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RENEWABLE ENERGY TECHNOLOGIES IN HOUSEHOLDS: CHALLENGES AND LOW CARBON ENERGY TRANSITION JUSTICE

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ABSTRACT. European Union (EU) has set the target of achieving carbon neutral society by 2050. The main way to ensure low carbon energy transition is to accelerate the penetration of renewables in households. However, there are many economic, social, technical, and behavioural barriers to this. In addition, the technologies for renewable energy generation are not affordable for low income households which are experiencing energy poverty and energy affordability problems. The paper critically analyses the barriers and state policies and measures for the support of renewable energy micro generation technologies in households. Based on the conducted analysis, the paper discusses the best ways to combat energy poverty and transition to low carbon energy in the EU. The main findings of the paper indicate that developing well-targeted policy measures for support of renewable energy technologies and energy renovation would be more beneficial than paying energy bills of low-income vulnerable population. Such policies would also help to solve the problem of just low carbon energy transition, as currently the vulnerable population are facing greater economic, social, behavioural, infrastructure and other barriers to using renewable energy in their homes.

JEL Classification: D63, Q01, Q20

Keywords: low carbon energy transition, renewable energy sources, barriers, households, energy poverty, energy justice.

Introduction

Renewable energy sources (RES) are expected to play a key role in households' energy consumption. Future energy consumption in households will be based on smart grids and energy management systems, however it is still a long way off due to various barriers to RES deployment in households. As policies and measures to promote renewables are mainly tackling economic or financial barriers of renewables penetration, social, behavioural, infrastructure and other barriers remain neglected by the governments.

Another issue is energy poverty (Bouzarovski et al, 2012) and energy justice in low carbon energy transition (Sovacool et al., 2014; Walker, Day, 2012). Low carbon energy transition and climate change mitigation policies have an impact on vulnerable households that is currently becoming more and more prominent, while energy justice considerations are related to good energy governance (Streimikiene et al., 2020ab). However, energy justice problems in low carbon energy transition remain under investigated.

According to behavioural economics, people show systematic and anticipated patterns of behaviour and decision-making that are not in line with rational choice theory presumptions. Therefore, policy-makers should analyse human behaviour in a more detailed way in order to develop well-targeted policies (Kahneman, 2003; Rieskamp, Hoffrage, 2008; Čábelková et al., 2022). It is important to stress that policy-makers can supplement conventional energy poverty mitigation policies with behavioural measures to improve vulnerable households' cognitive capacity (DellaValle, Sareen, 2020). These measures are also important for energy justice. It is possible to develop supportive choice systems for households exposed to higher risks linked to energy accessibility. These measures must help vulnerable people to make the right decision as they usually face more challenges in using renewable energy technologies (Luethi et al., 2009; Shafir, 2017).

There are many studies dealing with the barriers and drivers of RES penetration in households (Beck, Martinot, 2004; Allen et al., 2008; Luttenberger, 2015; Yeatts et al., 2017; Briguglio, Formosa, 2017; Palm, 2018; Jacksohn et al., 2019; Shimoda et al., 2020; Krepl et al., 2020; Bagaini et al., 2020; Pietrzak et al., 2021; however there are just few studies about barriers of renewable energy technologies for low income households (Hansla et al., 2008; Frondel et al., 2012; Pereira et al., 2019; Streimikiene et al., 2020ab). These studies showed that low income households face additional barriers of low carbon transition due to limited cognitive capacity and high burden of stress of living in poverty (Grey et al., 2017; Haushofer, Fehr, 2014). The studies analysing policies to promote renewables in households (Marques, Fuinhas, 2012; Claudia, Turek, 2014; Polzin et al., 2015; Wolske et al., 2018; Strielkowski et al., 2019; Lu et al., 2020; Tanil, Jurek, 2020; Matar, 2020; Rausser et al., 2022) didn't analyse low carbon energy transition policies from perspective of energy justice and coping with energy poverty problems during this transition. Few studies (Schleich, 2019; Hesselink, Chappin, 2019; Knobloch et al., 2019; Pererira et al., 2019) tried to address issues of energy poverty and energy justice in their studies of low carbon energy transition strategies however current increase in energy prices opens new opportunities for promoting energy efficiency and renewables and changing support schemes for low income households suffering from sharp energy price increase (Streimikiene, 2022; Streimikiene & Mikalauskiene, 2022).

The Russian invasion in Ukraine caused sharp increase in energy prices all over the world. Especially European Union member states are experiencing a lot of problems due to high energy import dependency due to Russian recent policies. Many EU Member have provided support for households due to increase of energy prices. Households having lower income continuously spend a higher share of their total consumption expenses on energy goods and are therefore more strongly affected by increases in energy goods prices.

Lithuanian situation in energy sector is similar to other EU member states. If no decisions are taken, electricity for household consumers could become more expensive by up to 50%, gas for cooking - by 100%, and gas for home heating - by up to 200%. in 2022 in January compared to 2021 in December, the number of persons who applied for compensation for housing heating costs increased by about 5 times (increased from 32 thousand to 150 thousand requests). Almost 100 percent the requests of all residents who apply for housing heating compensation are satisfied. In total, during the first three months of this year, approximately a quarter of a million residents of the country applied for compensation to cover home heating costs. Due to the increase in costs, in 2022 Lithuanian municipalities have been allocated an additional 16 million EUR from the state budget to provide home heating compensations for households.

Therefore, as energy prices increase, the number of people experiencing energy poverty in EU would increase. In Lithuania in 2022 the number of residents applying for housing heating cost compensation has increased 5 times compared to year 2021. As a result of increased costs for housing heating compensations, the state budget costs to cover these compensations will increase further. In the future, electricity prices for household consumers are expected to double and further growth of energy prices is expected. Slow rates of renovation of residential buildings and the usage of renewable energy technologies in households, especially in households experiencing energy poverty are the key challenges for policy makers in Lithuania and other EU member states. Unrealized energy efficiency improvement and Greenhouse gas (GHG) emission reduction potential in households need to be taken into account by policy makers.

The paper aims to analyse barriers, drivers and policies of low carbon energy transition from perspective of low income households experiencing energy poverty and provides policy recommendations taking into account energy justice and energy poverty alleviation solutions in promoting renewable energy sources in household's.

The paper is structured in the following way: the literature review on renewable energy usage and energy justice is discussed; the barriers of renewable energy penetration in households systematized and the policies and measures to promote renewable energy in households are analyzed; the policy recommendations for addressing energy justice in low carbon energy transition were developed based on research conducted.

1. Literature review

The main climate change mitigation measures in households are the use of RES micro generation technologies at home. The pathway to carbon neutral society requires the cutting of energy consumption by increasing energy efficiency and creating flexibility of energy demand to deal with fluctuations relevant to electricity production from renewables. With fast penetration of renewables in households traditional energy consumers also become producers. In European Union, the growth of renewable sources and prosumption corresponds to EU climate change mitigation policies and targets set for renewable energy sources (European Commission, 2020).

The literature studying low carbon energy transition and energy poverty issues in households can be divided into two main area: economic, environmental, and social drivers and barriers of renewable energy deployment and policies and measures to promote renewable energy sources. The scholars described financial and other policies to promote renewables and strived to evaluate their effectiveness (Marques, Fuinhas, 2012; Mengova et al, 2020; Istudor et al., 2021; Ying et al., 2022). Studies showed that transition to use of renewables for electricity generation was mostly effected by political pressure for use of carbon free energy sources due to climate change mitigation reasons (Streimikiene et al., 2020a). Policies to promote RES have been analysed in many studies but results of these policies were often evaluated as not effective (Jung et al., 2016; Schleich, 2019;. Matar, 2020).

The distributional effects of low carbon energy transition discussed in literature were evaluated just in few studies. These studies showed that low income households have financed the significant part of the cost of renewable energy deployment, through their energy bills (Frondel et al., 2015; Pererira et al., 2019). As renewable energy surcharges in electricity bills are proportional consumed electricity so, higher and lower income households are urged to pay the same surcharge for renewable energy. This redistribution of costs through RES surcharges, showed that burden of renewable energy deployment is higher for low income households than for high income households as they spend higher shares of their income to cover their energy costs (Frondel et al., 2015).

Scholars were arguing that new policies and measures for low carbon energy transition are necessary witch do threaten poorer households with energy poverty (Wee et al., 2012). The studies showed that the shift from fossil to renewable energy in power generation has impact on the double increase of electricity prices. This increase is due to increase of the cost of power generation and RES surcharges due to Feed-in tariffs for renewables. The negative effect for low income population of solar PV deployment through Feed in Tariffs was found in Germany, Australia etc. (Frondel et al., 2015).

Some scholars highlighted that it is necessary to analyse the impact of RES deployment by different source of RES and on all household types (Schleich, 2019; Dolan, 2013). Therefore, scholars expect that the low carbon energy transition in power sector, and the transition towards renewable electricity in households will have huge consequences on all groups of households. It is necessary to find the answer will low carbon energy transit transition benefit the overall society, or will benefit just high income households while harming low income households. So, it is crucial for scholars to find policies and measures that do not provide for prohibition of certain social groups from the new clean energy sources (Schleich, 2019; Streimikiene 2020ab). It is necessary to stress that some resources, like energy or IT infrastructure (Henrik et al., 2012; Lund, 2011) are unevenly distributed in the territory and distributional justice requires for fair treatment of all people (Jenkins et al., 2016). Non recognition of the need of specific social groups in terms of energy affordability is preserved as recognition injustice. This lack of recognition energy justice is obvious if decision makers didn’t take into account the particular needs of various groups of society in shaping and implementing low carbon energy transition policies. Another important problem of energy injustice pointed by scholars is unequal representation of societal groups in a various decision making institutions like national and local administrative bodies etc. It is obvious that some social groups are underrepresented in decision making bodies relevant to energy sector as well. Therefore, according energy procedural justice this type of energy inequality and injustice need to be taken into account and policies and measures proposed to reduce recognition energy inequalities (Bickerstaff, 2009). Therefore, three major types of energy justice can be defined: distributional, recognition and procedural (Bickerstaff, 2009; Jenkins et al. 2014; 2016).Several studies analysed energy poverty from different perspectives and showed that social relationship are very important effect on people’s ability to cope with energy poverty and get benefits from low carbon energy transition and penetration of renewables in households (Walker, Day, 2012; Bouzarovski et al., 2012). Good social relations can provide better access to necessary energy services, and also can be a desirable result of such access as well.

2. Generalization of the main statements

Through the qualitative analysis, the main focus was on identification and systematization of renewable energy barriers in households especially in low income vulnerable households experiencing energy poverty risk.

The main economic, social-behavioral, technological and infrastructure barriers of renewable energy usage in households are: standardization problems, inter-household relations, household heterogeneity; economic problems linked to market entry, high capital costs, behavioral attitudes and misconceptions with the reliability of renewable, problems of site selection and transmission, unequal playing field and flexibility issues etc. (Beck, Martinot, 2004; Allen et al., 2008; Claudy et al., 2010; Balcombe et al., 2013; Hesselink, Chappin, 2019; Lu et al., 2020). The main technological barriers are linked to standardization problems, inter-household relationship and household heterogeneity.

The economic barriers of RES usage in households are mainly linked to the high upfront costs and problems of market entrance. Difficulties of market entrance is one of the significant barriers of renewable energy penetration in households as RES technologies have to compete with traditional energy resources like natural gas, coal etc. New renewable energy technologies should make investors sure that they can generate a necessary quantity of energy and can replace traditional fossil fuels in homes. Also many companies providing traditional energy sources to households have expertise, infrastructure, and policy support therefore for new technologies it is difficult to enter market. State support and policies to promote renewables like subsidies or loans help wind and solar technologies to enter the households energy supply market (Lu et al., 2020). The high initial capital costs for installation of wind and solar farms is another important economic barrier to RES technologies penetration in households. Though renewables are cheap to operate and their maintenance costs are very low, however initial costs for installation of these technologies are quite high and not affordable for low income population. As installation costs of wind and solar technologies are higher than for traditional fossil fuels, the investments in renewables are being treated as more risky compared to traditional energy generation sources (Matar, 2020). Therefore, the loans for investors in renewables are being provided with higher interests. State policies to support renewable via subsidies and soft loans allows to reduce these barriers for renewable energy technologies and in addition their capital cost are constantly decreasing due to learning and economies of scale (Polzin et al., 2015; Mengova, 2020; Rus et al., 2020).

The social barriers of RES in households are linked to inquire time costs for implementing innovations such like renewable energy technologies (Lu et al, 2020; Larsen, Gram-Hanssen, 2020). There are also behavioral barriers for renewable energy generation technologies in households linked misconceptions with the reliability of renewable energy sources (Wilson, Dowlatabadi, 2007; Alam et al., 2014). In addition, the renewable energy generators would need fossil fuels as a backup because their intermittency. New policies to promote smart appliances, real-time energy consumption measurements and pricing, advanced energy storage, and other modern smart grid technologies assist to overcome these barriers.

The siting and connection to the grid are important technological barrier for renewable energy technologies. Selecting an appropriate location for renewables can be challenging as it requires many permits, contracts, community relations, and negotiations. The high transaction costs provides for increased costs of renewable energy projects (Henrik et al., 2012; Reinhard et al., 2013). As renewable energy sources are newcomers, and most transmission lines were built to for fossil or nuclear power generators and it is necessary to upgrade transmission systems and expand infrastructure (Katrin et al., 2012). This requires additional costs to be added to investments in renewable energy projects. In addition, it is necessary to stress that there is unequal playing field for traditional energy industries and renewables. There are many environmentally harmful subsidies implemented in fossil fuels industries. In addition, RES are usually getting less subsidies and fewer political support as new comers. Though, renewable energy industries provide clean energy they are competing with other industries that are directly subsidized and in addition external costs of pollution are not fully internalized for fossil fuel generators. Therefore, this is also can be treated as indirect subsidy to fossil fuel generators.

There are another barriers of renewable energy adoption indicated by scholars like the lack of information and communication technology (ICT) infrastructure which is necessary for wide range application of renewables in households. The lack of appropriate sensing, computing and communication/actuation equipment for necessary demand response and energy management also provide barriers for renewable energy technologies (Larsen, Gram-Hanssen, 2020).

There are also barriers linked to the lack of understanding of demand response and it's complexity as well as the lack of appropriate market structures for enabling effective demand response measures in households (Reinhard et al., 2013). Again, low-income households usually have lower education level and have higher cognitive burden for understanding and dealing with the newest IT technologies necessary for demand side management in residential buildings. The shortage of proper market structures is also a barrier for RES penetration in households. There are also other behavioral and informational consumer-related barriers.

Smart grids can enable home heating and electric cars to flexibly interact through decentralization of electricity generation in residential buildings. For example, the SINTEG pilot project in Germany is a good practice case for ensuring flexibility of renewable energy usage in household SINTEG (2022). SINTEG project has enabled more than 100 demonstration projects and 5 demonstration regions in more than 4 years. The project sought to assess how household flexibility can be integrated and used in the electricity system. One important lesson learned is that the goal should not be to control individual devices (such as individual heat pumps) but to integrate them as a whole flexibility resource for residential buildings. This would include district heating, heat pumps, solar panels, electric vehicle charging, batteries, energy management systems and more. smart hardware and software.

Electrification of heating and cars will increase the demand for electricity and increase peak loads on the network. The conventional way to ensure flexibility in electricity supply is to use fossil fuel power plants operating at higher voltage levels, but with the smart control and flexibility that can be provided by households using energy in buildings and electric cars, these challenges can be turned into opportunities for the transition to low carbon energy.

Smart grids and controls are inevitable to guarantee that new distributed energy sources would provide input for the stable power grid operation. By joining renewable energy production in buildings (e.g., rooftop solar PV) with a smart charging electric car and a smartly controlled heat pump (Heat pumps are the greenest way to provide heat to a home), households can use a greater share of locally produced renewable energy. It also makes it possible to better match consumption and timing of renewable energy sources to the grid based on the state of the grid, making the best decisions about when to charge an electric car or run a heat pump (Briguglio, Formosa, 2017).

There are several challenges arising from the energy flexibility of households and buildings. Flexibility is the resource's ability to respond to price or activation signals and adjust electricity demand or production, which is extremely important for systems with a large share of renewable resources at all voltage levels. Industrial processes, commercial facilities and complex technologies such as heating and ventilation can provide valuable system flexibility by reducing the share of dispatchable generation when replacing energy with renewable energy sources. Meanwhile, in buildings, the main sources of demand flexibility are electric cars and electric heating/ventilation systems; on the supply side, the main source of flexibility is solar PV on building roofs (Hesselink, Chappin, 2019).

Therefore, household flexibility can be used to address non-local network congestion issues or offered, for example, in balancing markets. New mechanisms for households to use flexibility are being debated across Europe. Local flexibility markets, such as time-varying tariffs in the UK, Germany and the Netherlands, are gaining more and more attention. However, harnessing the flexibility potential of households faces many challenges: slow digitization and infrastructure-related barriers (Palm, 2018).

It is necessary to stress, that using the flexibility offered by electric cars or domestic heat pumps in households also requires overcoming technological, economic and social barriers. First, players at various levels - network operators, manufacturers, suppliers of energy management systems, etc. - must cooperate and require standard access to smart hardware and software. Furthermore, household flexibility options are inherently heterogeneous, and the individual flexibility potential that each device can offer is limited. Thus, the time and investment costs of creating a digital infrastructure must be low in order to implement new business models based on flexibility (SINTEG, 2022). In addition, an important aspect is the consent and willingness of the population to participate. They must agree to have their electric car or heat pump controlled externally under certain circumstances. Naturally, external actors interfering with household heat supply or mobility are not very desirable.

Several important success factors related to the use of household flexibility emerged in the Smart Energy Showcase - Digital Agenda for the Energy Transition (SINTEG) project (SINTEG, 2022). In order to reduce complexity and increase the overall potential of flexibility, users of flexibility – usually network operators – should not seek to control individual devices, such as individual heat pumps, but to manage all flexibility resources in a given building. The installation of an energy management system (EMS) is a prerequisite for realizing the potential of the devices installed in the building, from batteries for energy storage to photovoltaic power plants on roofs and smart electric car charging systems. EMS controls the devices locally and can adapt to the user's preferences, for example, the electric car needs to be charged to a certain percentage by a certain time. External load signals to activate flex are then sent to the EVS, which executes them. The ability of EMS to take into account the individual needs of the population increase the willingness of users to offer flexibility. Connecting multiple devices using EVS provides more stability and flexibility. The idea of treating buildings as sources of flexibility by combining the potential of all devices behind the meter has already been used by the Munich utility team in the SINTEG project with the Digitaler Netzanschluss (DiNA).

In addition to aggregation methods such as DiNA, combining flexibility with other buildings makes it easier to overcome economic barriers. EMS is needed not only to offer flexibility, but also to monitor energy flows and capture energy efficiency potential in a building. Investments in EVS and other digital infrastructure can be amortized faster. In other cases of combined use, the comfort of residents' lives could be increased by enabling intelligent control of the heating system (SINTEG, 2022).

Another effective way to increase the cost-effectiveness of flexibility is to look not at individual buildings, but at residential areas. Buildings can only be equipped with smart controls and sensors by one player, such as the building owner or project developer. Therefore, such a solution is more economical and at the same time easier to implement from a technological point of view than at the individual household level. In addition, infrastructure such as district heating networks can be used flexibly without any interaction with residents. In this way, the building loads are added up according to the neighborhood principle.

3. Discussion of policies and measures to promote renewables in households

The measures applied so far to increase energy efficiency and promote the use of renewable energy resources in households have yielded limited results, especially in the segment of vulnerable households. Also, there is a lack of research on the behavior of people experiencing energy poverty and their views on why households do not take initiatives to help them get out of energy poverty, especially related to energy efficiency improvements such as home renovation or the installation of renewable energy sources.

There is an overall agreement among researchers that low-income households do not have the incentives to make the necessary investments to improve energy efficiency, as they often live in rented, social housing, receive housing heating compensation, etc. (Streimikiene 2020ab; Grey et al., 2017; Haushofer, Fehr, E. 2014). In addition, research has shown that households decisions are less rational when individuals experience high cognitive load or perform tasks that require a lot of mental effort. Living in chronic poverty is a critical barrier affecting the cognitive abilities of energy-poor households (Shafir, 2017). Scientists have provided evidence that when individuals face problems meeting their needs due to lack of income, they have even less cognitive capacity to make rational decisions (Kahneman, 2003; Rieskamp, Hoffrage, 2008; Luethi et al, 2009). Therefore, the cognitive abilities of those vulnerable to poverty are limited. Other situational factors, such as long-term stress, unsafe neighborhoods, fragile social relationships, etc., also influence this (DellaValle, 2019).

In addition, people tend to take more risks to evade losses rather than receive gain (Kahneman, 2003). Energy insecure households, feeling constant stress due to their difficult financial situation, take more risks to avoid possible losses rather than saving by investing. If the choice RES technologies is presented as an opportunity to avoid losses rather than gain, individuals will be much more likely to make decisions to implement these technologies. In a situation of energy shortage, the fear of loss increases. Vulnerable individuals may refuse to switch to new energy suppliers or carry out home renovations for fear of high bills in the future. In addition, according to behavioral economists, individuals focus more on short-term goals, meaning that a small immediate payoff is preferred over a larger potential benefit in the future. This situation affects irrational financial decisions, like not investing in energy efficiency improvements and the use of renewable energy resources, which will allow for lower energy bills in the future. It should also be taken into account the limited opportunities to make joint decisions regarding the renovation of an apartment building, as households have different priorities and find it difficult to agree (Lu et al., 2020).

New policies and measures for removing behavioral barriers and ensuring just low carbon energy transition in households are necessary. Such measures involve education and assistance to help households make the right decisions, save energy and use renewable energy resources and thus reduce energy poverty. Low-income households have no incentive to invest in energy efficiency, as they often live in rented, social housing, receive home heating allowances, etc. Scientists have provided evidence that living in chronic deprivation is a significant barrier to rational decision-making. Therefore, due to persistent poverty and factors such as long-term stress, unsafe neighborhood, fragile social relations, etc. residents experiencing energy poverty are unable to make rational decisions on how to get out of energy poverty (Stremikiene et al., 2020a).

Support for residents experiencing energy poverty should be focused on energy renovation of housing and the use of renewable energy resources in households, and not on support for heating compensations or reduced value added tax (VAT) for centralized heating, which do not encourage energy saving and increase climate change and are short-term. Therefore, the priority should be given to measures that address the long-term structural problems of energy poverty, like energy renovation of residential buildings, increasing energy efficiency and the wider use of RES technologies in households experiencing energy poverty, which together are the main means of mitigating climate change in households (Streimikiene, 2020b).

It is necessary to help vulnerable households to make long-term rational decisions that will allow them to reduce energy poverty. Nudges are effective, an example of which is the automatic registration of residents in programs for home renovation or installation of renewable energy resources, when a written refusal to opt out of this program is required (DellaValle, Sareen, 2020). In this way, households will be enrolled in home renovation programs or will sign a more beneficial utility or electricity contract and implement energy saving measures as pre-determined options for them. This allows vulnerable households to overcome barriers related to information search and reduce the cognitive burden of decision-making, as decision-makers themselves "nudge" them and offer the "correct" default solution. These schemes are sometimes criticized as being paternalistic and reducing people's free choice or allowing them to be manipulated. Therefore, it is necessary to provide households with clear information about the possibility of easily opting out of such programs (DellaValle, 2019).

In the future, renewable energy sources will play an increasingly important role in households due to the development of smart metering systems and smart grids, as demonstrated by demonstration projects in other countries. The use of energy management system (EVS) is a prerequisite for realizing the potential of all building equipment, from energy storage to rooftop solar collectors, heat pumps and smart electric car charging systems. EVS manages devices locally and can adapt to specific user preferences. The costs of creating a digital infrastructure should be reduced by involving entire residential areas. Such a solution is more economical and at the same time easier to implement from a technological point of view than in the case of an individual household.

Another important aspect is the consent and willingness of the population to participate in renewable housing projects (Hansla et al., 2008). Households must agree to have their electric car or heat pump controlled externally under certain circumstances. Naturally, external actors interfering with household heat supply or mobility are not very desirable. It is very important to communicate to the population that ensuring flexibility is at least not associated with additional costs and ideally brings net income to the population. Apart from the monetary arguments for participation as studies showed, consumers want to play an active role in mitigating climate change and transitioning to low-carbon energy (Briguglio, Formosa, 2017).

In residential buildings, the main sources of demand flexibility are electric cars and electric heating/ventilation systems; and on the supply side, the main source of flexibility is solar panels on building roofs. However, there are challenges in harnessing the flexibility potential of households, such as slow digitization and barriers related to infrastructure development. The policies to overcome these barriers are necessary.

Conclusion and policy implications

Decision makers in pursuing low carbon energy transition in households should take into account the benefits and disadvantages of policies for all society groups, especially protecting the vulnerable individuals throughout a fair redistributing of low carbon energy transition benefits between the high- and low-income households.

Support for residents experiencing energy poverty should be focused on energy renovation of housing and the use of renewable energy resources in households, rather than support for heating compensations that do not encourage energy saving and GHG emission reduction.

Due to behavioral barriers, the measures used to date have produced limited results for RES penetration in households. Policies and measures should be developed for removing behavioral barriers, such as education and assistance to help households make the right decisions, save energy and use renewable energy resources and thus reduce risk of energy poverty.

It is essential to unlock the mental potential of vulnerable households and enable them to make long-term rational decisions that will allow them a better future and reduce energy poverty. An example of nudge measures is the automatic registration of residents in energy renovation or renewable energy resource installation programs, when a written refusal to opt out of this program is required. In this way, households will be connected to an energy renovation program or whether more beneficial utility contracts will implement energy saving measures as pre-defined options for them. This allows vulnerable households to overcome barriers to information seeking to change the status quo. It also reduces the cognitive burden of decision-making, as decision-makers themselves suggest the "correct" default decision. Sometimes these schemes have been criticized as paternalistic, reducing people's free choice or allowing them to be manipulated. Therefore, it is necessary to provide households with clear information about the possibility of easily opting out of participation.

It is clear that increasing the efficiency of energy consumption in households makes it possible to solve energy poverty problems. Although there are many energy subsidies available to help vulnerable households cope with energy poverty, these measures provide short-term results in the fight against energy poverty. Thus, in the fight against energy poverty, long-term policies should focus on increasing energy efficiency and the use of renewable energy sources in low income households in this way also ensuring just low carbon energy transition.

The low carbon energy transition to the use of RES technologies in households will have positive impact on reducing energy bills of low-income residents if proper policies will be set. Therefore, it is necessary to implement targeted income support of low-income households through the social welfare system and subsidize renovation and renewable energy technologies in low income households instead of providing housing heating cost compensations, which do not solve the problem of energy poverty fundamentally. Hence, current energy poverty alleviation policies which are not socially optimal need urgent revision.

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