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Influence of the adoption of new mobility tools on investments in home renewable energy equipment: Results of a stated choice experiment

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ABSTRACT

The increasing shift of individuals to use new electric mobility tools like electric cars (EV) and electric bikes has changed household energy expenditure. It may also affect households' investments in renewable energy equipment, i.e. solar panels, heat pumps. Relatively little research has been conducted on how the decision to purchase electric vehicles affects the decision to invest in home renewable energy equipment. This paper, therefore, aims to examine the effects of mobility tools decisions on the intention to invest in solar panels and heat pumps, based on the data collected through a stated choice experiment. A mixed logit model is estimated to capture unobserved heterogeneity among individuals. Results show that mobility tools significantly influence the choice of home renewable energy equipment. Households who prefer to purchase electric vehicles have a higher probability to invest in solar panels and heat pumps than households who prefer other mobility tools. In addition, EV adopters' intention to invest in solar panels are stronger than the intention to invest in heat pumps. This suggests that electric vehicle users are likely the early adopters of solar panels.

1. Introduction

The growth in market penetration of electric mobility (incl. electric car and electric bike) is expected to continue for the foreseeable future. Electric cars (EV) have been predicted to account for 35% of new vehicle sales and 41 million EVs will be sold across the world annually by 2040 (MacDonald, 2016). The European Union has set a target of halving the use of 'conventionally fueled' vehicles in urban transport by 2030 and phase them out altogether in cities by 2050 (Harrison & Thiel, 2017). In addition to EV, the market share of electric bike is expected to increase across Europe. The market data have shown continuous growth in the sales of electric bikes, while sales of conventional bikes have remained steady (Fishman & Cherry, 2016; Jones, Harms, & Heinen, 2016; Weiss, Dekker, Moro, Scholz, & Patel, 2015). The large-scale adoption of EV and electric bike will lead to a dramatic growth in the electricity demand. A 20% EV market penetration would lead to a 35.8% increase in peak hour electricity demand (Qian, Zhou, Allan, & Yuan, 2011). For households owning EVs, their traditional transport expenditure on gasoline is transformed into electricity bills.

The shifting electricity demand increased in many countries of the world due to policies related to the climate change discussion. To deal with the challenges of increasing electricity demand and expenditure,

home renewable energy equipment are considered feasible solutions (Alsema & Nieuwlaar, 2000; Chua, Chou, & Yang, 2010; Kumar Sahu, 2015; Parida, Iniyar, & Goic, 2011; Tyagi, Rahim, Rahim, & Selvaraj, 2013; Willem, Lin, & Lekov, 2017).

In this study, solar panels and heat pumps were chosen to represent home renewable energy equipment. Solar panels convert solar energy to electricity with zero greenhouse gas emission (Awerbuch, 2000). Moreover, with the development of smart home energy management systems, EV and solar panels are connected efficiently and provide potential synergies (Hoarau & Perez, 2018). The combination of EV and solar panels could improve the utilization of the two technologies, aiming at zero net emissions of houses. Since a battery is included in EV without any additional cost, solar panels could also use the EV's battery as energy storage. With the application of smart charging and vehicle-to-home technologies, EV could benefit from cheap carbon-free electricity that is generated by solar panels. In return, the solar panels could use the capacity of EV batteries to store electricity and serve home energy consumption. Considering the possible time-of-use (TOU) electricity tariffs in the future, the combination of EV and solar panels generates extra profit by smart charging scheduling.

Similarly, heat pumps can improve energy efficiency of households by using ambient heat at useful temperature levels (Sarbu &

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Sebarchievici, 2014). The energy saved by heat pumps could offset the home energy expenditure. Integrated EV and heat pumps have been verified to result in 11% annual cost savings (Doroudchi, Alanne, Okur, Kyyr, & Lehtonen, 2018). Thus, EV users can acquire an efficient and flexible home energy system if they invest in equipment which can improve home energy efficiency in a smart house environment.

The efficiency and flexibility of the combination equipment is expected to encourage EV users to invest in home renewable energy equipment. However, EVs, solar panels, and heat pumps are relatively expensive. It is unclear to what extent EV users value the benefits of home renewable energy equipment. Whether households, who have paid for an EV, can afford and/or are willing to invest in solar panels and heat pumps needs to be investigated. If the answer is no, then achieving the policy aims underlying the transition to new forms of energy and transport may be problematic.

Knowledge regarding the influence of mobility tools decisions on household intentions to invest in solar panels and heat pumps is limited. Several studies have examined the intentions to invest in home renewable energy equipment. However, most studies focused on the influence of facility attributes and policy incentives on the acceptance of home renewable energy equipment (Rai & Beck, 2015; Rai & Sigrin, 2013; Scarpa & Willis, 2010). To the best of our knowledge, none has addressed the influence of new mobility tool decisions on the decision to invest in home renewable energy equipment. Yet, the relevance of this question is obvious. Individuals' electricity demand from the use of e-mobility may trigger the needs for households to buy and invest in home renewable energy equipment.

Therefore, the main objective of this study is to investigate households' intentions to invest in home renewable energy equipment conditional on the choice of mobility tools. The energy equipment attributes, policy incentives (e.g. tax refund), and the influence of the choice of mobility tools are considered. To analyze the influence of mobility tools comprehensively, the mobility tools including EV, electric bike (e-bike), car sharing, and conventional vehicle are considered. The e-bike is considered because it is the most common electric mobility tool besides EV. Car sharing is incorporated as it is expected to be a feasible alternative in the near future. Customers pay for the use of a car rather than for car possession. Therefore, their intentions to invest in the home energy equipment might be different from people who own a private EV. The convention vehicle is considered as a comparison of the mobility tools.

Thus, we investigate household' intentions to invest in solar panels and heat pumps considering their choice of mobility tools. To this end, we conducted a survey that included a stated choice experiment. In this experiment, respondents were first shown different options of EV, e-bike, conventional vehicle and car sharing, varied in terms of their attributes. They were asked to choose one of these options or none of them. Next, attributes of solar panels and heat pumps were varied and respondents were asked whether they would invest in one of these options, conditional on their choice of mobility tools. Using a mixed logit discrete choice model, this paper assesses the effects of purchase price, payback period, tax refund, compensation for energy usage and mobility tools on the intention to invest in solar panels and heat pumps, capturing unobserved heterogeneity among households.

The remainder of this paper is organized as follows. Section 2 describes the existing literature on household intentions to adopt home renewable energy equipment. Section 3 describes the experimental design and data collection process. In Section 4, a mixed logit model to investigate the factors influencing the choice of home renewable energy equipment is proposed. The estimated results are discussed in Section 5. The paper is completed with conclusions and a discussion of future research directions.

2. Literature review

This section discusses the existing literature concerned with the

main concepts of this study. First, studies related to the purchase of electric mobility and home renewable energy equipment are reviewed. Previous studies related to the efficiency and advantage of the combination of electric mobility and home renewable energy equipment in a smart home energy management environment are also discussed. The second part of the literature review focuses on the factors influencing the household decision on mobility tools and home renewable energy equipment.

2.1. The integration of EV and home renewable energy equipment in smart grid

Many literatures related to EV focused on their impact on electricity supply. These studies proposed different approaches to estimate electricity demand considering the adoption of EV. The expansion of EV increases electricity demand and burden on the power grid (Putrus, Suwanapongkarl, Johnston, Bentley, & Narayana, 2009). The additional demand for recharging EV batteries is mainly supplied at residential locations when vehicles are parked and recharged overnight. Muratori (2018) indicated that 10% market share of EV will lead to the electricity demand increase approximately 5%. In addition, charging for EV could significantly change the temporal distribution of aggregate residential electricity demand, even at low adoption levels of EV.

To mitigate the impact of EV charging, the smart grid and vehicle to home technology (V2H) have been introduced as one of the solutions. Optimization of charging scheduling and the integration of EV into home power network can reduce the peak load of the grid. They have clear advantages in flattening the grid load over time. (Jain, Das, & Jain, 2019; Mets, Verschueren, Haerick, Develder, & De Turck, 2010; Tan, Ramachandaramurthy, & Yong, 2016). Besides, the integration of renewable energy source equipment into a house energy system is considered a solution to satisfy the electricity demand. A growing literature has studied the integration of EV and renewable energy resource equipment in smart grids. Saber and Venayagamoorthy (2011) presented the effects of EV in a smart grid with renewable energy source equipment. The findings from this study indicate that EV charging becomes less costly in a smart grid with EV and renewable energy equipment. Coffman, Bernstein, and Wee (2017b) found a relationship between the adoption of solar panels and EV based on a case study in Hawaii. In a pilot EV time-of-use rates project in Hawaii, 73% of participants also installed solar panels. EVs with residential solar panels use for EV charging makes the EV about \$1200 less expensive on a lifecycle basis than a traditional vehicle. Ritte, Mischinger, Strunz, and Eckstein (2012) studied EV home-charging in houses equipped with solar panels. Households owning an EV and solar panels system can reduce energy cost thanks to the synergies between EV and solar panels. Bedir, Ozpineci, and Christian (2010) assessed the effect of the combination of EV and solar panels. The study found that using a smart energy management system, which controls the EV, solar panels, energy storage and residential load, leads to a 40% reduction in electric bills. In addition, EV can enhance the reliability and stability of the micro-grid with renewable energy sources (Singh, Jagota, & Singh, 2018). This literature suggests that the combination of EV and home energy resource equipment has obvious technical and financial advantages. However, the literature lacks studies of how these potential advantages influence household's decisions on electric mobility and renewable energy equipment.

2.2. Choice of mobility tools

Several studies examining consumers' adoption of EV have appeared in the literature over the last decade. The factors influencing consumer intentions to adopt EV can be mainly categorized into socio-demographics, EV attributes, policies, and psychological factors. Table 1 presents an overview of the factors influencing consumers' preferences on EV. Hackbarth and Madlener (2013) analyzed the potential

Table 1
Overview of factors influencing consumer preference on EV.

	Attributes	References
Socio-demographics	Age; Education; Income; Living environment	Hackbarth and Madlener (2013); Plotz et al. (2014); Bjerkan et al. (2016)
EV attributes	Purchasing cost; Operation cost; Maintenance cost; Driving range; Charging infrastructure	Coffman et al. (2017a); Liao et al. (2017); Rasouli and Timmermans (2016); Bjerkan et al. (2016); Langbroek et al. (2016); Lévy et al. (2017)
Policies	Tax incentives; Exemption from purchase restrictions and driving restrictions	Wang et al. (2017)
Psychological factors	Environment attitudes	Plotz et al. (2014); Rasouli and Timmermans (2016); Beck et al. (2017)

consumers of alternative fuel vehicles using stated preference discrete choice data. The study found that the groups who are most likely to adopt alternative fuel vehicles are the younger, well-educated, and environmentally aware vehicle buyers, and those who have the possibility to plug-in their vehicle at home, and undertake numerous urban trips. Plotz, Schneider, Globisch, and Du'tschke (2014) recruited early EV adopters and analyzed their socio-demographics. The results showed that middle-aged men with technical professions living in rural or suburban multi-person households are dominant among the EV buyers in Germany. Bjerkan, Nørbech, and Nordtømme (2016) investigated what groups of buyers respond to different types of incentives in Norway. The results showed that male respondents above 45 years of age are more likely to purchase an EV when there is a fixed cost incentive.

As for the EV attributes, purchasing cost, operation costs, maintenance costs, driving range, and charging infrastructure are the most considered factors in related studies (Coffman, Bernstein, & Wee, 2017a; Liao, Molin, & van Wee, 2017). Moreover, the effect of psychological factors such as environment attitudes plays a role in the EVs purchasing decision (e.g., Plotz et al., 2014; Rasouli & Timmermans, 2016).

The influence of policy incentives on the adoption of EV have been discussed in several studies (e.g. Bjerkan et al., 2016; Langbroek, Franklin, & Susilo, 2016; Lévy, Drossinos, & Thiel, 2017; Wang, Tang, & Pan, 2019). They conclude that tax incentives have a significant positive influence on the adoption of EVs. Besides of tax incentives, Wang, Tang, and Pan (2017) concluded that exemption from purchase restrictions and driving restrictions of EV have the most significant positive effects on the adoption of EV in China.

Regarding car sharing, the factors influencing the choice of car sharing include socio-demographics, latent attitudes, trip attributes and car sharing attributes. Kim, Rasouli, and Timmermans (2017) estimated the effects of cost, travel time uncertainty and latent attitudes using a hybrid choice model. The results showed that travel time uncertainty and latent attitudes have significant effects on the choice of car sharing. Yoon, Cherry, and Jones (2017) examined the factors that influence the use of car sharing systems in Beijing. The results of a logistic regression model show the savings of using car sharing instead of a traditional mode has a significant positive impact on choosing car sharing.

As for the e-bike, Cherry, Yang, Jones, and He (2016) developed a mode choice model and estimated the choice of e-bike. They found that increasing age, and male had a significant positive influence on e-bike use. Johnson and Rose (2013) concluded in the Australian context that the environmental benefits of the electric bike were considered as a motivation for purchasing an e-bike.

2.3. Intentions to invest in home renewable energy equipment

Several studies (e.g. Claudy, Michelsen, Driscoll, & Mullen, 2010; Vasseur & Kemp, 2015; Zoellner, Schweizer-Ries, & Wemheuer, 2008)

have examined the factors influencing household intentions to invest in home renewable energy equipment. These studies have identified the influential factors which mainly included energy equipment-related variables and consumer-related variables. An overview of the variables can be found in Table 3.

Energy equipment-related variables include the financial factors and technical factors, such as purchase price, installation and maintenance cost. Scarpa and Willis (2010) adopted a choice experiment approach to investigate the determinants of the adoption of solar panels and heat pumps by households in the UK. The logit model was used to estimate the coefficient of attributes of the home renewable energy equipment. The result showed that with the increase of the purchasing and maintenance cost, the probability of a respondent to invest in a home energy facility decreases. Rouvinen and Matero (2013) examined how attributes of residential heating systems affect private homeowners' choice of heating energy equipment, considering the heterogeneity among individuals. The results suggested that cost had the highest negative impact. The results also indicated significant unobserved preference heterogeneity among households.

In addition, several studies found that technical performance is critically important for households' intentions to invest in this equipment. Islam (2014) conducted a stated choice experiment investigating the factors influencing solar panels adoption. The results showed there is a positive impact of the reward of energy saving on households' preferences for home renewable energy equipment. Using multiple regression analysis, Alam et al. (2014) identified the relationship between the ease of use of household renewable energy equipment and usage intention. They found that adaptation intentions are higher if they could understand, operate and maintain the equipment easily.

To better understand consumers' intentions on investment, researchers have identified consumer related-variables potentially affecting the probability that a household invests in energy equipment. Socio-demographics are the most common variables included in the studies. Yuan, Zuo, and Ma (2011) conducted a survey about respondents' awareness of solar water heater and solar panels and attitudes towards the installation of these technologies at home. The results showed that income, age and education of residents influence the level of awareness of solar energy technologies and the decision to implement these technologies at home.

In addition to the socio-demographics, psychological factors such as environment attitudes, lifestyle, and social influence are also expected to influence home renewable energy equipment adoption. Sovacool (2009a; 2009b) conducted interviews at institutions including electric utilities, regulatory agencies, interest groups, energy systems manufacturers and examine the influence of technological, social, political, regulatory, and cultural factors. Results indicated that psychological factors of American people encourage wasteful electricity consumption and impede alternative energy systems. Scarpa and Willis (2010) found that a recommendation by a friend or an energy engineer for a system, increased the probability of a respondent to invest in a home energy

facility. Jayaraman,

2.4. The relationship between choice of mobility tool and home renewable energy equipment

Only a few studies have addressed the household investment decisions considering the trade-off between energy efficient equipment and transportation mode choice. Jäggi and Axhausen (2012) conducted a stated preference study to investigate household preference of four alternatives: insulating the house, installing heat pumps, buying a more efficient car, and switching to public transport. Respondents were asked to imagine a hypothetical market situation and select one alternative among a set of investments with different cost-benefit ratios. They included energy price, socioeconomic variables, living condition variables and composition of the private transport fleet into a Multinomial Logit Model. They found that prices have significant influence on the decisions. Yang, Timmermans, and Borgers (2016) published another study which incorporated context effects and allowed choosing any combination of the provided adaptation options (buying a more energy efficient car, using slow modes more often and using more efficient appliances and equipment at home). They used a mixture-amount experiment design to capture households' energy saving strategies under increased prices. The results showed that people are inclined to compensate for increased energy expenditures, although the choices are context dependent. Moreover, the result showed a significant heterogeneity among respondents in terms of their sensitivity to energy policies.

3. Experiment design and data collection

3.1. Experiment design

The main objective of this study is to investigate households' intentions to invest in home renewable energy equipment conditional on their choice of mobility tools. To achieve this goal, a web-based survey, which incorporated a stated choice experiment, was conducted. The survey started with socio-demographic questions about age, income, educational level, house ownership, and house type. Then, it moved to the stated choice experiment about the adoption of new mobility tools and home renewable energy equipment. In the stated choice experiment, respondents were requested to make two decisions in sequence: the first is the choice of mobility tools and the second is the choice of household energy equipment conditional on the choice of mobility tools. In other words, there are two steps in the stated choice experiment. The respondents make choice of home renewable energy equipment based on their choice of the mobility tools. The details of each decision are presented below.

3.1.1. Choice of mobility tools

In the first choice, respondents were asked to choose the mobility tool they prefer most. Five options were included such as EV, conventional vehicle, e-bike, car sharing, and none option. Each alternative was described in terms of a set of relevant attributes. Purchase price, maintenance costs and operating costs were selected for all mobility tools. Three levels were defined to vary the purchase price of EV: 15,000 euros, 30,000 euros, and 45,000 euros. The price of EV was calculated based on the price of the corresponding conventional vehicle. The net price of an EV relative to the price of the same conventional car was set at a premium price of +15%, +30%, and +45%. Similarly, two levels were defined for the maintenance costs of the conventional vehicle: 150 euros per month and 250 euros per month. The maintenance costs consist of insurance, battery replacement cost, and repair costs. Although the repair cost has been estimated to be lower for EV compared to conventional vehicle, EVs insurance costs are more expensive than conventional vehicles. In addition, the battery replacement costs also lead to the maintenance cost of EV higher than

conventional vehicles. The maintenance costs of EV are higher than conventional vehicles as a whole. To make the choice scenarios more realistic, the maintenance costs of the EV were set to 10% and 20% higher than the maintenance costs of the conventional vehicle. The operating costs of the EV were set to 0.04 euros per km and 0.06 euros per km, while the operating costs of the conventional vehicle were varied at 0.1 euros per km and 0.15 euros per km. The operating cost of car sharing was set to 0.2 euros per km and 0.3 euros per km according to prices commonly asked by car sharing companies. In addition, several alternative-specific attributes were selected. For EV, driving range, charging time, travel time to charging station, chance of charging opportunity and free parking policy were included. The driving range of the top selling EV models in Europe were announced to be between 130 km to 500 km. The BMW i3 2017/18 has a range of 183 km. Nissan Leaf has a range of 200 km. Tesla model S has a range longer than 500 km. However, the driving range were influenced by the road condition and driving habits. The real driving ranges are usually shorter than the official figures announced by the manufacturers. In most of existing studies which have conducted a stated choice experiment (Hidrué, Parsons, Kempton, & Gardner, 2011; Hoen & Koetse, 2014; Liao, 2019), the driving range of EV in stated choice experiments were set from 120 km to 450 km.

Considering the possible improvement of battery technology in the future, we set 150 km as the lower bound and 450 km as the upper bound of the driving range. Fast and slow charging was expressed in terms of charging time for every 100 km.

For car sharing, the hourly rate was selected as most car sharing companies charge by the hour. The hourly rate was set to 4 and 6 euros per hour. As to the convenience of car sharing, access time and vehicle availability were selected. Access time, which equals the time to the nearest pick up point, was varied at 5, 10, and 15 min. Vehicle availability, which means the chance that a car is available, was varied at 60%, 80% and 100%. For an e-bike, the driving range of a single charge was varied as 40 and 80 km. In addition, respondents were informed whether a dedicated bike lane was available or not for their main daily routes. A D-efficient fractional factorial design was constructed to generate the choice set of mobility tools. Gu, Yang, Feng, and Timmermans (2018) provide a more detailed description of the choice set generation.

3.1.2. Choice of home renewable energy equipment

In the second choice, respondents were asked whether they would invest in a home renewable energy equipment given their choice of the mobility tools. Two types of energy equipment, solar panels and heat pumps, were considered in the choice set.

Based on a screening of previous research on solar panels and heat pumps, we selected a set of attributes and attribute levels to describe the solar panels and heat pumps alternatives (Islam, 2014; Rouvinen & Matero, 2013; Scarpa & Willis, 2010). The selected attributes were determined to reflect existing costs, government policies, and technologies. The price of energy equipment was comprised of three different components: purchase price, installation cost, and maintenance cost. The cost was estimated based on the Europe market situation at the time of the experiment. The purchase price of solar panels varied at low (2500 euro), medium (5000 euro) and high (7500 euro) levels. Considering the market situation, the price of heat pumps were varied at 5000, 7500 and 10,000 euros.

Apart from the purchase price, other attributes related to economic benefits and technology were also included. First, the payback period is an important indicator of household investment. Payback period of the investment was set to 5 years and 10 years for the solar panels. Considering the actual market of heat pumps, the payback period of heat pumps was set to 10 years and 15 years. With regard to the energy conservation performance, the proportion of saved or generated energy by the equipment over household energy demand was selected. Solar panels play a role as an energy generator, and it has the possibility to

Table 2
Overview of factors influencing consumer preference on renewable energy equipment.

	Attributes	references
Energy equipment-related variables	Purchase price; Maintenance cost;	Faiers and Neame (2006); Scarpa and Willis (2010); Rouvinen and Matero (2013); Islam (2014); Alam et al. (2014); Sovacool (2009a; 2009b); Scarpa and Willis (2010); Yuan et al. (2011); Willis, Scarpa, Gilroy, and Hamza (2011); Jayaraman, Paramasivan, and Kiumarsi (2017)
consumer related-variables	Awareness of renewable energy equipment; Attitudes towards renewable energy technologies Income;	

meet total energy demand in households. The maximum of the compensation reaches 100%. However, heat pump is a kind of equipment which is used to increase the energy efficiency since it need electricity as an input. As a result, the levels of the proportion of energy composition were set as 25%, 50%, and 100% for solar panels, and 25%, 50%, and 75% for heat pumps. In addition, considering the important role of policy interventions, we included a tax incentive in the choice experiment. Two levels were specified for the tax refund, which included 15% and 30%. We explained to respondents that the tax refund means the percentage of taxes you can get back. The detailed attributes and attribute levels of home renewable energy equipment are shown in Table 2.

3.1.3. Generation of choice sets of home renewable energy equipment

The combination of attributes and attribute levels for the choice of home renewable energy equipment leads to a $3^4 \times 2^4$ full factorial design. To reduce the number of choice sets, an orthogonal fractional factorial design that satisfies the condition of orthogonality and attribute balance was created. The number of generated profiles is 72. The choice sets were randomly selected from the profiles and assigned to the respondents. Each respondent was given 8 choice scenarios. To avoid the potential issue of misunderstanding of the choice tasks, an explanation using example choice questions on how the experiment works was provided before respondents actually made choices. An example of

the stated choice experiment of Household Energy Equipment is shown in Fig. 1.

3.1.4. Context variables of home renewable energy equipment decision

To consider the influence of the mobility tools choice on the home renewable energy equipment decision, the attributes of the selected mobility tools were taken accounted as the context of the energy equipment decision. When the respondents make choice, their intentions to invest in mobility tools and energy equipment are both influenced by their disposable income. The amount of money a respondent willing to spend at once is limited. That is, the intentions and ability to invest in energy equipment will decrease if the respondents have chosen an expensive mobility tool. Another factor that influences the intentions to invest in energy equipment is the type of the mobility tools. As previously mentioned, the household selected electric mobility could benefit more from the smart house environment if they install a house energy equipment. The price and type of the selected mobility tools were chosen as the context variables of the home renewable energy equipment decision. The categories of the context variables are listed in Table 5.

3.2. Data

The data were collected in the city of Weiz, Austria in October 2017. Before estimating the model, the reliability of the responses was checked. After data cleaning, data from 203 respondents remained for analysis, which leads to 1624 choices for model estimation.

Table 4 presents the frequency distribution of the socio-demographic characteristics. It shows that the number of males and females is almost equally distributed. As for their house ownership, nearly one-third of the respondents rent a house, while the rest respondents own a house. Households live in apartment account for near 40% of the sample. More than 46% of the respondents live in detached house. Households living in terraced or semi-detached house share a relatively small proportion. The majority of respondents live in the houses between 60 and 150 square meters. Around 43% of the respondents have gross annual income between 25,000 and 50,000 euros, while 28% have higher income. The rest has relatively low income (less than 25,000 euros/year).

Data of respondents' choices show that in 60% of the hypothetical scenarios, respondents choose to invest in additional home renewable energy equipment. The percentage of choosing solar panels and heat

Table 3
Selected attributes and attribute levels of mobility tools.

	Attributes	Attribute levels
Conventional vehicle	Purchase price (euros)	15,000; 30,000; 45,000
	Maintenance costs (euros/ month)	150; 250
	Operating costs (euros/ km)	0.1; 0.12
Electric vehicle	Purchase price (euros)	15%; 30%; 45% (higher than CV)
	Maintenance costs (euros/ month)	10%; 20% (higher than CV)
	Operating costs (euros/ km)	0.04; 0.06
	Free parking	always; on non-peak hours; no
	Driving range (km)	150; 300; 450
	Average travel time to charging station (min)	5; 10 ;15
	Fast charging time per 100 km (min)	5; 10 ;15
	Slow charging time per 100 km (hour)	1.5; 3
E-bike	Chance of charging opportunity	60%; 80%
	Purchase price (euros)	1,000; 2,000; 3,000
	Maintenance costs (euros/ month)	5; 10
	Free parking	yes; no
Car sharing	Driving range (km)	40; 80
	Bike lane availability	yes; no
	Maintenance costs (euros/ month)	0; 10; 20
	Operating costs (euros/ km)	0.2; 0.3
	Hourly rate (euros/hour)	4; 6
	Access time (min)	5; 15; 25
	Vehicle availability	60%; 80%; 100%

Based on your decision of mobility tool, which home energy equipment do you prefer?

	Solar Panel	Heat Pump	None of above
Purchase price (including installation)	5000 euro	10000 euro	
Payback period of investment	10 years	15 years	
Tax refund	15%	15%	
Proportion of current energy compensate	50%	75%	
Your Choice	☐	☐	☐

Fig. 1. An example of the stated choice experiment of home renewable energy equipment.

Table 4
Selected attributes and attribute levels of home renewable energy equipment.

	Attributes	Attribute levels
Solar panels attributes	Purchase price (euros)	2,500
		5,000
		7,500
	Payback period (years)	5
		10
	Tax refund	15%
Heat pumps attributes	Compensate for energy usage	30%
		25%
		50%
	Purchase price (euros)	100%
		5,000
		7,500
	Payback period (years)	10,000
		10
	Tax refund	15
		15%
	Compensate for energy usage	30%
		25%
		50%
		75%

Table 5
Context variables of home renewable energy equipment.

	Attributes	Attribute levels
Context attributes	Mobility tools price	Price of the chose
		EV
	Mobility tools types	Conventional vehicle
		Electric bike
		Car sharing

Table 6
Descriptive statistics of the sample.

Characteristics	Levels	Percentage (%)
Gender	Male	49.3
	Female	50.7
Income	Lower than 50,000 euros / year	72.0
	Higher than 50,000 euros / year	28.0
House size	Smaller than 60 square meters	13.8
	60 – 90 square meters	25.1
	90 – 120 square meters	15.8
	120 – 150 square meters	22.7
	150 – 200 square meters	12.8
	Larger than 200 square meters	9.8
House ownership	Own	68.5
	Rent	31.5
House type	Apartment	40.9
	Terraced house	12.8
	Detached house	46.3

Fig. 2. Choice of home renewable energy equipment by choice of mobility tools.

pumps are 46% and 14%, respectively. People who have chosen an EV prefer solar panels over heat pumps; 70% of them choose solar panels and 20% of them choose heat pumps. For people who have chosen a conventional vehicle, 50% choose solar panels, while 16% choose a heat pumps. People who have chosen an EV have a higher probability to select both solar panels and heat pumps than people who have chosen a conventional vehicle. An overview is shown in Table 6 and Fig. 2. Chi-square tests was used to test for the independence between the choice of mobility tools and choice of energy equipment. The Chi-square test statistic is 166.16 with 8 degrees of freedom. The p-value is less than 0.01 which indicate there is an association between the two choices.

4. Method

Both the Multinomial logit model (MNL) model and Mixed logit model (ML) were applied in this study. The alternatives in the logit model include solar panels, heat pumps and the “none” option. The utility of alternative i for respondent n in choice situation t can be written as:

$$U_{int} = \alpha_{in} + \beta_i^A X_{int}^A + \beta_i^M X_{nt}^M + \beta_i^Z X_{nt}^Z + \varepsilon_{int} \quad (1)$$

where U_{int} is the utility of alternative i for individual n in choice situation t , X_{int}^A is an $(A \times 1)$ vector of the attributes of alternative i in choice situation t , which includes the purchase price, payback period, tax refund, the proportion of saved or generated by the equipment over household energy demand. The $(1 \times A)$ vector β_i^A contains the associated parameters. To investigate whether mobility tool adoption has effects on energy facility choice, the types and price of mobility tools were incorporated as the context of energy equipment decision. X_{nt}^M is a $(M \times 1)$ vector which describes the pre-selected mobility tools in choice

situation t . According to the mobility choice of the respondent, the type of mobility tools has been considered as a categorical variable, which has 5 levels including EV, conventional vehicle, electric bike, car sharing and none. The price of the chosen mobility tools was considered as a continuous variable. $(1 \times M)$ vector β_i^M is the parameters for the attributes of chosen mobility tools. X_n^Z is a $(Z \times 1)$ vector of socio-demographic attributes of individual n , which includes house ownership and household income. The $(1 \times Z)$ vector β_i^Z are the parameters for the socio-demographical variables. α_{in} is the alternative-specific constant. ε_{int} is a random term that is IID distributed across choice alternatives.

4.1. Mixed logit model

As solar panels and heat pumps are relatively new products, the intentions to invest in the equipment may differ in terms of respondents' personality and lifestyle. Therefore, the preference heterogeneity in the population should be considered. To capture such heterogeneity, a mixed logit model was used in this study, which accounts for unobserved heterogeneity among the individuals. It considers random effect correlations for intra-person observations as these observations are not independent of each other (Hackbarth & Madlener, 2013). The random effects of the important variables were considered. Moreover, a panel effect was included, because each participant was asked to respond to 8 choice sets. The random effects across individuals are assumed to be independently and identically distributed. All random errors were assumed to be normally distributed. For individual n , the k_{th} element β_{ikn}^A in vector β_i^A , which is the associated parameter for the k_{th} element in the vector X_{int}^A , can be specified as:

$$\beta_{ikn}^A = \beta_{ikn}^A + \delta_k v_{ikn}, \alpha_{in} = \alpha_{in} + \delta_i v_{in} \quad (2)$$

where β_{ikn}^A and α_{in} are the population means, $\delta_k v_{ikn}$ and $\delta_i v_{in}$ are additional error components to capture the heterogeneity in the population. v_{ikn} and v_{in} are random terms that vary across individuals, with mean zero and standard deviation one. δ_k is the standard deviation of the distribution of β_{ikn}^A . δ_i is the standard deviation of the distribution of α_{in} .

5. Results

The results of MNL and ML are listed in Table 6. For both models, almost all coefficients have signs in line with expectations. The price of energy equipment and the proportion of energy generated by the energy equipment over the energy usage demand of households have significant effects on the choice. The estimation results show the goodness of fit of the mixed logit model is better than that of the MNL model. The adjusted Rho-squared of the mixed logit model is increased from 0.148 (MNL model) to 0.511 (mixed logit model). In addition, the standard deviations of 8 parameters are highly significant suggesting that there is preference heterogeneity among individuals.

As shown in Table 6, the price has a significant negative impact on the acceptance of household energy equipment. The estimated coefficients for solar panels prices monotonically decrease with increasing price from 2500 euro to 7500 euro. The higher the price, the lower the probability people adopt the solar panels. However, the coefficient of heat pumps prices at the 5000 euro level is almost same as that for the level at 10,000 euro level, but the coefficient decreases when it is from 10,000 euro to 15,000 euro. By comparison, the coefficients of the solar panels price decrease continuously with the increasing of price, while the coefficients of heat pumps price have no remarkable change when the price increases from 5000 euro to 10,000 euro. The difference indicates that households are more sensitive to the price of solar panels. The result also indicates that the length of the payback period has different impacts on the intention to invest in solar panels and heat pumps. If the payback year of the investment is shorter, people are more likely to purchase solar panels. The payback period at 5 years

level is positive, which shows the solar panels are acceptable if the investments could be recovered in 5 years. Nevertheless, the parameter of a faster payback year (10years) of the heat pumps is negative and insignificant, which might be explained by the fact the diminishing marginal effect when an investment payback period is longer than 10 years. Tax incentives also play a positive role in the acceptance of home renewable energy equipment. The coefficients for a lower tax refund for solar panels and heat pumps are both negative, which indicates the positive impact of a higher tax reduction on the intention to invest in solar panels and heat pumps. The tax reduction increases the preferences for home renewable energy equipment, particularly in the case of heat pumps. The proportion of energy produced by the facility over the energy demand has significant positive effects on the intentions to invest in home renewable energy equipment. The intentions to invest in solar panels and the heat pumps increase with the increasing of the proportion. When the energy generated by the solar panels could satisfy 100% of the household energy demands, people are more likely to purchase solar panels.

Table 6 also lists the estimated standard deviation for the random parameters. It shows that the standard deviation is significant at the lowest level price of the solar panels. It suggests that heterogeneity in the preferences of solar panels across individuals is higher when the solar panels price is lower. It indicates that the solar panels are too expensive to choose for respondents when the price is higher than 5000 euro, and some respondents may likely change their decision to purchase solar panels because of the low price. Similar results are obtained for the proportion of energy generated by the solar panels over the energy demand of household. It shows the standard deviations are highest for the lowest levels of the proportion of compensating for energy usage. There is a significant heterogeneity if the solar panels could only generate only 25% of energy usage for the household. It suggests that the preferences for the solar panels may be primarily driven by environmental concerns but not by economic benefit. As for the price of the heat pumps, the estimated standard deviation is significant for the middle level, which suggests that some respondents truly prefer heat pumps regardless its price, while other respondents could not accept it when the expense is 7500 euro.

The influence of the choice of mobility tools on the decision of home renewable energy equipment was also identified. Several interesting results were found. First, the results suggest that the decision of purchasing an EV has positive, and highly significant impact. It shows that people who prefer to purchase an EV are more likely to invest in energy equipment, especially on solar panels. This is because both solar panels and heat pumps could decrease the electricity consumption. Moreover, the parameter of EV for the utility of solar panels (1.728) is higher than the parameter for the utility of heat pumps (0.954). The EV has a more significant effect on solar panels than on heat pumps, indicating the potential EV consumers prefer solar panels more than heat pumps. Fig. 3 shows that the estimated part-worth utility curve for the EV and electric bike are positive, suggesting that respondents are more interested in home renewable energy equipment when they have an electric mobility. The utility is highest for both of solar panels and heat pumps when the respondent have selected an EV. It could be explained by that solar panels could generate the electricity which can be used by EVs independently and directly. While heat pumps still need to rely on the grid and could only increase the energy efficiency. The solar panels could reduce the dependence on grid, in addition to reduce the expense. The choices of electric bike and car sharing, have positive effects on both solar panels and heat pumps. In contrast, the conventional vehicle has negative influences on the intention to invest in new energy equipment. Purchasing price of mobility tools has a negative impact on the choice of solar panels and heat pumps, indicating that, with the increasing of the cost of mobility tools, the preferences for energy equipment decrease.

For the socio-demographic variables, the results show that households with higher income tend to invest in solar panels or heat pumps.

Fig. 3. Estimated part-worth utilities for energy equipment attributes and mobility tools.

As for the effects of house ownership, results show households that own a house are more inclined to invest in solar panels or heat pumps. Household living in the detached house is more likely to invest in solar panels or heat pumps.

Regarding the constants of alternatives, the constants of the solar panels and heat pumps are significantly different from each other. The constant of the heat pump is smaller than the solar panels. The means people have a stronger intention to invest in solar panels. Moreover, both of the standard deviations of alternative-specific constants are highly significant, which suggests substantial heterogeneity in people's base preferences.

To test how changes of the mobility tools impact upon the choice probabilities for solar panels and heat pumps, a simulation was conducted using the estimated model. The shares of solar panels and heat pumps were simulated under scenarios that specify the type of mobility

Table 7

Crosstab for choice of mobility tools and choice of energy equipment.

Choice of energy equipment	Choice of mobility tools					sum
	EV	conventional vehicle	e-bike	car sharing	none	
solar panel	158	132	43	64	352	749
heat pump	46	42	23	34	86	231
None	23	89	24	44	464	644
Sum	227	263	90	142	902	1624

tools. The difference between scenarios represent the change in choice probabilities given a change from one type of mobility tool to another. Table 7 provides the comparison of the different simulation scenarios.

Table 8
Estimated parameters of MNL and mixed Logit models.

Alternative	Attribute	Levels	MNL			Mixed logit		
			Coef.		P	Coef.		P
Solar panels	Constant	Constant	0.438	***	0.004	−0.274		0.657
	Purchase price	2500 euro	0.145	**	0.048	0.307	*	0.096
		5000 euro	0.009		0.906	−0.008		0.963
		7500 euro	−0.154			−0.299		
	Payback period	5 years	0.075		0.155	0.151		0.259
		10 years	−0.075			−0.151		
	Tax refund	15%	−0.018		0.725	−0.028		0.818
		30%	0.018			0.028		
	Compensate for energy usage	25%	−0.203	***	0.006	−0.385	*	0.053
		50%	−0.002		0.982	−0.132		0.481
		100%	0.205			0.517		
	House ownership	Own	0.289	***	0.000	0.738	*	0.072
		Rent	−0.289			−0.738		
	House type	Apartment	0.119		0.245	0.350		0.650
		Terraced house	−0.197		0.179	−1.172		0.112
		Detached house	0.078			0.822		
	Income	Low	−0.299	***	0.000	−1.324	***	0.009
		High	0.299			1.324		
	Mobility tools price	Price	−0.007		0.418	−0.002		0.906
		Mobility tools types	EV	1.436	***	0.000	1.728	***
	Conventional vehicle		−0.112		0.570	0.154		0.753
	Electric bike		−0.039		0.873	0.507		0.480
	Car sharing		−0.249		0.246	−0.366		0.412
	−0.566		***	0.004	−4.607	***	0.000	
	0.208		**	0.038	0.358		0.139	
	−0.004			0.973	0.237		0.405	
	10,000 euro		−0.204			−0.595		
Payback period	10 years	0.025		0.734	0.201		0.284	
	15 years	−0.025			−0.201			
Tax refund	15%	−0.113		0.123	−0.440	**	0.020	
	30%	0.113			0.440			
Compensate for energy usage	25%	−0.073		0.486	−0.239		0.383	
	50%	0.007		0.949	−0.211		0.465	
	75%	0.066			0.449			
		0.233	**	0.059	0.044		0.945	
House ownership	Own	−0.233			−0.044			
	Rent							
House type	Apartment	0.186		0.248	0.737		0.272	
	Terraced house	−0.611		0.102	−1.666		0.139	
	Detached house	0.424			0.929			
Income	Low	−0.029		0.761	−0.269		0.570	
	High	0.029			0.269			
Mobility tools price	Price	−0.011		0.323	0.006		0.830	
	Mobility tools types	EV	1.306	***	0.000	0.954		0.192
Conventional vehicle		−0.226		0.360	−0.383		0.537	
Electric bike		0.292		0.298	1.108		0.158	
Car sharing		0.059		0.814	−0.007		0.991	
Standard deviation of random parameters								
Solar panels		Constant				5.769	***	0.000
	Purchase price	2500 euro				0.618	**	0.021
		5000 euro				0.318		0.585
	Payback period	5 years				0.479		0.060
	Tax refund	15%				0.107		0.901
	Compensate for energy usage	25%				0.927	***	0.001
50%					0.783	**	0.033	
Heat pumps		Constant				6.095	***	0.000
	Purchase price	5000 euro				0.436		0.452
		7500 euro				1.142	***	0.004
	Payback period	10 years				0.326		0.479
	Tax refund	15%				0.383		0.390
	Compensate for energy usage	25%				0.745	*	0.062
		50%				0.994	***	0.001

Table 9
The comparison of the different simulation scenarios.

	Conventional vehicle	E-bike	Car sharing	None	EV
Solar panel	50.99%	50.67%	47.37%	39.60%	57.98%
Heat pump	16.43%	21.42%	18.52%	14.65%	18.62%
None	32.59%	27.91%	34.11%	45.75%	23.40%

Results show the choice probability for the solar panels is 6.99% higher if a respondent choose an EV, comparing with the probability when the respondent choose a conventional vehicle. The choice probability for heat pumps is 2.19% higher if a respondent chooses an EV rather than a conventional vehicle (Tables 8 and 9).

6. Conclusion and discussion

The market share of electric mobility tools is expected to have a continuous growth rate due to policy incentives and technology improvements. The increasing penetration rate of electric mobility tools will push the transition of de-centralized energy production. It might create a synergy between transport energy and home energy consumption in future smart homes. As a result, the choice on mobility tools could affect the choice of home renewable energy equipment. Although the relationship between transport behavior and household energy consumption behavior have been studied in several studies, few studies systematically examined the effects of the acceptance of different mobility tools on the choice of home renewable energy equipment.

The main contribution of this study is to investigate the households' intention to invest in solar panels and heat pumps considering the adoption of electric mobility. A web-based survey incorporating a stated choice experiment was conducted. Both MNL and mixed logit models were estimated to analyze the influence of equipment attributes, pre-selected mobility tools, the associated price of mobility tools and socio-demographics. Results show households prefer to purchase an EV are more likely to invest in home renewable energy equipment, particularly on solar panels. We found the probability to purchase a solar panel increases 6.99% and the probability to purchase a heat pumps increases 2.19% when the household purchases an EV rather than a conventional vehicle. This finding contributes to our understanding of the influence of electric mobility on the home energy decision.

The results of the study can be a policy guide on how to incentivize the further adoption of household energy equipment. Therefore, to better improve the market share of energy equipment, consumers' preference for mobility tools need to be taken into account. Results of the substantial preference heterogeneity suggest that policies targeting specific groups may be more effective than generic measures. Policy makers should be particularly aware of that people purchasing an EV are likely to be early adopters of solar panels and heat pumps. The trend of mobility electrification provides a chance for the market breakthrough of home renewable energy equipment. Policy makers can take advantage of the synergy between electric mobility and renewable energy equipment to increase the penetration of each other in the way that the implementation of various policies related to home renewable energy equipment and EV could be linked.

Although the results provide better insight into the influence of the adoption of new mobility tools on the intention to adopt home renewable energy equipment, further research is needed to understand better the factors influencing the households practical actions to invest in home renewable energy equipment. First, while the current study considers the price of the mobility tools may influence the intention to invest on the energy equipment due to the financial limitation, the result shows price of mobility tools has no significant influence on the intention to invest in the renewable energy equipment. This is understandable because the respondents are not given a fixed amount of budget for them to invest on the mobility tools and home renewable energy equipment. The financial limitation in a hypothetical scenario is not as compelling as the limitation in a practical decision. When they make choice of energy equipment, respondents could not distinctly perceive that their abilities to pay were decreased even they have expended much on the mobility tools. Whether there is a mutual inhibition between investment on mobility tools and energy equipment when the budget is fixed, it needs to be further investigated. Second, respondents were assumed to have authority to invest in home renewable energy equipment in this study, which is probably ideal. In reality, people living in an apartment may need to negotiate sufficiently with their community members. Policy or regulation related to the energy facility installation permissions need to be considered in future research.

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