0.0007)	(0.0008)	(0.0011)	(0.001)	(0.0004)	(0.0004)	(0.0004)	(0.0004)	(0.0005)
Information policy	0.00006	0.0001	0.0012	0.00077	0.0005	0.0014	0.0022	0.0025	-0.0015	0.0043*	-0.0002	-000009	0.0010	-0.000006	-0.0003
	(0.0006)	(0.0006)	(0.0005)	(0.0005)	(0.0005)	(0.0002)	(0.0018)	(0.002)	(0.0025)	(0.0025)	(0.0007)	(0.0006)	(0.0006)	(0..0006)	(0.0005)
Energy prices,	-0.0514	-0.036	-0.043	-0.0184	-0.0844**	-0.0974	-0.0993**	-0.063	-0.0127	-0.1191	-0.0174	-0.0266	-0.0684	-0.0536	-0.0950*
household avg. (log)	(0.0393)	(0.040)	(0.047)	(0.0427)	(0.0453)	(0.073)	(0.0744)	(0.082)	(0.0905)	(0.0916)	(0.0617)	(0.0600)	(0.0726)	(0.0527)	(0.0579)
Real disposable	0.1245*	0.101	0.161**	0.1243	0.170**	0.147	0.145	0.179	0.0992	0.1692	0.1315	0.0510	0.0703	0.1231	0.1798*
income (log)	(0.0653)	(0.072)	(0.0714)	(0.0868)	(0.092)	(0.097)	(0.109)	(0.116)	(0.1622)	(0.1628)	(0.1074)	(0.1094)	(0.1055)	(0..1103)	(0.1071)
Heating days (log)	0.2155***	0.215***	0.122*	0.1450**	0.097*	0.0443	0.0514	0.0341	0.0446	0.0221	0.5818***	0.5965	0.309	0..2774	0.3078***
	(0.0665)	(0.067)	(0.066)	(0.0639)	(0.06)	(0.083)	(0.084)	(0.0849)	(0.0894)	(0.0765)	(0.1232)	(0.1235)	(0.1541)	(0.1212)	(0.1202)
Population (log)	-0.0731	-0.192	-0.436*	0.795**	-0.375	-0.123	-0.183	-0.564	-1.2074	0.7513	-0.813	0.301	-0..5142	0.1417	-0.305
	(0.206)	(0.215)	(0.245)	(.326)	(0.375)	(0.236)	(0.261)	(0.329)	(0.483)	(0.5787)	(0.500)	(1.150)	(05351)	(0.5087)	(0.497)

Notes - *** indicates a 1% significance, ** indicates a 5% significance, and * indicates a 10% significance level

Interpreting this table - the models are a mix of log-level and log-log regressions. The variables that captire the government policies that promote energy efficiency should be interpreted as a log-level regression. Thus a one-point increase in any one of the government policies that promote energy efficiency (financial, regulatory, information) should be seen as affecting household energy spending by 100 * the value for the respecitve policy shown in the table (i.e. 100*βFP, 100*βRP, 100*βIP). While the remaining variables should be interpreted as a log-log regression. Thus a 1% increase in any of the log variables (prices, disposable income, heating days, or population) is expected to see household energy consumption spending change by the value shown in the table.

energy consumption by -0.18% after a one-point increase in the policy measure – the negative, albeit statistically insignificant, effect continuing in later periods This is encouraging since it potentially shows that financial policies would need ample time to be absorbed by households/builders, and that spending behaviour changes for the better after an initial increase in spending, upon the instillation of subsidised household energy efficiency improvements.

As for **CEB non-target countries**, model two also shows a slight change from the base model. Regardless of the time lag placed on information policies, they no longer remain statistically significant (although they are negative with most lags). Financially oriented policies are significant in the year of implementation and a one-point increase in the policy measure will reduce household energy consumption by -0.11%. While the signs of the coefficients are similar to those in the base model, the primary difference is that, after six years, financial policies no longer increase household energy spending. Regulatory policies remain significant and have a negative effect on energy spending five years after implementation, when a one-point increase in regulatory policies may reduce household energy spending by -0.09%.

The variations in the significance levels between the base model and model two as well as those in some cases of policies encouraging more energy spending could, in part, stem from how the different policies were designed. These differences are not fully captured in our quantitative country-level variables. The micro/household level data within countries may shed light on how the design and implementation of these policies alter energy spending patterns.

Energy poverty and energy efficiency

A final model examines to what degree improvements in energy efficiency or a decrease in the proportion of low-quality dwellings decreases the proportion of a country's population that is unable to keep their homes adequately warm. This model employs a fully modified OLS approach, and the variables of interest are the energy efficiency index (same as in table 4.1) and the proportion of people living in low-quality dwellings. Each variable of interest is estimated in a separate model, with a series of country-level control variables: energy consumer price index, public spending on housing investments, GDP per capita, heating days, and population (for full details see methodology in appendix 3).

As in the previous section, the models are run using **all countries** in the sample – columns one and two in table 4.3. When examining all countries, a one-point increase in energy efficiency (column 1) is significant and decreases the surveyed proportion of people

Table 4.3 – Energy poverty and energy efficiency – empirical results

FMOLS estimation

Dependent - *Ability to keep home warm*	**All countries**		**Target-countries**		**Non-Target countries**	
Energy residential efficiency index	-0.214*** (0.023)		-0.188*** (0.037)		-0.164*** (0.027)	
Low quality dwellings		0.280*** (0.088)		0.510*** (0.042)		0.856*** (0.192)
HICP (log)	12.196*** (1.352)	7.489** (3.137)	13.597*** (1.985)	8.162*** (1.715)	3.038* (1.608)	-2.089 (1.348)
Gov. housing investment (log)	-3.512*** (0.345)	-3.077*** (0.79)	-5.341*** (0.634)	-5.496*** (0.634)	-1.791*** (0.190)	-1.963*** (0.085)
GDP per capita (log)	-15.952*** (2.297)	-11.85* (6.015)	-18.540*** (3.598)	-1.175 (2.884)	-17.080*** (1.908)	-2.031 (1.400)
Heating days (log)	0.338 (1.320)	1.259 (3.501)	1.390 (2.017)	3.155* (1.682)	-2.613** (1.242)	-0.484 (1.997)
Population (log)	7.382 (4.893)	-8.284 (13.19)	-15.724* (8.527)	-16.684** (8.527)	30.152*** (4.294)	2.250*** (0.258)
Observations	233	233	110	110	123	123
Countries	24	24	11	11	13	13

Notes - *** indicates a 1% significance, ** indicates a 5% significance, and * indicates a 10% significance level

Interpreting this table - the models are a mix of level-level and level-log regressions. The household energy efficiency index and the low quality of dwelling variables should be interpreted as a level-level regression. Thus a one-point increase in either one should as affecting household energy spending by the value for the respecitve policy shown in the table. While the remaining variables should be interpreted as a level-log regression. Thus a 1% increase in any of the log variables (HCIP, reald GDP, government housing investment, heating days, or population) is expected to see household energy consumption spending change by the value shown in the table divided by 100 (i.e. βHCIP/100, βGHOUSE/100, βGDP/100, βHDD/100, βPOP/100) unable to keep their homes warm by -0.21%. At the same time, a 1% increase in the proportion of people reporting living in low-quality dwellings (a proxy for lack of energy efficiency) in column 2, is statistically significant and will increase the percentage of people unable to keep their homes warm by 0.28%.

Importantly, a 1% increase in the consumer price index for energy is also a significant variable in both the energy efficiency and low-quality dwelling models, and can potentially increase the percentage of people unable to keep their homes warm by 0.12% or 0.75% (the results from the respective models).

Government investment in housing is a statistically significant variable in helping reduce the percentage of people in energy poverty. However, the impact is not very great; a 1% increase in government housing investment is associated with reducing the proportion of people in energy poverty by between -0.035% (energy efficiency model) and -0.031% (low-quality dwelling model). Furthermore, an increase in GDP per capita is statistically significant in both models, and a 1% increase can help reduce energy poverty rates by between -0.16% (energy efficiency model) and -0.12% (low-quality dwelling model).

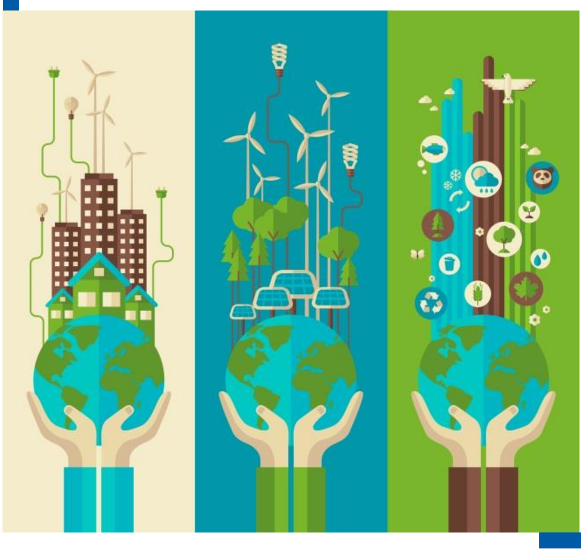
As in the previous section, the same models are examined for **target-countries**. The findings are similar to the models that are run with all countries, but with magnitudes of the variables being larger in some instances – bar energy efficiency, which though significant, a one-point increase will be associated with a decrease in energy poverty by -0.19% (slightly lower than the model with all countries). However, if the proportion of people that live in low-quality dwellings increases by one point (equal to one percentage point), the energy poverty rate will increase by 0.5%.

The effect of an increase in the consumer price index for energy is significant and slightly higher for both models in target countries – a 1% increase in the energy price index is associated with an increase in energy poverty of 0.14% (energy efficiency model) and of 0.82% (low-quality dwelling model). At the same time, the effect of government investment in the housing sector also remains significant and greater in magnitude of effect– with a 1% increase in public investment decreasing the percentage of those in energy poverty by 0.053% (energy efficiency model) and by 0.055% (low-quality dwelling model). A 1% increase in GDP per capita is only significant and positive in the energy efficiency model, and may contribute to a decrease in energy poverty by 0.19%.

When focusing the analysis on **non-target countries**, we observe that a one-point increase in the energy efficiency index score is statistically significant and is associated with a -0.16% drop in reported energy poverty. However, if the percentage of people reported living in low-quality dwellings increases by 1%, we see a 0.86% increase in the percentage of people reported to be energy poor – indicating that a potentially higher number of vulnerable people may slip into energy poverty if dwelling quality is left unchecked.

GDP per capita growth is only significant for the energy efficiency model, and a 1% increase is associated with a -0.17% decline in the energy poverty rate. On the other hand, the impact of government spending on housing remains significant in both models, but a 1% increase in spending will only decrease energy poverty rates by less than 0.02%.

In the final analysis, we see that GDP per capita remains one of the primary drivers for decreasing energy poverty rates throughout Europe. Moreover, the impact of improving energy efficiency in households may have slightly greater effects in reducing energy poverty rates in target countries as there is still increased room for the uptake of energy efficiency products/building materials.



Conclusion

Energy poverty is mostly the result of households having limited incomes and low-quality dwellings, and being faced with fluctuations in energy prices; as a result, it is a problem that can be found in most CEB member countries. As of 2016, there were an estimated 30 million people living in energy poverty and unable to keep their homes adequately warm; moreover, it is the most vulnerable groups that have the greatest likelihood of being affected.

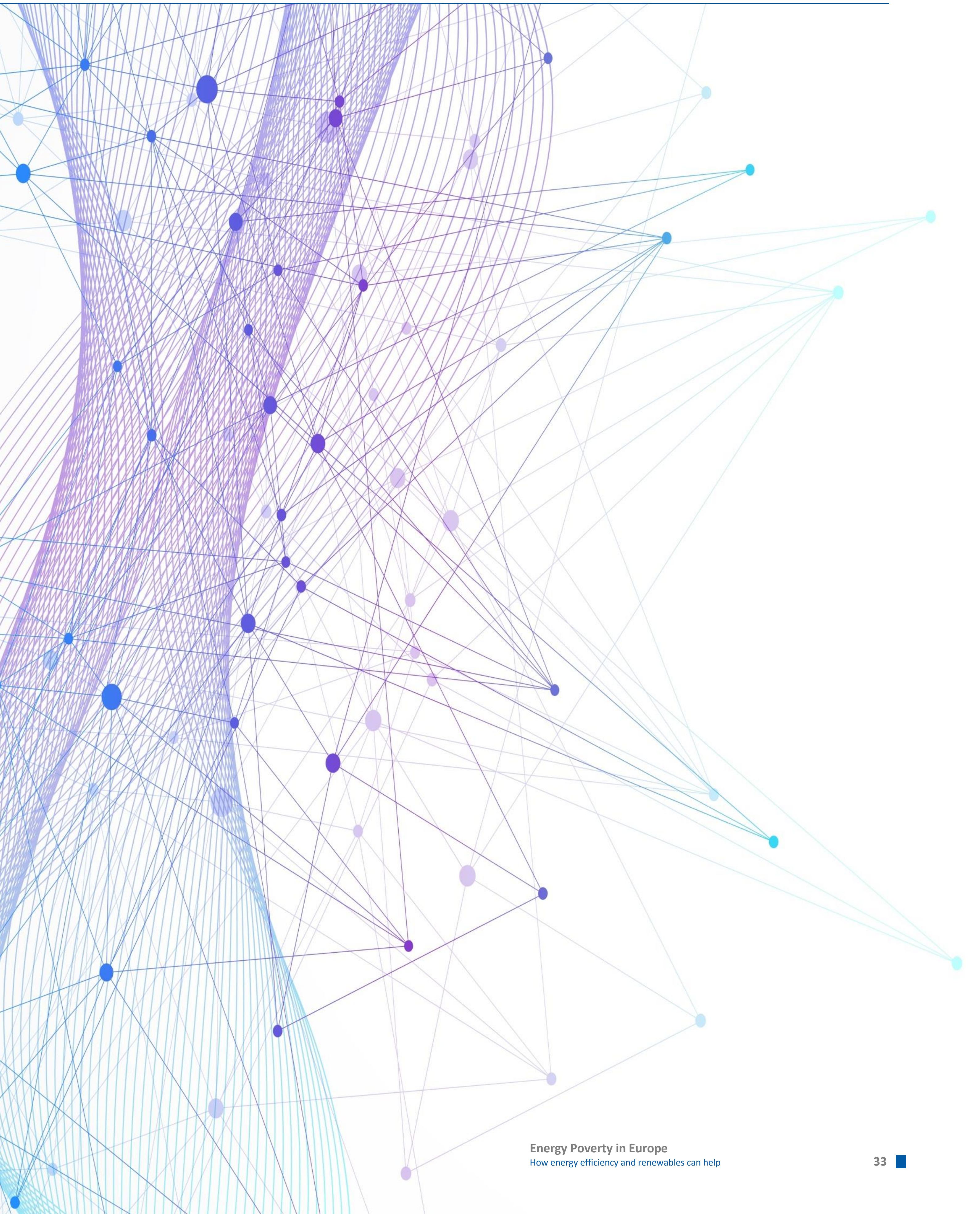
Under limited income constraints, households that are in energy poverty are faced with having to choose between energy consumption and other basic necessities, all of which can come at the cost of health, education and productivity outcomes. These choices are exasperated when energy price increases result in households having to pay significantly more for energy or reduce their energy consumption levels. Based on demand elasticity calculations, in the absence of household income growth, most families are unable to afford to increase their energy consumption in order to alleviate energy poverty hardships.

Encouragingly, governments throughout Europe are stepping in to soften the blow of energy poverty. Energy efficiency policies can contribute to educating consumers and improving the quality of homes, so as to help reduce energy consumption levels and, in turn, lower energy poverty rates. In the last 20 years, the number of regulatory, financial, and education/information related policies to promote household energy efficiency has increased six fold. Countries which have actively promoted sustainable and long-term energy efficiency have tended to see energy poverty rates drop and to rely less on providing subsidies to low-income households to overcome energy poverty. Moreover, energy poverty will be further reduced as energy efficiency improvements, coupled with increased use of renewable energy (and the corresponding renewable energy price drops) continue to move forward.

Empirical analysis suggests that household energy efficiency improvements and increases in household income growth, as well as government housing investment, can help significantly to alter household consumption patterns for the better. Year-on-year improvements in household energy efficiency standards have helped reduce average household energy consumption levels by 0.24% to 0.71% annually and energy poverty rates by 0.21%. The research conclusions of this study, along with numerous other works in the field, highlight the noticeable energy bill savings that households can achieve if more emphasis is placed on improving energy efficiency standards.

Energy poverty can be combated in Europe by resolute, sustained and multifaceted action, thereby easing pressure on the already strained wallets of low-income households, decreasing wasteful and environmentally detrimental consumption of energy, and narrowing the impact of income inequalities.

Methodological Annexes



Annex 1 – Elasticity methodology
(Chapter 1)

For the household electricity demand elasticity calculations presented in chapter 1, we construct the following demand elasticity model that we utilise twice – once to determine household electricity demand elasticity, and again to determine household natural gas demand elasticity:

$$\ln(\mathrm{EC})_{it} = \alpha + \beta_Y \ln(Y_{it}) + \beta_P \ln(P_{it}) + \beta_{HDD} \ln(HDD_{it}) + \delta_i + \mu_{it} \quad (1)$$

where EC_{it} indicates average household energy spending per capita on either electricity or natural gas (we run elasticity models for both types of energy) in country $i = 1, \dots, N$ at time $t = 1, \dots, T$, Y_{it} denotes real disposable income in 2010 euros, P_{it} is average price for a KwH of electricity or gas, and HDD_{it} is the heating degree days. We take the natural log of all variables so that we are able to examine the percentage changes in electricity demand, which in turn can be interpreted as elasticities. The variable δ_i denotes individual country fixed effects, and μ_{it} represents the error term.

To determine the long-term relationship between electricity demand and price/income changes we first examine if the underlying data in our panel data set are integrated at an order of one $I(1)$. To do this, we undertake a panel-unit root test formulated by Im, Pesaran, and Shind (1997), which tests the stationary properties of the variables in our model. The IPS test permits heterogeneity in the intercept and slop for all units in our sample and works to solve serial correlation issues (which our model has). Moreover, the IPS model relaxes assumptions made concerning common autoregressive parameters; the data is not pooled as in the Levin-Lin-Chu (2002) model, but rather the Dickey-Fuller (DF) statistics are calculated for each cross-sectional unit. The IPS panel unit root equation below tests for the null-hypothesis if $\rho_i = 0$ for all i, with the alternative hypotheses being if $\rho_i < 0$ for some i=1,…,N and $\rho_i < 0$ for i=$N_1 + 1, \dots, N$.

$$\Delta y_{it} = \alpha_i + \rho_i y_{i,t-1} + \sum_{j=1}^{p} \theta_{ij} \Delta y_{i,t-j} + \varepsilon_{it} \quad (2)$$

Table 1 – IPS Panel Unit Root tests

	Variable models					
	Ln(EC)	Ln(P) – electricity	Ln(P) –gas	Ln(Y)	Ln(HDD)	Ln(POP)
Level	-3.667*** (0.0001)	2.024 (0.979)	-1.34* (0.09)	-0.970 (0.166)	-10.73*** (0.000)	6.600 (1.00)
First Difference	-10.06*** (0.000)	-10.10*** (0.000)	-10.03*** (0.000)	-6.315*** (0.000)	--19.95*** (0.000)	-6.55*** (0.000)

Note - *** indicates a 1% significance, ** indicates a 5% significance, and * indicates 10% significance

The IPS panel unit root test shows that for three of the six variables we fail to reject the null hypothesis that the variables contain a unit root. When we test the same variables when they are first differences we reject the null hypothesis for all variables at the 1% level, thus concluding that the variables are non-stationary in nature.

Upon determining the level of stationarity for the variables in our model we must determine if there is a long-term relationship between the variables. To do so, we run a panel cointegration test formulated by Pedroni (1999, 2004) for the $I(1)$ variables. Pedroni's cointegration test for panel data allows for heterogeneity among cross-sectional units. Pedroni's work utilises the augmented Dickey Fuller (ADF) and the Phillips-Perron (1988) (PP) tests, and differentiates from Kao's (1999) work in that it allows for the same AR coefficient over all the panels in the sample. The calculations of the test utilise the estimated residuals of the following long-run regression:

$$y_{it} = \alpha_i + \delta_i t + \gamma_t + \beta_{1i} X_{1it} + \dots + \beta_{Mi} X_{Mit} + \varepsilon_{it} \qquad \text{for } i = 1, \dots, N; t = 1, \dots, T; m = 1, \dots, M \quad (3)$$

In the model, N denotes the number of individuals, T denotes the number of observations, M refers to the number of exogenous variables, α_i is the individual specific event, $\delta_i t$ is the individual specific linear trend, and γ_t is the individual specific trend. The null hypothesis of no cointegration assumes that the AR coefficient $\rho_1 = 1$, and the structure of the estimated residuals for the DF statistics is:

$$\hat{e}_{it} = \rho \hat{e}_{i,t-1} + v_{it} \quad (4)$$

and for the estimated residuals for the PP statistics is

$$\hat{e}_{it} = \rho_i \hat{e}_{i,t-1} + v_{it} \quad (5)$$

Pedroni's cointegration test estimates four statistics for the within-dimension (the panel v-statistic, panel p-statistic, panel PP-statistic, panel ADF PP-statistic). Pedroni also calculates statistics on the between-dimensions (group p-statistic, group PP-statistic, and ADF-statistic). The within statistics limit the AR parameter to be the same across all cross-sectional units of the estimated residuals, whereas the between statistics permit the AR parameter to vary each cross-sectional unit. While the null hypothesis is the same for both between and within statistics the alternative hypotheses are different: the Within H_A: $\rho_i = \rho < 1$ for all i; the Between H_A: $\rho_i < 1$.

Table 2 – Panel cointegration tests

Dimension	Test-statistics	Model 1 – electricity elasticity	Model 2 – natural gas elasticity
	Test-statistic	Intercept	Intercept
Within-dimension	Panel v-Statistic	-4.23***	-4.71***
	Panel rho-Statistic	2.83***	2.49***
	Panel PP-Statistic	-1.71**	-3.26**
	Panel ADF-Statistic	-2.13***	-2.85***
Between-dimension	Panel rho-Statistic	4.29***	4.07***
	Panel PP-Statistic	-2.59***	-3.13**
	Panel ADF-Statistic	-2.36***	-3.65***

Note - *** indicates a 1% significance, ** indicates a 5% significance, and * indicates 10% significance

The presence of cointegration of the $I(1)$ variables as seen in table 2, implies that OLS estimation would be inconsistent. Moreover, in attempting to determine a long-run relationship standard pooled OLS techniques would present serial autocorrelation and endogeneity issues. To solve this we can run a dynamic ordinary least squares (DOLS) to correct for the inconsistent estimation (Mark and Sul 2003, Masih and Masih 1996, Madlener, Bernstein and Gonzalez 2011, Kao and Chian 2000, Pedroni 2000). The DOLS works to obtain unbiased estimators of the long-run parameters by using a parametric approach that augments equation (1) by utilising the lead and lag dynamic values of the differenced $I(1)$ variables, which are ΔY_{it}, ΔP_{it}, ΔHDD_{it}. The DOLS estimator can be written as:

$$\ln(EC)_{it} = \delta_i + \beta_Y \ln(Y_{it}) + \beta_P \ln(P_{it}) + \beta_{HDD} \ln(HDD_{it}) + \sum_{l=-l_i}^{l_i} \lambda_{yil} \Delta Y_{i,t-l} + \sum_{l=-l_i}^{l_i} \lambda_{Pil} \Delta P_{i,t-l} + \sum_{l=-l_i}^{l_i} \lambda_{HDDil} \Delta HDD_{i,t-l} + \mu_{it} \quad (6)$$

Where l_i is the lead and lag lengths. To simplify matters, we place all the exogenous variables into one ɔsite variable denoted by X, and the dependent variable becomes y_{it} thus simplifying equation (6) into

$$y_{it} = \delta_i + \beta_Y \ln(X_{it}) + \sum_{l=-l_i}^{l_i} \lambda_{xil} \Delta X_{i,t-l} + \mu_{it} \quad (7)$$

where the coefficient of the DOLS estimator is as follows:

$$\hat{\beta}_{DOLS} = \sum_{i=1}^{N} \left(\sum_{t=1}^{T} (z_{it} z_{it}')^{-1} \left(\sum_{t=1}^{T} (z_{it} \hat{y}_{it}^{*}\right)\right. \quad (8)$$

where z_{it} is a $2(l+1)$x1 vector of regressors $z_{it} = (x_{it} - \bar{x}_i, \Delta x_{it-l,\ldots,} \Delta \bar{x}_{il+1})$ and $\hat{y}_{it}^{*}$ is the transformed y_{it} that works to correct for endogeneity issues.

The short-run elasticities are calculated using a panel error correction model as outlined by Madlener, Bernstein and Gonzalez (2011). The speed of adjustment to the long-run equilibrium is derived from the residuals that are obtained from the DOLS regression (as they can be interpreted as the deviation from the long-run equilibrium) and become the error correction term (ECT) in our panel error correction model, which can be written as:

$$\Delta(EC)_{it} = \delta_i + \theta_i ECT_{i,t-1} + \omega_{yi} \Delta Y_{i,t} + \omega_{pi} \Delta P_{i,t} + \mu_{it} \quad (9)$$

where δ_i continues to denote the country-fixed effect, θ_i is the speed of adjustment to the long-term equilibrium, ECT is the error correction term (lagged by one year) and ω_{yi} and ω_{pi} are the short-run income and price elasticities.

Annex 2 – Household Energy Spending Scenario Analyses

In chapter 3, we present a series of scenario analyses which aim to quantify the cost of household transition to renewables. This annex briefly outlines the methodology that was employed.

In our analyses, we examined the EU-28 countries for the year 2016. The following were the steps taken to make the calculations for all four scenarios (see § 5 below).

1. **First, we identified the total amount of household energy consumption in kWh for the year 2016 for all respective countries in our sample and by source of energy for the said energy consumption**. This included energy that was obtained from solid fuels, petrol, natural gas, derived heat, electricity and renewables. The data was acquired from Eurostat.
2. **Then, for each of the different sources of energy production, data was disaggregated to capture all the energy from renewables**. For instance, energy produced under the category 'electricity' could be obtained from inputs such as gas, nuclear, petrol/oil, and renewables. The disaggregation went further to capture the different subcomponents of what is categorised as renewable energy, which could include sourcing the energy from solar, hydro, geothermal, tide/wave, wind, municipal waste, and/or solid biofuels. We therefore had to disaggregate all renewable sources as the price levels for final energy consumption varied according to the source of the renewable. This allowed us to accurately measure the percentage of the different sources of energy in household consumption.
3. **We then looked at the average energy prices that households paid for both standard electricity and natural gas**. We obtained household price levels for each kWh, and used the data that included all taxes, levies, and VAT charges. This data was acquired from Eurostat. However, data on the prices of renewable energy was not widely available. In order to price renewable energy sources for each kWh (CPS, geothermal, hydropower, offshore wind, onshore wind, solar photovoltaic, and solid biomass) we used data from the International Renewable Energy Agency (IRENA).
4. **Finally, we had to collect data on the average household energy consumption levels based on household socioeconomic conditions**. Specifically, we wanted to examine the difference in total spending allocated to energy between low- and high-income households. This data was obtained by examining the Household Budget Surveys (HBS) of each of the EU-28 countries. The surveys disaggregate the share of the household budget dedicated to energy-related expenditures based on household income characteristics. Typically, the HBS separates household economic characteristics into quintiles or quartiles (hence, in table 3.1, five countries have comparisons of household energy -related spending levels based on income quartiles rather than quintiles).
5. **Once we obtained the above data, we were able to derive how much of a household budget was being dedicated to energy-related expenditure**, given the current supply and price levels of the different energy sources (conventional electricity, natural gas, and renewables). We were then able to generate the different scenarios by changing the respective data. **The four scenarios are as follows**:
    - <u>Baseline Scenario</u> – uses the above data as is, with no changes
    - <u>Scenario One</u> – changes the amount of renewable energy in the household consumption levels in step one above to meet the 32% minimum set out by EU goals. In increasing the amount of renewables, we had to decrease the amount of energy derived from other sources – to do this, we focused first on reducing high CO2 generating sources such as coal and oils/gas.
    - <u>Scenario Two</u> - includes scenario one criteria, and increases energy efficiency to meet frontier country levels – in this case, this was Sweden, and we were able to obtain energy efficiency savings data from the Odyssee household energy efficiency database.
    - <u>Scenario Three</u> – includes all criteria from scenarios one and two and imposes a further 5%. reduction in renewable energy prices.

Annex 3 – Methodology for the Econometric Models (Chapter 4)

Models for Household Energy Demand

In chapter 4, we present the results of econometric models that examine how changes in household energy efficiency and energy efficiency related policies may affect household energy consumption. We consider the following two models to examine this relationship:

$$\ln EC_{it} = \alpha + \beta_{EF} EF_{it} + \beta_Y \ln(Y_{it}) + \beta_P \ln(P_{it}) + \beta_{HDD} \ln(HDD_{it}) + B_{POP} \ln(POP_{it}) + \mu_{it} \quad (1)$$

$$\ln EC_{it} = \alpha + \beta_{FP} FP_{it} + \beta_{RP} RP_{it} + \beta_{IP} IP_{it} + \beta_Y \ln(Y_{it}) + \beta_P \ln(P_{it}) + \beta_{HDD} \ln(HDD_{it}) + B_{POP} \ln(POP_{it}) + \mu_{it} \quad (2)$$

where EC_{it} indicates average household energy spending per square meter in country $i = 1, \dots, N$ at time $t = 1, \dots, T$ and is the dependent variable for models (1) and (2). Each model has a series of control variables: Y_{it} denotes real disposable income in 2010 euros, P_{it} is the average price for a KwH of electricity and gas, HDD_{it} is the heating degree days, POP_{it} is the population of country $i = 1, \dots, N$ at time $t = 1, \dots, T$, and μ_{it} represents the error term.

The two models differ regarding the variables of primary interest. In model (1), EF_{it} represents our primary variable of interest and represents the Odysee household energy efficiency index. In model (2), the variables of interest are FP_{it}, RP_{it}, IP_{it}, which represent, respectively, financial, regulatory and information/education-based policies that promote energy efficiency in households and have a numerical value based on impact on energy efficiency. In both models, (1) and (2), these variables of interest are not logged – this is to allow us to see how a one-point change in either energy efficiency improvements (model 1) or policies (model 2) will affect household energy spending. This log-linear relationship is preferred because we are interested to see how a change in the index or policy score affects the percentage change in household consumption. In both models, we lag these variables by t-1, t-3, and t-5 (and t-6, but just for the policy variables in model 2) to see if the effect of either energy efficiency improvements (model 1) or policies (model 2) is delayed after one, three, or five years, respectively (and six years for model 2).

The data set that we use is a cross-sectional panel of 21 countries (N) with a short time series of 11 years (T), from the years 2005 to 2016. Given that this is a cross-country panel data set, we estimate both equations, (1) and (2), utilising the Panel Least Squares method. The error term μ_{it} is thus divided into a disturbance term and an error term of other factors. Within our estimation, we assume a two-way error component model with respect to the error in order to account for both unobserved individual (country) and time (year) heterogeneity. The two-way error term can thus be written as

$$u_{it} = \delta_i + \delta_t + \varepsilon_{it} \quad \text{for i=1,…,N and t=1,…,T} \quad (3)$$

where δ_i and $\gamma_t$denote unobservable individual time-fixed effects, conditional inference on the N individuals over time $1 \to T$, and ε_{it} is the pure disturbance term. In matrix form, this can be rewritten as

$$U = (I_N \otimes \tau_T)\delta + (\tau_N \otimes I_T)\gamma + \varepsilon \qquad \text{where } \delta = (\delta_1, \dots, \delta_N)' \text{and } \gamma = (\gamma_1, \dots, T)' \quad (4)$$

In order to simplify matters, we generalise equations (1) and (2) so that all the explanatory variables are defined by a single composite variable X_{it}. To further simplify matters, we reduce equations (1) and (2) into one equation (see steps below), which can be seen as an interchangeable equation that can be applied to both (1) and (2). Thus, given the two-way error component structure, equations (1) and (2) can be written as:

$$EC_{it} = \beta_X X_{it} + \delta_i + \gamma_t + \varepsilon_{it} \quad (5)$$

The fixed-effect estimate of β uses the following transformation matrix Q:

$$Q = I_N \otimes I_T - I_N \otimes \frac{\tau_T \tau'_T}{T} - \left(\frac{\tau_N \tau'_N}{N}\right) \otimes I_T + \left(\frac{\tau_N \tau'_N}{N}\right) \otimes \frac{\tau_T \tau'_T}{T} \quad (6)$$

so that the transformed disturbance term $\tilde{u}_{it} = Qu$ becomes:

$$Qu = \tilde{u}_{it} = (u_{it} - \bar{u}_i - \bar{u}_t + \bar{u})_{it} \quad (7)$$

the Within estimates for $\hat{\beta}, \hat{\delta}_i, \hat{\boldsymbol{\gamma}}_t$ are:

$$\hat{\beta} = (X'QX)^{-1}X'QY \quad (8)$$

$$\hat{\delta}_i = (\bar{y}_i - \bar{y}) - \hat{\beta}(\bar{x}_i - \bar{x}) \quad (9)$$

$$\hat{\gamma}_t = (\bar{y}_t - \bar{y}) - \hat{\beta}(\bar{x}_t - \bar{x}) \quad (10)$$

We expand our analysis by constructing a second model specification, which includes the lag-dependent variable EC_{it-1} as an explanatory variable to capture the dynamic nature of household energy consumption. The level of energy production should remain continuous over time because of the expectation that consumption levels would follow a similar pattern to that of the previous year. Thus equations (11) and (12) below are identical to equations (1) and (2) apart from the inclusion of the lag-dependent variable on the right-hand side:

$$\ln EC_{it} = \beta_i + \beta_{EC}EC_{it-1} + \beta_{EF}EF_{it} + \beta_Y \ln(Y_{it}) + \beta_P \ln(P_{it}) + \beta_{HDD}\ln(HDD_{it}) + B_{POP}\ln(POP_{it}) + \delta_i + \gamma_t + \varepsilon_{it} \quad (11)$$

$$\ln EC_{it} = \beta_i + \beta_{EC}EC_{it-1} + \beta_{FP}FP_{it} + \beta_{RP}RP_{it} + \beta_{IP}IP_{it} + \beta_Y \ln(Y_{it}) + \beta_P \ln(P_{it}) + \beta_{HDD}\ln(HDD_{it}) + B_{POP}\ln(POP_{it}) + \delta_i + \gamma_t + \varepsilon_{it} \quad (12)$$

However, since we introduced the lag-dependent variable, which is correlated with the fixed effects, both OLS and fixed-effect estimation techniques would generate biased coefficient estimates (Nickell 1981). As EC_{it} is a function of the fixed effect, $EC_{it-1}$is thus correlated withε_{it}. Let us once again simplify matters by placing all exogenous variables from (11) and (12), with the exception of the lag-dependant variable, into a single composite variable X_{it}, thus reducing our equation to the following:

$$\mathrm{EC_{it}} = \theta \mathrm{EC_{it-1}} + \beta_X \mathrm{X_{it}} + \delta_i + \gamma_t + \varepsilon_{it} \quad (13)$$

And by using a within transformation for an AR(1) model:

$$\mathrm{EC_{it}} - \overline{\mathrm{EC}}_{it} = \theta(\mathrm{EC_{it-1}} - \overline{\mathrm{EC}}_{it-1}) + \beta_X(\mathrm{X_{it}} - \overline{\mathrm{X}}_i) + (\delta_i + \bar{\delta}_i) + (\gamma_t - +\bar{\gamma}_t) + (\varepsilon_{it} - \bar{\varepsilon}_{it}) \quad (14)$$

The transformed equation establishes a correlation between $(EC_{it-1} - \overline{EC}_{it-1})$ and $(\varepsilon_{it} - \bar{\varepsilon}_{it})$; this is due to the fact that $\bar{\varepsilon}_{it}$ will include ε_{it-1} within its equation. This further means that θ will continue to be biased when estimated. Nickell (1981) shows that the bias of the estimator declines as $\to \infty$, but that the bias persists when T is finite in an AR(1) panel-model.

In comprehensive econometric research, several methods have been proposed to address this bias. One of the most notable methods was to utilise an instrumental variable (IV) approach, by using instruments of the lag-dependent variable. These included the Anderson and Hsiao (1981) method that used a twice lagged level of the dependent variable as an instrument for the lag-dependent variable; but, while this technique generates consistent estimates, they are not efficient due to the limited use of all available moment conditions. Expanding on this work, the Arellano and Bond (1991) method utilised a first-difference generalised method of movements (GMM) approach to generate valid instruments; the Blundell and Bond (1998) system-GMM approach exploits additional movement conditions, and their estimation employs the lagged first differences instruments for the levels equation and the levels instruments in the first-differenced equation.

The limitations of the IV and GMM based approaches is that they work well when N is large, but generate estimates that are biased when N is small (Bruno 2005). Since our model is a cross-country macro level panel data set – 21 cross-country observations over 11 years - we would be unable to use the above estimation techniques to effectively eliminate biased estimates.

However, an alternative approach developed by Kiviet (1995) undertakes a bias corrected fixed-effect LSDV (Least Square Dummy Variable) dynamic panel model estimation technique for short panels. Kiviet proposes to replace the true parameters with estimates that are derived from a consistent estimator. Kiviet (1999) expanded and refined the bias approximation techniques to include terms up to the order of N-1T-1, and the techniques were tested by Bun and Kiviet (2003) to analyse their precision (Bruno 2005). Research using Monte-Carlo simulations have shown that the dynamic LSDV technique outperforms the GMM-IV techniques in small sample sizes – and thus it is more applicable to our case of a relatively small sized N and T (Judson and Owen 1999). Bruno (2005) expanded on the bias approximation techniques for unbalanced dynamic panels, but assumed a strict heterogeneity selection rule. Our work uses Bruno's expanded bias approximation technique, which has also been shown by Buddelmeyer et al. (2008) and Bruno (2005) to be the favoured estimation technique in small N and T dynamic panels.

Model for analysing Keeping House Warm

Chapter 4 concludes with a final empirical analysis to see what has been helping fight fuel poverty rates in European countries (measured by the percentage of people unable to keep their homes warm). While similar in scope to the above models, here we focus only on household energy efficiency index data and not on policy environments – the chief reason being that it is difficult to detangle which policies are aimed at households vs. builders/building owners, thus making it difficult to generate a potential direct link with the rates of energy poverty. However, in light of this limitation, we do introduce a second model that also examines the percentage of low quality homes, as this variable can potentially act as a proxy for energy inefficient homes because of limited policy interventions (be they regulatory, financial, or informative) – as well as other factors.

To examine the relationships described above, we introduce the following econometric models that use a fully modified ordinary least squares (FMOLS) approach for cointegrated models:

$$\ln KPC_{it} = \beta_i + \beta_{EF}EF_{it} + \beta_{GDP}\ln(GDP_{it}) + \beta_{HCIP}\ln(HCIP_{it}) + \beta_{HOUSE}\ln(HOUSE_{it}) + \beta_{HDD}\ln(HDD_{it}) + B_{POP}\ln(POP_{it}) + \varepsilon_{it} \quad (15)$$

$$\ln KPC_{it} = \beta_i + \beta_{EF}HQ_{it} + \beta_{GDP}\ln(GDP_{it}) + \beta_{HCIP}\ln(HCIP_{it}) + \beta_{HOUSE}\ln(HOUSE_{it}) + \beta_{HDD}\ln(HDD_{it}) + B_{POP}\ln(POP_{it}) + \varepsilon_{it} \quad (16)$$

As a starting point, we test the stationary properties of the variables in our model by means of IPS panel unit root tests[1]. The model proposed by Im, Pesaran, and Shind (1997)) permits heterogeneity in the intercept and slop for all units in our sample and works to solve serial correlation issues (which our model has). Moreover, the IPS model relaxes assumptions made concerning common autoregressive parameters; the data is not pooled as in the Levin-Lin-Chu model, but rather the Dickey-Fuller statistics are calculated for each cross-sectional unit. The IPS panel unit root equation below tests for the null-hypothesis if $\rho_i = 0$ for all *i*, with the alternative hypotheses being if $\rho_i < 0$ for some i=1,…,N and $\rho_i < 0$ for i=$N_1 + 1, \dots, N$.

$$\Delta y_{it} = \alpha_i + \rho_i y_{i,t-1} + \sum_{j=1}^{p} \theta_{ij}\Delta y_{i,t-j} + \varepsilon_{it} \quad (17)$$

Table 1 – IPS Panel Unit Root Tests

	Variable models							
	KPC	EF	HQ	Ln(GDP)	Ln(HCIP)	Ln(HOUSE)	Ln(HDD)	Ln(POP)
Level	-3.184***	-1.208	3.636***	-2.41***	-2.047**	-2.77***	-6.38***	3.715
	(0.001)	(0.114)	(0.0001)	(0.008)	(0.02)	(0.003)	(0.000)	(0.999)
First Difference	-7.63***	-1.75**	-12.86***	-6.41***	-8.12***	-6.61***	-11.02***	-1.68**
	(0.000)	(0.04)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.046)

Note - *** indicates a 1% significance, ** indicates a 5% significance, and * indicates 10% significance

Upon determining the level of stationarity for the variables in our model, we must determine if there is a long-term relationship between the variables. To do this, we run a panel cointegration test formulated by Pedroni (1999, 2004) for the $I(1)$ variables. Pedroni's cointegration test for panel data allows for heterogeneity among cross-sectional units. Pedroni's work utilises the augmented Dickey-Fuller (ADF) and the Phillips-Perron (1988) (PP) tests, and differentiates from Kao's (1999) in that it allows for the same AR coefficient over all the panels in the sample. The calculations of the test use the estimated residuals of the following long-run regression:

$$y_{it} = \alpha_i + \delta_i t + \gamma_t + \beta_{1i}X_{1it} + \cdots + \beta_{Mi}X_{Mit} + \varepsilon_{it} \qquad for\ i = 1, \dots, N; t = 1, \dots, T; m = 1, \dots, M \quad (18)$$

In model (18), N denotes the number of individuals, T denotes the number of observations, M refers to the number of exogenous variables, α_i is the individual specific event, $\delta_i t$ is the individual specific linear trend, and γ_t is the individual specific trend. The null hypothesis of no cointegration assumes that the AR coefficient $\rho_1 = 1$, and the structure of the estimated residuals for the DF statistics is:

$$\hat{e}_{it} = \rho\hat{e}_{i,t-1} + v_{it} \quad (19)$$

[1] For information, we ran a series of other panel unit tests that are not presented here. We found that, although they have different underlying model assumptions, the Levin-Lin-Chu and Fisher-type tests generated similar significance values for all variables identifying the existence of panel unit root.

and for the estimated residuals for the PP statistics is

$$\hat{e}_{it} = \rho_i \hat{e}_{i,t-1} + v_{it} \quad (20)$$

Pedroni's cointegration test estimates four statistics for the within-dimension (the panel v-statistic, panel p-statistic, panel PP-statistic, panel ADF PP-statistic). Pedroni also calculates statistics on the between-dimensions (group p-statistic, group PP-statistic, and ADF-statistic). The within statistics limit the AR parameter to be the same across all cross-sectional units of the estimated residuals, whereas the between statistics permit the AR parameter to vary for each cross-sectional unit. While the null hypothesis is the same for both between and within statistics, the alternative hypotheses are different: the Within H_A: $\rho_i = \rho < 1$ for all *i;* the Between H_A: $\rho_i < 1$.

Table 2 – Panel cointegration tests

Dimension	Test-statistics	Model 1 –energy efficiency equation (15)	Model 2 - quality of dwelling equation (16)
	Test-statistic	Intercept	Intercept
Within-dimension	Panel v-Statistic	-5.45***	-6.08***
	Panel rho-Statistic	4.88***	4.90***
	Panel PP-Statistic	-2.31**	-1.86**
	Panel ADF-Statistic	-2.76***	-2.37***
Between-dimension	Panel rho-Statistic	6.90***	7.18***
	Panel PP-Statistic	-3.57***	-2.13**
	Panel ADF-Statistic	-3.71***	-2.61***

Note - *** indicates a 1% significance, ** indicates a 5% significance, and * indicates 10% significance

The presence of cointegration of the $I(1)$ variables, as seen in table 2, implies that an OLS estimation would be inconsistent. To solve this, we could run either the dynamic ordinary least squares (DOLS) or the fully modified ordinary least squares (FMOLS) to correct for the inconsistent estimation. We opted to run an FMOLS estimation on equations (15) and (16) as it provides reliable estimates for small sample sizes and is able to account of the heterogeneity that is found in fixed-effect models. The FMOLS estimator modifies the pooled OLS to correct for issues related to endogeneity and serial correlation, and is defined as:

$$\hat{\beta}_{FMOLS} = \left[\sum_{i=1}^{N} \sum_{t=i}^{T} (x_{it} - \bar{x}_{it})\right]^{-1} \left[\sum_{i=1}^{N} (\sum_{t=1}^{T} (x_{it} - \bar{x}_i)) \hat{y}_{it}^{*} - T\theta_i^{*}\right] \quad (21)$$

where $\hat{y}_{it}^{*}$ is the transformed y_{it} (the dependent variable of equations (15) and (16) that corrects for endogeneity issues), and θ_i^{*} is the serial correction term.

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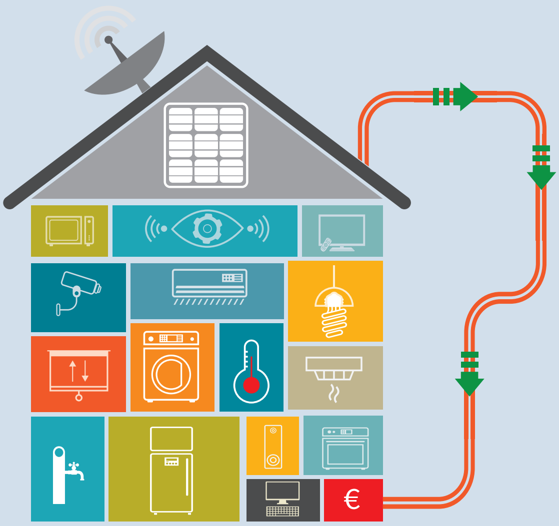

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