Investment in Energy Efficiency, Adoption of Renewable Energy and Household Behaviour: Evidence from OECD countries

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Abstract

There exist some possible synergies between energy efficiency measures and renewable energy adoption in the sense that the former reduces the energy demand so that the latter can begin to cut future GHG emissions with a high potential in residential sector. In this residential sector, many works have been done either on demand for clean energy or on investment in energy efficiency, but to our knowledge there is no specific study that investigates the interaction between the two decisions. This paper fills this gap in literature and first theoretically shows that there exist interactions between the two decisions depending on a threshold on the pro-environmental index of the consumer. Second, the paper empirically shows that the two decisions are positively interrelated and cannot be estimated independently. As a result, univariate methods that estimate separately the two decisions of renewable energy adoption and investment in energy efficiency potentially produce biased results because it may exist unobserved characteristics that determine both decisions. Third, the paper investigates characteristics of the household that significantly affect the interaction between the two decisions by using generalized ordered logit model. More precisely, the paper provides evidence on factors that affect the joint probability of adopting renewable energy and investing in energy efficiency and the probability of doing nothing. This contribution can serve to define incentive policies to boost the energy transition.

Keywords: *Energy efficiency, renewable energy, bivariate probit, generalized ordered logit.*

1 Introduction

The world's electricity is consumed mostly (60%) in residential and commercial buildings (IEA 2008a). More precisely, residential buildings contribute at 23% to the world final energy demand (IEA, 2007) and at 17% to the world CO2 emissions (IEA, 2014). Moreover, cooking, lighting, water heating, appliances and space heating account in the residential sector for 5%, 5%, 16%, 21% and 53%, respectively (IEA, 2008b). Then, there exists a substantial potential in residential sector to reduce the overall energy demand. In order to reduce the quantity of energy that is used to get the same energy service, a household can decide to invest in energy efficient technology that induces energy saving. In 2014 for instance, improvements in energy efficiency were driven by efficiency improvements of space heating (through a home renovation for instance), water heating, lighting and appliances in residential buildings (IEA/ OECD, 2014). The energy conservation actions can also be curtailments (Jansson et al., 2009), which refer to behaviour changes such that scheduling efforts, turning off lights, cutting down on heating or on air conditioning and switching off standby mode. By reducing its consumption of energy, the household contributes to reducing future greenhouse gas (GHG) emissions. In one policy scenario of the International Energy Agency (IEA), 72% of the global decrease in CO2 emissions between 2010 and 2020 will come from energy efficiency improvements.

There exist some possible synergies between energy efficiency measures and renewable energy adoption in the sense that the former reduces the energy demand so that the latter can begin to cut future GHG emissions. The household can also invest in renewable energy by installing solar panels or wind turbines, which represents a share of 19% of world final energy consumption in 2012 (REN21, 2014). This investment produces clean energy and contributes to reducing CO2 emissions. For instance, the deployment of renewable energy can reduce annual CO2 emissions by 8.6 Gt by 2030 (IRENA, 2104). Additionally, the report of IRENA (2104) states that such emissions savings combined with energy-efficiency gains, would be sufficient to set the world on a path to prevent catastrophic climate change. Though investments in both energy efficiency and renewable energy are costly, they give future gains that make it profitable after several years of use.

Thus, the two issues of clean energy adoption and investment in energy efficiency are both important for a transition to a green economy. There is a huge literature on either demand for clean energy (Gerpott and Mahmudova, 2010; Sardianou and Genoudi, 2013; Zhai and Williams, 2012) or investment in energy efficiency (Dietz et al., 2009; Heslop et al., 1981; Howarth, 1997; Urban and Scasny, 2012) in the residential sector. To our knowledge, there is no specific study that investigates the behaviour of household to jointly adopt renewable energy and to invest in energy efficiency; and the relatedness of the two decisions. This paper fills this gap in literature and makes three contributions. First, we use a simple theoretical model to investigate the possible interactions between the two decisions of investing in energy efficiency and in renewable energy. In this model, we assume that a household devotes its energy budget to undertake investments in energy efficiency and in renewable energy, which contribute to a transition to a low carbon economy. The household gets some private or direct utilities for investing in energy efficiency and for investing in renewable energy. The household may also gain some additional environmental-related satisfaction depending on its environmental conscientiousness. We show that there is a threshold on the pro-environmental index below (resp. above) which investment decisions in energy efficiency and in renewable energy of the household are substitutes (resp. complements). As a consequence, there exist interactions between the two decisions. Moreover, we show that the effect of the energy budget on this threshold of the pro-environmental index depends on the inter-temporal elasticity of substitution in energy efficiency investment. As corollary, we find that the decisions are always complements or substitutes for some household depending on their energy budget and on their inter-temporal elasticity of substitution.

The second part of this paper focuses on the empirical investigations of the interactions between the two decisions. We explore whether the decision of household to adopt renewable energy and that of investing in energy efficiency in residential sector are related. We use a bivariate probit (biprobit) model for the joint decision. Additionally, we investigate the determinants of the interaction between the two decisions by using generalized ordered logit model. Basically, we intend to explain why some households decide to invest both in energy efficiency and in renewable energy, while others decide to only invest in renewable energy or to only invest in energy efficiency or to do nothing. The household that only adopts renewable energy or only reduces his energy consumption contribute to the energy transition better than the household who does nothing and less than the one who undertakes the two investments. For the two empirical investigations, we use the survey on Environmental Policy and Individual Behaviour Change (EPIC) from the Organisation for Economic Co-operation and Development (OECD). This survey was run in 2008 and 2011 across a total of fifteen countries and several areas (energy, food, transport, waste and water) and provides evidence on what affects household decisions-making. Precisely, it provides socio-economic and environmental factors, attitude and policy at the household level that can influence the real decisions of the household to invest in energy efficiency and to adopt renewable energy.

Second, the results of the biprobit model show that there is a positive interrelation between the decisions of the household to invest in energy efficiency and to adopt renewable energy due to unobserved characteristics such as environmental motivations. In fact, the environmental conscientiousness as a true environmental motivation is not observed and may lead to such positive correlation in the sense that a more pro-environmental household is more likely to invest in energy efficiency and in renewable energy. Thus, bivariate probit model is more appropriate than separate univariate probit models. Moreover, the paper provides evidence on factors that affect the probability of adopting renewable energy and that of investing in energy efficiency. Notably, people living in poorer household are less likely to invest in energy efficiency and may end up using a high share of their income to pay electricity. In literature, it is referred to as energy poverty. There is evidence of split incentives regarding decisions to invest in energy efficiency and to invest in renewable energy: the ownership positively affects the two probabilities to invest in renewable and in energy efficiency. Regarding the dwelling characteristics, we find that there is significant effect of the type of dwelling and its size on the decision of the household to invest in energy efficiency and no effect on their decision to adopt renewable energy. Also, environmental motivations and commitment have mixed effects on both investment in energy efficiency and adoption of renewable energy. Trust in researchers, scientists and experts has positive effect on the two decisions.

Third, in the generalized ordered logit model we find that people living in wealthier household are more likely to jointly invest in energy efficiency and in renewable energy if they have undertaken any of these investments, and if not, they are more likely to undertake one of the investments as well. In the same vein, tenants are less likely to combine the two investments due to split incentives. Also, household that has already undertaken one of the investments and living in detached dwelling is more likely to make additional effort to invest in the second, while there is no significant effect of the size of the residence. This limitation can be overcome by environmental motivations. In this sense, people who have already undertaken one of the investments and for whom environmental issues are generally more important than non-environmental issues are more likely to have additional motivation to deal with barriers that could refrain them from fully contributing to the energy transition. Also, there is a positive effect of participation in charitable, environmental and local organizations, and trusts in scientists and local authorities.

The remaining of the paper is structured as follow. In section 2, we provide literature on both adoption of renewable energy and investment in energy efficiency. In section 3, we present the theoretical predictions. Section 4 is devoted to the empirical analysis. Finally, we conclude in section 5.

2 Literature review

There is a huge literature on either demand for clean energy or investment in energy efficiency in the residential sector. In section 2.1, we provide some important studies on demand of clean energy and household behaviour while section 2.2 provides some analysis on household' behaviour to invest in energy efficiency. To our knowledge, there is no specific investigation of the simultaneous decisions of renewable energy adoption and investment in energy efficiency at household level. As the two decisions of adoption of renewable energy and investment in energy efficiency are taken by the same household in a residential sector and both issues are important in a transition to a green economy, an analysis of a joint decisions needs a particular attention.

2.1 Clean energy demand and household behaviour

There is an important literature on demand for green energy due to the importance of energy in CO2 emissions that induce climate change. Notably, in a residential sector, studies mainly focus on real behaviour or hypothetical behaviour to explain the decision of the household to adopt a renewable energy. However, the two approaches often give different results (Cameron et al., 2002; Kotchen and Moore, 2007 and Poe et al., 2002). The hypothetical behaviour based on stated-preference methods can rely on the willingness decision to adopt a renewable energy (Gerpott and Mahmudova, 2010; Ozaki, 2011; and Zhai and Williams, 2012; and Sardianou and Genoudi (2013)), on the willingness to pay for a renewable energy (Ek and Söderholm, 2008; Zoric and Hrovatin, 2012; Liu et al., 2013.) or on both decisions (Krishnamurthy et al., 2014; and Shi et al., 2013).

Gerpott and Mahmudova (2010) finds a strong influence of environmental attitudes of the consumer and its social environment on the propensity to adopt green electricity. On contrary, Ozaki (2011) uses correlation analysis and finds that pro-environmental consumers do not necessarily adopt green electricity. It is a result of lack of strong social norms and personal relevance that affect the adoption of renewable energy as well as the value of the renewable energy (benefits and costs). Additionally to environmental concern, Zhai and Williams (2012) investigates the influence of social acceptance and shows in a specific case of photovoltaics (PV) adoption that social acceptance also affects the adoption of renewable energy. Financial incentives through tax or subsidy are also important to promote adoption of clean energy. Sardianou and Genoudi (2013) finds in Greece that a tax deduction is better than an energy subsidy to promote consumers' acceptance of renewable energies in the residential sector.

Substantial studies investigate the willingness to pay for a renewable energy. Ek and Söderholm (2008) investigates norm-motivated and economic-motivated behaviour in the Swedish green electricity market. They find that variables such as cost of adoption, personal responsibility, perception of the benefit of adoption and social norm are the most important determinants of households' choice to pay a price premium for green electricity. Zoric and Hrovatin (2012) suggests that awareness-raising campaigns should follow green marketing, which should target younger, well-educated and high-income households. In a specific case of developing countries, Liu et al. (2013) investigates rural social acceptance of renewable energy adoption and finds that rural residents are generally supportive renewable electricity development given its positive impacts on environment. Krishnamurthy et al. (2014) and Shi et al. (2013) focus on the willingness to accept and the willingness to pay to use only renewable energy and their disparities across OECD countries. The former uses the 2011 EPIC-OECD survey while the latter uses the 2007 EPIC-OECD survey. Krishnamurthy et al. (2014) finds a low willingness to pay (WTP) that corresponds to 11-12% of current electric bill and ambiguous effect of income. By the same way, Shi et al. (2013) find that economic variables are less important, while environmental concern or attitude consistently drives the decision to enter the hypothetical market of green electricity and membership in environmental organizations has effects on the WTP.

In the literature, there are less studies that investigate the real behaviour of consumers towards the renewable energy adoption relying on real survey than hypothetical consumer's behaviour. A survey that relies on the real behaviour of consumers can help to investigate how consumers actually react according to different financing mechanisms for green electricity. Roe et al. (2001) finds that hypothetical analysis based on the WTP and hedonic analysis of actual price premiums charged for green electricity give similar values for key environmental attributes. Some studies only focus on green consumers (Young et al., 2010) and can suffer from selection bias because policy recommendations could not be extended to consumers who do not adopt green behaviours. There are also disparities in the effect of different financing mechanisms for green electricity. For instance, Kotchen and Moore (2007) considers the voluntary contribution mechanism (VCM) and the green tariff mechanism (GTM) to finance a new generation capacity. They find that the two financing mechanisms are not equivalent when the constraint related to the level of contribution is binding. Arkesteijn and Oerlemans (2005) investigates factors that influence the early adoption of green electricity by Dutch residential users combining cognitive and economic approach. They find that additionally to economic variables, variables that are related to cognitive, basic knowledge and to actual environmental behaviour in the past, strongly predict the probability of the early adoption of green electricity.

Variables that affect green demand in the residential sector may also affect the household's decision to investment in energy efficiency. We provide some literature on factors that influence investment's decision in energy efficiency in residential sector in the following section.

2.2 Energy efficiency and household behaviour

There is a substantial literature on how the household's behaviours affect adoption and investment in energy efficiency. Energy efficiency is relatively cheap way to reduce green house gas emissions in the short and medium term horizons (Dietz et al., 2009; and Vandenbergh et al., 2008), while in a long term a complete transition to a low carbon economy is likely to be very slow (Fouquet, 2010). There is a large evidence that economic factors are motivations for energy efficiency (Howarth, 1997; Kempton and Neiman, 1986; and Steg, 2008) and can be helpful in designing appropriate taxes or subsidies mechanism to promote energy saving actions. For instance, saving money or reducing energy bill can be incentives to invest in energy efficiency. However, the potential gain from reducing energy use can be hindered by some problems such as split incentives, uncertainty about the gain, moral hazard problem that may refrain households from adopting or investing in an energy conservation system. Reducing energy use can also lead to reverse effects such as rebound effect or take-back effect (Greening et al., 2000; and Urban and Scasny, 2012). The rebound effect can be solved by capturing efficiency gains for reinvestment in natural capital rehabilitation (Wackernagel and Rees, 1997) or in supporting environmental actions through donation (Bindewald, 2013). Alternatively, the rebound effect can also be solved by pro-environmental motivation (Urban and Scasny, 2012).

But in the literature on energy-saving behaviour, there is a no evidence of the effect of pro-environmental motivation on energy-saving actions at household level. The early literature found that environmental concern does not have any effect on both energy consumption and energy-saving actions (Heslop et al., 1981). However, there has been growing concern about climate change in recent years (Capstick et al., 2015) and many studies recently find significant effects of environmental concerns on energy-saving actions (Barr et al., 2005; and Whitmarsh and O'Neill, 2010). Some few studies still support limited effect (Carlsson-Kanyama et al., 2005; and Whillans et al., 2015) or no effect (Steg et al., 2011) of pro-environmental motivation. Also, both economic and environmental concerns have different effects when we distinguish the actions of investing in energy efficiency.

The two main types of energy conservation actions are efficiency investment and curtailments (Jansson et al., 2009). The former involves the acquisition of new technologies, low-energy appliances (Top-rated energy-efficient appliances, low-energy light bulbs, energy-efficient windows, etc.) or energy efficient systems (automated control systems, domotic or home automation), that needs monetary investment. The latter refers to non-monetary investments that are behaviour changes such that scheduling efforts, turning off lights, cutting down on heating or on air conditioning and switching off standby mode. For instance monetary efficiency investments that rely on external conditions (Urban and Scasny, 2012) such as economic concerns, are less affected by internal motivations (Guagnano et al., 1995) such as pro-environmental motivations. While, Black et al. (1985) finds the opposite effect on non-monetary efficiency investments. In the end, both economic and environmental concerns may have significant effects on energy-saving actions which are the outcome of both monetary and non-monetary investments. Additionally to socio-economic and demographic factors, Urban and Scasny (2012) investigates in a multi-country setting using EPIC-OECD data how environmental concern affects the adoption of monetary and non-monetary investments in energy efficiency. They find a positive and significant effect for pro-environmental motivation and mixed effect for the other variables.

The different variables that affect the renewable energy adoption decision of household may have significant effects on energy efficiency investments as well. The fact that studies mostly focus on either renewable energy adoption or energy efficiency investment may explain empirical disparities in the effect of economic and environmental concerns. Interestingly enough, if the two decisions are interrelated, it cannot be estimated independently. In this case, univariate methods that estimate separately the two decisions of renewable adoption and energy efficiency potentially produce biased results because it may exist unobserved characteristics that determine the two decisions. For instance, household that is pro-environmental can find it necessary to additionally invest in renewable energy (resp. in energy efficiency) if he has already invested in energy efficiency (resp. renewable energy). In this case, the household may rely on its environmental conscientiousness to combine the two investments. By the same way, household that already invests in energy efficiency (resp. renewable energy) may have limited financial capacity to additionally invest in renewable energy (resp energy efficiency). Therefore, by jointly analysing the two possible decisions of the adoption of renewable energy and investment in energy efficiency that are taken by the household, one can capture the interrelation and the interaction between them. Such investigation has potential gain for policy implications as adoption of renewable energy and investments in energy efficiency are both important in the future world energy market (Sheffield, 1997) and in the energy transition. To our knowledge, there is no such investigation in economics literature and our study aims at filling this gap in literature.

3 Theoretical predictions

In the following, we develop a simple model to explore the possible interactions between the two decisions of investing in energy efficiency and in renewable energy at household level.

3.1 The model

As in Ekholm et al. (2010), let us assume that the consumption of energy can be separated from other consumption to its own consumption problem, i.e. that the utility from energy is separable from other sources of utility and that the consumer has a specific energy budget which we denote R. This energy budget can be seen as the income that a household devotes to energy problems. It can also include a financial support or a "green grant" such that subsidies, tax-credits from government or interest-free eco-loans from a bank that target energy efficiency and renewable energy adoptions.[1] We assume that a household devotes this energy budget to undertake investments in energy efficiency and in renewable energy, which contribute to a transition to a low carbon economy.

During the first period ($t = 0$) investments in energy efficiency ee and in renewable energy re are undertaken at a cost k_1 and k_2 respectively. The energy budget constraint of the household can be written as:

$$R = k_1 ee + k_2 re. \tag{1}$$

The energy budget constraint (1) expresses the limited investment capacity of the household. In fact, investment in energy efficiency is negatively related to investment in renewable energy for a given energy budget. This limited investment capacity may not favour a joint investment in both renewable energy and energy efficiency.

The household gets some satisfaction by using energy services for fundamental needs as cooking, lighting, electric home appliance, etc. Following Charlier et al. (2011), we assume that household invests in energy efficiency in order to lower the cost of the energy service in the future. Investing in energy efficiency help the household to save energy during the following periods and therefore to enjoy more energy services. We assume that the household gets the utility $u(ee)$ at each period of time due to the investment in energy efficiency ee in the first period. Also, investing in renewable energy re gives

[1] In order to promote greener purchasing decisions, several countries have implemented different policies that provide financial support to households. According to OECD (2013) report, in Canada, the ecoEnergy Retrofit-Homes programme helps home-owners to invest in energy-efficient upgrades such as insulation, upgrades or replacement of the heating and cooling systems. Financial incentives such as tax-credit or interest-free eco-loan are available in France as well to promote energy efficiency investments in the residential sector and investment in renewable energy.

utility $v(re)$ to the consumer at each period of time as energy services. The utility function $u(.)$ and $v(.)$ are assumed increasing and concave ($u' > 0$, $u'' < 0$, $v' > 0$ and $v'' < 0$).

Additionally to personal or direct gain, investments in energy efficiency and in renewable energy help to protect environment by reducing global CO2 emissions. Hence, household gets additional environmental-related satisfaction by investing in energy efficiency and in renewable energy. Doni and Ricchiuti (2013) considers the sensitivity of consumers for environmental improvements as depending on their degree of environmental awareness. Zhang et al. (2015) and Liu et al. (2012) explicitly model this sensitivity as the consumer environmental awareness. This formulation is also close to that of Ekholm et al. (2010) which considers that the consumer additionally gets some disutility from consuming inconvenient fuel. As investments in energy efficiency and in renewable energy positively contribute to reduce global CO2 emissions, by undertaking the two investments the consumer gets some additional satisfaction which depends on his pro-environmental motivation.

In the same vein, we assume that the additional environmental-related satisfaction depends on the household environmental sensitivity that is measured by a "pro-environmental index" and is denoted θ. Additionally, we consider the joint or cross effect of the two decisions in reducing CO2 emissions. The joint or cross effect can be defined as the cross derivative of the gross instantaneous utility U which is defined later in eq.2:

$$\frac{\partial^2 U}{\partial ee \partial re} = \frac{\partial^2 U}{\partial re \partial ee} = \theta > 0.$$

The marginal utility of investing in renewable energy (resp. energy efficiency) rises with investment in energy efficiency (resp. renewable energy). Therefore, this additional utility is high for environmental-friendly household who takes both decisions. We define it as $\theta ee * re$, where θ lies between 0 and 1.

Investments in energy efficiency and in renewable energy last for finite horizon of time[2]. Thus, the consumer cannot benefit infinitely from the two investments. We assume that the future gains from investment in energy efficiency is limited to p periods, while that of renewable energy is limited to q periods. The gross instantaneous utility of the household can be defined as:

$$U(ee, re, \theta) = u(ee)\mathbb{1}_p + v(re)\mathbb{1}_q + [\theta ee * re]\,\mathbb{1}_{min(p,q)}, \tag{2}$$

where $\mathbb{1}_i$ is an indicator function with $i \in \{p, q, min(p, q)\}$ defined as:

$$\mathbb{1}_i = \begin{cases} 1, & \text{if } t \leq i \\ 0, & \text{if } t > i \end{cases}.$$

The min(p,q) implicitly assumes that the consumer does no longer benefit from the cross effect ($\theta ee * re$) if the gain from one of the two investments disappears at the end

[2]Major renovations or refurbishment of residential building occur at 30-40 year intervals (Laustsen, 2008), while photovoltaic modules are usually guaranteed for a lifetime of 25 years (OECD/IEA, 2014).

of its lifetime. But the consumer still gets the direct gain ($u(ee)$ or $v(re)$) from the remaining investment until the end of its lifetime.

3.2 Optimal allocation

The household maximizes the discounted sum of instantaneous utilities defined in eq.2 subject to the energy budget constraint eq.1 with respect to investment in energy efficiency ee and investment in renewable energy re as follows:

$$\begin{aligned} \max_{ee,re} \quad & \sum_{t=0}^{p} \beta^t u(ee) + \sum_{t=0}^{q} \beta^t v(re) + \theta \sum_{t=0}^{min(p,q)} \beta^t ee * re \quad , \\ st \quad & R = k_1 ee + k_2 re \end{aligned} \tag{3}$$

where β is the discount factor. By replacing ee from eq.1 into the objective function of the programme (3), the first order condition with respect to re gives the following equation that defines the household optimal allocation of investments in energy efficiency and in renewable energy:

$$\frac{k_2}{k_1}\beta_p u^{'}\left(\frac{R - k_2 re^*}{k_1}\right) + \frac{k_2}{k_1}\theta\beta_{pq} re = \beta_q v^{'}(re^*) + \theta\beta_{pq}\left[\frac{R - k_2 re^*}{k_1}\right] = 0, \tag{4}$$

where $\beta_p = \sum_{t=0}^{p} \beta^t$, $\beta_q = \sum_{t=0}^{q} \beta^t$ and $\beta_{pq} = \sum_{t=0}^{min(p,q)} \beta^t$.

Equation (4) is an arbitrage condition. It states that the additional forgone utility by not investing in energy efficiency should be equal to the additional utility of investing in renewable energy. The marginal utility of investing in renewable energy has two components: direct marginal gain ($\beta_q v^{'}(re^*)$) and marginal satisfaction due to the cross effect ($\theta\beta_{pq}[\frac{R}{k_1} - \frac{k_2}{k_1} re^*]$). The additional forgone utility by not investing in energy efficiency has two components as well: additional direct forgone gain ($\frac{k_2}{k_1}\beta_p u^{'}([\frac{R}{k_1} - \frac{k_2}{k_1} re^*])$) and additional forgone satisfaction due to the cross effect ($\theta\beta_{pq}\frac{k_2}{k_1} re^*$).

In order to determine if the two decisions are substitutes or complements depending on the pro-environmental index θ, we focus on cross price elasticities[3]. Mainly, we analyze the sign of the cross price elasticity of the optimal investment in renewable energy which only depends on that of the derivative of the optimal level of investment in renewable energy with respect to the cost of investment in energy efficiency ($\frac{\partial re^*}{\partial k_1}$). A positive sign means that an increase in the cost of investment in energy efficiency will increase investment in renewable energy so that the two decisions are substitutes.

Proposition 1: *There is a threshold on the pro-environmental index θ below (resp. above) which investment decisions in energy efficiency and in renewable energy of the*

[3] The definition of complementarity and substitutability in this paper is based on price elasticity of demand because we aim at analyzing the decisions of a household who faces an energy budget constraint and costly investments in energy efficiency and in renewable energy. There exist other complementary vs substitutability concepts such as Fisher perfect complementarity, Edgeworth-Pareto complementarity (Samuelson, 1974).

household are substitutes (resp. complements).

The proof of proposition 1 is provided in appendix A. The threshold level of the pro-environmental index θ is given by:

$$\overline{\theta} = \frac{\beta_p[ee^* u^{"}(ee^*) + u^{'}(ee^*)]}{\beta_{pq}[\frac{R}{k_2} - 2re^*]}.$$

A household with a pro-environmental index lower than $\overline{\theta}$ substitutes one decision to the other, while a household with higher pro-environmental index adopts the two decisions. This can be explained by the fact that a less environmental-friendly household is more looking for energy saving in order to reduce his energy bill than contributing to reducing global emissions of CO2. While a more environmental-friendly household is getting additional satisfaction from protecting environment. This result is consistent with intuition in Ning and Yang (2006). In the latter, the household behaves like he has two decisions ee and re which are divided into two different sets S_1 and S_2 depending on their function. S_1 refers to energy saving or economic motive while S_2 refers to environmental protection motive. Decisions in the same set are substitutes and decisions across the two sets are complements. In the same vein, the decisions of a household with a low pro-environmental index are mostly for economic motives (S_1) and are then substitutes. While the decisions of a more environmental-friendly household are complements because they are guided by both economic and high environmental motivations (S_1 and S_2).

Let us now focus on the effect of the energy budget on this threshold level of pro-environmental index $\overline{\theta}$.

Proposition 2: *A household with a higher energy budget has a higher (resp. lower) threshold on the pro-environmental index $\overline{\theta}$ if his inter-temporal elasticity of substitution in investment in energy efficiency is high (resp. low).*

We provide the proof of proposition 2 in appendix B.

Proposition 2 states that for a household with a high inter-temporal elasticity of substitution, an increase in the household energy budget increases the threshold of the pro-environmental index under which the two investments decisions are substitutes. In fact, a high inter-temporal elasticity of substitution means that the substitution effect between investments in energy efficiency and in renewable energy is greater that the energy budget effect. Therefore, an increase in the energy budget of household enlarges the possibilities of substitution between investments in energy efficiency and renewable energy.

We claim the following corollary:

Corollary: *For a household with a high (resp. low) inter-temporal elasticity of substitution, there exist levels of energy budget R_1 and R_0 such that: (i) for energy budget* *higher than R_1, the two investments decisions are substitutes (resp. complement) and (ii) for energy budget lower than R_0, the two investments decisions are complements (resp. substitutes).*

The proof of the above corollary is straightforward from proposition 2 since the pro-environmental index lies between 0 and 1. A household with a high inter-temporal elasticity of substitution and energy budget higher than R_1 could not have a pro-environmental index higher than the corresponding threshold level $\overline{\theta} = 1$. Also, if the inter-temporal elasticity of substitution is high, a household with energy budget lower than R_0 could not have a negative pro-environmental index.

4 Empirical analysis

In this section, we first present the data and methods that are used. Second, we present the bivariate probit model (biprobit) to analyse the joint decision of renewable energy adoption and investment in energy efficiency. Third, we focus on interaction between renewable energy adoption and investment in energy efficiency using the generalized ordered logit model.

4.1 Data and Method

4.1.1 Data

We use the two rounds large-scale household surveys of Environmental Policy and Individual Beharviours changes (EPIC) that were conducted by the Organisation for Economic Cooperation and Development (OECD). The two rounds focus on five thematic areas (energy, food, transport, waste and water) and aim at understanding household's reactions to different environmental policies, the interactions of these policies and the role of household's attitudes towards environment (Serret and Brown, 2014). Information were collected on household's characteristics (age, income, education), their environmental attitudes (environmental concerns), their perception, etc., using an internet-based questionnaire.

The first round of EPIC survey was carried out in January-February 2008 in ten OECD countries (Australia, Canada, France, Korea, Netherlands, Sweden, Czech Republic, Italy, Norway and Mexico.). The sample size was approximately 1,000 households in each country for a total of 10,251 households. In 2011, the same survey was carried out in six same countries as in 2008 (Australia, Canada, France, Korea, Netherlands and Sweden) and in five additional countries (Chile, Japan, Spain, Israel and Switzerland.). As in the first round, approximately 1,000 households were interviewed in each country for a total of 12,202 households. The sample of the two rounds are 22,453 households. The dataset of the 2011 EPIC survey is richer than that of 2008 because it includes additional news areas such as eco-innovation, knowledge, policy preferences and country-specific questions. Unfortunately, we could not use this additional information in this paper because we intend to use the two datasets to account for time variation. Then, we need to use the same types of information (variables) on the household's behaviour across the two rounds surveys. As the same respondent cannot be identified in the EPIC survey from 2008 to 2011, we decide to pool the two datasets for the fifteen countries and to control for the effect of year. Note that efforts are made to avoid sample bias through stratification (age, gender, etc.) and quota sampling with a large geographical coverage [4]. Also, the two rounds are independent surveys and each represents a random sample from the population. Then, there is no correlation in the error terms within the observations of each survey.

We use data from the energy section (Part E) that we combine with socio-demographic characteristics (Part A), Attitudinal characteristics (Part B). More precisely, in the energy section we mainly focus on questions that concern the adoption of renewable energy (solar panels, wind turbines, hydro, etc.) and monetary investments (Energy-efficiency-rated appliances, low-energy light bulbs, etc.) in energy efficiency. For robustness check, we additionally consider non-monetary investments (turn off lights when leaving a room, cut down on heating or air conditioning, turn off appliances when not in use, switch off standby mode of appliances or electronic devices, etc.) that help to reduce the consumption of energy as well. Both independent and dependent variables that are used in this paper are described in the following section (section 4.1.2).

4.1.2 Description of variables

The dependent variables are constructed from questions related to renewable energy adoption and investments in energy efficiency. In the two rounds surveys, a question was asked and identifies households that installed over the past ten years in their current primary residence, a renewable energy equipments (Solar panels for electricity or hot water and Wind turbines). Households can answer that they installed renewable energy items or that the residence was already equipped. As we focus on the decision to adopt renewable energy, we do not consider households in which the residence was already equipped. We cross the information on the installation of renewable energy items with the source of electricity that the residence uses. We consider that the household stating that the energy from electricity provider is already from renewable energy sources (EPIC 2008) or that they have chosen the "renewable or green" energy tariff from their electricity provider (EPIC 2011), has adopted renewable energy as well. Additionally, the 2011 survey provides a refinement giving some information on household that uses thermal solar panel for water heating, who is considered as having adopted renewable energy as well.

The EPIC surveys provide information on monetary investment in energy efficiency such as: top-rated energy-efficient appliances, low-energy light bulbs, energy-efficient windows, thermal insulation of walls or roof, etc.). Households were asked whether or not they installed energy efficiency items over the past ten years in their current primary residence. As before, we only consider own installed items and not already installed items as adoption of energy efficiency items to reduce the use of energy. The EPIC surveys also provide information on behaviour changes to reduce the use of energy that we

[4] For more details, see OECD (2011, 2014).

call non-monetary investments in energy efficiency. Households were asked how often in their daily life, they adopt behaviours that could help to reduce their energy use such as: cutting down on heating or air conditioning, switching off standby mode of appliances or electronic devices (TV, computer), air dry laundry rather than using a clothes dryer, etc. For robustness check, we include later on non-monetary investments in energy efficiency that we combine with monetary investments in energy efficiency. Whether the household invests in energy efficiency by using a part of his income or makes efforts to reduce his consumption of energy towards behaviours changes, in the end it reduces its consumption of energy.

There is no evidence in the literature about the importance of either socio-economic and residential variables or attitudinal and perception variables in the decision of household to adopt renewable energy or to invest in energy efficiency. We decide to include in our independent variables, some variables that are available in the two EPIC datasets and can also be useful for policy recommendations. We consider three categories of characteristics. First, we use socio-economic and residential variables such as gender, age, income of household, characteristics of the residence, etc. The size of the residence and the type of residence (attached or collective residence) are used as proxies for the characteristics of the residence. Second, we consider perception, vote in elections, trust and commitment in any local, charitable or environmental organization as attitudinal variables. Third, some variables are also related to the energy use: individual metering, peak price of electricity, factors that encourage to reduce energy consumption, etc. Finally, we control for the year. The full description of the independent variables that are used and the summary statistics are presented in appendix C.

4.1.3 Method

We use the two rounds surveys of EPIC in 2008 and in 2011 and our analysis focuses on the fifteen countries. The two rounds are independent surveys and each represents a random sample from the population. Then, there is no correlation in the error terms within the observations of each survey. Moreover, as the same respond cannot be identified in the EPIC survey from 2008 to 2011, we decide to pool the two datasets and to control for the effect of year of survey.

The household faces two different decisions that contribute to energy transition. It can decide whether to invest or not in renewable energy. It can also decide whether or not to invest in energy efficiency. Then, the household has two decisions that could be related. For instance, the household that is pro-environmental may have high incentives to protect environment and then to decide to make additional effort to invest in renewable energy (resp. in energy efficiency) if he has already invested in energy efficiency (resp. in renewable energy). In this case, the two decisions are positively related. On the contrary, the two decisions can be negatively related in the case a household is financially constrained to invest in energy efficiency (resp. in renewable energy) if he invests in renewable energy (resp. in energy efficiency). Although the two decisions do not directly depend on each other, their errors terms may be correlated. Following, Cameron and

Trivedi (2010), we first use bivariate probit model that accounts for the joint decisions based on their correlation and provide more-efficient estimator. Note that the probit model assumes that unobservable variables and residuals are normally distributed and independent of the explanatory variables. The general specification of the model is:

$$re^* = X_1^{'}\beta_1 + \epsilon_1$$

and

$$ee^* = X_1^{'}\beta_1 + X_2^{'}\beta_2 + Z_1^{'}\beta_3 + \epsilon_2,$$

where re^* and ee^* are latent variables (resp. investment in renewable energy and investment in energy efficiency), which determine the observed binary outcomes re (decision to adopt a renewable energy) and ee (decision to invest in an energy efficiency) such that $j = 1$ if $j^* > 0$ and $j = 0$ otherwise, with $j \in \{ee, re\}$. X_1 denotes the vector of regressors (economic and residential variables; variables of perception, commitment and trust; etc.) that determine both re^* and ee^*. X_2 denotes the vector of regressors that are only related to energy use (implicitly related to energy efficiency), while Z_1 are the vector of regressors (characteristics of residence) that directly affect ee^* but not re^* (exclusion variables). Moreover, the error terms ϵ_1 and ϵ_2 are assumed to be jointly normally distributed with means 0, variances of 1 and correlations of ρ.

Additionally, we use the ordered probit/logit model to account for the interaction between the two decisions. More precisely, we focus on factors that affect the joint probability of adopting renewable energy and investing in energy efficiency and that of doing nothing. In fact, we intend to explain why some households decide to invest both in energy efficiency and in renewable energy, while others decide to only invest in renewable energy or to only invest in energy efficiency or to do nothing. Then, the household that only adopts renewable energy or only reduces his energy consumption (i.e $re = 1$ and $ee = 0$ or $re = 0$ and $ee = 1$) contribute to the energy transition better than the household who does nothing (i.e $re = 0$ and $ee = 0$) and less than the one who undertakes the two investments (i.e $re = 1$ and $ee = 1$) . In this case, the ordered probit/logit model is appropriate because the outcomes can be ranked and its general specification can be written as:

$$eere^* = X^{'}\beta + \epsilon,$$

where there exist thresholds values α_c such that $eere = c$ if $\alpha_{c-1} < eere^* < \alpha_c$, for $c = 1, 2, 3$. Moreover, $eere = 1$, $eere = 2$ and $eere = 3$ correspond respectively to no investments (i.e $re = 0$ and $ee = 0$), investment in either renewable energy or energy efficiency (i.e $re = 1$ and $ee = 0$ or $re = 0$ and $ee = 1$) and investments in both re and ee (i.e $re = 1$ and $ee = 1$). X denotes the vector of regressors that includes X_1, X_2 and Z_1 and ϵ is standard normally (resp. logistically) distributed for ordered probit (resp. logit).

4.2 Joint decision of renewable energy adoption and investment in energy efficiency.

Table 1 below displays the cross repartition of the two decisions of renewable adoption and investment in energy efficiency.

Table 1: **Investment in energy efficiency by adoption of renewable energy**

	Adoption of renewable energy		
Investment in energy efficiency	no	yes	Total
no	1,967	551	2,518
yes	10,423	1,698	16,301
Total	12,390	6,429	18,819

According to table 1, 87% of the sample invest in energy efficiency. Then, a large majority of household undertake monetary investments in energy efficiency. On contrary, only 34% adopt renewable energy by installing their own solar panel or wind turbines or by subscribing to green energy from the electricity provider. Cross analysis shows that among those who invest in energy efficiency, only 10.4% of households additionally adopt renewable. There are 11% of households who decide neither to adopt renewable energy, nor to invest in energy efficiency. Finally, very few households in the sample (2%) adopt renewable energy without investing in energy efficiency. There are then good reasons to believe that the two decisions may be correlated. To check this, we provide the correlation between the decision to adopt renewable energy and that of investing in energy efficiency.

Table 2: Cross-correlation table

Variables	Adoption of re energy	Investment in ee
Adoption of re	1.000	
Investment in ee	0.1018	1.000

The correlation coefficient of 0.1018 is positive and different from zero (table 2). Following, Cameron and Trivedi (2010), we use bivariate probit model that accounts for the joint decisions based on their correlation and provide more-efficient estimator. First, we check for the validity of the residence characteristics as exclusion variables and the results are presented in table 3. We find that both the size of residence and living in a non-detached residence significantly affect the decision to invest in energy efficiency and has no effect on the decision to invest in renewable energy. Second, we check whether the bivariate probit model is necessary. The result from the bivariate probit provides the test of the null hypothesis that the true correlation coefficient is equal to 0 and justifies the importance of using bivariate probit model instead of estimating the two decisions separately. Our results reject the null hypothesis of the correlation coefficient at 1% (Prob>chi2=0.0000). Then, bivariate probit model is more appropriate than separate univariate probit models because the two decisions are interrelated and cannot be estimated independently. As a result, univariate methods that estimate separately the two decisions of renewable adoption and energy efficiency potentially produce biased results because it may exist unobserved characteristics that determine the two decisions. We then provide the results of the separate estimation for the probit models as benchmark together with the results of the bivariate probit model in table 5. The two estimations do not give the same results and confirm that the bivariate probit is more appropriate than the separate estimation of the two probit models.

Table 3: Validity of exclusion variables

	(Probit) ee	(Probit) re
Living in a non-detached residence	-0.0726**	-0.0241
	(0.0364)	(0.0248)
Size of the residence	0.0645***	-0.00598
	(0.0232)	(0.0166)
N	11198	16471

Standard errors in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Third, we perform the goodness of fit and prediction test in order to evaluate how well the model fits the observations. We then compare the predicted probability with sample frequencies that is summarized in table 4. We find that the predicted probability is close to the frequency of the sample. Additionally, we compare predicted outcomes with actual outcomes and find that the percentage of correctly specified values which is also called the rate of prediction is high (53.22 %).

Table 4: Comparison of predicted probabilities with sample frequencies

Variable	**Mean of Prob**	**Frequency**
re=1	0.40	0.34
ee=1	0.89	0.87
re=0 and ee=0	0.08	0.11
re=0 and ee=1	0.51	0.56
re=1 and ee=0	0.03	0.02
re=1 and ee=1	0.38	0.31

We can now turn to the interpretation of the results of the bivariate probit model which focuses on the residential characteristics, the economic and environmental motivations, split incentive issues and how to sensitize people to the issues of energy transition.

The results show that there is a positive interrelation between the decisions of the household to invest in energy efficiency and to adopt renewable energy due to unobserved characteristics such as environmental motivations. In fact, motivations are derived from households' declarations in which they were asked to give their importance regarding many types of problems including environmental issues. Thus, the environmental conscientiousness as a true environmental motivation is not observed and may lead to such positive correlation in the sense that a more pro-environmental household is more likely to invest in energy efficiency and in renewable energy.

The income of household has a positive and significant effect on the decision of household to invest in energy efficiency, while there is no significant effect on their decision to adopt renewable energy. People living in wealthier household are more likely to invest in energy efficiency as found in Urban and Scasny (2012). As investments in energy efficiency such as home renovation and energy saving technologies are costly, household with high income has high financial capacity to afford them and to benefit from the reduction of the energy bill. Then, people living in poorer household may end up using a high share of their income to pay electricity. This is referred to as energy poverty (Bird and Hernandez, 2012). Unexpectedly, income has no significant effect on the adoption of renewable energy as in shi et al. (2013) for some countries and not consistent with the results in Zoric and Hrovatin (2012). This can be explained by the existence of many financial supports in several countries to promote renewable energy. On contrary, investment in energy efficiency includes energy-efficient appliances or low-energy light bulbs for instance, which benefit less from financial supports that mainly target home renovation. Additionally, household benefits from policy mechanisms such as feed-in tarif, which allows them to sell their renewable energy at a price based on its cost of generation. This may give them additional incentive for renewable energy investments. Also, household can directly buy green electricity from their electricity provider, which may avoid huge investments and may be profitable in a short term.

Ownership positively affects the adoption of renewable and investment in energy efficiency. The fact that the household owns the residence increases his probability to undertake investments in energy efficiency and in renewable energy. This is intuitive in the sense that investment in renewable energy generation such as solar panels or wind turbine and in home renovations are mostly profitable after many years of use (30-40 years for home renovations and 25 years for photovoltaic modules). Such investments are then risky in the case of a short stay. Although there is a possibility to move solar or wind installations, dismantling and re-installation are costly and maybe very problematic. Therefore, without certainty to stay longer a tenant will have less incentives to undertake investment in renewable energy. In literature, this is commonly referred to as the 'split incentive' (Bird and Hernandez, 2012), which is a barrier to energy efficiency. The novelty is that our results also show the presence of this barrier for the renewable energy adoption. Regarding the dwelling characteristics, we find that there is significant effect of the type of dwelling and its size on the decision of the household to invest in energy efficiency and no effect on their decision to adopt renewable energy. A household living in a non-detached dwelling is less likely to invest to reduce its energy consumption. As shown in Santin et al. (2009), a non-detached dwellings use less energy than detached dwellings. In this sense, household living in such non-detached dwellings has less incentive to reduce its energy consumption. Similarly, Sardianou (2008) finds that dwelling's size positively affects the energy use. As suggested by our results, a household with a bigger dwelling has more incentive to reduce its electricity consumption and is more likely to invest in energy efficiency.

It is important to understand more how sensitive people are or their motivations in order to design appropriate communication policy to sensitize them on the energy transition. More specifically, the opinions of household can help to target specific environmental issues that would serve to boost both the adoption of renewable energy and the reduction of energy use. In this paper, we make a distinguish between environmental problems as general issue and specific environmental problems such as climate change, resource depletion, pollution, etc. The former is compared to other general issues such as unemployment, economic crisis, etc. Acceptedly, this consideration of environmental motivation which is a proxy may not correspond to the true environmental conscientiousness which is a private information. Our results show that environmental motivations have mixed effects on both investment in energy efficiency and adoption of renewable energy. Namely, people who think that environmental issues are generally more important than other issues (unemployment, economic crisis, etc.) are more likely to invest in renewable energy. This is consistent with results in Gerpott and Mahmudova (2010) and Zoric and Hrovatin (2012). Investments in renewable energy are mostly undertaken to reduce CO2 emissions and less probably to save money. People for whom environmental issues are the priority and who are aware that renewable energy is an alternative energy that is clean and helps protect environment, will have more motivations to overcome barriers that they may encounter to adopt renewable energy. On contrary, additionally to reduce CO2 emissions, investments in energy efficiency are also for money saving. Then, people who intend so save their energy bill can have motivations to invest in energy efficiency as well as people who are pro-environmental. Therefore, it does not have a significant effect on their investment decision in energy efficiency. However, when it comes to compare specific environmental issues between themselves, people who think that climate change problem is the priority are more likely to invest in energy efficiency, while those who choose resource depletion problem as priority are less motivated to invest in energy efficiency. They may prefer alternatives energy which do not rely on depletable energy resources. Though there is no significant effect of resource depletion issues on investment in renewable energy, the coefficient is positive.

It is also interesting to identify the ways policy may affect how people behave. Commitment is important in the sense that it may help to identify targeted people through organisation, events, etc. As in the case of general environmental issue, we find that commitment in environmental organization (donation or physical participation) has no significant effect on decision of households to invest in energy efficiency while it has positive effect on their decision to adopt renewable energy. Moreover, commitment in local and charitable organizations positively affect the two decisions. In fact, energy issues can be related to public good and also treated as a local problem. Mostly, people participate in environmental organisation in order to protect environment which itself is a public good. As a renewable energy is not polluting and then not negatively affecting environment, they may have more incentives to consume cleaner electricity. Moreover, an altruist who participates in a charitable organization is more likely to be favourable to any types of investments such that in renewable energy or in energy efficiency that could help to reduce CO2 emissions which is profitable for future generations. Also, some environmental problems related to energy use like air pollution are local issues and may have a great interest for local organization. In the same vein, people who participate to local vote show their attachment to their locality and are more willing to invest in energy efficiency. Trust in sources of information about the environmental impacts of products is another way to affect their behaviour. We find that trust in researchers, scientists and experts has positive effect on the two decisions, while trust in local or national authorities has positive effect only on the adoption of renewable energy. As there is a large consensus between scientists regarding the negative consequences of using a polluting energy and also the importance of saving energy and adopting cleaner energy, people who trust them are more likely to invest in the two.

Additionally, we focus on some specific energy-related considerations. As expected, we find that people who take into account the cost of electricity before renting or buying a house are more likely to invest in energy efficiency, while there is no significant effect on the adoption of renewable energy. The intuition is that people who do not care much the cost of electricity before renting or buying a house may have less motivation to reduce their energy bill and are then less likely to invest in energy efficiency. The fact that the household has access to differentiated electricity rate for peak time and off-time does not significantly affect their decision to invest in energy efficiency. Although peak tariff may help to reduce the energy bill, it has some disadvantages such as effort and time that are needed to schedule the use of energy and the fact that people cannot use electricity at their most convenient time. Surprisingly, paying according to the amount of electricity (for instance through individual electricity metering) does not significantly affect the decision of household to invest in energy efficiency. Though investment in energy efficiency maybe more profitable if there is an individual electricity metering which avoid free-riding behaviours, people may have others motivations than reducing their own energy bill.

For robustness check, we extend energy efficiency to non-monetary investments also called curtailments. In this sense, we now focus on energy conservation actions that can be both monetary and non-monetary investments. Almost 9% of our sample adopts curtailment behaviours and do not adopt monetary investments in energy efficiency. The results are presented in see table 11 (in appendix C). We find that this consideration mostly affects the results of energy conservation. Mainly, size of residence, income, commitment in charitable and local organizations, and taking into account energy costs before buying or renting a house become non significant. In fact, most of these variables are related to the monetary capacity of the household. Potentially, as the curtailment behaviours are not guided by financial capacity, the energy conservation decision of the household may not be affected by those variables. Also, in order to check the robustness of our results with respect to attitudinal characteristics such that perception, commitment and trust, we compare the results with and without the consideration of attitudinal characteristics. We find that there is no change in the significance of the other

Table 5: Estimation of Probit and Bivariate probit Models

	Probit		Biprobit	
Variables	ee	re	ee	re
Residential and economic variables				
Living in a non-detached residence	-0.0726**		-0.0695*	
	(0.0364)		(0.0364)	
Size of the residence	0.0645***		0.0657***	
	(0.0232)		(0.0233)	
Income of household	0.0267***	0.00198	0.0270***	0.00231
	(0.00629)	(0.00400)	(0.00630)	(0.00509)
Owner	0.152***	0.135***	0.151***	0.108***
	(0.0383)	(0.0243)	(0.0383)	(0.0322)
Perception, commitment and trust				
Environmental concerns (general issues)	-0.00711	-0.0203***	-0.00767	-0.0250***
	(0.0105)	(0.00683)	(0.0105)	(0.00885)
Climate change issues	-0.0662**	0.0668***	-0.0649**	0.0797***
	(0.0268)	(0.0194)	(0.0267)	(0.0245)
Resource depletion issues	0.0745**	-0.0302	0.0747**	-0.0426
	(0.0292)	(0.0215)	(0.0292)	(0.0273)
Participation in local vote	0.0776**	0.0741***	0.0788**	0.0296
	(0.0369)	(0.0245)	(0.0369)	(0.0325)
Commitment in charitable organization	0.151***	0.115***	0.147***	0.122***
	(0.0413)	(0.0250)	(0.0412)	(0.0319)
Commitment in environmental organization	0.0575	0.138***	0.0565	0.134***
	(0.0486)	(0.0312)	(0.0486)	(0.0389)
Commitment in local organization	0.116**	0.0674**	0.115**	0.0918**
	(0.0476)	(0.0301)	(0.0475)	(0.0370)
Trust in scientists	0.0541***	0.0794***	0.0549***	0.0818***
	(0.0146)	(0.0116)	(0.0147)	(0.0146)
Trust in local authorities	0.00182	0.0160	0.00202	0.0332***
	(0.0136)	(0.0100)	(0.0136)	(0.0124)
Energy use				
Energy costs before buying or renting a house	0.105***	0.00902	0.103***	0.00844
	(0.0367)	(0.0239)	(0.0367)	(0.0308)
Individual metering	0.0831		0.0700	
	(0.0860)		(0.0856)	
Peak Tariff	0.0219		0.0472	
	(0.0331)		(0.0333)	
Label to reduce energy use	0.183***		0.172***	
	(0.0562)		(0.0561)	
rho			0.1618***	
			(0.0234)	
Log pseudolikelihood	-3680.8267	-9217.5155	-9183.1129	
Pseudo R2	0.0586	0.2295		
Observations	11198	18158	11198	

***1%, **5%, *10% and ()= robust std errors.

variables and in the sign of the effects except for the peak tariff which become significant at 10%. Also, there is only slight difference in the coefficients of these variables (see table 10 in appendix C).

4.3 Interaction between renewable energy adoption and investment in energy efficiency.

In this section, we are interested in the interaction between the two decisions of adopting renewable energy and of investing in energy efficiency. Basically, we intend to explain why some households decide both to invest in energy efficiency and also to invest in renewable energy, while others decide to only invest in renewable energy or to only invest in energy efficiency or to do nothing. As a result, the household has four possible choices. It can decide (i) both to reduce the energy use and to invest in RE, (ii) to only invest in RE, (iii) to only reduce its own energy consumption or (iv) do nothing. In fact, it is difficult to rank the two decisions of only adoption of renewable energy or only reduction of energy consumption. Also, Table 1 shows that only very few households (2%) adopt only renewable energy without investing in energy efficiency. Then, we combine the two outcomes. The implication is that the household that only adopts renewable energy or only reduces his energy consumption contribute to the energy transition better than the household who does nothing and less than the one who jointly adopts renewable energy and invests in energy efficiency. The outcome variable can then take three different values: 3 for both adoption of renewable energy and investment in energy efficiency, 2 for adoption of renewable energy or investment in energy efficiency and 1 for none of them.

The ordered probit (oprobit) and ordered logit (ologit) methods are good candidates for the estimation of our model. First, we base our choice on AIC, BIC and log-likelihood criteria. As suggested by table 6, the ologit method is the best for our model because it has the lower AIC and BIC and the higher log-likelihood. Second, we test the significance of cut points cut1 and cut2 for the ologit and find that cut2 is significant and different from cut1 (table 7). So, the three categories should not be collapsed into two categories. Third, we perform the Brant test that checks the assumptions of the parallel-lines. The Brant test shows that the assumptions of the parallel-lines model are violated (table 7). Therefore, the parameters of the ordered logit change for different categories of the outcome (eere) and their interpretations are wrong. Following Williams (2006), we use a generalized ordered logit (gologit) method that offers an ordinal alternative in which the parallel-lines assumption is not violated.

Table 6: Statistics of ologit and oprobit

Model	Obs	ll(null)	ll(model)	df	AIC	BIC
oprobit	11198	-10063.62	-8376.696	32	16817.39	17051.74
ologit	11198	-10063.62	-8279.595	32	16623.19	16857.54

Before going into details of the estimation results, we perform the goodness of fit and prediction test in order to evaluate the fit of the gologit model. As before, the frequency

Table 7: Test on cut1 and cut2 and Brant test for ologit

cut1=0	cut2=0	cut1-cut2=0	Brant test (all)
0.2142035	4.029378***	-3.815174***	418.91 ***

***1%, **5%, *10%

of the sample is compared with the predicted probability summarized in table 8. We find that the two results are close to each other. Also, the comparison of predicted outcomes with actual outcomes gives a high rate of prediction (69.05 %).

Table 8: Comparison of predicted probabilities with sample frequencies

Variable	**Mean of Pred Prob**	**Frequency**
re=0 and ee=0	0.08	0.11
re=0 and ee=1; re=1 and ee=0	0.54	0.58
re=1 and ee=1	0.38	0.31

The results of the gologit model are presented in table 9. The results show that significance and the sign of the effect are the same for the two categories regarding income of household, ownership, commitment in charitable and in local organizations, trust in scientists, taking into account energy costs before buying or renting a house, peak tariff and importance of label to reduce energy use. For instance, people living in wealthier household are more likely to jointly invest in energy efficiency and in renewable energy if they have undertaken any of these investments, and if not, they are more likely to undertake one of the investments as well. Undertaking investments in both energy efficiency and renewable energy is costly. As argued before, people living in wealthier household have higher financial capacity and are more likely to combine the two investments. Therefore, such investments are not affordable for poorer households which are vulnerable, and it may limit their contribution to the energy transition. In the same vein, tenants are less likely to combine the two investments due to split incentives. This limitation can be overcome by environmental motivations. In this sense, people who have already undertaken one of the investments and for whom environmental issues are generally more important than non-environmental issues are more likely to have additional motivation to deal with barriers that could refrain them from fully contributing to the energy transition.

Household that has already undertaken one of the investments and living in detached dwelling is more likely to make additional effort to invest in the second, while there is no significant effect of the size of the residence. We also find a positive effect of participation in charitable, environmental and local organizations, and trusts in scientists and local authorities. People who are involved in such organizations and have already undertaken one of the investments, are more likely to understand the importance of the energy transition, which itself is related to environmental and local problems and intergenerational equity. Moreover, scientists or national or local authorities are the most suitable to communicate on the energy transition. Therefore, people who trust in them

Table 9: Generalized ordered logit (gologit) estimation

Variables	Gologit eere=1	eere=2
Residential and economic variables		
Living in a non-detached residence	-0.115	-0.103**
	(0.0806)	(0.0520)
Size of the residence	0.114**	0.00739
	(0.0494)	(0.0343)
Income of household	0.0455***	0.0162*
	(0.0143)	(0.00901)
Ownership	0.265***	0.184***
	(0.0817)	(0.0564)
Perception, commitment and trust		
Environmental concerns (general issues)	-0.0330	-0.0365**
	(0.0241)	(0.0150)
Climate change issues	-0.0663	0.102**
	(0.0545)	(0.0422)
Resource depletion issues	0.0886	-0.0165
	(0.0600)	(0.0482)
Participation in local vote	0.174**	0.0698
	(0.0789)	(0.0549)
Commitment in charitable organization	0.308***	0.230***
	(0.0978)	(0.0539)
Commitment in environmental organization	0.157	0.275***
	(0.105)	(0.0676)
Commitment in local organization	0.308***	0.178***
	(0.113)	(0.0628)
Trust in scientists	0.125***	0.121***
	(0.0308)	(0.0265)
Trust in local authorities	0.0227	0.0402*
	(0.0299)	(0.0224)
Energy use		
Energy costs before buying or renting a house	0.144*	0.0946*
	(0.0801)	(0.0525)
Individual metering	0.334*	0.0507
	(0.172)	(0.129)
Peak Tariff	-0.120*	-0.557***
	(0.0724)	(0.0483)
Label to reduce energy use	0.364***	0.375***
	(0.111)	(0.104)
Pseudo R2	0.1955	
Log pseudolikelihood	-8096.1711	
Observations	11198	

***1%, **5%, *10% and ()= robust std errors.

are more likely to invest in both energy efficiency and renewable energy. The results also show that people who take into account energy cost before renting or buying a house are more likely to combine investments in energy efficiency and renewable energy, and less likely to do nothing. Though, it has no effect on the decision to adopt renewable energy and a positive effect on the decision to invest in energy efficiency (biprobit). Contrary to the biprobit model, having access to peak tariff has negative effect while having individual metering positively affect the decision of household if they have not undertaken any of the investments.

5 Conclusion

It may be of great interest for policy implications, to investigate the possible interactions between decisions of household to invest in energy efficiency and in renewable energy, due to the synergies that exist between the two. This paper fills this gap in literature and first uses a simple theoretical model to show that there exist interactions between the two decisions depending on a threshold of the pro-environmental index of the consumer. Second, using a bivariate probit model the paper empirically shows that there is a positive interrelation between the decisions of the household to invest in energy efficiency and to adopt renewable energy due to unobserved characteristics such as environmental motivations. As a result, univariate methods that estimate separately the two decisions of renewable adoption and energy efficiency potentially produce biased results. Moreover, the paper provides evidence on factors that affect the probability of adopting renewable energy and that of investing in energy efficiency. Notably, people living in poorer household are less likely to invest in energy efficiency and may end up using a high share of their income to pay electricity. In literature, it is referred to as energy poverty. There is evidence of split incentives: the ownership positively affects the two probabilities to invest in renewable and in energy efficiency.

Regarding the dwelling characteristics, we find that there is significant effect of the type of dwelling and its size on the decision of the household to invest in energy efficiency and no effect on their decision to adopt renewable energy. Also, environmental motivations and commitment have mixed effects on both investment in energy efficiency and adoption of renewable energy. Trust in researchers, scientists and experts has positive effect on the two decisions. Third, we investigate the determinants of the interaction between the two decisions by using the generalized ordered logit model. We find that, people living in wealthier household are more likely to jointly invest in energy efficiency and in renewable energy if they have undertaken any of these investments, and if not, they are more likely to undertake one of the investments as well. In the same vein, tenants are less likely to combine the two investments due to split incentives. This limitation can be overcome by environmental motivations. In this sense, people who have already undertaken one of the investments and for whom environmental issues are generally more important than non-environmental issues are more likely to have additional motivation to deal with barriers that could refrain them from fully contributing to the energy transition. Also, there is a positive effect of participation in charitable, environmental and local organizations, and trusts in scientists and local authorities.

As policy implications, first one should consider the two decisions when designing incentive instruments for renewable energy adoption and for energy efficiency investment in order take advantages on the synergies between the two decisions. Second, regulation of housing markets could help to solve split incentives in order to give incentives to tenant to undertake investments in energy efficiency and in renewable energy as well. Financial supports to reduce the costs for dismantling and for re-installation of renewable energy equipments could give incentives to tenants to undertake such investments as well. However, there exist many others factors which we do not consider in this paper and that may limit tenants to install renewable energy equipment. For instance, living in an apartment without balcony, having limited space on rooftop, etc. may limit the possibility to install renewable energy equipments. Third, policies targeting investments in energy efficiency need to be improved. In many countries, financial supports on energy conservation systems are mostly profitable for wealthier households. As household needs to first invest before applying for the reimbursement, poorer households are financially limited and investments are not affordable to them. Therefore, it is necessary to set green grants which should be an interest-free eco-loan that target only energy poor households. Fourth, it may be of great interest to take advantages on existing charitable, local and environmental organisations to communicate with their members on the importance of energy transition. These members have large predisposition to better understand the crucial contribution of the energy transition in protecting the environment. Moreover, scientists or national or local authorities are the most suitable to communicate on the energy transition. Therefore, they should be more involved in sensitization and academic findings should be more vulgarized as well.

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7 Appendices

7.1 Appendix A

The household solves the following programme.

$$\begin{array}{ll} \max\limits_{ee,re} & \sum\limits_{t=0}^{p} \beta^t u(ee) + \sum\limits_{t=0}^{q} \beta^t v(re) + \theta \sum\limits_{t=0}^{min(p,q)} \beta^t ee * re \\ st & R = k_1 ee + k_2 re \end{array},$$

From the energy budget constraint eq.1, we can deduce investment in energy efficiency ee as a function of investment in renewable energy re:

$$ee(re) = \frac{R}{k_1} - \frac{k_2}{k_1} re.$$

Then, the programme that the consumer solves can be rewritten as:

$$\max_{re} \quad \sum_{t=0}^{p} \beta^t u(\frac{R}{k_1} - \frac{k_2}{k_1} re) + \sum_{t=0}^{q} \beta^t v(re) + \theta \sum_{t=0}^{min(p,q)} \beta^t [\frac{R}{k_1} * re - \frac{k_2}{k_1} re^2].$$

The first order condition with respect to re gives:

$$-\frac{k_2}{k_1}\beta_p u^{'}\left(\frac{R - k_2 re^*}{k_1}\right) - \frac{k_2}{k_1}\theta\beta_{pq} re + \beta_q v^{'}(re^*) + \theta\beta_{pq}\left[\frac{R - k_2 re^*}{k_1}\right] = 0, \quad (5)$$

where $\beta_p = \sum_{t=0}^{p} \beta^t$, $\beta_q = \sum_{t=0}^{q} \beta^t$ and $\beta_{pq} = \sum_{t=0}^{min(p,q)} \beta^t$.

After arranging equation (5), we can derive an implicit function Q for re^* defined as follows.

$$Q \equiv -\frac{k_2}{k_1}\beta_p u^{'}(ee^*) + \beta_q v^{'}(re^*) + \theta\beta_{pq}[\frac{R}{k_1} - 2\frac{k_2}{k_1} re^*] = 0$$

We use this implicit function Q to derive the derivative of the optimal level of investment in renewable energy with respect to the cost of investment in energy efficiency. Taking total derivative of Q, we get:

$$\frac{\partial Q}{\partial re^*} dre^* + \frac{\partial Q}{\partial k_1} dk_1 = 0,$$

where

$$\frac{\partial Q}{\partial re^*} = \underbrace{\frac{k_2^2}{k_1^2}\beta_p u^{''}(ee^*)}_{<0} + \underbrace{\beta_q v^{''}(re^*)}_{<0} + \underbrace{-2\frac{k_2}{k_1}\beta_{pq}\theta}_{<0} < 0$$

and

$$\frac{\partial Q}{\partial k_1} = \frac{k_2}{k_1^2}[\beta_p u^{'}(ee^*) + \beta_p ee^* u^{''}(ee^*) - \beta_{pq}\theta(\frac{R}{k_2} - 2re^*)].$$

We can then deduce that:

$$\frac{\partial re^*}{\partial k_1} = -\frac{\frac{\partial Q}{\partial k_1}}{\frac{\partial Q}{\partial re^*}}.$$

The sign of $\frac{\partial re^*}{\partial k_1}$ depends on the sign of $\frac{\partial Q}{\partial k_1}$. We have the following condition:

$$\frac{\partial Q}{\partial re^*} > 0 \iff \theta < \overline{\theta} = \frac{\beta_p[ee^* u^{''}(ee^*) + u^{'}(ee^*)]}{\beta_{pq}[\frac{R}{k_2} - 2re^*]}.$$

7.2 Appendix B

The derivative of the threshold level of pro-environmental index $\overline{\theta}$ with respect to the energy budget is given by:

$$\frac{\partial\overline{\theta}}{\partial R} = \underbrace{\frac{\beta_p}{\beta_{pq}} \frac{1}{(\frac{R}{k_2} - 2re^*)^2}}_{>0} \{(\frac{R}{k_2} - 2re^*)[\frac{2u''(ee^*)}{k_1} + \frac{ee^*}{k_1} u^{'''}(ee^*) + u^{'}(ee^*)] - \frac{1}{k_2}[ee^* u^{''}(ee^*) + u^{'}(ee^*)]\}.$$

After arranging the above expression, we can then deduce the following condition:

$$\frac{\partial\overline{\theta}}{\partial R} > 0 \iff \frac{ee^{*}u^{''}(ee^{*})}{u^{'}(ee^{*})} > \frac{2R}{3k_1}\frac{u^{''}(ee^{*})}{u^{'}(ee^{*})} + \frac{1}{3} + \frac{1}{3}(\frac{R}{k_1} - 2ee^{*})ee^{*}\frac{u^{'''}(ee^{*})}{u^{'}(ee^{*})},$$

where $\frac{ee^{*}u^{''}(ee^{*})}{u^{'}(ee^{*})}$ is the elasticity of marginal utility or the reciprocal of the inter-temporal elasticity of substitution of investment in energy efficiency.

7.3 Appendix C

Table 10: Robustness check: estimation with and without attitudinal variables

	(With) ee	(Without) ee	(With) re	(Without) re
collective	-0.0695*	-0.0830**		
	(0.0364)	(0.0356)		
size_residence	0.0657***	0.0798***		
	(0.0233)	(0.0228)		
income	0.0270***	0.0287***	0.00231	0.00618
	(0.00630)	(0.00609)	(0.00509)	(0.00499)
owner	0.151***	0.165***	0.108***	0.112***
	(0.0383)	(0.0374)	(0.0322)	(0.0316)
exante	0.103***	0.121***	0.00844	0.0266
	(0.0367)	(0.0359)	(0.0308)	(0.0299)
ind_metering	0.0700	0.0768		
	(0.0856)	(0.0836)		
peak	0.0472	0.0576*		
	(0.0333)	(0.0326)		
est_label	0.172***	0.192***		
	(0.0561)	(0.0541)		
N	11198	11444		

Standard errors in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 11: Robustness check: Estimation of Bivariate probit with both monetary and non-monetary investments in energy efficiency

Variables	Biprobit ee2	re
Residential and economic variables		
Living in a non-detached residence	-0.322***	
	(0.0501)	
Size of the residence	0.000470	
	(0.0317)	
Income of household	-0.00237	0.00314
	(0.00855)	(0.00469)
Ownership	0.109**	0.0799***
	(0.0501)	(0.0286)
Perception, commitment and trust		
Environmental concerns (general issues)	-0.0153	-0.0269***
	(0.0140)	(0.00804)
Climate change issues	-0.0915***	0.0944***
	(0.0351)	(0.0229)
Resource depletion issues	0.158***	-0.0485*
	(0.0382)	(0.0255)
Participation in local vote	0.118**	0.0414
	(0.0490)	(0.0296)
Commitment in charitable organization	-0.00547	0.122***
	(0.0538)	(0.0291)
Commitment in environmental organization	-0.0845	0.118***
	(0.0629)	(0.0359)
Commitment in local organization	0.0967	0.0781**
	(0.0639)	(0.0344)
Trust in scientists	0.0796***	0.0841***
	(0.0183)	(0.0136)
Trust in local authorities	-0.0155	0.0217*
	(0.0177)	(0.0117)
Energy use		
Energy costs before buying or renting a house	0.0253	-0.00857
	(0.0490)	(0.0280)
Individual metering	0.0688	
	(0.109)	
Peak Tariff	0.0278	
	(0.0437)	
Label to reduce energy use	0.264***	
	(0.0707)	
rho	0.1779681***	
	(0.0308717)	
Log pseudolikelihood	-8464.4579	
Observations	13133	13133

***1%, **5%, *10% and ()= robust std errors.

Description and summary of independent variables.

Variables	Description	Mean
Residential and Socio-demographics variables		
Living in a non-detached residence (collective)	1 for non-detached and 0 for detached	.43
Size of the residence (size_residecne)	1-<50m^2; 2-50-100; 3-100-200 ; 4->200	2.41
Age of the respondent (age)	Continuous variable	42.53
Gender of the respondent (sex)	0 for Female and 1 for Male	.49
Employment status (employme)	0 for not working and 1 for working	.63
Income of household (income)	1 for usd 1- usd 24200….up to 10 for more than usd 127000	5.0
Size of household (size_hh)	1 for 1… up to 5 for 5+	2.86
Ownership (owner)	0 for no owner and 1 for owner	.64
Type of area of residence (urban)	0 for not living in urban area and 1 for living in urban area	.70
Duration in the residence (duration)	1 for less than 2 years… up to 4 for more than 15 years	2.62
Attitudinal variables		
Perception		
Environmental concerns (general issues) (env_conc)	1 for most important... up to 6 for least	3.52
Air pollution issues (air_poll)	1 for most important... up to 4 for least	3.44
Climate change issues (climate_)	1 for most important... up to 4 for least	3.35
Resource depletion issues (resource)	1 for most important... up to 4 for least	3.46
Waste generation issues (waste_ge)	1 for most important... up to 4 for least	3.33
Commitment and trust		
Participation in local vote (vote_loc)	0 for no and 1 for yes	.70
Commitment in charitable organization (com_char)	0 for no and 1 for yes	.24
Commitment in environmental organization (com_env)	0 for no and 1 for yes	.14
Commitment in local organization (com_loca)	0 for no and 1 for yes	.15
Trust in scientists (trust_sc)	1 for least truthworthy... up to 5 for most	3.80
Trust in local authorities (trust_lo)	1 for least truthworthy... up to 5 for most	2.68
Trust in manufacturers (trust_ma)	1 for least truthworthy... up to 5 for most	2.34
Trust in NGOs (trust_NG)	1 for least truthworthy... up to 5 for most	3.51
Energy use and other variables		
Individual metering (ind_mete)	0 for no and 1 for yes	.95
Peak Tariff (peak)	0 for no and 1 for yes	.45
Energy costs before buying or renting a house (exante)	0 for no and 1 for yes	. 29
Importance of information to reduce energy use (est_info)	0 for no and 1 for yes	.88
Importance of environmental benefits to reduce energy (est_env)	0 for no and 1 for yes	.88
Importance of label to reduce energy use (est_labe)	0 for no and 1 for yes	.88
Importance of less expensive ee to reduce energy use (est_lexp)	0 for no and 1 for yes	.89
Year of the survey (year)	0 for 2008 and 1 for 2011	.54