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Review

Climate Change Mitigation in Households between Market Failures and Psychological Barriers

Dalia Streimikiene [1,*], Tomas Balezentis [2,*] and Irena Alebaite [1]

[1] Lithuanian Energy Institute, Breslaujos 3, LT-44403 Kaunas, Lithuania; irena.alebaite@lei.lt
[2] Lithuanian Institute of Agrarian Economics, A. Vivulskio g. 4A-13, 03220 Vilnius, Lithuania
* Correspondence: dalia.streimikiene@lei.lt (D.S.); tomas.balezentis@laei.lt (T.B.)

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Abstract: Though there are areas of climate change mitigation linked to household's energy consumption having huge greenhouse gas (GHG) emission reduction potential as energy renovation or installation of micro generation technologies using renewable energy sources, these GHG emission reduction potentials are not realized so far. The main input of the paper is to overcome this gap and to provide a systematic review of the main barriers of climate change mitigation behavior linked to energy consumption in households and to develop policies to overcome these barriers. The main policies and measures to reduce GHG emissions of energy combustion in households are promotion of renewable energy consumption and energy efficiency improvements however, these policies have been not successful in overcoming some important barriers of climate change mitigation in households. The empirical evidence of behavioral failures is deepened in this paper and the correlation between market barriers, unsuccessful climate change mitigation policies and behavioral and psychological barriers is provided based on systematic literature review.

Keywords: climate change mitigation; households; energy consumption; policies and measures

1. Introduction

Climate change mitigation measures in households linked to energy consumption can provide many benefits to households, including external benefits linked to reduction of negative environmental and health impacts, however there are many barriers for these measures and the greenhouse gas (GHG) emission reduction potential is not fully utilized. Buildings consume one third of global final energy, and the same share of GHG emissions related to this sector, and in the European Union (EU), this sector is responsible for 40% of primary energy and for 36% of total economy wide GHG emissions [1].

Therefore, the main climate change mitigation measures linked to energy consumption in households are energy efficiency improvements and use of renewable energy sources by implementing micro generation technologies at home. Energy efficiency improvement in households by deep energy retrofitting of residential buildings has the highest GHG emission reduction potential in households. It is necessary to stress that though energy efficiency improvements are the most efficient way to reduce GHG emissions, the so-called Energy Efficiency Paradox was revealed by scholars [2]. Consequently, due to important barriers related to energy efficiency measures in buildings the "energy efficiency paradox" [3]. It indicates the divergence between optimal or desired and real obtained energy efficiency improvement levels. The similar greenhouse gas emission reduction paradox can be defined indicating situation that actual GHG emission reduction level does not correspond to the optimal GHG reduction level. The optimal energy efficiency or GHG reduction levels are hardly achieved in a sector branded by dualities in stock (existing vs. new buildings), in the use of technologies (renewables vs. fossil fuel-based technologies), and in the preferences of the agents (landlords vs. lenders). This is because of the fact that various impediments preventing from energy savings and GHG reduction in these sectors

(Ramos et al., 2015 [4]). Hence, in household sectors associated with many dualities described above the energy efficiency improvements and GHG reduction does not reach levels corresponding to the various 'win-win' resolutions provided in the market, or even do not reach the level of willingness to pay (WTP) by households.

There many studies dealing with WTP for energy efficiency improvement measures, energy renovation or efficient cooling and heating systems at households. The research concluded by scholars in diverse countries revealed the positive WTP for these measures. A study by Banfi et al. [5] analyzed the hypothetical change of insulation systems Swiss households. Alberini et al. [6] also found a positive WTP for Swiss residents, though this was only for those households who were expecting energy prices increase. Similar results were conducted in Germany [7], Hong Kong [8], South Korea [9], and Lithuania [10]. Based on studies conducted, informational failures were defined to be persistent and most pertinent in energy efficiency improvements of residential buildings. The scholars agree that for addressing information and behavioral barriers, the well targeted specific policy instruments are necessary [4].

Several important studies [11–13] were conducted to analyze the impact of urban form and geomorphometry impact on residential energy consumption. The studies found that neighborhood street configuration and tree shade have significant effect on residential energy consumption and, consequently, greenhouse gas emissions. Therefore, exploration of the spatial complexity of residential energy usage intensity, with a focus on urban form and the geomorphometry attributes of urban ventilation, solar insolation, and vegetation is very important and should be addressed by climate change mitigation policies and measures.

Several scholars [14–19] analyzed the main drivers and barriers of energy renovation in Eastern Europe and energy poverty issues. Zoric et al. [20] discovered that age of apartment owner is important barrier. Most of the studies were concentrated on economic barriers of energy renovation and low incomes of households [15,21].

There are also studies on WTP for renewables in households carried out in US [22]; Italy [23]; Great Britany [24]; Lithuania [25,26]; Slovenia [20]; Czech Republic [27]. There are a plethora of studies dealing with methodical taxonomy and taxonomy of barriers to the adoption of renewable energy technologies (regulatory, economic and financial, technological, and informational) and rating them based on the insights of various stakeholders [28]. A study [29] analyzed the effects of social, economic, technological, and regulatory barriers linked to penetration of renewable energy in the markets. Alam et al. [30] analyzed barriers of diffusion of renewable energy sources in households and stated that perceived ease of use, behavioral control, awareness, relative advantage, and cost decrease have meaningful influence on intension to apply small-scale renewable energy technologies. Palm and Tengvard [31] defined the main drivers and hurdles to customers' adoption of small-scale electricity generation technologies in Sweden. Lu et al. [32] analyzed the similar social, economic, technological, regulatory, and informational barriers of renewable energy penetration in three Baltic States. Gifford et al. [33,34] in their study analyzed the main drivers of global climate change and systematized the behavioral and psychological responses to its impacts.

Though there are studies dealing with energy efficiency barriers in households and energy efficiency paradox and there are studies providing analysis of renewable energy barriers in households there are no studies addressing all these climate change mitigation barriers in households together in systematic way as these barriers are related and overlapping.

The main input of the paper is to overcome this gap and to provide systematic review of the main barriers of climate change mitigation behavior linked to energy consumption in households and to develop policies to overcome these barriers.

The following second section of paper presents literature review on barriers of energy efficiency improvements, the third section analyses literature on barriers of renewable energy usage at households, the fourth section discusses results and findings of conducted analysis, and the fifth section concludes.

2. Barriers of Energy Efficiency Improvement and Assessment of Policies to Overcome Them

Usually, the standard approach for addressing energy efficiency gap in households is based on the conventional analysis of various energy market failures. The policies and measures were developed to overcome energy market failures by introducing economic of flexible market instruments and pollution standards. As energy prices of fossil fuels do not internalize environmental externalities, the excessive GHG emission and other pollutants emission levels or a higher than optimal energy consumption level is reached in the market [35]. Based on this traditional approach, if the social (private and external) energy costs do not correspond to the real marginal cost, there is no initiative to implement energy efficiency measures. Therefore, this market failure is corrected by public policies or state interventions in the market aiming to increase energy prices to their right level by involving all social costs of energy supply.

Additional important economic problem is the lack of access to the capital because of the several uncertainties available in the capital market [36], energy poverty, or regulatory problems [37]. But even with governmental intervention to overcome market failure, the energy efficiency paradox still is not solved.

The growing use of energy standards did not provide expected results. The consequences of building codes were found to be negligible on energy savings in may studies [38–40]. The economic instruments such as GHG or energy taxes have also provided a limited effect due to low elasticity of demand for energy services [41,42]. The subsidies due to limited access to capital is useful financial measure however, the of these measures was limited on energy efficiency improvement [43,44].

The traditional approach in dealing with market failure is not effective in term of dealing with barriers of climate change mitigation in households is based on assumptions that customers have perfect information and are able to make rational decisions [45]. However, imperfect information, asymmetric information, and various behavioral failures [46–49] do not allow to allow to reach desirable energy efficiency and GHG emission reduction levels households [50]. The new approach is linked with information and behavioral barriers and measures to overcome these new types of barriers [2,3,41,51,52].

Cattaneo [53] has identified the following external market barriers for energy in households: capital market failures, information, or asymmetric information problems; financial and technological barriers. Internal barriers were defined as barriers linked to behavioral and psychological barriers.

Due to problems of asymmetric information and split incentives, investment in profitable energy efficiency technologies are not realized as the decision to adopt them is related with the ownership status of households, as tenants do not like to invest in energy renovation or efficient energy appliances at their homes, though Papineau [54] showed that energy efficient but unlabeled buildings can deliver significant price premiums when they are sold.

Schleich et al. [55] pointed out that financial and technological risks are the main barriers. Additionally, energy efficiency investments are associated with some risks due to the uncertainty related to achieved in reality actual and expected energy savings. All barriers can be grouped in the following clusters [56]:

- Economic and financial barriers linked to high costs of energy efficiency measures due to not internalized external costs of fossil fuel-based energy and external benefits linked energy efficiency improvements or other financial barriers linked to the problem of access to and availability of capital funds;
- Institutional and regulatory barriers linked to not well-established regulatory requirements and regulations for insulation of buildings, especially regulation of old residential buildings stock;
- Technology barriers linked to lack of knowledge of available renovation technologies, options and other energy efficiency improvement issues and their costs and benefits;
- Informational barriers linked to market failures linked to information asymmetry and split incentives between landlords and tenants;

- Organizational barriers linked to the lack of set process on how to entitle individuals or institutions with the responsibility and authority to identify, plan, and implement renovation of multi-flat buildings. Logistical barriers include a lack of skilled energy renovation service providers in the market. In addition, there are significant switching costs linked to any change.

There are other typologies of barriers and market failures hindering penetration of sustainable energy options [57].

In Table 1 the main barriers of energy efficiency improvements are presented.

Table 1. Barriers and market failures linked to energy efficiency improvement in households.

Barriers and Market Failures	Typologies	Explanations
Economic and financial barriers	High costs of energy efficiency measures	High costs of energy efficiency measures and high costs of energy renovation of buildings are linked to the fact that external costs of fossil fuel-based energy and external benefits linked energy efficiency improvements are not internalized and do not sent clear market signals to customers to undertake energy efficiency improvements [5,6,9].
	Limited access to capital	Households usually encounter problems related to access to capital due to high cost of borrowing and low anticipated earnings. They do not want to take loans due to debt defaults or other individual reasons [11,36].
	Uncertainties linked to property prices	Low and uncertain property values are also important barriers torenovation of multi-flat buildings, as owners who anticipate selling their property in the future may not feel encouraged to renovate their property [44,54,55].
	Hidden and high transaction costs	There are hidden costs linked to energy renovation in residential buildings. These costs are also linked to risks due to possible irreconcilabilities and associated risks etc. Higher transaction costs for energy renovation are linked with organizational problems in terms of renovation of multi-apartment buildings as there are many actors in process of initiating renovation of multi-flat building and agreement of all apartment owners is necessary making transaction costs higher than in the case of public or commercial buildings [7].
Institutional and Regulatory barriers	Problems with legal framework for renovation of residential buildings	There are no firm frameworks and well-established schemes for implementation of energy renovation programmes, especially in multi-flat buildings [11–15,19,21,52].
	Insufficient enforcement of standards	For energy efficiency improvements in old buildings there are no standards and any other regulatory enforcements to renovate these buildings [4,39,40].
	Lack of equipment for monitoring	Households which do not have possibilities to monitor their energy consumption are unwilling to search for information on energy renovation or energy efficiency improvement options for their homes [36].
	Inadequate energy service levels	Energy services provided by utilities to households are not well established like in case of commercial and public buildings [16–18].

Table 1. *Cont.*

Barriers and Market Failures	Typologies	Explanations
Technological barriers	Technological difficulties linked to micro generation technologies in buildings	Due to the lack of well-established standards for micro generation technologies and the lack of equipment, components and spare parts for renewable energy technologies create additional barriers [53].
	Scarcity of investment in R&D of energy efficiency enhancement	R&D investments for energy efficiency improvements are inadequate. Additional R&D investments are necessary in this field to ensure innovations in renovation pro cesses, heating technologies, management and financing [3].
	Lack of technical or commercial skills and knowledge	There is a lack of trained professionals and other skills in energy renovation supply chain [16,17].
Information barriers	Lack of awareness and information	No confidence in information about possible energy efficiency improvement options and lack of environmental awareness about energy efficiency benefits and climate change mitigation impacts. In addition, there is a lack of experts and resources in the market to deliver this information to consumers [4].
	Uncertainties about cost-effectiveness	Uncertainties are mainly linked to the problem that; though cost-effective solutions can be achieved under specific conditions it does not mean that the same benefit will be achieved for all investments in energy efficiency improvements. This is because there is too much conflicting data on the costs and benefits of renovation of multi-flat buildings, often resulting in mistrust of the information [4,21].
Organizational barriers	Ignoring of small energy efficiency improvement options	The households usually ignore small energy saving or energy efficiency improvement options and do not implement them though they can provide energy saving with low or no costs [34,56].
	Organizational failures	Problems in making common decision and obtaining agreement of all apartment owners for large scale renovation of multi-apartment building due to conflicting interests [46,54–56].
Behavioural barriers	Resistance to change	Adoption of energy efficiency measures is associate with customers perceptions of the quality and usefulness of these actions by comparing them to status quo situation. The use of energy efficiency options or energy renovation of residential buildings are often perceived to be associated with discomfort and problems. Households are not interested to make changes in their daily routine, they prefer status quo situation [45,48–50].
	Time constrains, and the ability to use information	Various constrains associated with time, ability to use full information, necessary attention efforts often lead to irrational decisions by households. Additionally, then making decision on energy renovation or other energy efficiency improvement measures households use the advice and consultancy with friends which are not qualified enough instead of consulting experts. Therefore, they make economically irrational decisions in this area [33,34,46–51].

One can notice from information provided in Table 1 that the largest barrier to energy efficiency improvements and GHG emission reductions in residential buildings is the high initial costs of energy renovation in buildings households have very limited time to recover the cost of their investments in renovation [58–61]. Another important issue is that success of policies in this area depend on more

than one stakeholder. Behavioral and psychological issues are not being properly addressed by policies and measures targeting renovation multi-apartment buildings [62,63].

Therefore, most of the world's countries have many policies in place to mitigate climate change at households, however these polices have not resulted in optimal desired GHG emission reduction levels. Many studies have been conducted dealing with energy efficiency gaps, especially in residential buildings [16,17,64–69]. Energy renovation of multi-apartment buildings is the main measure to achieve significant energy savings in residential buildings. Many countries have implemented financial measures to support energy renovation such as capital subsidies, grants, and subsidized loans to urge households to invest in energy efficiency measures and equipment, however these support measures are not enough to realize the full energy saving potential in residential buildings. The review of policies and measures to promote large scale energy renovation indicated that these measures have brought only little success in in Germany, the UK, Denmark, US, Japan, and other countries [59,60,63,65,66,68,69].

Existing instruments are not properly combined with other measures and do not address the barriers of decision making by households for energy renovation. The main policies and measures to encourage energy renovation of multi-apartment buildings are grouped in the following way: regulatory and control instruments, financial incentives, flexible market instruments, energy and CO2 taxes and support, information, and voluntary action.

Regulatory and control measures are mainly linked with labeling and certifications. Energy Labeling system was implemented in EU, but this label is not being utilized by energy consumers in various countries having these systems [65]. The Energy Performance Certificate, (EPC), indicating the energy efficiency class of the buildings, was introduced to stimulate homeowners to do energy improvements in their homes, however the effectiveness of the scheme is limited so far. The similar can be attributed to energy audit schemes. It can be explained by the fact that households generally experience that the information provided by the EPC and energy audit have a general and trivial character. The results indicated that low outcome of this scheme in Denmark is not linked to a lack of understanding of the information provided by the label [17]. Building a monitoring system [66] also to deal with informational barriers and provides a good understanding of what works and what does not in building operation, but the impact of a monitoring system on an occupant's decision to renovate apartments is limited due to other barriers of energy renovation.

Financial support to overcome high capital costs is provided in many countries. A range of funding grants have been implemented in the UK aiming to improve energy efficiency of the domestic stock in the UK. Green Deal, New Fuel Poverty Scheme were targeting different groups of inhabitants. Due to frequent changes eligibility criteria the schemes had low uptake [58]. In France, energy renovation was set as the top priority in energy and climate change mitigation policies. One significant enabling policy is the zero interest "eco" loans. The introduction of loans was linked to the limited improvements achieved in residential buildings through the income tax credits implemented in 2005. Under this scheme the numbers of loans have even been falling [68].

The Energy Company Obligation (ESCO) is a scheme which requires the energy utilities to install GHG reduction measures in households. Utilities can face penalties if they do not comply with ESCO obligations. The utilities pass all costs of implementation of GHG reduction measures to their customers through household's energy bills. This system was implemented in the UK more than 20 years ago however the results were not very good [17]. ESCO and tradable white certificates have been implemented also in Denmark, France, Italy, the UK, and Poland. In France, Italy, and the UK, ESCO is dominating in residential and public sectors but in Denmark ESCO is dominating in industrial and commercial sectors.

Energy or CO_2 taxes introduced to fossil fuels have a positive impact on energy efficiency improvement in households as provides for the price increase of energy produced by using fossil fuels.

There are various supports, information, and voluntary measures. France has also introduced various voluntary training programs for trades of buildings, and several programs for micro generation and low-carbon conversion technologies [17].

Assessment of policies and measures to promote renovation of multi-flat buildings in term of energy and costs savings are generalized in Table 2.

Table 2. Assessment of strengths and weaknesses of policies and measures in dealing with main barriers of energy efficiency improvements in households.

Policy Instruments	Key Barriers Addressed	Strengths and Weaknesses in Dealing with Barriers
Regulatory instruments		
Appliance standards	Regulatory and informational barriers	These measures have provided for insignificant success, as they collapse to address information barriers and organizational barriers in decision making for renovation of multi-apartment buildings. These measures can be effective if periodical updated, if independent control is being ensured. Mandatory schemes are more effective than voluntary ones. Mostly they are effective if combined with other measures. Provision of information, communication, education is crucial for success of appliance standards [4,6].
Building codes	Regulatory and information barriers	Though building codes had limited success in energy savings, the mandatory schemes are more effective than voluntary ones. These measures also do not tackle organizational barriers of decision making on energy renovation of multi apartment buildings. Therefore, insignificant success was achieved in dealing with energy efficiency or GHG reduction gap and they are efficient if enforced and periodically updated and monitoring and control and proper certification procedures are established. Provision of information, communication, education is crucial for success. Mostly they are effective if combined with other measures [8,37–41,52,65].
Mandatory audit requirement	Regulatory and information barriers	These measures alone are not effective. They do not allow to overcome high capital costs barriers. Mostly they are effective if combined with other measures [41,53].
Building monitoring system	Regulatory and information barriers	The influence of monitoring system on apartment owner's decision to renovate apartments is restricted due to other energy efficiency barriers in households [53,60,66].
Demand-side management programs	Regulatory and information barriers	These instruments are more cost-effective for the commercial buildings and do not fit very well for residential buildings [66,67].
Detailed billing and disclosure programs	Regulatory and information barriers	Successful in combination with other measures. It is necessary to ensure periodic evaluation for success [69].
Economic and market-based instruments		
Energy savings performance contracting (ESCO)	Economic and financial barriers	These instruments have had slight impact on energy renovation decision making in residential buildings as they are more effective in public buildings. This measure also does not tackle the organizational barriers of energy renovation decision making in multi-flat buildings. Provision of information, communication, education is crucial for success [18,69].
Cooperative procurement	Economic and financial barriers	This measure implemented in several countries. Only effective in combination with standards and labeling etc. [53].
White certificates or Energy efficiency certificate schemes	Economic and financial barriers	This measure also does not tackle the organizational barriers of energy renovation decision making and require high monitoring and enforcement costs and institutional support, not clear interaction with other measures [41,51,53].

Table 2. *Cont.*

Policy Instruments	Key Barriers Addressed	Strengths and Weaknesses in Dealing with Barriers
Fiscal instruments		
Taxation	Economic and financial barriers	Effectiveness is linked to price elasticity. Most effective when combined with other tools. In some countries: Germany, Sweden etc. high taxes have some influence on energy saving in households though in other countries taxes are low and external energy costs are not internalized. GHG taxes are high in several Scandinavian countries but in other countries they are too low to make influence on households' decisions to invest in energy efficiency improvements [42,43,68].
Tax allowances	Economic and financial barriers	Tax allowances for energy efficiency measures like VAT reduction for insulation of buildings are effective just if they are properly structured to stimulate large scale energy renovation [42,43].
Public benefit charges	Economic and financial barriers	Successful if independent administration of funds is ensured, regular monitoring and feedback and simple and clear design is necessary [53].
Financial instruments		
Capital subsidies	Economic and financial barriers	The success of these programs was limited because of free-rider's problems. There households receiving capital subsidies which is not necessary for them and they can renovate their houses without the subsidy [56,60].
Grants, soft loans	Economic and financial barriers	They can provide access to capital of low-income population however cannot address other important barriers of energy efficiency in households like organizational or behavioral [63,68].
Support, information and voluntary action		
Public leadership programs	Informational barriers	Mandatory leadership programs have higher potential than voluntary programs. Combined with financial incentives can provide for better results [53,69].
Education and information programs	Informational and technological barriers	Most effective then they are implemented with other measures [50,60,64].
Investments in Research and Development and Demonstration	Technological barriers	Investments in research and development is necessary to ensure the development of new energy saving technologies having long-term market scaling and risky investments [53].

As one can see from Table 2, various policies and measures were implemented to encourage energy efficiency in households but their effectiveness is rather low especially they do not address organizational and behavioural barriers. Most of the instruments in order to be successful should be implemented in combination of other instruments. Especially it is important for support, information, and voluntary actions. Regulatory and informative policies would also provide for more effective results if they are well structured and enforced in combination with other measures, especially targeting behavior changes.

3. Barriers of Renewable Energy Sources and Assessment Policies to Overcome Them

According to many scholars, the main barriers of penetration of renewables in energy markets and successful competition with traditional fuels are economic as renewable energy technologies have higher investment costs and consequently total private costs due to negative externalities not being integrated in the price of energy produced from fossil fuels. In addition, there are large subsidies for fossil fuels which have even lower final energy prices, providing a renewable energy source at a competitive disadvantage in the end.

There are traditional policies and measures aiming to overcome these economic barriers by offering extra subsidies for renewables in the form of tax allowances, grants, and subsidies for RES projects

or introduction of special pricing schemes and lowering transaction costs. In this area, the policies tend to focus on increasing subsidies for renewables instead of reducing available environmentally harmful subsidies for traditional energy carriers and nuclear energy. One can notice that initial capital costs for renewable energy technologies are higher than for fossil fuels due to market failures as high external costs of fossil fuels are not reflected in the price of energy produced from these fuels. In addition, the comparison between various energy carriers should be performed based on total "lifecycle" costs including initial capital costs, future fuel costs, future operation and maintenance costs, decommissioning costs, and equipment lifetime costs. However, assessment of energy generation technologies based on lifecycle costs is problematic due to many uncertainties linked to discount rates etc. Therefore, the main economic and financial barriers for penetration of the renewables are high initial capital costs; difficulties of fuel price risk assessment; unfavourable power pricing rules; high transaction costs and non-internalized environmental externalities [70,71].

There are also important legal and regulatory barriers hampering penetration of renewable energy technologies in households: lack of access to credit; perceived technology performance uncertainty and risk; lack of technical or commercial skills and information.

The main economic, institutional, and regulatory, market, technological, information and behavioural barriers of renewables are summarized in Table 3.

Table 3. Barriers of renewables penetration in households.

Barriers and Market Failures	Typologies	Explanations
Economic and financial barriers	High initial capital costs	Renewable energy sources have lower operating costs comparing with fossil fuels however, higher initial capital costs make them less competitive than conventional energy sources as RES project necessitate higher financing for unit of installed capacity. Therefore, the capital markets often require a premium in lending rates for financing of RES projects. RES technologies encounter also import duties providing for the high first-cost attentions relative to fossil energy-based technologies [27,32,37,70].
	Difficulties to assess fuel price risk	Future development of fossil fuel prices is considered to be reasonably stable. RES technologies do not encounter fuel costs therefore avoid fuel price risk. Nevertheless, the "risk-of fuel price premium," is usually not included in economic comparisons as it is problematic to assess such risks. Regulated utilities have fuel costs included into regulated electricity tariffs; therefore, consumers should deal with the fuel price risks while utility decisions to invest is not include fuel price risk considerations [72–75].
	Unfavourable electricity pricing rules	RES feeding into the grid sometimes do not receive full payment for the value of their electricity supplied. RES power is generated near to final consumers and do not require transmission and distribution. However, utilities pay only wholesale rates for electricity, as if the capacities require transmission and distribution. Therefore, this benefit of RES also is not taken by the producer. Additionally, as RES energy is an "intermittent" and utilities cannot control such generation at any given time they lower prices for it by imposing a zero price for the "capacity value" and paying the lower price at peak times even if the renewable electricity is produced at peak demand and have to correspond to peak prices [29,37].

Table 3. *Cont.*

Barriers and Market Failures	Typologies	Explanations
	High transaction costs	Higher transaction costs make RES technologies more expensive. RES projects are usually minor in comparison with traditional fossil energy projects and sometime require costly extra information or extra time to obtaining permits of finances due to unfamiliarity with RES technologies [28,30].
	External costs and benefits	The fossil fuels burning has negative environmental impacts on human health, agriculture, infrastructure decay biodiversity etc. The costs of climate change also matter. As environmental externalities are difficult to evaluate the investors do not include external costs in decision making. Renewable energy generation have external benefits like avoided external costs and creation of new jobs, especially for local communities which are also not taken into account during decision making [32,72].
Institutional and Regulatory barriers	Problems with legal framework for independent power producers	Utilities control energy production and distribution and independent power producers encounter problems then investing in RES projects and selling electricity to the utility or to third parties. Utilities tend to negotiate power purchase agreements with independent energy producers on an ad-hoc basis, creating difficulties for RES project developers to finance projects and to plan investments and they pay back [69,70].
	Constraints for and construction	RES installations often encounter many constraints based on environmental regulation for height, aesthetics, noise, or safety, especially in urban areas. Urban planning departments are not familiar with RES technologies and lack of established procedures for siting and permitting of such projects. Struggle for land usage with agriculture and tourism sectors often occur [70].
	Problems with transmission access	Utilities have to provide transmission access to RES power plants and sometimes charge high prices for transmission access. Transmission or distribution access is also necessary for direct third-party sales between the RES energy producer and a final customer. Sometimes there are problems with transmission access to remote renewable energy sites [28].
	Requirements for Utility interconnection	Individual houses or apartments can sometimes encounter unclear utility interconnection to the grid requirements. Unavailable uniform requirements can also increase transaction costs of small producers. The transaction costs will increase due to necessity to pay extra for legal and technical experts in order to satisfy requirements for interconnections [26,28].
	Liability requirements	Small power producers usually encounter additional requirements for liability. Although proper equipment standards are in line with safety requirements, the liability is still an issue for RES projects. Utilities usually demanding additional insurance as part of net metering requirements for renewable energy technologies [13,28,70].

Table 3. *Cont.*

Barriers and Market Failures	Typologies	Explanations
Market barriers	Problems with access to credit	RES project developers usually lack access to credit for investing in RES because of distorted capital markets. For example, "microcredits" for RES projects usually do not exist. Loan terms sometimes are very short relative comparing to the long project lifetime. RES project developers have also difficulties in obtaining bank financing because of uncertainty linked to long-term power purchase agreements with utilities [16,17,28].
	Perceived risks linked to technology performance uncertainties	RES technologies are considered as risky duet to the lack of experience with them. The lack of acquaintance with RES technologies can create wrong perceptions about higher technical risk than for traditional energy carriers. These issues usually result in less capital availability. Utilities may be hesitant to use unfamiliar RES technologies [20,28,37].
	Lack of technical or commercial skills and knowledge	Markets need low-cost access to information and the necessary skills. However, there is lack of skilled personnel able to install, proper, operate, and maintain RES equipment. RES project developers also usually do not have sufficient technical, financial, and business development skills. Professionals in supply chain like engineers, architects, lenders, lack information about RES technologies, their costs and benefits, maintenance requirements, sources of finance, etc. These problems can block decisions in favour of RES projects [68,72].
Technological barriers	Technological difficulties related to the intermittency and storage requirements	Due to the lack of well-established standards for renewable energy technologies linked to the intermittency and reliability of performance these technologies encounter additional barriers. The main technical challenge of RES technologies is storage requirements. The lack of equipment, components and spare parts for renewable energy technologies create additional barriers [28,32,72].
	Lack of investment in R&D for renewable energy technologies	Investments in R&D for RES technologies are inadequate. The risks associated with renewable energy technologies are high and additional R&D investments are essential in this field [28,32,70,72].
	Limited availability of infrastructure for renewables	RES projects are often implemented in remote areas, requiring additional transmission lines to connect power plants to the grid, and investments to upgrade this grid are necessary as well [28,70].
Information barriers	Lack of awareness and information	Scholars agree that the adoption of RES technologies are hampered due to the lack of information or knowledge or a lack of confidence in obtaining such information and lack of environmental awareness about benefits of renewables [33,34,71].
	Not in my backyard (NIMBY) syndrome	NIMBY syndrome is linked with RERS projects then people do support renewable energy sources in general, but do not support them in their neighbourhood; so, renewable energy projects face hostility from individual citizens due to this syndrome as well making additional barriers to RES projects [68,73].

Table 3. *Cont.*

Barriers and Market Failures	Typologies	Explanations
Behavioural barriers	Resistance to change	Adoption of renewable energy technologies are linked with customers perceptions about usefulness of these technologies by comparing them with fossil fuel-based technologies. RES instead of providing energy supply at lower cost. Households do not want to shift from one technology to another as they prefer status quo [33,34,71–73].
	Constraints on time, attention, and the ability to process information	Various constrains associated with time, attention, and ability to process full information often leads to households' decisions that are not rational. Additionally, while purchasing a renewable energy technology, consumers consult their friends instead of experts and take economically irrational decisions [34,71–73].

As one can see from information provided in Table 3 there are various barriers for penetration of renewables in households including behavioural one however there are no well targeted policies to overcome these barriers [72,73].

In Table 4 the effectiveness of policies and measures to address barriers of renewables energy penetration in households are provided.

Table 4. The effectiveness of policies and measures to address barriers of renewables.

Policies and Measures	Key Barriers Addressed	Strengths and Weaknesses in Dealing with Barriers
Regulatory instruments		
Standards and certification: building codes, zero building standards, low-carbon fuel standards etc.	Institutional and regulatory barriers	Important for supply chains and snowballing consumer confidence. Unlikely to result in much deployment without financial incentives [37,70].
Power grid access policies	Institutional and regulatory barriers	Well-established regulation for independent power producer regulation can provide for better transmission access, the priority of access to grid of renewable energy generators can allow to deal with regulatory barriers for penetration of RES [28,32].
Competitive wholesale and retail power markets	Institutional and regulatory barriers as well as economic and financial barriers	Introduction of market in electricity sector. These measures can reduce high costs barriers, transaction costs, and lack of fuel price risk assessment as well as unfavorable power pricing rules, therefore they are quite efficient in dealing with many barriers [28,72].
Restructuring of power sector and unbundling of electricity generation, transmission and distribution and privatization of utilities	Institutional and regulatory barriers as well as economic and financial barriers	These measures can guarantee more incentives to self-generate, including RES. This measure also has impact on mitigation of financial barriers like access to subsidies, but may increase barriers of high capital costs and rise perceived risks [28].
Net metering and net billing	Institutional and regulatory barriers	The measure can reduce transmission, distribution losses, but the tariffs based on net metring do not reveal the actual value of RES electricity at each location and time period [66].
Economic and market-based instruments		
Energy savings company performance obligations (ESCO)	Economic and financial barriers	These instruments have had little impact on decision to use renewable energy. Provision of information, communication, and education is crucial for success [29,32,37].

Table 4. *Cont.*

Policies and Measures	Key Barriers Addressed	Strengths and Weaknesses in Dealing with Barriers
Administratively set pricing instruments: feed-in tariffs, feed-in premiums.	Economic and financial barriers	Allows to deal with unfavorable power pricing rules and ensure support during long-term period, however they can cause high snowballing costs effect and do not address properly problems linked to high upfront costs of RES generators [28,29,32].
Competitive price instruments: auctions	Economic and financial barriers	Flexible and has potential for real price setting for RES electricity. However, due to high risks of underbidding there are problems for small or new RES generator for entering energy market [29,32].
GHG emission trading schemes	Economic and financial barriers	Flexible market-based mechanisms might provide extra revenue to RES generators. However, the scheme has high enforcement and implementation costs [32].
Financial instruments		
Subsidies and grants	Economic and financial barriers	Subsidies provides for tackling barrier of higher capital costs of renewable energy. These schemes do not provide clear signals for investors in RES projects as support provided is fluctuating due to changes in governments [28,32].
Capacity credits for renewable energy generators	Economic and financial barriers -	Allows to overcome the barriers of high transaction costs, lack of access to credit however not always as efficient as supposed to be in overcoming other barriers like uncertainties of perceived risks [37].
Renewable energy mandates and portfolios	Technological barriers	This measure provides clear signals to companies as delivers clear information about anticipated RES deployment levels however is applied mostly in new-buildings, corresponding to the small share of energy consumption in residential buildings [32,37].
Fiscal instruments		
Tax allowances	Economic and financial barriers	Taxation policies to promote renewables, like VAT reduction for electricity from renewables and allows to deal with high initial capital costs problem [23,27,31,32].
GHG and energy taxes	Economic and financial barriers	GHG and energy taxes do not deliver clear signals for investors in RES projects as support provided is fluctuating due to changes in governments as taxes are difficult to implement due to political reasons, they are usually too low to internalize externalities and overcome this market failure. In addition, exclusions and rebates are very often making taxes less ineffective measure [30–32].
Support, information, and voluntary actions		
Informational measures: awareness campaigns and labelling.	Information barriers	These measures provide for increase of awareness about RES benefits and are more effective then implemented in the form of tailored energy advice. However, this form of information dissemination is costly [34,68].
Public green procurement	Economic and financial barriers	Allows to increase share of RES in final energy consumption however, additional measures are necessary to stimulate RES technologies uptake in the market [68].
Voluntary programmes	Market barriers, information barriers	Voluntary measures are less effective then obligatory however, they allow to save cost for government as well as consumers. They should be implemented together with awareness rising and information dissemination programmes [32,68,73–75].
Investments in R&D and demonstration.	Market barriers, information barriers	Investments in R&D for new technologies allow to improve them and reduce the costs making them more competitive in the market. The pilot commercial demonstration projects are very useful for long-term market scaling perspectives of new RES technologies and reduction of financial risks anticipated in the case of RES project failures [32,73].

As one can notice from information provided in Table 4, behavioral and psychological barriers of renewable energy sources are not properly addressed by policies and measures implemented around the world and targeting various barriers for penetration of renewables in households [73–77].

4. Discussion of Results

A popular explanation about the main reasons of energy efficiency and GHG emission paradoxes provided in scientific literature [64–69,74] is the fact that all these policies and measures do not adequately address the behavioral and psychological as well organizational barriers in household's decision making. Authors agree that traditional GHG mitigation policies in households have mostly focused on fiscal and financial incentives i.e. subsidies and tax allowances [6]. Several scholars recommend in addition to financial incentives to implement information dissemination and environmental awareness rising policies, providing more understanding about RES technologies and benefits of energy renovations of multi-flat buildings as well as to ensure middle actors activities in the market by increased assignment of energy efficiency renovation specialists [5].

There is huge heterogeneity in individual's values, preferences, and risk, time which is reflected in their decisions on investments in climate change mitigation measures (RES microgeneration technologies, energy renovation and other energy efficiency improvements) therefore, such type of heterogeneity should be addressed by developing policies targeting specific actors in this sector and linked markets [59,74]. It is important to stress that RES micro generation technologies and energy renovation decisions are a risky decision and many behavioral barriers, including organizational ones, exists. The result of energy renovation of multi-flat buildings depends on apartment owners' possibilities to reach a common decision on renovation though sometimes they have conflicting preferences due to the different income, age, education, environmental awareness, etc.

Policies to promote climate change mitigation at households should aim to reduce the perceived risk of these measures. One of the best ways to mitigate perceived risk is to provide apartment owners with guaranteed future earnings due to energy and associated costs savings. Governments can support energy renovations and installation of RES micro generation technologies in residential buildings by sharing the costs and risk but also the benefits from future savings.

For example, the ESCO model can be applied for contracting on energy renovation in order to rise investments which are profitable but too risky to be undertaken by apartment owners unwilling to take risks. Similarly, policies can provide "early benefits" for apartment owners who decide to renovate in order to make less future oriented households more willing to renovate as social norms also have a big impact on apartment owner's decisions on energy renovation [75,76].

In addition, scholars confirmed that the reluctance in energy renovation investments should not only be understood as an individual energy efficiency or GHG mitigation gap but also as a replication of a household's risk, time, and environmental and social preferences [77].

The review of climate change mitigation barriers in households and assessment of policies and measures tackling these barriers performed in this paper confirmed that very important behavioral and psychological barriers of climate change mitigation actions in households are not addressed by climate change mitigation policies and measures targeting households [78–80]. Though during the last years, there is huge potential in application of the insights of behavioral economics in shaping climate change mitigation measures in households not so much has been done in this field and the energy efficiency and GHG emission reduction gap is not closed. Therefore, as it is clear from the findings of behavioral economics that households' decisions tend to deviate from the perfect rationality as stated in neoclassical economics, the public policies need to take this into account [81–83].

In a study by Shogren and Taylor [49] the term of 'behavioral failures' was used for all those situations in which the individual does not behave according to rational choice theory. There are many behavioral failures and also many typologies [33,34,84,85], therefore the main behavioral barriers overlapping also with other market failures and barriers of climate change mitigation measures in households given in Table 5.

Table 5. Climate change mitigation barriers and market failures in households.

Climate Change Mitigation Barriers	Market Failure	Behavioral and Psychological Barriers
Limited cognition and decision-making heuristics		X
Uncertainty and irreversibility	X	X
Ideologies		X
Social comparison and social norms		X
Information failures		X
Sunk costs		X
Discredence		X
Perceived risks		X
Limited behavior		X

Source: created by authors based on [33,34].

Explanation: Symbol X indicates the overlapping market failures and behavioral and psychological barriers.

As one can see from information provided in Table 5, uncertainty and information failures are overlapping with behavioral barriers by strengthening them. Gifford's [33,34] exhaustive account of proposed behavioral barriers organizes them into seven categories: limited cognition, ideologies, comparison with other people, sunk costs, discordance, perceived risks, and limited behavior.

Though in studies by [51,81,86–88] an empirical evidence of behavioral failures was provided in many fields, its extension to climate change mitigation field is very limited. Especially in dealing with renewables [89] and energy efficiency [90] barriers in households. Recent studies [91–95] on climate mitigation behaviors identified the other non-economic drivers of climate change mitigation behavior are much more important but not properly addressed in shaping policies. Awareness, personal, and social norms were found to be equally important as monetary factors [91]. The study by Hung and Bayrak [92] found that interdependency of husbands and wives' motivations for behavioral change to climate change mitigation also plays an important role in climate change mitigation behavior of the household. Perceived knowledge and financial self-efficacy as well as other behavioral factors were found as having significant influence on households' climate change mitigation behavior in Mexican households [93,94]. The study by Nauges and Wheeler [95] revealed that climate change concerns of households positively influence specific mitigation actions, but mitigation behavior may negatively affect households' climate change concerns as well.

Considerable analysis is still required to reconcile many issues, such as how these behavioral failures affect deployment of RES technologies and energy efficiency in households, how behavioral and other market failures and barriers relate, how these all failures may be corrected through policies and measures addressing learning or repetition issues.

In Table 6 the relationship between unsuccessful climate change mitigation measures to overcome market failures and behavioral and psychological barriers is generalized.

One can notice from information presented in Table 6 that behavioral and psychological barriers are overlapping and they are affecting all climate change mitigation policies, making them less successful in overcoming various market barriers. Therefore, by developing new climate change mitigation instruments, the behavioral and psychological barriers should be taken into account in order to enhance the success and effectiveness of climate change mitigation policies in households.

Conducted analysis and assessment suggests that a new approach is necessary for development of climate change mitigation policies. First of all, the main opportunity and challenge is incorporation of relevant non-economic issues in the decision making of households especially those linked to behavioral change. Behavioral barriers of behavioral changes were overlooked and not being adequately addressed

by current policies and measures targeting climate change mitigation at households. The main thread is linked to complexities in addressing the psychological barriers in climate change mitigation actions. The choice experiments and other studies on assessment of Willingness to Pay for climate change mitigation are necessary to evaluate households' preferences towards climate change mitigation policies. Another opportunity is based on idea that current climate change mitigation policies which are properly shaped can provide for changes in public preferences towards climate change mitigation policies and a positive impact on climate change mitigation behaviors.

Table 6. The relationship between unsuccessful climate change mitigation measures to overcome market failures and behavioral and psychological barriers.

Climate Change Mitigation Policies and Measures	Kay Market Barriers Addressed	Behavioral and Psychological Barriers
Regulatory instruments	Regulatory, institutional, informational and economic barriers	Limited cognition and decision-making heuristics; limited behavior; social comparison and social norms
Economic and market-based instruments	Economic and financial barriers	Decision-making heuristics; sunk costs, discordance, and perceived risks
Financial instruments	Economic and financial barriers, technological barriers	Decision-making heuristics; sunk costs, discordance, and perceived risks
Fiscal instruments	Economic and financial barriers	Decision-making heuristics; sunk costs, discordance, and perceived risks
Support, information and voluntary actions	Informational, organizational market; economic and financial barriers	Limited cognition and decision-making heuristics, limited behavior; ideologies, social comparison, and social norms discordance and perceived risk.

Source: created by authors.

5. Conclusions and Future Research Orientations

Due to important barriers related to climate change mitigation actions in households, the energy efficiency and GHG emission reduction paradoxes are obvious, indicating the divergence between optimal or desired and real obtained energy efficiency improvement and GHG emission reduction levels. As the household sector is associated with many dualities, the energy efficiency improvements and GHG reduction do not reach levels corresponding to the various 'win-win' resolutions provided in the market, or even do not reach the level of willingness to pay (WTP) by households.

These barriers and market failures preventing climate change mitigation actions in households are: economic and financial linked to the limited access to capital and high costs of mitigation measures, lack of knowledge; split initiatives and the difficulties of households in reaching a cooperative decision on building renovation due to difference in incomes, profession, and size of apartments, etc.

The review of climate change mitigation barriers in households and assessment of policies and measures tackling these barriers performed in this paper confirmed that very important behavioral and psychological barriers of climate change mitigation actions in households are not addressed by climate change mitigation policies and measures targeting households.

Successful implementation of policies and measures to promote climate change mitigation in households wanting to achieve the full potential of GHG emission reductions requires revision of climate change mitigation policies by addressing behavioural and psychological barriers linked to climate change mitigation actions.

Climate change mitigation actions in households are affected by household's perceptions of the usefulness or benefits of these items when compared to their status quo situation. The implementation of various, even simple, climate change actions are often perceived to be associated with discomfort and problems. Households are not interested to make changes in their daily routine, they prefer a status quo situation.

Additionally, there are other important behavioural constrains associated with time, attention, and ability to process full information about possible climate change mitigation action leading to households' decisions that are not rational. Additionally, then making decision on climate change mitigation households take the advice of their friends instead of consulting experts and take economically irrational decisions.

Most of the instruments in order to be successful should be implemented in combination of other instruments. Especially it is important for support, information, and voluntary actions. Regulatory and informative policies would also provide for more effective results if they are well structured and enforced in combination with other measures. The policy packages being introduced together became more popular in recent years however they do not provide evidence so far on their effectiveness in dealing with climate change mitigation paradox at households.

The main theoretical findings from conducted analysis is linked to identification of the main reasons of weak performance of climate change mitigation policies targeting the households sector. The overlooked behavioural and psychological barriers in shaping these policy instruments are the main reasons of their weak performance.

Conducted analysis and assessment suggests that additional research is necessary to addresses policies and measures design by incorporating relevant non-economic issues in the decision making of households, especially those linked to behavioral changes which are not being adequately addressed by current policies and measures targeting climate change mitigation at households.

Therefore, considerable analysis is necessary to reconcile many issues about behavioral failures and their influence on deployment of RES technologies and energy efficiency improvements in households. It is very important to define how behavioral and other market failures and barriers are related and how all these overlapping failures may be corrected through well shaped and innovative climate change mitigation policies and measures.

The conducted study has limitations and future research is necessary to grasp the correlation between market failures and barriers, specific climate change mitigation policies, and psychological barriers of climate change mitigation actions in households. The polices and measures can be also ranked by providing scores and introducing expert panels to assess the policies and measures based on important criteria including opportunities to overcome behavioral and psychological barriers.

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