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5	Corresponding Author	Family Name	**Mar Solà**
6		Particle	**del**
7		Given Name	**María**
8		Suffix	
9		Organization	University of the Basque Country (UPV/EHU)
10		Division	Basque Centre for Climate Change (BC3)
11		Address	Scientific Campus, Building 1, 1st Floor, Leioa 8940, Spain
12		e-mail	mar.sola@bc3research.org
13	Author	Family Name	**Ayala**
14		Particle	**de**
15		Given Name	**Amaia**
16		Suffix	
17		Organization	University of the Basque Country (UPV/EHU)
18		Division	Basque Centre for Climate Change (BC3)
19		Address	Scientific Campus, Building 1, 1st Floor, Leioa 8940, Spain
20		Organization	University of the Basque Country (UPV/EHU)
21		Division	Department of Applied Economics I
22		Address	Leioa 48940, Spain
23		e-mail	
24	Author	Family Name	**Galarraga**
25		Particle	
26		Given Name	**Ibon**
27		Suffix	
28		Organization	University of the Basque Country (UPV/EHU)
29		Division	Basque Centre for Climate Change (BC3)
30		Address	Scientific Campus, Building 1, 1st Floor, Leioa 8940, Spain
31		Organization	Economics for Energy
32		Division	

33		Address	Doutor Cadaval 2, 3E, Vigo 36202, Spain
34		e-mail	
35	Author	Family Name	**Escapa**
36		Particle	
37		Given Name	**Marta**
38		Suffix	
39		Organization	Faculty of Economics and Business
40		Division	Department of Foundations of Economic Analysis I
41		Address	Bilbao 48015, Spain
42		e-mail	

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46	Abstract	The household sector is one of the most energy-intensive sectors in Europe, and thus a focal point for reducing greenhouse gas emissions associated with energy consumption. Energy efficiency is considered a key measure to reduce household energy consumption, but several factors could lead to an underinvestment in energy efficiency. This is the so-called energy efficiency gap or paradox. The factors in question are grouped under market failures (including informational failures), behavioural failures and other factors. Various policies can be used to address these failures and promote the adoption of energy-efficient technologies, including energy standards and codes, economic incentives and information instruments. This paper reviews the empirical evidence to date on energy efficiency policies and discusses their effectiveness. On the one hand, command and control instruments seem to be effective policies, but they have to overcome several barriers. In the case of price instruments, subsidies and taxes do not seem to be effective while rebates present mixed results as they sometimes are effective and in other cases, they could present significant shortcomings. Finally, the effectiveness of informational policies is not always ensured as they depend on the country, sector and product category. Information feedback tools also seem to be effective as they work as a constant reminder of energy-efficient behaviour. Some limitations of energy efficiency policies are also identified, such as the difficulties of implementing codes and standards given that a minimum level need to be achieved, differences in the effectiveness of rebate programmes and non-conclusive results in regard to the effectiveness of monetary energy efficiency labels.

47	Keywords separated by ' - '	Energy Efficiency gap - Energy Efficiency Policies - Effectiveness of policies

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REVIEW ARTICLE

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Promoting energy efficiency at household level: a literature review

Q1 **María del Mar Solà · Amaia de Ayala · Ibon Galarraga · Marta Escapa**

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Abstract The household sector is one of the most energy-intensive sectors in Europe, and thus a focal point for reducing greenhouse gas emissions associated with energy consumption. Energy efficiency is considered a key measure to reduce household energy consumption, but several factors could lead to an underinvestment in energy efficiency. This is the so-called energy efficiency gap or paradox. The factors in question are grouped under market failures (including informational failures), behavioural failures and other factors. Various policies can be used to address these failures and promote the adoption of energy-efficient technologies, including energy standards and codes, economic incentives and information instruments. This paper reviews the empirical evidence to date on energy efficiency policies and discusses their effectiveness. On the one hand, command and control instruments seem to be effective policies, but they have to overcome several barriers. In the case of price instruments, subsidies and taxes do not seem to be effective while rebates present mixed results as they sometimes are effective and in other cases, they could present significant shortcomings. Finally, the effectiveness of informational policies is not always ensured as they depend on the country, sector and product category. Information feedback tools also seem to be effective as they work as a constant reminder of energy-efficient behaviour. Some limitations of energy efficiency policies are also identified, such as the difficulties of implementing codes and standards given that a minimum level need to be achieved, differences in the effectiveness of rebate programmes and non-conclusive results in regard to the effectiveness of monetary energy efficiency labels.

Keywords Energy Efficiency gap · Energy Efficiency Policies · Effectiveness of policies

M. del Mar Solà (✉) · A. de Ayala · I. Galarraga
Basque Centre for Climate Change (BC3), University of the Basque Country (UPV/EHU), Scientific Campus, Building 1, 1st Floor, 8940 Leioa, Spain
e-mail: mar.sola@bc3research.org

A. de Ayala
Department of Applied Economics I, University of the Basque Country (UPV/EHU), 48940 Leioa, Spain

I. Galarraga
Economics for Energy, Doutor Cadaval 2, 3E, 36202 Vigo, Spain

M. Escapa
Department of Foundations of Economic Analysis I, Faculty of Economics and Business, 48015 Bilbao, Spain

Introduction

One of the overall objectives set by the Paris Agreement is to limit global temperature increase to less than 2 °C, with the ambitious goal of limiting the temperature increase to 1.5 °C (Roman De Lara and Galarraga 2016). For that to happen, greenhouse gas emissions (GHG) need to be reduced, and one of the primary drivers for this is the production and consumption of energy in different sectors (Eurostat 2019a). Final energy consumption is defined as the total amount of energy consumed by end users such as industry, households, transport, services and agriculture (Eurostat 2019b). In Europe, the household sector accounts for 36.4% of the total European energy consumption (followed by industry at 29%). Energy efficiency (EE), defined as improvements in the efficiency with which energy is used to provide a service (Linares and Labandeira 2010), is a measure proposed to reduce energy consumption. Europe is committed to an improvement in EE of at least 32.5% by 2030 according to the revised Energy Efficiency Directive (2018/2002). According to the latest report by the Coalition for Energy Savings in 2018,[1] investments in EE should grow and play a key role in the years to come.

EE can lead to multiple benefits for individuals and industry, including cost reductions, decreases in GHG emissions and other local pollutants and the subsequent health benefits. However, households and business invest less in EE than what may appear economically rational, and some other EE investments do not seem economically worthwhile (Gerarden et al. 2017; Jaffe et al. 2004; Linares and Labandeira 2010). This is an expression of the so-called *energy efficiency gap* or *energy efficiency paradox* (Jaffe and Stavins 1994a). It is known that some of the benefits from EE investments are private (e.g. cost reductions) while others are public (e.g. GHG emissions reductions or health benefits). Corradini et al. (2014) and Markandya and Rübbelke (2012) study how environmental policies should be designed to achieve optimal EE investments by taking into account this joint provision of private and public benefits. Following the convention from previous literature, we use the term EE gap to refer to both the private and public deviations from optimality.

The high-energy consumption and potential underinvestment in EE of the household sector make this one of the principal sectors that needs to reduce its associated GHG. In this context, understanding the factors that promote the EE gap is crucial to fostering reductions in energy consumption. The EE gap has been explained in terms of many reasons that can be classified in different ways. In this paper, we review the factors explaining the EE gap according to the relevant literature (Frederiks et al. 2015; Gerarden et al. 2017; Jaffe and Stavins 1994b; Linares and Labandeira 2010; Ramos et al. 2015). These are grouped into (i) market failures, (ii) behavioural failures and (iii) other factors.

Depending on what failure generates the EE gap, different instruments may be necessary to prevent or reduce it and promote appropriate behavioural changes to successfully nudge consumers towards more energy-efficient decisions (a review of how public policies can promote behavioural changes can be found in Cecere et al. 2014 and D'Amato et al. 2016). The policy instruments proposed include energy standards and codes, economic incentives, feedback information and energy labelling, among others (Gerarden et al. 2017; Gillingham and Palmer 2014; Linares and Labandeira 2010; Markandya et al. 2015; Ramos et al. 2015). The design of EE policies depends on their objectives and those objectives can be reviewed and modified to increase their effectiveness.[2] For instance, a change in the legislation on EE labels for household appliances was accepted in 2017 (Directive 2017/1369/EU) to improve on the effectiveness of the previous label design. Additionally, EE policies could be designed with programmes fitted to regional characteristics and specificities (Borozan 2018).

This paper focuses on the role of the EE gap in the household sector. It seeks to review the literature on the policy instruments used to promote EE and discusses their effectiveness. Several other authors have produced interesting reviews relayed to this in recent years (Linares and Labandeira 2010; Ramos et al. 2015). Linares and Labandeira (2010) and Gerarden et al. (2017) focus on reviewing market failures and policies for addressing them, while Ramos et al. (2015) analyses both informational and behavioural failures and the policies designed to address them. This paper builds on previous literature on the EE gap at household level in order to update the evidence on the effectiveness of EE policies to address the different failures and bring updated conclusions. Updated results have been collected for example in the case price instruments.

In preparing this paper, we have reviewed more than 200 papers published between 2000 and 2020.[3] Combinations of keywords related to behavioural and policy aspects were used (e.g. behaviour, EE, tax, subsidy, EE gap, failures) on SciVerse, Scopus, the Web of Knowledge and Science Direct. The findings were selected on

[1] More details about the report: https://www.eceee.org/all-news/news/new-analysis-member-states-must-do-more-to-meet-2030-eu-energy-efficiency-target/

[2] For more details, see the results of the CONSEED project: https://www.conseedproject.eu/conseed-survey-report

[3] Including some relevant and theoretical papers from the 1980s and 1990s (Kahneman 1994; Kahneman and Tversky 1984, 1979; Tversky and Kahneman 1981).

the basis of their relevance (number of citations) with no restriction on years, although preference was given to more recent papers.[4] This procedure follows the recommendations of Berrang-Ford et al. (2015) for a semi-systematic review process.

The rest of the paper is structured as follows: 'Households and the energy efficiency gap' review and updates the literature on the EE gap. 'Policies to address the energy efficiency gap at household level' presents and classifies the main policies for dealing with the EE gap while analysing their effectiveness and impact of EE policies in reducing the EE gap at European level. Finally, 'Conclusions' outline the main conclusions and the policy implications of the paper, linking the evidence reported in 'Households and the energy efficiency gap' and 'Policies to address the energy efficiency gap at household level'.

Households and the energy efficiency gap

The EE gap arises when a technology that may be profitable for consumers in terms of EE is available, but consumers do not take advantage of it. It can be explained through different failures and factors, which are grouped in this paper into: (i) market failures (including informational failures); (ii) behavioural failures; and (ii) other factors (Bertoldi 2020; Frederiks et al. 2015; Gerarden et al. 2017; Linares and Labandeira 2010; Ramos et al. 2015). Table 1 presents the main failures and factors that may explain the EE gap with some of the studies in the literature that address them.[5]

(i) Market failures include (a) *informational failures* and (b) *other market failures.*

a. *Informational failures* may refer to *asymmetric and imperfect information* (a1); *hidden* and *transaction costs* (a2); and *myopia* (a3). In asymmetric and imperfect information (a1), markets do not reflect the real value of an investment or purchase.[6] This is common with products such as appliances or properties and is found on both the supply and demand sides (Carroll et al. 2016a, 2016b; de Ayala et al. 2016; Giraudet 2020; Kallbekken et al. 2013; Orlov and Kallbekken 2019). Consumers informed about EE benefits may be willing to buy more energy-efficient goods (Allcott and Sweeney 2016; Davis and Metcalf 2016), and owners of rental properties may invest in energy-efficient goods if they know that tenants are willing to pay more for energy-efficient buildings (Phillips 2012). Moreover, electricity suppliers could adapt electricity supply to demand as price changes if they were perfectly aware of the price elasticity of demand[7] (Labandeira et al. 2012). Hidden costs (a2) refer to real costs borne by consumers that are not always taken into consideration by modellers (e.g. a lower level of energy services such as lighting quality) (Linares and Labandeira 2010). Transaction costs (a2) are associated with economic transactions that could lead to a non-optimal outcome. Transaction costs are generally not accounted for in models but are real and are especially common in the residential sector due to their combination with behavioural failures, resulting in lower investment in EE (Ramos et al. 2015; Sorrell et al. 2004). Myopia (a3) is usually observed when willingness to pay (WTP) for a good is not affected by changes in expected future operating costs. Under myopia, consumers do not consider reductions in future costs as benefits (Busse et al. 2013; Cohen et al. 2017; Gerarden et al. 2017).

b. *Other market failures* are *lower-than-efficient energy prices* (b1); *slowness of technology adoption* (b2); *capital market failures* (b3); and the *principal-agent problem* (b4). These factors usually arise from various market externalities. For instance, investments in energy-efficient products are affected by extremely low-energy prices because they do not reflect the external costs of energy and incentives to invest in EE are thus very low, as the return period for the investment becomes very long. This is known as *lower-than-efficient energy*

[4] An Excel spreadsheet with the different stduies reviwed ha been built and is available on request

[5] An in-depth review of the literature has been undertaken by the authors in the framework of H2020 CONSEED project. For more information, see www.conseed.eu.

[6] Giraudet (2020) explains the difference between symmetric information problems and information asymmetries.

[7] Price elasticity of demand is an economic measure of the change in the quantity demanded of a good in relation to changes in its price.

prices (b1) (Gillingham and Palmer 2014; Linares and Labandeira 2010).

Barriers to technology adoption (b2) also play an important role in consumer decision-making related to EE (Gilli et al. 2014; Michelsen and Madlener 2016). The fast dissemination of new energy-related technologies is sometimes overstated (Linares and Labandeira 2010), but some studies show that slowness of technology adoption could explain the EE gap because consumers do not consider some technologies even if they are available on the market[8] (Jaffe and Stavins 1994b). Concerning capital market failures (b3), potential adopters may lack access to the capital needed to undertake EE investments. Low access to capital by consumers in lower income segments leads them to reduce their valuation of future benefits (i.e. they have a high implicit discount rate), which results in their not investing in EE (Train 1985).

Principal-agent problems (b4) arise when one party makes a decision with respect to EE investment, but another party bears the cost or enjoys the benefits of that decision (Gillingham and Palmer 2014). The split incentives problem, for instance, is a particular example of the principal-agent problem in the household sector: it occurs in transactions where investment and benefits are driven by different incentives between parties and do not coincide. This arises particularly with landlords and tenants, whose incentives for investing in EE may differ (Bird and Hernández 2012; Phillips 2012). In particular, Davis (2011) studies the landlord-tenant problem considering data from different households with US ENERGY STAR appliances and finds that renters tend to invest less in energy-efficient appliances (refrigerators, washing machines and dishwashers). Split incentives can impact tenants' behaviour as they do not usually pay energy bills directly. Maruejols and Young (2011) show that temperature settings during the day in households that do not pay directly for heating appear to be 1°C higher than in those that do.

(ii) **Behavioural failures** include a) *inattention;* and b) *decision-making heuristics and biases*. *Inattention* (a) to future energy costs has clear implications and could potentially explain underinvestment in EE. The level of inattention among individuals may change and depends on the decision environment (Andor et al. 2016; Cattaneo 2019; Gerarden et al. 2017). Decision-making *heuristics and biases* (b) suggest that individuals are constrained by cognitive limitations and/or bounded rationality (Cattaneo 2019). In addition, consumers are frequently unable to process all the information required to trade-off all the alternatives in real decision-making processes (Andor et al. 2016; Blasch et al. 2019; Kahneman 1994). This may lead them to place more value on initial costs. Reviews of behavioural failures concerning energy use and investment and waste management can be found in Cattaneo (2019) and Cecere et al. (2014), respectively.

(iii) Other factors can also explain the EE gap. These include (a) *social norms* (Liu et al. 2016); (b) *procrastination* (Lillemo 2014); and (c) *personal experience* (Franke et al. 2012; Jensen et al. 2014). Social norms (a) refer to the collective norms that establish what should or should not be done in a specific society. These norms can positively influence the use of heating and cooling in public buildings (Liu et al. 2016). Normative messages have mixed results in the field context (Allcott 2011a; Brühl et al. 2019) and sometimes result in boomerang effects (Schultz et al. 2007).

Personal beliefs seem also to affect energy consumption and investment in EE. For instance, households with eco-friendly behaviour tend to invest more in energy-efficient products (Ramos et al. 2016). *Procrastination* (b), understood as the tendency to postpone tasks, is another relevant factor that could affect investment in EE. Lillemo (2014) shows that people with a tendency to procrastinate are significantly less likely to invest in energy-efficient equipment and adopt energy-saving attitudes. Finally, *personal experience* (c) also affects investment in EE. Jensen et al. (2014) show that previous personal experience with electric vehicles affects preferences and attitudes towards such vehicles.

[8] There are several potential explanations: lack of awareness by consumers of the technology (information problems), the principal agent problem or unobserved costs and other explanations that do not represent market failures (private information costs, high discount rates etc.).

Table 1 The main failures and factors that explain the EE gap

Failures	Factors promoting the EE gap	Literature
(i) Market failures		
a. Informational failures	a1. Asymmetric and/or incomplete information	Allcott and Sweeney (2016) Labandeira et al. (2012) Phillips (2012) Carroll et al. (2016a) Carroll et al. (2016b) de Ayala et al. (2016) Kallbekken et al. (2013) Orlov and Kallbekken (2019) Allcott and Sweeney (2016) Davis and Metcalf (2016) Giraudet (2020)
	a2. Hidden and transaction costs	Ramos et al. (2015) Sorrell et al. (2004) Linares and Labandeira (2010)
	a3. Myopia	Busse et al. (2013) Cohen et al. (2017) Gerarden et al. (2017)
b. Other market failures	b1. Lower-than-efficient energy prices	Linares and Labandeira (2010) Gillingham and Palmer (2014)
	b2. Slowness of technological adoption	Michelsen and Madlener (2016) Linares and Labandeira (2010) Jaffe and Stavins (1994a) Gilli et al. (2014)
	b3. Capital market imperfections	Train (1985)
	b4. Principal agent problem (e.g. split incentives problem)	Gillingham and Palmer (2014) Phillips (2012) Maruejols and Young (2011) Bird and Hernández (2012) Davis (2011)
(ii) Behavioural failures	a. Inattention	Andor et al. (2016) Cattaneo (2019)
	b. Decision-making heuristics and biases	Andor et al. (2016) Cattaneo (2019) Blasch et al. (2019)
(iii) Other factors	a. Social norms	Liu et al. (2016) Allcott (2011a, 2011b) Brühl et al. (2019) Schultz et al. (2007)
	b. Procrastination	Lillemo (2014)
	c. Personal experience	Franke et al. (2012) Jensen et al. (2014)

Apart from personal factors and the failures mentioned above, other features could indirectly affect investment in energy-efficient products. For instance, *uncertainty* could make consumers decisions more complicated and may lead consumers to use heuristics. In other words, in a context of uncertainty, consumers may think in terms of expected payoffs and ignore gains and losses relative to a reference point rather than in absolute terms. Greene (2011) shows that uncertainty about fuel and electricity prices, combined with the loss aversion of buyers, results in a decision-making bias. Uncertainty can also be present at regulation level when there are frequent and unexpected policy changes (Ramos et al. 2015). Other factor that could affect the decision making are socio-demographic characteristics (e.g. number and age of family members) and dwelling characteristics (e.g. number of bedrooms, age and size of buildings etc.) as they could influence energy consumption (Jones and Lomas 2015) and therefore EE investments. These characteristics may also affect the effectiveness of EE policies, as explained later in 'Effectiveness of energy efficiency policies'.

Policies to address the energy efficiency gap at household level

Several policies have been proposed to address the failures and features mentioned previously and thus reduce the EE gap. These policies are designed to promote the purchase and adoption of energy-efficient technologies and include energy standards and codes, financial incentives, feedback information tools, audits and energy labelling (Bye and Bruvoll 2008; Galarraga et al. 2013; Gerarden et al. 2017; Gibbons and Gwin 2004; Gillingham and Palmer 2014; Ramos et al. 2016). We classify the policies drawn up to date below and discuss their effectiveness based on our in-depth literature review.

Classification of household energy efficiency policy instruments

EE policies are classified mainly according to the purpose of each policy. In this case, our classification is based on Markandya et al. (2015) and Ramos et al. (2015).

Following Markandya et al. (2015), policy instruments can be classified into three groups: *command and control instruments* (including code and standards); *price instruments* (including taxes, subsidies, credits, permits etc.); and *information-based instruments* (including energy audits, energy labels, smart meters etc.).

Regarding *command and control instruments*, codes are a policy instrument that specifies how energy-efficient products must be constructed or must perform, while standards establish how a product should be constructed in order to save energy effectively (Markandya et al. 2015). Codes and standards are among the main policies for promoting the adoption of EE, and are usually implemented in industries and buildings. Such policies are commonly chosen by governments although they are considered as inflexible policies.

Price instruments include taxes, subsidies, tax deductions, credits, permits and tradable obligations. All these policies are related to fiscal incentives and are intended to encourage or discourage some decisions by consumers. Taxes and subsidies are among the most common fiscal incentives used to reduce energy consumption and GHG emissions. However, an optimal combination of subsidies and taxes seems also to be a good option (Markandya et al. 2009). Taxes are usually applied directly to energy consumption and their major effect is to generate revenues and sometimes also change energy use behaviour.

The last group comprises *informational instruments,* which are designed mainly to address informational and behavioural failures. Markandya et al. (2015) and Ramos et al. (2015) both classify these instruments into *energy certificates and labels* (Banerjee and Solomon 2003; Bull 2012; Chegut et al. 2014; Fuerst and McAllister 2011), *information feedback tools* (Allcott 2011b) and *energy audits* (Abrahamse et al. 2005; Alberini and Towe 2015). *EE labels* are used to address the EE gap by giving more information (e.g. energy consumption, EE level) to potential customers at the point of sale. Energy labels are usually designed to help and encourage consumers to make efficient decisions, so they are designed to tackle information asymmetry and incomplete information. Labels become the cheapest and easiest way of providing consumers with EE-related information (Markandya et al. 2015). In particular, energy certificates and labels seem to be a very widespread EE policy instrument in the building and residential sectors.

Other options such as *information feedback tools* include smart meters and energy bills with comparative information. Smart meters provide households with information on how much energy appliances consume and other environmental information (e.g. health-related information, energy consumption information, CO_2 emissions information, real-time pricing) and are often used to promote an efficient use of energy. In particular, energy bills with comparative information are intended to inform households of how well/badly they are doing compared to their neighbours. Apart from smart meters, there are other new technologies known as Smart Decision Support Systems (SDSS) which help consumers to make decisions in daily life regarding EE.

Energy audits, for instance, are based on an inspection to test whether a building, enterprise or household is doing its best to maximise energy savings. They are therefore usually designed to tackle informational failures and give recommendations on potential EE improvements. This policy is designed to let households know their potential for increasing their energy savings. Audits are very common in the service sector and in industry, less so in the household sector (Markandya et al. 2015).

In summary, EE labels, smart meters, information feedback tools and energy audits can be said to be designed to tackle most failures (market failures, behavioural failures and other personal factors), while price instruments are designed to deal mainly with market failures. In addition, command and control instruments such as codes and standards are designed to ensure a minimum level of adoption of energy-efficient technologies.

Effectiveness of energy efficiency policies

Some earlier studies have already analysed the effectiveness of EE policies using evidence from the literature (Gerarden et al. 2017; Linares and Labandeira 2010; Ramos et al. 2015). Linares and Labandeira (2010) focus their analysis on policies that help to address market failures (e.g. taxes, subsidies) while Ramos et al. (2015) mainly focus on the effectiveness of informational instruments and Gerarden et al. (2017) look for the elements that minimise the cost of EE-related decisions. In this context, we seek to update common knowledge regarding the effectiveness of EE policies.

This section seeks to analyse the effectiveness of EE policies based on empirical studies. Given that the objective of this section is to discuss findings on the impact of EE policies in Europe, preference was given to European studies. However, some non-European studies are included to supplement the analysis of the effectiveness of EE policies since their results could be useful in designing and implementing EE policies in Europe. In fact, in the case of command and control instruments most of the papers included are non-European studies.

Tables 2 and 3 list some of the papers used to provide evidence on the effectiveness of EE policies worldwide, focussing especially on European studies. These tables also summarise the review conducted here. More than 200 papers are reviewed in total, but the sample used to give evidence in this work is limited to a selection of the most relevant among them (e.g. more recent articles). A detailed outline of all the studies reviewed is available in the form of an Excel spreadsheet[9].

Command and control

Command and control instruments are commonly used to address market failures. It is known that these instruments, particularly codes and standards, can be hard to implement because all those agents who are unable to achieve the minimum EE levels established by the governments would have no other option than to quit the market due to their high implementation costs (Galvin 2010; Markandya et al. 2015). In fact, Rosenow et al. (2018) review different EE obligations all around the world. The result of this global review shows that around $26 billion is invested in such instruments (10% of global annual investment in EE). Although there are cost differences among different programmes, they show that costs derived from programmes are below the typical costs of producing a kWh in most sectors and locations. Nevertheless, there are several barriers and limitations to effectively implementing codes and standards. In this regard, Lang (2004) identifies the current barriers and the challenges[10] to be overcome and proposes government funding to promote EE building improvements (e.g. improvements in heating systems) in China.

Regarding the effectiveness of energy codes, Aroonruengsawat et al. (2012) show that a significant proportion of buildings reduced their energy consumption with the introduction of residential building codes in USA. In a similar context, Jacobsen and Kotchen (2011) find decreases in electricity and gas consumption following a change in the energy building code. The effectiveness of energy codes for improving the EE of buildings is confirmed by Papineau (2013), who analyses whether commercial real estate owners are willing to

[9] The Excel spreadsheet used for this study is available on request

[10] The vast size of the country, the temperature differences between north and south and the large number of buildings that do not comply with EE standards are just a few examples of these barriers and challenges.

Table 2 Effectiveness of EE policies: overview of studies and main results of command and control and price instruments (in order of appearance)

EE policy	Reference	Year of the study	Country	Sector/product category	Methodology	Evidence on the effectiveness of the policy	Comments
Command and control							
Codes	Aroonruengsawat et al. (2012)	2005–2007	USA	Appliances	Difference in Difference	+	Decrease in energy consumption
	Jacobsen and Kotchen (2011)	2000–2009	USA	Appliances	First difference regression with EPA's Energy Star data base	+	Decrease in electricity and gas consumption
	Papineau (2013)	2007	USA	Buildings	Modelling	+	Price premium: 2.7–10%
Standards	Rosenow et al. (2018)	–[a]	Global	–[a]	Review	–[a]	
	Lang (2004)	–[a]	China	Buildings	Review	–[a]	
Price instruments							
Taxes	Villca-Pozo and Gonzales-Bustos (2019)	2018	Spain	Buildings	Modelling	–[a]	
	Sterner (2011)	–[a]	–[a]	Transport	–[a]	–	The main beneficiaries are not the poor
	Sterner (2007)	–[a]	OECD countries	Transport	Analysis of price elasticities	–	The main beneficiaries are not the poor
Subsidy	Jiménez et al. (2016)	2007–2010	Spain	Transport	Difference in difference	+	Subsidies lead to an increase in selling price of €600
Combination of tax and subsidies	Galarraga et al. (2016)	2012	Spain	Appliances	Dead weight loss estimation	–[b]	Optimal combination of taxes and subsidies
	Jacobsen (2019)	–[a]	–[a]	Appliances	Theoretical framework	–[a]	
	Markandya et al. (2009)	2007	Europe	Household durables	Modelling	–[a]	Boilers: taxes are cost-effective in Denmark and Italy Lightbulbs: subsidies are cost-effective in France and Poland
	Panzone (2013)	2010–2012	UK	Appliances	Modelling	–[b]	Washing machines should be subsidised; lightbulbs and refrigerators taxed
Rebates	Galarraga et al. (2013)	2008–2009	Spain	Appliances	Dead weight loss estimation	–	Effect
	Houde and Aldy (2017)	2009	USA	Appliances	Difference in difference	–[a]	Consumers do not always buy energy-efficient appliances

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Table 2 (continued)

EE policy	Reference	Year of the study	Country	Sector/product category	Methodology	Evidence on the effectiveness of the policy	Comments
	Datta and Filippini (2016)	2005–2007	USA	Appliances	Difference in difference	+	Increase in the sales share of US Energy Star appliances
	Drivas et al. (2019)	2011–2015	Spain	Buildings	Econometric model	+	Increase in the subsidy rate for lower income households
	Olsthoorn et al. (2019)	2016	EU	Heating systems	Choice experiment	–[b]	A share higher than 50% of free riders

Source: own work. For more details, see the Annex

'+' positive impact; '–' negative impact

[a]No impact

[b]Non-conclusive results

pay a premium for properties with stringent energy codes in the USA. The results of this study indicate that buildings constructed under stringent building codes have a price premium of between 2.7 and 10%, and tenants are willing to pay 5.7% higher rents.

Overall, command and control instruments help to reduce energy consumption and increase the price premium for buildings built under such policies. But these policies are considered as legislative or normative measures so the renovation of a building (e.g. thermal upgrades) might lead to high costs (Galvin 2010; Markandya et al. 2015). For instance, Galvin (2010) shows for thermal upgrades in Germany a power-law relationship between the money invested and the energy saved per €. The costs of renovating to standards above a specific point (70 kWh/m^2) rise exponentially while the energy saved rises a small amount.

Price instruments

As shown in Table 2, the main price instruments studied in the literature are taxes, subsidies, combinations of taxes and subsidies and rebate programmes. These instruments are commonly used to address different market and behavioural failures.

Regarding the effectiveness of taxes in improving EE in buildings, Villca-Pozo and Gonzales-Bustos (2019) show that price instruments such as property tax, personal income tax and property transfer tax, do not seem to be effective in Spain, especially in the case of old buildings. In order to overcome the apparent ineffectiveness of price instruments, authors propose to implement a rebate in the personal income tax for dwellings built before 2007.

For subsidies, Jiménez et al. (2016) show that subsidies on green cars (Plan 2000E) seem to be ineffective in promoting more energy-efficient purchases. They show that the subsidy programme leads to an increase in selling price (€600 on average in Spain), which does not encourage consumers to acquire more energy-efficient vehicles despite the subsidy.

Regarding subsidies and taxes, Galarraga et al. (2016) propose an optimal combination of taxes and subsidies for the purchase of dishwashers, refrigerators and washing machines. The optimal combination of policies depends on the goal pursued (e.g. increasing the market share of energy-efficient appliances, budget neutrality or reduction of emissions).

Table 3 Effectiveness of EE policies: overview of studies and main results of information-based instruments (in order of appearance)

EE policy	Reference	Year of the study	Country	Sector/product category	Methodology	Evidence on the effectiveness of the policy	Comments
Information-based instruments							
Energy labels	de Ayala et al. (2016)	2013	Spain	Buildings	Hedonic regression	+	Price premium: 5.4–9.8%
	Aravena et al. (2016)	2006	Ireland	Buildings	Modelling	+	Increase EE adoption by focusing on the economic benefits
	Brounen and Kok (2011)	2008–2009	Netherlands	Buildings	Logit model	+	Improvement in EE brings financial benefits
	Chegut et al. (2016)	2008–2013	Netherlands	Buildings	Hedonic real estate valuation	+	Price premium of 2.0–6.3%
	Hyland et al. (2013)	2008–2012	Ireland	Buildings	Hedonic regression	+	Price premium of 9.3%
	Stanley et al. (2016)	2009–2014	Ireland	Buildings	Hedonic regression	+	Sales premium 1.5%
	Fuerst et al. (2015)	1995–2012	England	Buildings	Hedonic regression	+	Price premium: A, B vs. D: 5%; C vs. D: 1.8%
	Fuerst et al. (2016)	2003–2014	Wales	Buildings	Hedonic regression	+	Price premium: A, B vs. D: 12.8%; C vs. D: 3.5%
	Jensen et al. (2016)	2007–2011	Denmark	Buildings	Econometric modelling	+	Price premiums between 6.2 and 6.6%
	Cajias and Piazolo (2013)	2008–2010	Germany	Buildings	Econometric modelling	+	Increase rent prices by 0.08%.
	Carroll et al. (2016a)	2014	Ireland	Buildings	Discrete choice experiment	+	Renters value EE positively
	Marmolejo-Duarte et al. (2020)	2016	Spain	Buildings	Discrete choice experiment	−	Poor reputation of the EPC scheme, weak supervision of the policy
	Murphy (2014a)	2008–2011	Netherlands	Buildings	Survey	+	EWE ratings influence 10% of respondents' buying decisions
	Amecke (2012)	2009	Germany	Buildings	Survey	−	EE is only a minor factor
	Alberini et al. (2014)	2010–2011	Switzerland	Transport	Hedonic regression	+	Price premium for A-rated vehicles: 5–11%
	Galarraga et al. (2014)	2012	Spain	Transport	Hedonic regression	+	Price premium for A- and B-rated vehicles: 3–5.9%
	Galarraga et al. (2020)	2012	Spain	Transport	Econometric modelling	–[b]	Both absolute and relative labels could be effective depending on consumer decision making
	Shen and Saijo (2009)	2012	China	Appliances	Survey	+	WTP for highly energy-efficient refrigerators > WTP for highly

t3.22 **Table 3** (continued)

EE policy	Reference	Year of the study	Country	Sector/product category	Methodology	Evidence on the effectiveness of the policy	Comments
							energy-efficient air conditioners
	Galarraga et al. (2011a)	2009	Spain	Appliances	Regression analysis	+	Price premium for dishwashers:15.6%
	Galarraga et al. (2011b)	2009	Spain	Appliances	Regression analysis	+	Price premium for refrigerators: 8.9%
	Galarraga et al. (2012)	2009	Spain	Appliances	Hedonic regression	+	WTP for washing machines:8–19%
	Sammer and Wüstenhagen (2006)	2004	Switzerland	Appliances	Choice experiment	+	Price premium: 30%
	Sanchez et al. (2008)	–[a]	USA	Appliances	Review	+	
	Davis and Metcalf (2016)	2014	USA	Appliances	Choice experiment	+	State-specific labels lead to better choices
	Faure and Schleich (2020)	2016	Spain	Appliances	Survey	–	Conveyance promote the EE gap
	Lucas and Galarraga (2015)	2012	Spain	Appliances	QBDS	+	Consumers value EE positively
	Kallbekken et al. (2013)	2009	Norway	Appliances	Field experiment	+	Decrease in average energy use for tumble driers (4.9%)
	Allcott and Sweeney (2016)	2013	USA	Appliances	Natural field experiment	–[b]	Sales incentives and monetary information should be jointly treated. Consumers tend to overestimate savings.
	Carroll et al. (2016b)	2013	Ireland	Appliances	Field experiment	–[b]	The results do not show any statistically significant effect
	Heinzle and Wüstenhagen (2012)	2009	Germany	Appliances	Field experiment	+	Higher price premium when 10-year monetary cost is displayed
	Deutsch (2010)	2006	Germany	Appliances	Choice experiment	+	Reduction in average energy use: 0.8%
	Min et al. (2014)	2010	USA	Appliances	Experiment	+	Liberal consumers → low-energy consumption lightbulbs Annual energy-cost information → lower implicit discount rates
	Allcott and Knittel (2019)	2014	USA	Transport	Experiment	–[a]	
Feedback		2009–2010	Ireland	Appliances	Randomised control trial	+	

t3.38

Table 3 (continued)

EE policy	Reference	Year of the study	Country	Sector/product category	Methodology	Evidence on the effectiveness of the policy	Comments
	Carroll et al. (2014)						Feedback information is effective
	Gölz (2017)	2010	Germany Austria	Appliances	Field experiment	–	None of the feedback strategies decreases household energy consumption
	Rodriguez Fernandez et al. (2016)	–[a]	–[a]	Appliances	Evaluation of policies	+	Analyse big data to improve EE policies
	Bastida et al. (2019)	2019	Europe	–[a]	Modelling	+	Reduction in final energy consumption
	Casado et al. (2017)	2014	Spain	–[a]	Experiment	+	Messages of EE + behavioural guidelines are more effective than current energy consumption information
	Vassileva and Campillo (2014)	2011	Sweden	Energy consumption	Survey	+	Giving feedback to families with high-energy savings potential
	Abrahamse et al. (2005)	–[a]	–[a]	–[a]	Review	+	Effective in encouraging energy conservation
	Allcott (2011a, 2011b)	2009	USA	Appliances	Natural field experiment	+	2% of energy reduction
	Brühl et al. (2019)	–[a]	South Africa	Appliances	Field experiment	+	Bar graph were comprehensible
	Schultz et al. (2007)	–[a]	USA	Appliances	Field experiment	–[b]	In some households, the information generates energy reductions while in others a boomerang effect
	Asensio and Delmas (2016)	2011–2012	USA	Appliances	Field experiment	+	Energy savings of 8–10%
Energy audits	Krutwig and Tanţău (2018)	2014–2016	Germany	Household	Innovative methodology	+	Voluntary energy audits are more effective than compulsory ones
	Anderson and Newell (2004)	1981–2000	USA	–[a]	Regression analysis	–[b]	Those who received information in shorter paybacks have higher adoption rates
	Frondel and Vance (2013)	2007	Germany	Building	Mixed logit model based on German Residential Energy Consumption Survey	–[b]	Different effects depending on the type of household
	Murphy (2014b)	2012	Netherlands	Building	Survey	–	Low impact

Q9

t3.53 **Table 3** (continued)

EE policy	Reference	Year of the study	Country	Sector/product category	Methodology	Evidence on the effectiveness of the policy	Comments
	Alberini and Towe (2015)	2011	USA	Building	Difference in difference approach	+	5% reduction in energy use
	Kontokoska et al. (2020)	2011–2016	USA	Building	ANOVA	–[b]	There is a consumption reduction but not enough for achieving the objectives of NY city.
	Palmer et al. (2013)	2011	USA	Appliances	Survey	–	Not enough homeowners know about/understand energy audits

Q10

Source: own work. For more details, see the Annex

'+' positive impact; '–' negative impact

[a]No impact

[b]Non-conclusive results

Governments have also introduced rebate programmes for energy-efficient products such as the RENOVE plan in Spain (Galarraga et al. 2013) and the State Energy Efficient Appliance Rebate Program in the USA (Houde and Aldy 2017). Galarraga et al. (2013) analyse the effectiveness of the RENOVE rebate programme for dishwashers in Spain and find that it generates welfare losses, a rebound effect and a deficit in public budgets. Houde and Aldy (2017) develop a system for assessing a rebate programme for household appliances in the USA (the 2009 Recovery Act's State Energy Efficient Appliance Rebate Program). Their results show that consumers tend to buy appliances which are of higher quality but not necessarily more energy efficient. They conclude that the long-term impact of this rebate may not lead to a decrease in energy demand. Datta and Filippini (2016) estimate an increase due to rebate policies in the sales share of 'US ENERGY STAR' household appliances of 3.3 to 6.6%. Rebate programmes have also been applied to the building sector.

Regarding the effectiveness of rebate programmes for the housing sector, Drivas et al. (2019) analyse the effectiveness of an EE house retrofit programme in Greece (2011–2015). During the programme, the Greek government changed the amount of money assigned to it. This change led to an increase in the subsidy rate for lower-income households which produced an increase in EE investments by such households. Olsthoorn et al. (2017) analyse the cost-effectiveness of a rebate programme for the adoption of energy-efficient heating systems through a contingent valuation choice experiment at European level. Their results indicate that the effectiveness of the rebate is affected by the income, risk and time preferences of the recipients. They also show how weak free-riders (consumers that do not need the programme but make use of it) affect the cost-effectiveness of the rebate programme.

Finally, Jacobsen (2019) seeks to understand how EE incentives (rebates, taxes and incentives) are distributed across income groups in the USA. He shows that incentives and taxes always seem to be the policies which are concentrated most in higher-income households, while rebates are the least.

Therefore, tax and subsidies seem to have limitations when used. For instance, in developing countries fuel taxes commonly generate negative distributional effects (Markandya et al. 2015). Similarly, Sterner (2007, 2011) has shown that the main beneficiaries of fuel taxes are not the poor. Conversely, Markandya et al. (2009) show that taxes are cost-effective for boilers in Denmark and Italy, and subsidies are also cost-effective for lightbulbs in France and Poland. Finally, Panzone (2013) recommends that washing machines and TVs should be subsidised while lightbulbs and refrigerators should be taxed in the UK.

Overall, price instruments have mixed results depending on the country, the product subsidised/taxed, etc. For instance, taxes seem not to be effective for building sector in Spain as well as subsidies for the case of vehicles. In addition, there might also have notable side effects such as negative distributional effects on the recipient of the incentive (Markandya et al. 2015).

The evidence on rebates is mixed; on the one hand, there is evidence that shows that rebates could lead to welfare losses and promote the rebound effect (Galarraga et al. 2013) while other studies show that rebates are effective in the USA to promote the adoption of energy-efficient technologies (Datta and Filippini 2016).

Informational instruments

Information-based instruments include EE policies such as energy labels, smart meters and information feedback tools and energy audits. These policy instruments are commonly designed to address behavioural and informational failures. In this section, we review studies that analyse such instruments (see Table 2). The main objective is to understand the effectiveness of such instruments in nudging consumers towards making more energy-efficient decisions.

- Energy labels

EE certificates or labels are among the most widely used EE policies. Most research on energy labels has focussed on their effectiveness when applied to housing, vehicles and appliances, which is also the scope considered here. We focus on two different types of paper: (i) studies that analyse the effectiveness of EE labels; and (ii) studies that analyse how the specific design features of an EE label affect its effectiveness and affect consumer decision-making processes. A detailed recent analysis of how the EE level of products is estimated is provided by Goeschl (2019).

For the residential market, studies generally show a positive price premium for high labelled buildings (Brounen and Kok 2011; de Ayala et al. 2016). Indeed, de Ayala et al. (2016) estimate a price premium of between 5.4 and 9.8% for dwellings with high EE levels compared to those with lower levels. Aravena et al. (2016) show that investment in EE is driven mainly by monetary or financial factors such as potential savings, followed by comfort gains, while environmental benefits seem to be of little concern. Brounen and Kok (2011) show that buildings certified as ‘Green’ in The Netherlands obtain a 3.7% sales premium. Also in the Netherlands, Chegut et al. (2016) show that A-rated properties in the affordable housing market obtain a 6.3% premium (compared to C-rated). Hyland et al. (2013) also find a positive sales effect in Ireland: each upwards step in the BER certificate scale leads to a price premium, with properties in the highest A-rated category having a premium of 9.3% compared to those with a D rating. Stanley et al. (2016) report similar sales premiums (1.5%) for the Dublin market in Ireland. Significant sales premiums are also observed in England (Fuerst et al. 2015), Wales (Fuerst et al. 2016) and Denmark (Jensen et al. 2016) (5%, 12.8% and 6.2–6.6% for A/B-rated dwellings compared to D-rated ones, respectively).

EE improvements also affect rental properties and rents. Cajias and Piazolo (2013) show that a 1% increase in a building’s energy consumption leads to a 0.08% drop in rent in Germany. In a multi-region analysis, the EC (DG Energy, 2013) finds that EE improvements are associated with a 4.4% rent increase in Austria (for a one-letter improvement: e.g. from D-rating to C-rating) and a 3.2% increase in Belgium (for a one-letter improvement). Using a discrete choice experiment, Carroll et al. (2016a) also find that Irish renters value improvements in the Building Energy Rating (BER) of the least efficient properties (e.g. the WTP is €80/month for an improvement from an F rating to an E).

Marmolejo-Duarte et al. (2020) consider the impact of the Energy Performance Certificate (EPC) scheme in Spain and show that it has a poor reputation due to weak supervision, inaccuracies and misunderstanding of information. In order to increase the scheme’s reputation and therefore is effectiveness, policy improvements are needed. Murphy (2014a) finds that only 10% of respondents in the Netherlands say that EE ratings influence their buying decision. In line with this result, Amecke (2012) also finds that EE is only a minor factor when purchasing a dwelling.

Regarding vehicles, Alberini et al. (2014) show that A-rated vehicles have a price premium of 5–11% over

B-rated ones in the Swiss car market. Similarly, Galarraga et al. (2014) conclude that A- and B-labelled Spanish vehicles are sold at prices 3 to 5.9% higher than those with similar characteristics but lower EE. A recent paper explores EE labels as an instrument for promoting the purchase of energy-efficient cars in Spain (Galarraga et al. 2020), in particular, the authors analyse consumer responses to changes in vehicles prices. They find that both absolute and relative EE labels[11] could be useful depending on how consumers make their decisions.

Most of the studies that analyse EE labels for appliances conclude that there is a positive WTP for highly energy-efficient appliances. For instance, Shen and Saijo (2009) find a significant WTP for highly energy-efficient refrigerators and air conditioners in China (air conditioner 276 yuans; refrigerators 757 yuans). Similarly, Galarraga et al. (2011a, 2011b) find that in Spain, 15.6% of the final price paid for dishwashers and 8.9% for refrigerators is due to their EE level. The same authors find a WTP of between 8 and 19% for energy-efficient washing machines in the Spanish market (Galarraga et al. 2012). In line with these studies, Q17 Sammer and Wüstenhagen (2006) estimate a price premium of up to 30% for labelled washing machines in Switzerland.

A review of the effectiveness of EE labels in the USA is reported by Sanchez et al. (2008). They consider all the product categories (e.g. residential appliances) tagged with the US labelling system and conclude that the US Energy Star programme is effective but needs to be adapted to new market trends and to different products (e.g. office equipment) in order to maintain its effectiveness. In line with this argument, Davis and Metcalf (2016) test the effectiveness of providing state-specific energy price information on the EE labels of appliances. They find that consumers tend to invest more in EE in those states in the USA where energy prices are higher due to their knowledge of electricity prices.

Another relevant issue regarding EE for appliances is how the conveyance of appliances (understood as 'leaving the appliance behind when moving out') affects the adoption of energy-efficient products. Faure and Schleich (2020) present a survey that analyses this effect in Spain. Their findings suggest that the take-up of efficient appliances is 8% lower when they are conveyed, and that the effects on renters and owners are comparable. The results of this study could show that conveyance promotes the EE gap.

Regarding the design of EE labels, even though consumers value EE positively and there is a positive price premium for EE, Lucas and Galarraga (2015) show that consumers do not perceive differences between highly energy-efficient appliances (A++ and A+++) and A-labelled ones. They suggest that consumers may think that A-labelled appliances are efficient enough. In line with this argument, some studies have focussed on the different ways of effectively providing information on labels or on specific design features in order to better inform consumers. This is the case of the monetary label. For example, Kallbekken et al. (2013) run a field experiment with two product categories (fridge-freezers and tumble driers) to test the role of providing monetary energy-cost information through labels and through sales staff training. They find a decrease of 4.9% in the average energy use of tumble driers sold for the combined treatment (complementary labels plus staff training) and 3.4% when sales staff are trained in EE-related issues. A similar field experiment is carried out by Allcott and Sweeney (2016), who find that information and sales incentives need to be treated jointly if they are to influence consumer purchases. By contrast, Carroll et al. (2016b) conclude that the 5-year energy-cost information may not provide consumers with appropriate incentives to invest in EE.

Heinzle and Wüstenhagen (2012) conduct a discrete choice experiment and find that consumers will pay a higher price premium for televisions when 10-year monetary costs are displayed but a lower price when 1-year cost information is displayed (compared to non-monetary EE information). Using an online field experiment for washing machines, Deutsch (2010) finds a small but significant reduction in average energy use (0.8%) when consumers receive additional information on life-cycle costs. In the UK, DECC (2014) finds a reduction of 0.7% in the average annual energy consumption of washer-dryers sold when lifetime energy-cost information is given to customers. However, Min et al. (2014) show that providing estimated annual energy costs has no effect on consumers' decision-making for the purchase of lightbulbs in the USA. Similarly, Allcott and Knittel (2019) find that running-cost

[11] Relative labels establish EE level and fuel consumption compared with the relevant market segment, while absolute labels establish that A-labelled cars consume least (these are usually small cars) and higher vehicles are rated as B or higher.

information has no effect on car purchases in the USA. Overall, the results of the studies examined show no clear conclusions regarding the effectiveness of monetary energy labels and monetary information.

In conclusion, the literature shows that consumers have a positive WTP for energy-efficient products. Even when they value the attribute of EE positively, it is not a major attribute when purchasing a dwelling. In the case of appliances, some studies also find a positive WTP but they identify a major concern of EE labels: consumers do not invest in A+++ and A++ because they think that A is efficient enough, while others find EE labels effective. In fact, the evidence show that EE labels should be adapted to new market trends in order to remain being effective. In addition, the results concerning the effectiveness of monetary labels are mixed; effectiveness is not ensured and depends on the product and country.

- Smart meters and information feedback tools

The evidence as to the effectiveness of smart meters is mixed. Carroll et al. (2014) carry out a randomised smart meter trial in Ireland and conclude that insofar as such meters work as a reminder and motivator, they are effective in terms of reducing energy demand. However, Gölz (2017) uses smart meter readings to identify energy behaviour indicators in German and Austrian households and shows that none of the feedback strategies for gaining knowledge and awareness decreases household energy consumption. The study by Rodriguez Fernandez et al. (2016) sets out to analyse big data from smart meters to design and improve EE policies. In fact, they designed a new approach with machine learning to have smart meters learning based on experience. The proposed system could contribute to reaching future energy objectives.

Information feedback tools other than smart meters seem to play a key role in promoting public awareness. Bastida et al. (2019) show that information and communication intervention-based effects on consumer behaviour could reduce final household electricity consumption by 0–5%. Casado et al. (2017) test the effectiveness of different types of information in boosting EE and find that EE messages combined with behavioural guidelines and financial benefits are more effective than those based on current consumption alone. Vassileva and Campillo (2014) show that giving feedback to families with high-energy-saving potential is effective in Sweden. Moreover, their study shows that households prefer to receive feedback by letter and via in-home displays with environmental and financial factors to save energy[12] as consumers are willing to reduce their energy consumption even if they are not interested in energy-related topics. Finally, Abrahamse et al. (2005) argue that feedback is effective in encouraging energy conservation, particularly when it is repeated over time.

Allcott (2011a, 2011b) runs a natural field experiment in the United States to test the effectiveness of sending residential utility consumers a detailed report comparing their electricity use to that of their neighbours. They observe that in the wake of the report, energy consumption decreases on average by 2%. In addition, those households in the high decile of pre-treatment energy consumption reduce consumption by 6.3%, while those in the low decile reduce theirs by 0.3%. Continuing with energy bills, Brühl et al. (2019) carry out an experiment to redesign bills (nine different bills) to test the effectiveness of the information provided. How well bills are understood is tested via a questionnaire. The results show that displaying electricity consumption with bar graphs has a positive effect on understanding, while complex graphics to explain tariff calculations are not comprehensible at all.

Using the power of social norms, Schultz et al. (2007) run a field experiment to test the effectiveness of normative messages in energy bills to promote energy conservation. They find that reporting the average energy usage of a neighbourhood generates energy savings in some households but in others has a boomerang effect. In the same vein, Asensio and Delmas (2016) carry out a field experiment on the effectiveness of smart meters using two treatments: one group received information on cost savings compared to their neighbours, the other received information on health issues. The results obtained after 9 months of control and 100 days of treatment show that health-related information could change behavioural patterns in the long run. However, cost-saving information seems able to change behaviour very fast (in the short-term), though people return to the same non-energy-saving behaviour in the long run.

Overall, the evidence reviewed shows that smart meters and information feedback tools could be effective in promoting more energy-efficient attitudes as they work as constant reminders for users. In fact, individuals and households are willing to receive recommendations

[12] Compared to receiving the same information via e-mail, apps, SMS or websites.

in order to reduce their energy consumption even if they are not interested in energy-related topics. So, smart meters could also be an effective policy to increase public awareness related to EE. However, we cannot provide general recommendations, as the effectiveness of this policy may change depending on the message (how and in what form it is provided) and the country.

- Energy audits

This effectiveness also depends on the type of audit conducted (Krutwig and Tanţău 2018), on how the information is provided (Anderson and Newell 2004) and on the characteristics of each household (Frondel and Vance 2013). Krutwig and Tanţău (2018) use an innovative approach to compare the effectiveness of mandatory and voluntary energy audits in Germany between 2014 and 2016. They find that voluntary energy audits are more effective than mandatory ones. Regarding household characteristics, Frondel and Vance (2013) conclude that in Germany, energy audits can have different effects depending on household characteristics such as windows, insulation, heating system or age of the household. Moreover, Murphy (2014b) finds that the impact of energy audits on EE investments in Netherlands is low. A potential explanation provided by the author is that households may think that their dwellings are efficient enough, given that a comparison between audit recipients and non-recipients shows that recipients do not tend to adopt, plan to adopt or invest more in energy-efficient technologies.

Despite these results, Alberini and Towe (2015) show that both energy audits and rebate programmes reduce energy use by 5% for heat pumps in the USA. The effects of energy audits are stronger in summer, while the rebate programme has stronger effects in winter. In a recent study based on the mandatory audit policy implemented in New York City, Kontokosta et al. (2020) show that mandatory energy audits reduce energy use by 2.5% for multifamily residential buildings and 4.9% for office buildings. However, the results of their study also show that audits do not provide sufficient incentive to invest in EE. It seems that the reduction in energy use produced by this audit policy is not sufficient to attain the carbon-reduction goals of New York City.

Another element that could affect the effectiveness of energy audits is how information is provided. Anderson and Newell (2004) find that the way in which information is provided in energy audits is crucial for promoting EE investments. In fact, audits that show shorter paybacks have higher adoption rates than those that show savings, and consumers are more responsive to initial costs than to annual savings. In line with these results, Palmer et al. (2013) find that some households find understanding energy audits of EE equipment in the USA difficult and only a tiny minority follow-up the recommendations given by auditors.

The effectiveness of energy audits depends on several factors and circumstances: the country in question, how information is provided, the type of audit etc. For instance, compulsory energy audits seem to be less effective than voluntary ones, as individuals applying these are the ones interested in EE. The conclusions derived from this section points out that while energy audits have a positive impact in USA, this policy has a low impact in Netherlands. Therefore, the effectiveness of this policy is not always ensured and further research is needed to reach a consensus.

Conclusions

Understanding how consumers make decisions related to energy use is necessary to achieve significant energy savings and reaching the European (and global) 2030 and 2050 Energy Efficiency targets. According to the revised Energy Efficiency Directive (2018/2002), an improvement of at least 32.5% needs to be made by 2030 in Europe. In this task of reducing energy consumption, the adoption of energy-efficient technologies plays a major role. Taking into account that the household sector is responsible for 36.4% of all European energy consumption, the promotion of EE in this sector becomes crucial.

Despite all the energy-efficient technologies available in the market, evidence shows that the adoption of such technologies is not yet the optimal one. In particular, investment in EE may not be what it seems to be economically rational. There are several failures and factors that help to explain the underinvestment in EE, such as market failures, behavioural failures and other personal factors. EE policies are being designed to address these failures and try to be effective in promoting energy-efficient technologies.

This paper discusses the effectiveness of different EE policies for the household sector based on empirical evidence in the literature. These papers can be grouped according to the failure they seek to address, i.e. market failure, behavioural failure and other factors. An in-depth review of more than 200 papers was undertaken, focussing especially on the following policy instruments: (i) command and control instruments (codes and standards); (ii) price instruments (policies such as taxes, subsidies and rebates); and (iii) informational instruments (energy labels, smart meters, information feedback tools and energy audits).

Codes and standards are set by governments and are instruments that establish how products should be constructed in order to save energy effectively. They are quite common in the USA but less so in the EU. These instruments are frequently used to address market failures and seem to be effective policies both in industry and in the household sector (especially for dwellings). However, they usually set some minimum requirements for construction. The evidence proposes government funding to overcome barriers and challenges of standards.

Price instruments such as taxes and subsidies are designed to address market failures in the household sector. While subsidies are mainly related to building renovations, taxes aim at changing the household's energy related behaviour and rebate programmes are focused on promoting the purchase of highly energy-efficient appliances. However, these price instruments do not always successfully nudge consumers towards more energy-efficient products. Taxes do not seem to be effective for the improvement of EE in the case of old dwellings and subsidies for the purchase of highly efficient vehicles but could work well for some other goods such as lightbulbs. Some studies show that the beneficiaries of price instruments tend to be wealthier people that would have bought energy-efficient products anyway. In the case of the rebates nor the effectiveness nor the efficiency of this policy can be ensured. Although they can increase the number of energy-efficient appliances purchased, they can also increase the consumption of energy at home.

Informational instruments such as energy labels, smart meters and information feedback tools are commonly used in the household sector, while energy audits are less common in that sector. These instruments are designed to address informational and behavioural failures. Energy labels are used especially on almost all energy-consuming products in the household sector. They seem to be one of the most widely EE policies used for overcoming informational barriers and they generally lead to positive price premiums and reductions in energy consumption. Awareness of EE labels varies from one sector and product category to another. In general, there is some misunderstanding of EE levels and consumers may think that they are buying an efficient product when this is not the case. One way to overcome this point could be to adapt the EE label to new market trends in order to be as updated as possible. Another way would be providing monetary information which has been recently tested in the literature. The effectiveness of this label depends on the product category, the country and the way the monetary information is provided (e.g. energy savings).

Information feedback tools such as smart meters and energy bill tools seem to be effective as they work as constant reminders to users to maintain energy-efficient attitudes. Smart meters could provide different types of information with differences in effectiveness. For instance, health-related information seems to be effective in the short and long term, while monetary information seems to be only effective in the short term. The literature points out that social norms may play a role by comparing the energy consumption of a household with that of its neighbours and could be effective in reducing energy consumption.

Energy audits are commonly used in the service and industry sectors but less so in the household sector. While businesses find energy audits useful in reducing their energy consumption, households seem to find them difficult to understand. Giving information about energy consumption in monetary terms could be helpful also in this case to understand energy audits. The type of audit seems also to be an important factor. Our evidence shows that voluntary energy audits are more effective than compulsory ones, as voluntary audits are done by households interested in improving their EE.

In this context, assessing the effectiveness of EE policies is crucial to nudge consumers towards deciding on energy-efficient products. This effectiveness could depend not only on the design of the policy but also on the failure that the policy seeks to address. This assessment plays a key role in ensuring the effectiveness of EE policies in addressing the EE gap. The more effective policies are, the more people will adopt energy-efficient products and the sooner European EE targets will be reached.

Different conclusions can be drawn from this work. On the one hand, command and control instruments seem to be effective in terms of reducing energy consumption, but there are several barriers to implement them (e.g. large number of buildings that do not comply with EE standards). Regarding the effectiveness of price instruments, while subsidies and taxes do not seem to be effective, rebates presents mixed results as they are sometimes effective and in other cases, they present shortcomings such as the rebound effect. Finally, the effectiveness of informational instruments is not always ensured as depends on the sector, the users, the product category, the country and the instruments itself. The effectiveness of EE policies alone seems not to be ensured due to different shortcomings (e.g. misunderstanding of the information received). It might better work the combination of instruments such as subsidising energy audits. More research is needed to provide a better understanding of the consumer decision-making process and to learn how each type of information induces consumers to buy more energy-efficient products. Future research could hold simultaneous field trials in different countries not only to obtain a better understanding of the effectiveness of a specific policy (e.g. monetary energy label, energy audit) or combination of policies (e.g. subsidies and rebates) but also to control for country effects.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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