FLEXBEAN
Flexibility for Energy Transition PROJECT

D2.1.4, D2.1.1

# Household’s energy literacy and flexibility survey

## -flexibility model, survey design and conclusions

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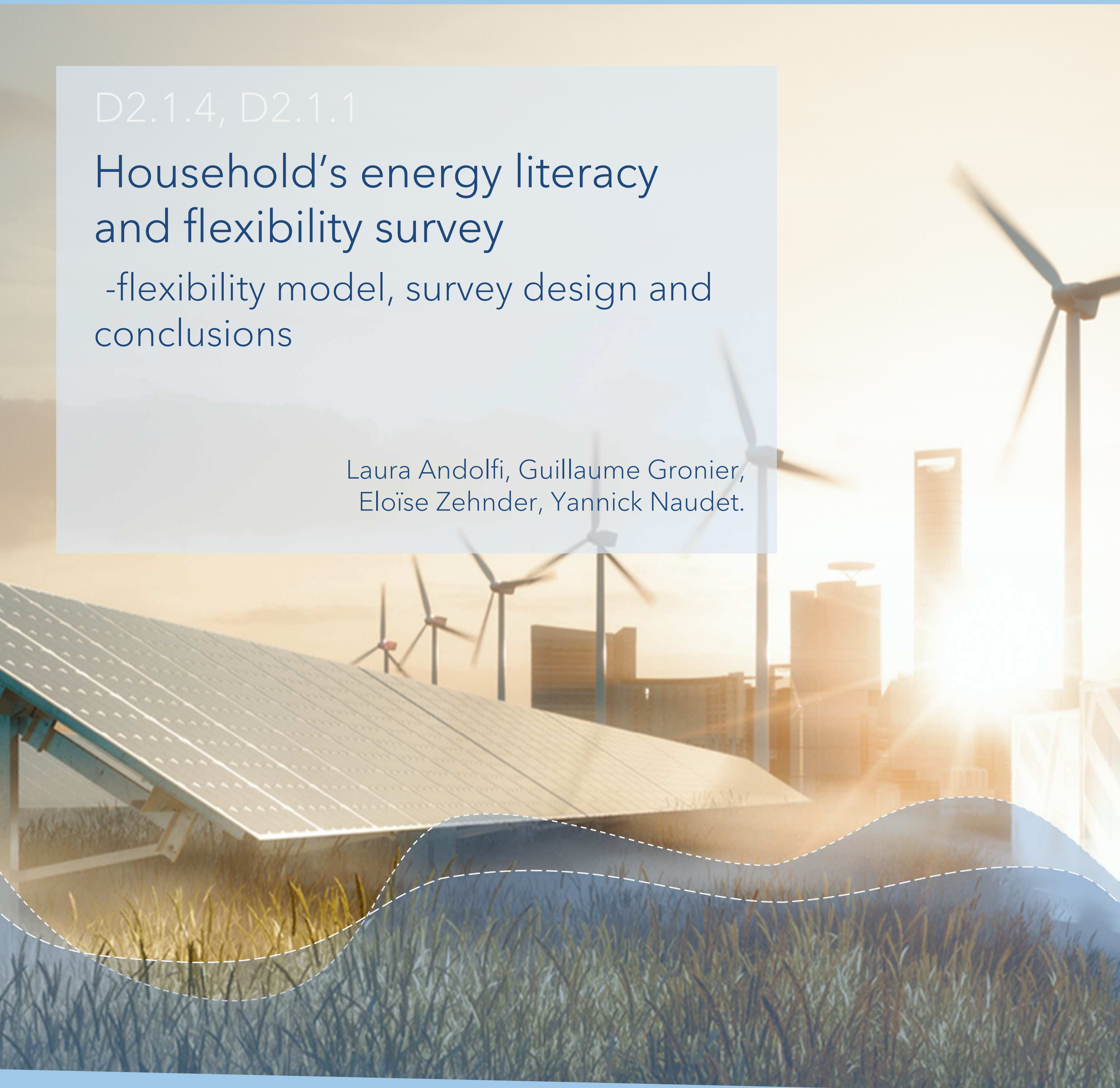

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This report details the energy literacy and flexibility survey conducted in the WP2 of the FlexBeAn project on a set of households in Luxembourg. It details the household flexibility model designed as a result of a state-of-the-art analysis, the design of the survey approach and questionnaire, the results obtained from the analysis of answers. Conclusions are given as well as recommendations and perspectives for future work.

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# 1. Energy literacy state of the art and Household flexibility model

This section presents a theoretical flexibility model for households (section 1.4) as a result of a state-of-the-art analysis focused on energy literacy and factors impacting flexibility (summarized in section 1.3.2.2). The published energy literacy state-of-the-art analysis can be found in Annex.

## 1.1. Abstract

Faced with the global increase in electricity demand and environmental constraints on production, including the growing integration of intermittent renewable energy, consumer energy flexibility has become a necessary adaptation. This article proposes a theoretical model to better understand the individual determinants of household energy flexibility, an aspect little explored in the literature. Through a combined literature review, integrating integrative and narrative approaches with a structured research protocol, we identified three main determinants of flexibility: Ability (biographical characteristics, energy literacy, personality), Opportunity (socio-demographic aspects), and Motivation (personal values, technology acceptance). This AOM model provides a framework to analyze the factors that influence households' ability and willingness to adjust their energy consumption. By distinguishing these determinants and their subcomponents, this work paves the way for the design of targeted interventions aimed at promoting sustainable energy flexibility behaviors at the household level. Although the adopted methodology has some limitations inherent to non-systematic reviews and potentially linguistic and source biases, this model constitutes an essential first step in informing strategies promoting a more flexible and sustainable energy system.

## 1.2. Introduction

The demand for electricity from homes and industry is increasing around the world year on year. In developed countries, transport is making the biggest contribution to this increase, with the introduction of electric vehicles (EVs): according to the most optimistic scenarios, the market share of EVs is set to rise from 8% in 2021 to 50% in 2030 (International Energy Agency, 2022). In emerging countries, population growth and the installation of cooling systems (such as air conditioners) are having a major impact on demand for electricity. At global level, this demand is expected to increase by 75% to 150% by 2050, depending on the forecasting models (International Energy Agency, 2022).

Electricity production is also subject to severe environmental constraints. For example, the European Union has set itself the target of producing 80% of its electricity from renewable energy sources by 2050 (European Commission. Directorate-General for Climate Action, 2019). In the shorter term, by 2030, 60% of electricity should come from wind or solar power (European Commission. International Renewable Energy Agency, 2018). This poses a number of challenges, including that of managing intermittency: renewable energies do not produce electricity at all times, and the power they supply can vary greatly over short periods.

In this context, energy flexibility represents as a necessary adaptation from the point of view of both electricity producers and consumers. For producers, energy flexibility is defined as the ability to react to unexpected changes in electricity demand (Impram et al., 2020). From the point of view of consumers, flexibility refers to the ability to adjust their own demand

(and energy production where appropriate) according to overall demand on the electricity network and local conditions (such as weather conditions) (Li et al., 2021).

It is therefore essential that consumers are willing to be flexible and ready to change their habits in the way they use electricity. Energy consumers are considered flexible if they adapt their consumption to times with less demand, in other words, they are willing to react to an external signal (in this case, an incentive) by modifying their consumption (Huber et al., 2014). Currently, this can involve the provision of incentives for changing the consumption pattern, or the implementation of a particular tariff structure. Albadi and El-Saadany (2007) define them as Demand-response (DR) measures. DR measures are a type of Demand-side management (DSM): a set of techniques to influence the way customers consume electricity and produce a change in the load shape (Gellings and Parmenter, 2016). According to Biegel et al. (2014), the transition toward renewable energy production presents a double challenge in terms of power balancing: the power generated through renewable sources is characterized by a high level of fluctuation, and renewable sources are unable to provide the conventional balancing services. Therefore, there is a need for alternative sources of balancing services. The ENTSO-E (European Network of Transmission System Operators for Electricity) (2016) stated the importance of DSM measures for the functioning of alternative balancing services, such as smart grids.

While external demands often define energy flexibility, the literature lacks a clear understanding of the internal individual factors that promote it. Although theories like the Elaboration Likelihood Model (Petty & Cacioppo, 1986) and the Theory of Planned Behavior (Ajzen, 1991) demonstrate the influence of attitudes, showing how internalized awareness of the benefits of energy flexibility can predict behavior (e.g., someone valuing sustainability proactively adjusting consumption), identifying other key individual drivers remains a challenge. Studies suggest potential links between personality (Milfont & Sibley, 2012), beliefs (Mogles et al., 2017), and energy consumption, but a comprehensive understanding is missing. Identifying these individual factors is essential because it allows us to distinguish between malleable characteristics, which can be targeted with interventions to promote more sustainable energy behaviors, and relatively stable traits, which may require different approaches. Therefore, this paper explores these individual factors and proposes a model to better understand and ultimately promote energy flexibility behavior in individuals and households, with the ultimate goal of informing targeted interventions for lasting change.

## 1.3. Method

We use a combined literature review approach to develop a graphical representation of how households are willing to provide flexibility. Our approach integrates principles from two review types while considering established literature review guidelines. First, we adopt the integrative review approach outlined by Torraco (2016). The integrative review approach suits emerging topics well, allowing us to deconstruct them into foundational elements such as key concepts and their relationships. Second, we rely on a narrative review approach based on Pare (2015) to provide timely, opportunistic insights into the field. To enhance transparency and mitigate common pitfalls associated with integrative and narrative reviews, we follow the guidelines of Snyder (2019) and establish a structured search and analysis protocol. While this protocol defines a clear step process, it is not intended to be a quantitative or systematic review due to the topic's complexity.

We apply our protocol to one topic: households' potential for flexibility flexible. We conduct two parallel search streams: one in academic literature and the other in non-academic sources. For the academic stream, we explore established databases like IEEE, ACM, and

Scopus. Our focus is on English-language journals and conference proceedings. We analyze core components such as the title, abstract, and full manuscript when deemed appropriate by the authors. For non-academic sources, we analyze official documentation from international institutions, including regulations, directives, guidelines, and frameworks, such as the RACE for 2030 final report from Roberts *et al*. (2021). Additionally, we review consultant reports and research projects. We retrieve policy documents, consultant reports through Google searches, and research project reports from the CORDIS repository. Furthermore, we expand our search by analyzing citations (backward search) and identifying subsequent works that cite relevant literature (forward search). Tools like Elicit helped us during these steps. The resulting corpus provides a final topic corpus, which the author team discussed in three meetings.

#### *1.3.1.1. Energy flexibility and potential determinants*

Energy flexibility, for users, refers to the ability and willingness to adjust their energy consumption patterns in response to signals or incentives, often with the goal of optimizing energy use, reducing costs, or supporting grid stability. It involves shifting the timing or intensity of electricity usage without significantly impacting comfort or productivity. This can include actions like shifting appliance usage to off-peak hours, reducing consumption during peak demand periods, or even generating and storing energy locally, when possible.

This section reviews the individual-level determinants of energy flexibility identified in the literature, with the goal of developing a comprehensive model. Theses determinants are grouped into the motivation for flexibility (including the environmental beliefs and behaviours, as well as technology acceptance), opportunity for flexibility (including sociodemographic data as household income or composition) and ability for flexibility (including psychological personality, biographic characteristics and energy literacy (Schwartz & Boehnke, 2004; Roberts et al., 2021).

### 1.3.2. Ability

The ability for energy flexibility encompasses individual characteristics and variables that influence an individual's likelihood of engaging in flexible energy practices. These include biographical characteristics (such as age and gender), personality traits (e.g., openness to change, conscientiousness), and energy literacy (understanding of energy concepts and conservation strategies). This section reviews how these variables collectively shape an individual's capacity and willingness to adapt their energy consumption.

#### *1.3.2.1. Biographical characteristics*

A few demographic characteristics have shown to have an impact on behaviour related to energy such as age or the degree of education. Research in Singapore suggests that education and occupation may influence willingness to adapt energy use (Shen et al., 2019), while age and gender appear to play a moderating role in the relationship between various variables and energy flexibility. Torriti et al., (2015) found that regarding use, women go through more fragmented days with short energy-related activities compared to men. Households with children also start and finish using energy earlier during days and evenings than households without children.

In the study of Tomat et al., (2023), individuals between 26 and 40 years old were especially reluctant to change their habits regarding energy use management and women were more willing to participate in energy flexibility strategies. Younger adults (20 to 29 years old) tend to be more aware of smart grids (Li et al., 2017). Pfeiffer et al., (2020) showed that individuals with a higher education level are generally more open to new technologies, while higher education is generally linked with a greater willingness to adjust temperature settings to reduce costs (Tomat et al., 2023).

In a review from Frederiks et al., (2015), age does not appear as a significant variable influencing energy use and some studies seem to suggest that energy use peaks during the middle stages of life with larger households. Their review also suggest that gender doesn't have a consistent influence on energy use overall. The same authors found a positive relationship that is sometimes significant, sometimes not, of education on energy consumption and pro-environmental behaviours. Individuals with full-time employment have generally a higher income to invest in energy-saving appliances but also spend more energy. They spend fewer days at home than unemployed or part time individuals.

In summary, the impact of age and gender is complex and inconsistent across studies, meanwhile education and occupation are more consistent with a positive correlation with energy flexibility. However, higher education and occupation can also lead to an increased energy consumption. The inconsistent influence of these variables highlights the need for further research to understand how these variables shape energy flexibility.

#### *1.3.2.2. Energy Literacy*

The U.S. Department of Energy (2017) defines energy literacy as "an understanding of the nature and role of energy in the world and daily lives accompanied by the ability to apply this understanding to answer questions and solve problems". This description is well in line with the one given by (Dewaters & Powers, 2013) according to whom energy literacy is indeed a set of knowledge and understandings, behaviour, and attitudes towards energy systems in a social context. They outline three aspects of energy literacy: cognitive, behavioural, and affective, and each of them is addressed by one of the sections of the questionnaire that they defined. They state that an energy literate person is someone who not only has an understanding of how energy is commonly used and produced, is aware of the impact of energy decisions and the need for energy conservation, but also concretizes this knowledge by acting accordingly and is committed to use resources efficiently. Martins et al. (2020) add a financial component to it, which is needed to understand the prices and make cost-benefit analyses.

In her literature review, van den Broek (2019) identified four types of energy literacy. The first one is device energy literacy, which consists of knowing how many kWh the different appliances consume. Action energy literacy includes the previous one, but also involves the awareness of which actions can save energy at home and what their effect is. Financial energy literacy also incorporates the device aspect, but gives it an economic perspective; households with these skills can assess the financial consequences of their energy consumption. Finally, multifaceted energy literacy comprehends all the aforementioned types and implies awareness of the impact of the own consumption on the socioeconomic system.

The most common questionnaire to measure energy literacy is the one developed by DeWaters and Powers (2011, 2013). It consists of three sets of questions that explore the cognitive, behavioural, and affective dimensions of energy literacy. Different adoptions of this scale exist worldwide (Lee et al., 2015; Reis et al., 2021). Other methods have been used in research, for example, Brounen et al. (2013) assessed the energy literacy of their respondents with three questions: whether they were aware of their gas bills, if they used green power, and to make a choice between an expensive but efficient and a cheap but less efficient heating system. Having a fair and objective evaluation of energy literacy is highly important since people tend to overestimate their knowledge about energy, which is generally low. Low levels of energy literacy could partly be due to the fact that, in the absence of crises, people do not pay much attention to energy, especially in industrialized countries (Boudet, 2019). The energy crisis of 2022 could change this and lead to greater awareness related to energy issues.

It is not immediately evident whether energy literacy programmes lead to higher household flexibility. Some studies have found that energy literacy has an impact on energy decision-making in the household. Reis et al. (2021) found that people with higher levels of energy literacy are less subject to cognitive biases when deciding on their energy tariff. Furthermore, according to Li et al. (2017), households who are more aware of smart grids and technologies are also more likely to adopt them. But also in this case, the literature does not present homogeneous results. In fact, other studies did not find any link between energy literacy and the intention to change behaviour as seen in DeWaters and Powers (2011) and Dwyer (2011).

A recent literature review by Andolfi et al., (2023) highlights that most studies on energy literacy and energy related behaviour focus on energy savings and adoption of energy efficient technologies, but do not explore the relation between flexibility provision and energy literacy. They propose an organisation of energy literacy in three levels, where the lowest level implies that the people are able to perform energy saving behaviours, such as turning off appliances instead of leaving them in stand-by. The moderate level includes the abilities of the second together with the financial skills to identify effective investment to improve the energy efficiency of the household. The third and highest level includes "a combination of the identification of appliances and activities to shift from the first group, the financial literacy to invest in flexibility enabling appliances from the second group, plus the understanding of dynamic tariffs, energy community, energy mix, and other new energy concepts, together with the desire to become a proactive participant in the energy system".

#### *1.3.2.3. Personality*

One of the most popular frameworks for comprehending human personality is the Big Five personality traits, often known as the Five-Factor Model. This model organizes personality into five dimensions: extraversion (the degree to which someone is outgoing, energetic, and sociable), openness to experience (the tendency to be imaginative, curious, and open to exploring new ideas or unconventional perspectives), neuroticism (the tendency to experience negative emotions such as anxiety, anger, or sadness), conscientiousness (the tendency to be organized, disciplined, and goal-oriented), and agreeableness (the tendency to be kind, empathetic, and cooperative). Together, they provide a comprehensive yet flexible structure for analyzing and comparing personalities across different individuals (Digman, 1990; McCrae & John, 1992). Personality traits can evolve but tend to remain stable across the lifespan (Roberts and DelVecchio, 2000), making them a potential foundational ability for energy flexibility.

While the literature doesn't show studies on the impact of personality traits on energy flexibility, there are results on their impact on pro-environmental behavior or energy consumption. While different, those two concepts are closely tied to energy flexibility, as both aim to optimize energy use, reduce environmental impact, and support the integration of renewable energy sources into the grid. In Milfont & Sibley's research (2012), openness and agreeableness were the strongest predictors of environmental engagement (measured through the environmental performance index). Despite a small effect size, the neuroticisms' of the household's head, and the partner's openness and extraversion showed significant effects on the purchase of a photovoltaic system (Poier, 2021). Through the HEXACO model, Brick & Lewis (2016) found that Openness, Conscientiousness and Extraversion can predict emissions-reducing behaviors, through a large sample (n= 345). Shen et al., (2019) found that agreeableness, openness and conscientiousness have positive correlations with energy conservation behaviour. In a meta-analysis of 38 sources, openness is the strongest correlate of proenvironmental attitudes and behaviors, and to a lesser extent, agreeableness, conscientiousness and extraversion (Soutter et al., 2020). Hämpke et al., (2024) also mention from other studies that individuals with higher oppenness show more environmentally friendly behaviors and have more pronounced intents to engage in proenvironmental behaviors. Though, their research shows that some beliefs (that the world is less hierarchical, more cooperative and abundant) add more explanatory value in reported pro-environmental behavior than the Big Five traits. Finally, Hidalgo-Crespo et al., (2023) found neuroticism, openness, and consciousness to have an impact on pro-environmental behavior, but not agreeableness and extraversion.

In the context of energy flexibility, we could assume, for example, that individuals with higher levels of conscientiousness may be more inclined to adopt energy-saving practices due to their tendency to be organized and planful. Similarly, those with a greater openness to experience may be more receptive to trying innovative energy-efficient technologies or solutions. Thus, personality represents a valuable variable to integrate as an ability for energy flexibility.

### 1.3.3. Opportunity

The opportunity for energy flexibility refers to a household's capacity to adjust its energy consumption in response to external variables like price, grid demands, or renewable energy availability. This capacity is significantly influenced by socio-economic and sociodemographic factors. Our model incorporates key variables such as household type, income, and household composition to capture these crucial influences on a household's flexibility potential.

#### *1.3.3.1. Sociodemography*

The work of Ribó-Pérez et al., (2021) highlights that, in Spain, higher-income households generally have 50% more flexibility than lower-income households, as they possess better-equipped homes with more appliances. They also spend less time home. Southern and eastern mediterranean regions have the highest flexibility capacities (up to 100% higher than the national average during spring and autumn), compared to central and northern regions. This is due to climatic conditions and the types of heating systems used. We could thus assume that city of residence can influence energy flexibility.

Also, low-income households spend an average of 2 additional hours per day at home, limiting their ability to increase energy consumption.

The study of Tomat et al., (2023) showed the impact of numerous sociodemographic factors. For example, individuals living alone have different views on changing ironing schedules compared to those living with a family or roommates and are more susceptible to change their habits. Users sharing a flat are more likely to accept direct load control, while those living with parents are less inclined to it. Household size affects the willingness to reduce heating temperatures, with larger households less inclined to do so.

Having young children can impact laundry habits and the perceived barriers to changing them. In their study, having a middle income makes individuals more motivated by financial incentives to adopt a smart grid technology.

Living as a couple also has an impact, as Yang et al., (2015) showed that the combined attitudes of a couple have more impact on the home heating use, than the attitude of one partner.

The research of Fjellså et al. (2021) focused on a different population and showed that young adults and students tend to have fewer opportunities for flexibility, due to it being "locked-in". This means students are often in a situation where they are unable to modify their energy consumption due to social, material and structural factors (lower quality housing, life rythms and social norms, ...), even when they have the willingness to be flexible. Timetables could thus also have an impact on energy flexibility, especially if we consider low and high demand hours.

We also consider the impact of housing tenureship (renter vs. owner) on energy flexibility. As shown in the review of Frederiks et al., (2015), homeowners generally have greater control over energy-saving upgrades, such as installing solar panels or upgrading insulation. In some cases, home ownership has also been among the most powerful socio-demographic factors distinguishing conservers from non-conservers of home energy and explaining large capital investments in household energy-saving measures.

In contrast, renters may face limitations imposed by landlords, potentially restricting their ability to fully participate in energy flexibility programs. Some studies found that homeowners consume more energy than tenants (Rehdanz, 2007; Holloway & Bunker, 2006).

### 1.3.4. Motivation

Motivation, influenced here by personal values and technology acceptance, is a key variable in driving energy flexibility. Indeed, self-determination theory (Deci and Ryan, 1985) explains that motivation exists on a continuum. The more internalized the motivation (towards the intrinsic end), the greater the performance, commitment, and satisfaction. In the context of energy flexibility, this means that individuals whose values support flexible energy use, and who accept the necessary technologies, will experience more internalized motivation, leading to greater engagement and positive outcomes. Building upon this foundation of intrinsic motivation, the following sections will review the role of personal values and technology acceptance in shaping individual energy flexibility behaviours.

#### *1.3.4.1. Personal values*

Values represent internalized guiding principles that function as life goals or standards for individuals. These values are significant determinants influencing an individual's beliefs, norms, and behaviors, thereby constituting a crucial component of their internal organizational system and distinguishing them from mere beliefs (Olson et al., 1993). In 1992, Schwartz proposed a framework with a set of ten base values and later, Stern (2000) took Schwartz's work on values and applied it specifically to the environmental domain with the Value-Belief-Norm (VBN) Theory. Based on this previous research, the work of DeGroot and Steg (2014) finally identified altruistic (concern for others), egoistic (concern for personal resources), biospheric (concern for the environment) and hedonic (concern for comfort) values as key value orientations highly correlated with pro-environmental behaviour.

In the literature, more results show that energy-saving behaviours, pro-environmental personal norms, climate change beliefs, use of green design packaging, policy support have been correlated to those personal value (Bouman et al., 2018; Mogles et al., 2017; Liu & Wu, 2020). At last, the work of Bouman et al., (2018) led to the environmental portrait value questionnaire (EPVQ) which measures those values related to an environmental behavior.

Given that values significantly shape pro-environmental behaviors and the acceptance of energy policies, it's logical to assume they could impact energy flexibility. Individuals with strong biospheric and altruistic values are more likely to adopt behaviors that reduce energy consumption and support renewable energy. Conversely, those with egoistic or hedonic values may be less inclined to change their habits unless there are direct personal benefits. For those reasons, it appears relevant to consider personal values as variables impacting energy flexibility.

#### *1.3.4.2. Technology acceptance*

The willingness and acceptance of smart technologies are crucial for energy flexibility as they enable active participation of users and optimized demand management. The willingness to use smart technology directly correlates with a willingness to change energy behaviors (Li et al., 2017). For example, technologies like smart meters and Home Energy Management Systems (HEMS) are essential for users to adjust their consumption based on grid signals and dynamic pricing. Without these tools, it is difficult for consumers to actively participate in demand response programs and take advantage of energy flexibility.

Several factors influence the acceptance of smart grid technologies. Research indicates that perceived utility, ease of use, and concerns about data privacy and security are key considerations (Li et al., 2017). Further studies have highlighted the importance of norms, hedonics, social influence, and awareness in the adoption of distributed energy resources (Borragán et al., 2024). In their model, Toft et al. (2014) specifically found that perceived ease of use, usefulness, and a sense of moral obligation are crucial drivers of smart grid technology acceptance. Ultimately, fostering widespread adoption of smart technologies requires addressing user concerns and highlighting the benefits of participation in a flexible energy system.

## 1.4. Towards a theorical model of household energy flexibility

Through a review of the literature, we have identified three main individual determinants of energy flexibility: ability, opportunity and motivation. Each of these determinants includes different sub-determinants. Ability is characterised by biographical aspects, the level of energy literacy and personality. Opportunity is characterised by sociodemographic aspects. Motivation brings together personal values and technological acceptance.

All of these factors constitute a theoretical model influencing the potential for flexibility of individuals (Fig 1.)

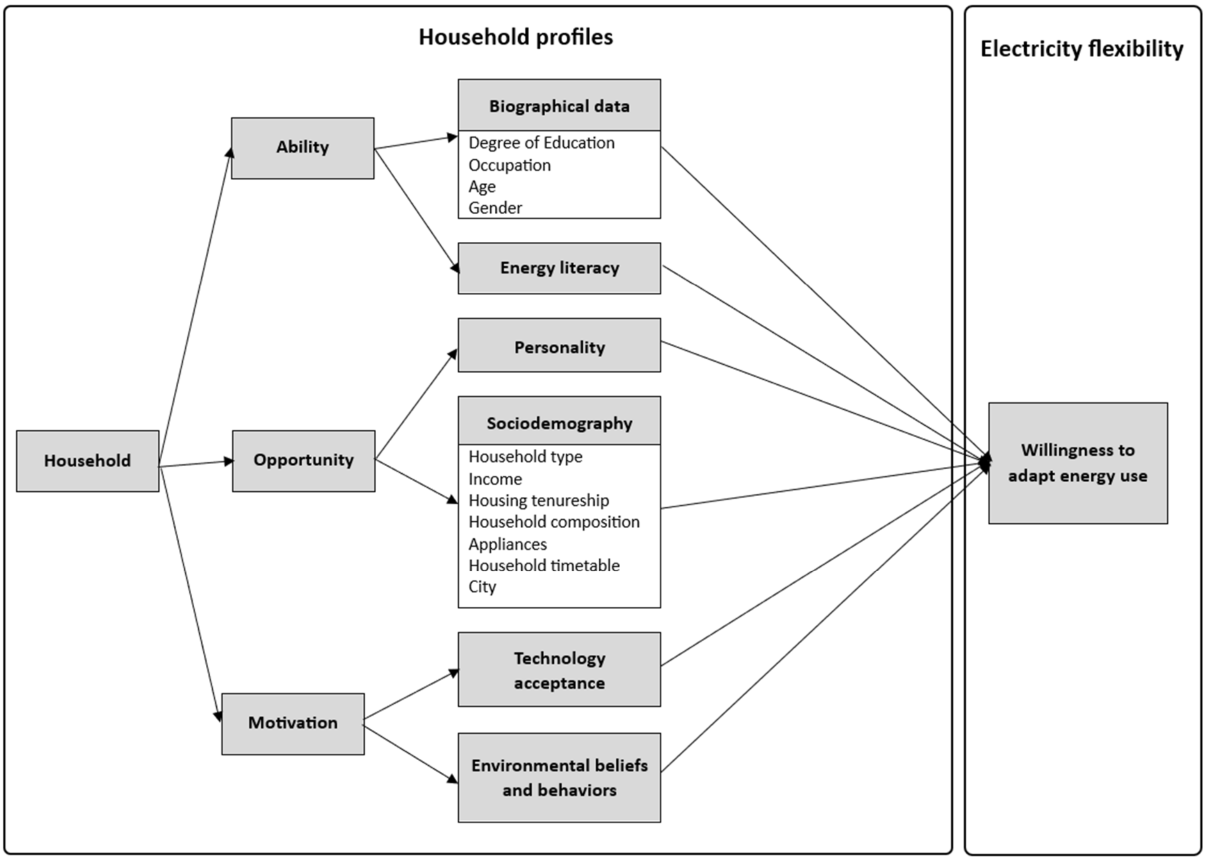


Figure 1. Theorical model of household energy flexibility

While the proposed model, centered on ability, opportunity, and motivation, offers a first framework for understanding household energy flexibility, it's important to acknowledge its potential for expansion. Indeed, the starting inspiration for this model has mostly been draw from Roberts et al. (2021), which explains this type of breakdown into ability, opportunity and motivation (AOM). From this inspiration, the selection of their specific factors was discussed justified through a detailed analysis of their potential influence on energy flexibility.

Recognizing the nuanced interplay of biographical, sociodemographic, and psychological factors, it's conceivable that additional determinants, such as habit formation or social influence, could further enrich the model. Nevertheless, this simplified yet comprehensive approach, focusing on the core AOM factors and their sub-factors, provides a core lens through which to analyze and address the practical challenges of promoting energy flexibility.

By identifying the specific barriers and enablers within each category, targeted interventions can be developed and tailored to diverse user groups, ultimately fostering more effective and sustainable energy practices.

## 1.5. Conclusion

To conclude, the proposed theoretical model of household energy flexibility, centered on ability, opportunity, and motivation, provides a valuable framework for understanding the individual determinants influencing flexible energy practices. The next steps in validating this model involve conducting a structural equation analysis. It will be conducted within the framework of the Luxembourgish FlexBeAn project, whose main task is to study the potential of flexibility in households, industry, SMEs and the e-mobility sector, considering three perspectives: The technical dimension of flexibility, its potential and limitations; the behavioural aspects of consumers, their influences, knowledge and motivation regarding flexibility provision; the economic and market perspective, to assess the influence of future market developments on customer flexibility. The project enabled a survey to be conducted, which received more than 450 responses, allowing data to be collected that will be used to validate the model.

The model validation process will be crucial in determining the strength and significance of the relationships between the identified factors and household energy flexibility. Furthermore, the model is intended to be adaptable, with the possibility of adding or removing factors based on empirical findings and further theoretical developments.

Ultimately, future research should aim to identify specific levers for enhancing energy flexibility in households. Understanding these levers will be essential for designing targeted interventions and policies to promote more effective and sustainable energy consumption behaviors.

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# 2. Energy literacy survey

In 2023, Creos, LIST and SnT rolled out a survey to study the flexibility potential of Luxembourgish households. The goal was to understand the relationship households have with energy consumption: their knowledge about it, their habits and their openness to adapt their consumption and production behaviour towards the requirements of the power system (known as flexibility). 544 households completed the survey. The survey is composed of 73 questions related to 7 topics (a complete list of the questions can be found in the Appendix):

- Socio-demographic and household characteristics
- Ownership of energy appliances
- Environmental values
- Personality traits
- Affinity for technology interaction
- Openness to energy flexibility
- Energy literacy

The survey had two goals:

- First, find the households' characteristics which can be used to define nudging strategies to increase their energy literacy or change their behaviour, with the final goal of increasing their openness to flexibility.
- Second, evaluate how households' characteristics and monetary incentives are related to the openness to flexibility. Specifically, we investigated whether households would hypothetically shift whiteware appliances or accept direct load control (DLC) on their heating system or EV charging.

The survey was developed based on the theoretical model of household flexibility, which was developed in the first phase of the project. More information on the model can be found in the Appendix. In this document, we highlight the main findings from the survey analysis.

## 2.1. Information about the respondents

Our sample consists of 80.21% men, while one-fifth of the sample is female. Participants are on average 49 years old, have a high level of education (more than 40% with a master's degree) and an average household net income of more than 5000 Euros per month (70%). 49.89% of the participants own an EV, 50.80% PV systems, and 23.91% a HP.

The sample primarily includes customers who requested power connection upgrades from Creos. This implies there is a large share of energy technology early adopters. Hence, we must be careful when applying these findings to the broader population. For example, in Luxembourg, the EV adoption rate is 3,13% and the share of households with a low voltage PV installation is 4,65% of the total. The advantage of such a sample is that it ensures that more respondents were familiar with the technologies when asking them about their openness to flexibility.

## 2.2. A focus on energy literacy

"Energy literacy is an understanding of the nature and role of energy in the world and daily lives accompanied by the ability to apply this understanding to answer questions and solve problems". Energy-literate individuals understand how energy is typically utilised and generated. They recognise the implications of energy-related decisions and the importance of saving energy. Ultimately, they apply this understanding by taking appropriate actions which help the energy system.

In the survey, we assessed it by combining questions from established questionnaires and added further questions to assess if respondents have the knowledge required to provide flexibility (e.g. they know when the peak consumption time in Luxembourg is).

The 13 energy literacy questions can be divided into three main groups: energy consumption knowledge, energy-related financial knowledge, and flexibility-related knowledge. It emerged from the survey analysis that the easier questions were the ones related to financial knowledge, with an average share of correct answers of 75%, the ones related to energy consumption have a share of 62%, and the most difficult ones were the questions related to flexibility. A full breakdown of the questions and the share of correct answers is provided in the appendix. Finally, while other studies on energy literacy have shown low levels everywhere, in our sample, there is a high proportion of respondents who answered correctly to more than half of the questions. The figure below represents a distribution of the scores (min 0 – max 13).

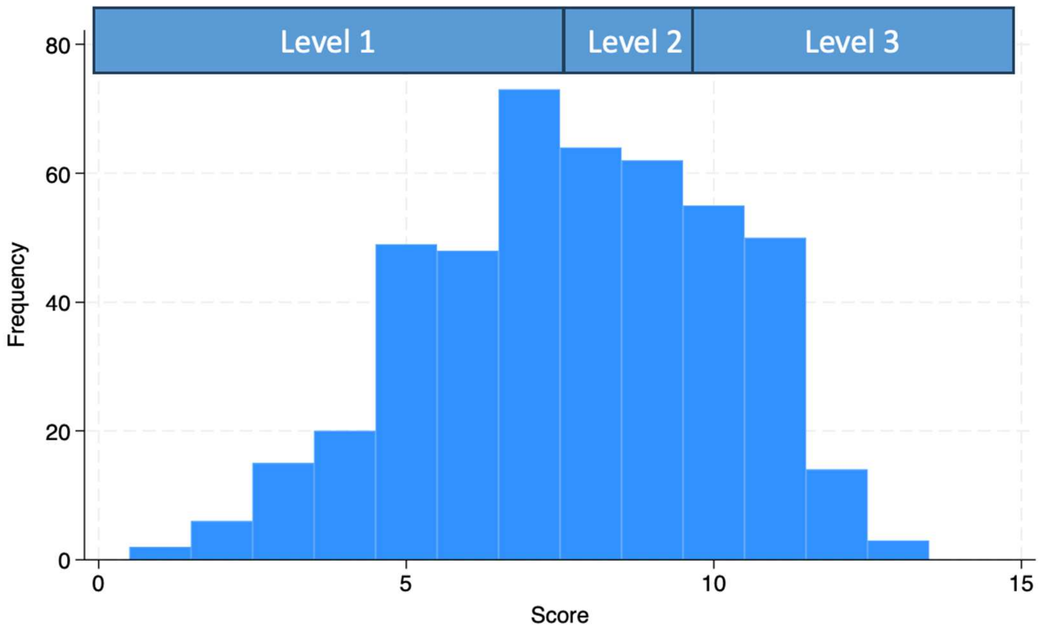


Figure 1. Distribution of Energy Literacy scores among respondents

It is highly likely that the energy literacy levels are higher than expected because a high share of the sample is already familiar with the newest energy technologies, and it has EVs, PV, or heat pumps.

Based on the distribution of points among the respondents, we divided the energy literacy score in three levels. Scores of 7 points or less correspond to level 1, scores between 8 and 9 correspond to level 2, and scores from 10 to 13 correspond to level 3.

 

## 2.3. Results

### 2.3.1. Goal 1: What household characteristics can affect a nudging strategy?

The survey identified several key motivating factors that are important for designing a nudging strategy aimed at promoting flexibility and improving energy literacy :

- sensibility to the environment and personality traits,
- sociodemographic characteristics.

All results presented in this section are related to the correlations and descriptive statistics carried out.

#### *2.3.1.1. Sensibility to environment and personality traits*

In general, the households from the sample care about the environment and want to make positive changes. This concern isn't tied to how much people know about energy. Having more knowledge about energy doesn't necessarily mean being concerned about environmental issues. In fact, sensitivity to the environment seems to be linked to personality traits.

Individuals having a conscientious personality, meaning they are organised, motivated, and goal-oriented while accepting limitations, tend to be the most dedicated to environmental protection. Based on this, we can expect high commitment from these individuals towards energy flexibility. This commitment can be encouraged through persuasive communication using reliable information and recommendations from authoritative sources like experts or specialists.

Conversely, individuals from the survey who are extroverted, meaning they are influenced more by others, especially from their close circles, tend to have less interest in the environment. Based on this, we can expect to involve them with rewards, competition with others and gamification features, or by influencing their circles.

The higher the participant's level of education, the more energy-literate they are. Thus, it seems important to focus on people with lower or medium levels of education to improve their energy literacy as a priority, and thus their potential for flexibility.

### 2.3.2. Goal 2: What are the factors influencing the intention to provide flexibility?

For the second objective, we studied the impact of monetary incentives and household characteristics on the intention to provide flexibility by accepting Direct Load Control (DLC) for EV charging and heating or shifting whiteware use outside peak times.

To assess respondents' openness to flexibility, we asked them whether they would allow their energy supplier to control their EV or heating system during the peak time on the low voltage grid (17h – 20h). In the case of whiteware, we asked them whether they would refrain from using their washing machine, dryer, or dishwasher in the same time interval. There were 7 possible answers which went from Strongly Disagree (1) to Strongly Agree (7). These are the actions that refer to flexibility provision in this document. It is important to notice that their response do not indicate their actual flexibility provision or a real behaviour, but an intention. This implies that we can only get an indication of what real behaviour may look like.

#### 2.3.2.1. *Impact of monetary incentives*

To determine the impact of financial incentives, we asked the respondents about their openness to flexibility several time, the first one without offering any monetary compensation, and the subsequent ones by proposing them three different incentive levels (low, medium, high). We tailored the incentives to the respective of the different appliances. We offered small sums for providing flexibility with the whiteware ones, which have a relatively smaller consumption. The heating system and EV were associated with higher incentives.

It emerged from the data analysis that low monetary incentives can be counterproductive when presented in comparison with higher ones and could even discourage flexibility provision. Higher monetary incentives have a positive impact in encouraging DLC acceptance and shifting whiteware usage outside peak hours. This implies that, to function in the direction intended, incentives and tariffs must be carefully designed and communicated to the residential customers. Additionally, framing effects need to be addressed. If the incentives appear very small compared to others or to what people spend in electricity bills, they may have a negative effect. In practice, it is important that the respondents have the perception that they are earning a fair amount of money or even making a bargain by providing flexibility.

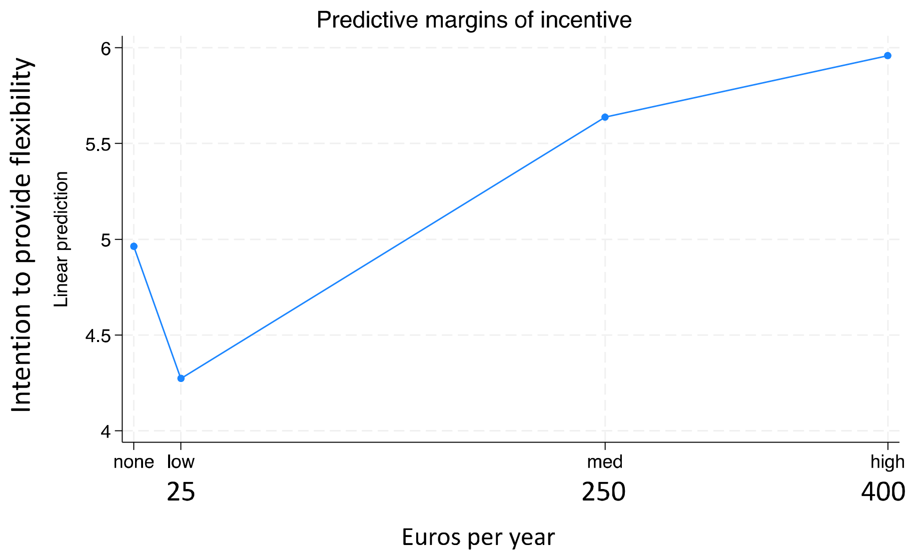


Figure 2. Example (EV charging) of how the intention to provide flexibility changes according to the incentive offered

#### 2.3.2.2. *Other determinants of Flexibility*

We also analysed how the individual and household characteristics collected through the survey impact openness to flexibility.

*Socio-demographic characteristics*

Older individuals are less likely to accept DLC for EV and Heating but are more likely to shift whiteware usage. Women are also more flexible with whiteware usage. We also analysed income, education, household composition, house type, but could not find any effect.

### *Technology ownership*

Owning a heat pump has a positive effect on heating flexibility. Owning (or planning to buy) an EV has a positive effect on EV charging flexibility. This suggests that familiarity with technologies can increase the flexibility potential, because people are more aware of how the flexibility provision (in this case DLC) works and are more likely to accept it.

Owning a PV installation with battery has a negative effect on flexibility, which is stronger in the case of DLC. This may be because these people prefer to have complete control over their consumption to do self-consumption. On the other hand, owning PV without battery does not make a difference.

### *Intrinsic motivations*

Individuals with higher environmental values are more likely to provide flexibility either by accepting DLC or shifting consumption. This implies that intrinsic motivations do play a role in flexibility provision. For these individuals, stressing the importance of flexibility for the environment may work even better than monetary incentives. An example would be stressing the fact that thanks to flexibility they can minimize the use of fossil fuels.

People with hedonic tendencies (prioritizing pleasure over other life values) are less likely to accept DLC. This may be related to the fact that they are not motivated to give up control of their comfort, unless something is provided in exchange. We can suppose that high financial incentives are needed to receive flexibility from these individuals.

### *Energy literacy*

Energy literacy has a positive effect on the intention to provide flexibility either by accepting DLC or shifting consumption. The effect is smaller compared to the one of environmental values. However, if the goal is to increase flexibility provision, it may be easier to upskill and educate people rather than to shift their values and motivations (Andolfi et al., 2024).

The effect is also visible when comparing the flexibility levels according to the energy literacy levels defined previously. We notice that either in the situation of shifting whiteware use outside of peak times and accepting DLC for heating and EV charging, the individuals with level 3 energy literacy are more likely to be flexible. Although the effect may seem small, we must again consider the type of sample, where a large majority of people are already literate and have a higher propensity to flexibility compared to the wider population. The fact that energy literacy consistently has a positive impact highlights its importance.

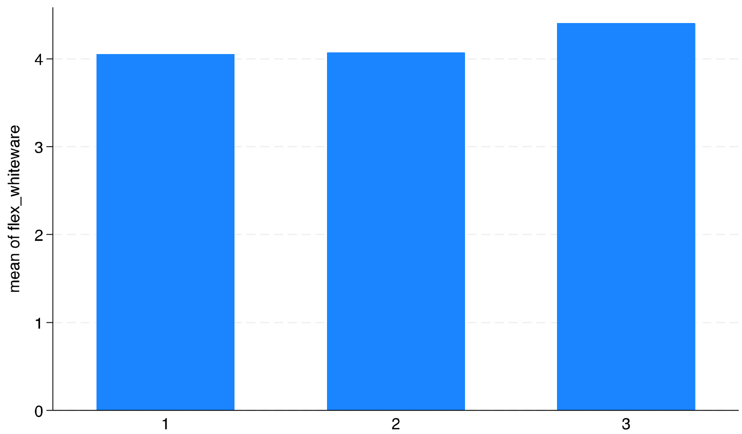


Figure 3. Intention to shift whiteware use per level of energy literacy

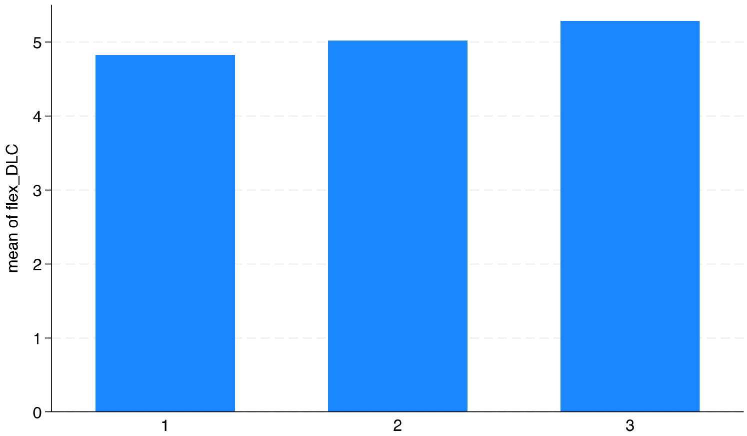


Figure 4. Intention to accept DLC (EV charging or heating) per level of energy literacy

# 3. Conclusions

The FlexBeAn Survey provided valuable insights into the flexibility potential of Luxembourgish households regarding their energy consumption behaviours and openness to adapting these behaviours for the power system's needs. Key findings include:

- Demographics and Sample Characteristics: The survey sample predominantly consisted of educated men with high incomes, many of whom are early adopters of energy technologies such as EVs, PV systems, and heat pumps. This group may not fully represent the broader population, which should be considered when generalising findings.
- Energy Literacy: Energy literacy among respondents was relatively high, likely due to their familiarity with advanced energy technologies. The survey revealed varying levels of energy literacy, categorised into three levels, with a notable impact on flexibility intentions. Higher energy literacy was associated with a greater willingness to provide flexibility.
- Nudging Strategy Influencers:
    - Environmental Sensitivity and Personality Traits: Individuals with conscientious personalities showed a strong commitment to environmental protection and were more likely to engage in energy flexibility. Extroverted individuals, influenced by social circles, may respond better to competitive or gamified incentives.
    - Sociodemographic Characteristics: Higher education levels correlated with increased energy literacy. Women and tenants showed higher neuroticism, indicating sensitivity to social influence, suggesting that social comparison and shared practices could enhance their engagement in flexibility.
- Intention to Provide Flexibility:
    - Monetary Incentives: Higher financial incentives effectively encouraged flexibility, while lower incentives could be counterproductive. Incentives must be perceived as fair and significant to positively influence behaviour.
    - Other Determinants: Older individuals and women were more inclined to shift whiteware usage. Ownership of heat pumps and EVs positively influenced flexibility, while PV system owners with batteries were less likely to provide flexibility due to a preference for consumption control. Intrinsic motivations, particularly environmental values, also played a significant role in flexibility intentions.

## 3.1. Recommendations

- Tailor Communication Strategies: for example, utilise persuasive communication from authoritative sources to encourage flexibility to encourage Conscientious Individuals. On the other hand, implement competitive and gamified features to engage Extroverted Individuals, leveraging their social influence.
- Design Effective Incentive Programs: Ensure monetary incentives are perceived as fair and significant. Avoid presenting low incentives that could discourage participation.
- Focus on Education and Upskilling: Prioritise energy literacy programs, especially for individuals with lower or medium education levels, to enhance overall

flexibility potential. Develop and promote the use of educational tools, such as the upcoming energy literacy upskilling smartphone application.

- Leverage Social Influence: Encourage practices that allow individuals, especially women and tenants, to share and compare their energy behaviours with friends, family, and colleagues to foster a culture of flexibility.

## 3.2. Future Research

- Broader Population Studies: Conduct further research with more diverse samples to validate the current findings across different demographic groups. This will ensure that strategies and recommendations are applicable to the wider population. Implement longitudinal studies to assess the long-term impact of educational programs, incentives, and social influence strategies on energy flexibility behaviour.
- Detailed Analysis of Incentive Structures: Investigate the optimal levels and types of financial incentives that maximise flexibility while ensuring cost-effectiveness. Explore non-monetary incentives that could complement financial rewards.

# Appendix A. Original survey questions in English

## A.1. Pre-questions

1. What is your gender?
    a. Woman
    b. Man
    c. Non-binary
    d. Prefer not to disclose
2. How old are you (value in years)?
3. Which highest degree of education do you have?
    a. No school diploma
    b. Middle School and Highschool
    c. General Educational Diploma (GED) / Vocational training
    d. Bachelor's degree
    e. Master's degree
    f. Doctoral degree
4. In which sector are you currently working?
    a. Healthcare
    b. Education
    c. Information Technology
    d. Finance
    e. Retail
    f. Hospitality
    g. Manufacturing
    h. Transportation and Logistics
    i. Marketing and Advertising
    j. Government and Public Administration
    k. Student
    l. Unemployed
    m. Other
5. What is your current job timetable?
    a. Dayshift (e.g. 8am-6pm)
    b. Nightshift (out of 8am-6pm)
    c. Other (special/rotating…)

6. What is your household monthly net income? (yours and other adults incomes combined)
    a. < 1000 €
    b. 1000-2999 €
    c. 3000-4999 €
    d. 5000-6999
    e. 7000-8999 €
    f. ≥ 9000 €
    g. Prefer not to disclose
7. What is your household composition?
    a. One person household
    b. Couple without children
    c. Couple with child(ren)
    d. Single-parent household
    e. Multiple adults in cohabitation
    f. Prefer not to disclose
8. Do you live in your own house/apartment or rent one?
    a. I am an owner
    b. I am a renter
9. What is your household type?
    a. Apartment
    b. Detached house
    c. Semi-detached house
    d. Row house (attached to another house on both sides)
    e. Other, please specify: *Enter other household type*
10. In which city do you live? (optional)
    a. *List of Luxembourgish cities*
11. Do you have a Smarty+ dongle?
    a. Yes
    b. No
    c. I don't know what it is
    d. I plan to buy one

 

## A.2. Energy appliances and usage

12. Is your household participating in our "Smarty+ campaign"?
    a. No, we are not participating
    b. Yes, we are registered under the following email address: Enter your email address
13. Which of the following devices are regularly in use in your household?
    a. Washing machine
    b. Tumble dryer
    c. Electric water heater
    d. Fridge
    e. Deep freezer
    f. Dish washer
14. What is your main heating system?
    a. Oil heating system
    b. Gas heating system
    c. Electric heat pump
    d. Wood pellets / Wood chips
    e. District heating
    f. Liquified petroleum gas (LPG)
    g. Wood stove (as the main heating system, not in addition to the main heating system)
    h. Electric convection heater
    i. I don't know
    j. Other, please specify: Enter other
15. Is your household owning or using an electric vehicle?
    a. Yes, we are using an electric car in our household
    b. No, we do not use an electric car yet, but it is likely that we would change to an electric car in the coming 3 years
    c. No, we do not use an electric car and are not intending to change this.
16. Does your household have a photovoltaic (solar panels) installation?
    a. Yes, we have a photovoltaic installation and a battery storage system connected to it
    b. Yes, we have a photovoltaic installation without battery storage system
    c. No, we do not have a photovoltaic installation, but intend to purchase one in the coming three years
    d. No, we do not have a photovoltaic installation and are not able or interested to install one

 

## A.3. Values related to environmental behaviors and beliefs

This section focuses on your values related to environmental behaviors and beliefs.

You will find several brief descriptions of different people. For each person we describe what is very important to him or her. Please read each description carefully and indicate how much this person is like you.

The meaning of the scores is as follows:

1 means that the person is totally not like you

7 means that the person is totally like you

The higher the score, the more the person is like you.

There are no right or wrong answers. Answer spontaneously.

<Note: in the implemented survey, questions appear according to a random scheme, but same for all participants (see order in the second list)>

17. It is important to [him or her] to prevent environmental pollution.

    *Not like me at all o o o o o o o Very much like me*

18. It is important to [him or her] that every person has equal opportunities.
19. It is important to [him or her] to have fun.
20. It is important to [him or her] to have control over others' actions.
21. It is important to [him or her] to protect the environment.
22. It is important to [him or her] to take care of those who are worse off.
23. It is important to [him or her] to enjoy the life's pleasures.
24. It is important to [him or her] to be influential.
25. It is important to [him or her] to respect nature.
26. It is important to [him or her] to be in unity with nature.
27. It is important to [him or her] that every person is treated justly.
28. It is important to [him or her] that there is no war or conflict.
29. It is important to [him or her] to be helpful to others.
30. It is important to [him or her] to do things [he/she] enjoys.
31. It is important to [him or her] to have authority over others.
32. It is important to [him or her] to have money and possessions.
33. It is important to [him or her] to work hard and be ambitious.
34. This is an attention question, please tick "Very much like me" on the right.

## A.4. Some questions about your personality

The following statements concern your perception about yourself in a variety of situations. Some personality aspects provide a better understanding of the behaviours related to energy flexibility.

For each statement, please indicate your level of agreement using a scale from 1 "Disagree strongly" to 5 "Agree strongly".

 

There are no right or wrong answers. Please answer spontaneously.

How well do the following statements describe your personality?

I see myself as someone who...

35. …is reserved

    *Strongly disagree* o o o o o *Strongly agree*

36. …is generally trusting
37. …tends to be lazy
38. …is relaxed, handles stress well
39. …has few artistic interests
40. …is outgoing, sociable
41. …tends to find fault with others
42. …does a thorough job
43. …gets nervous easily
44. …has an active imagination

## A.5. Your affinity with technologies

In the following questionnaire, we will ask you about your interaction with technical systems. The term "technical systems" refers to apps and other software applications, as well as entire digital devices (e.g., mobile phone, computer, TV, car navigation).

Please indicate the degree to which you agree/disagree with the following statements.

There are no right or wrong answers. Answer spontaneously.

45. I like to occupy myself in greater detail with technical systems.

    *Completely disagree* o o o o o o *Completely agree*

46. I like testing the functions of new technical systems.
47. I predominantly deal with technical systems because I have to.
48. When I have a new technical system in front of me, I try it out intensively.
49. I enjoy spending time becoming acquainted with a new technical system.
50. It is enough for me that a technical system works; I don't care how or why.
51. I try to understand how a technical system exactly works.
52. It is enough for me to know the basic functions of a technical system.
53. I try to make full use of the capabilities of a technical system.

## A.6. Flexibility potential DIRECT questions

Electricity tariffs are the prices we pay for the electricity we use in our homes. There are two types of tariffs: flat tariffs and variable tariffs. Flat tariffs are the same price for all hours of the day and night. Variable tariffs change based on the time of day. Prices are usually higher during the hours when more people are using electricity and lower during the hours when fewer people are using it.

Variable tariffs are needed to manage the demand for electricity. When many people are using electricity at the same time, it puts a strain on the power grid and the environment.

By charging more for electricity during peak hours, variable tariffs encourage people to use less electricity during those times. Using appliances like washing machines, dryers, dishwashers, and ovens at off-peak hours instead of peak hours, you can save money on your electricity bills. By shifting your energy usage to off-peak hours, you can take advantage of lower prices and reduce the stress on the power grid.

54. In general, from a household perspective, which period marks the time where the electricity consumption is the highest? (peak consumption hours)
    a. From 23:00 to 03:00
    b. From 14:00 to 17:00
    c. From 17:00 to 20:00
    d. I don't know
    e. I don't understand the question

Indicate how much you agree with the following statements (likert scale from 1 (strongly disagree) to 7 (strongly agree)):

<u>IMPORTANT: Even if you don't have some of the next appliances/devices, answer what you would do if you owned them.</u>

55. I habitually use the washing machine during the peak time (17h – 20h)

56. I habitually use the tumble drier during the peak time (17h – 20h)

57. I habitually use the dishwasher during the peak time (17h – 20h)

58. I would allow the energy supplier to adapt my heating system during the peak time (17h – 20h) if needed. (This does not affect your comfort since you have sufficient hot water storage and insulation to keep your preferred temperature throughout the day)

59. I would allow my energy supplier to slow down the charging of my electric vehicle during the peak time (17h – 20h) if needed. (Your electric vehicle will have the desired battery charge when you need it the morning after)

With the following questions we would like to understand how you would respond to different variable tariffs. So please base your replies only on the monetary incentive proposed in each question.

<u>IMPORTANT: Even if you don't have some of the next appliances/devices, answer what you would do if you owned them.</u>

For the next questions, imagine you get home from work in the evening and you need to do some household chores. Your electricity tariff is variable, meaning that you pay a higher price from 17h00 to 20h00.

Indicate how much you agree with the following statements.

60. I would NOT use the washing machine during the peak time (17h – 20h) to save [randomized low/medium/high INCENTIVE]

61. I would be willing to shift the use of the washing machine between 17h and 20h for

1h /2h/ 3h if I could save (incentive)

62. I would NOT use the tumble drier during the peak time (17h – 20h) to save [randomized low/medium/high INCENTIVE]

63. I would NOT use the dishwasher during the peak time (17h – 20h) to save [randomized low/medium/high INCENTIVE]

As in the previous scenario, imagine that you pay a higher price for electricity from 17h00 to 20h00. You have the possibility to let your energy supplier adapt the heating system of your house (heat pump, water boiler, ..) during high price periods. This does not affect your comfort since you have sufficient hot water storage and insulation to keep your preferred temperature throughout the day.

Indicate how much you agree with the following statements:

64. I would allow the energy supplier to adapt my heating system during the peak time (17h – 20h) if needed to save [randomized low/medium/high INCENTIVE]

As in the previous scenario, you pay a higher price for electricity from 17h00 to 20h00. Imagine that you have an electric vehicle and you plug it in for charging for the whole night. You have the possibility to let your energy supplier control the charging of your car to charge it during low price periods. The energy supplier assures that your electric vehicle has the desired battery charge when you need it the morning after.

On average, charging an electric vehicle at home costs between 5€ and 10€.

Indicate how much you agree with the following statements:

65. would allow my energy supplier to slow down the charging of my electric vehicle during the peak time (17h – 20h) if I could save [randomized low/medium/high INCENTIVE]

## A.7. Energy literacy

This part of the survey aims to assess your knowledge on energy literacy.

Energy Literacy is an understanding of the nature and role of energy in the world and daily lives accompanied by the ability to apply this understanding to answer questions and solve problems.

66. What is the impact if you largely increase your consumption during peak consumption hours (e.g. by charging your Electric Vehicle)? *You can select maximum of 3 choices*

   a. There is no impact
   b. Increased stress on the electricity grid
   c. Provoking the necessity for electricity expansion works in the electricity grid
   d. A shorter battery life time as batteries of smartphones, laptops or Electric Vehicles heat up more if charged during peak consumption hours
   e. I don't know
   f. I don't understand the question

67. What are the benefits of shifting your consumption from peak hours to a time of day where the consumption is lower? *You can select maximum of 3 choices*

   a. Charging an electric vehicle, smartphone or laptop is faster
   b. To have a lower electricity bill due to lower grid expansion costs
   c. There is no benefit for the household consumer

d. Generally lower CO2 emissions because fewer gas power plants need to be deployed
e. I don't know
f. I don't understand the question

68. Assuming there are a lot of Photovoltaic - PV (solar) installations in your neighbourhood. Are there any benefits of shifting your consumption from peak hours to a sunny time of day?
    a. Yes, it is important to consume the electricity when and where it is produced to prevent grid congestions
    b. Yes, otherwise the electricity is lost as soon as it enters the grid
    c. No, we can easily store all excess energy in summer and use it in winter
    d. No, the electricity can easily be transported over long distances, so it can be consumed elsewhere
    e. No, there is not a lot of electricity production during sunny weather
    f. I don't know
    g. I don't understand the question
69. Do you know how to delay the start of your dishwasher?
    a. Yes
    b. No
    c. It does not have this function
    d. I don't have a dishwasher
    e. I don't understand the question
70. Do you know how to delay the start of your Electric Vehicle charging?
    a. Yes
    b. No
    c. It does not have this function
    d. I don't have an Electric Vehicle
    e. I don't understand the question
71. What challenges does the switch to 100% renewable electricity generation entail? *You can select maximum of 4 choices*
    a. Renewable energy generation is highly volatile (changes constantly)
    b. Renewable energy generation is decentralized (a lot of small production plants instead of few large ones)
    c. Difficult to store renewable energy
    d. Difficult to align generation and consumption
    e. I don't know
    f. I don't understand the question
72. This is an attention question, please tick "Yes".

a. Yes
b. No
c. I don't know

73. On average, when a device works for one hour, rank them from the highest (up) consumption to the lowest (below) consumption
    a. Dishwasher / laundry
    b. Tumble dryer
    c. 5 light bulbs, each at 10 W
    d. Electric Vehicle
    e. TV and music player
    f. Heat pump
74. How much electricity does it take to fully charge an electric vehicle?
    a. 0.3 - 1 kWh
    b. 1 - 30 kWh
    c. 30 - 100 kWh
    d. 100 - 300 kWh
    e. 300 - 1000 kWh
    f. I don't know
    g. I don't understand the question
75. Do you know the amount of your monthly electricity bill? NB: Please indicate your best guess without checking your bill!
    a. No
    b. Yes, I pay approximatively: Enter your bill amount €/month
76. Suppose you had $100 in a savings account and the interest rate was 2 percent per year. After 5 years, how much do you think you would have in the account if you left the money to grow:
    a. More than $102
    b. Exactly $102
    c. Less than $10
    d. Do not know
77. Imagine that the interest rate on your savings account was 1 percent per year and inflation was 2 percent per year. After 1 year, would you be able to buy:
    a. More than today
    b. Exactly the same as today
    c. Or less than today
    d. Do not know
78. Do you think that the following statement is true or false? "Buying a single company stock usually provides a safer return than a stock mutual fund."

a. True
b. False
c. Do not know

79. Which heating system would you prefer for your home, considering both have a 15-year lifespan?
    a. Model A with a retail price of €3750 and a monthly bill of €100
    b. Model B with a retail price of €5000 and a lower monthly bill of €80
    c. I have no preference, both models are equally adequate
    d. I don't know
    e. I don't understand the question
80. Which of these household appliances uses the most electric energy during one day?
    a. fridge/freezer
    b. stove/oven
    c. I don't know
    d. I don't understand the question
81. Which of these household appliances generates the highest peak power demand?
    a. fridge/freezer
    b. stove/oven
    c. I don't know
    d. I don't understand the question

## A.8. Conclusion

Thanks for taking the time to answer our survey. As a reward you have the possibility to give us your email address so that we can send you a 20€ voucher

Additionally, we offer you the possibility to register to participate to our pilot phase for energy flexibility next year. Selected participants will have the opportunity to experiment our mobile applications and give their feedback on new ways to manage energy at home. Another voucher can be then obtained.

I accept to provide my email address to receive the 20€ voucher

I don't want to provide my email to receive the 20€ voucher

I accept to provide my email address to participate to the pilot phase next year

I don't want to provide my email to participate to the pilot phase next year

If you checked one of the boxes above please provide your email address, we will use it only in the context you chose above: *Enter your email address*

# Appendix B. Share of correct answers to the energy literacy questions

| question text | correct answers |
|---|---|
| In general, from a household perspective, which period marks the time where the electricity consumption is the highest? (peak consumption hours | 73% |
| What challenges does the switch to 100% renewable electricity generation entail? | 34% |
| What are the benefits of shifting your consumption from peak hours to a time of day where the consumption is lower? | 39% |
| Do you know the amount of your monthly electricity bill? NB: Please indicate your best guess without checking your bill! | 80% |
| How much electricity does it take to fully charge an electric vehicle? | 57% |
| Do you know how to delay the start of your Electric Vehicle charging? | 40% |
| Do you know how to delay the start of your dishwasher? | 60% |
| Which of these household appliances uses the most electric energy during one day? | 73% |
| Which of these household appliances generates the highest peak power demand? | 88% |
| Which heating system would you prefer for your home, considering both have a 15-year lifespan? | 69% |
| What is the impact if you largely increase your consumption during peak consumption hours (e.g. by charging your Electric Vehicle)? | 63% |
| Assuming there are a lot of Photovoltaic - PV (solar) installations in your neighbourhood. Are there any benefits of shifting your consumption from peak hours to a sunny time of day? | 71% |
| On average, when a device works for one hour, rank them from the highest (up) consumption to the lowest (below) consumption | 19% |

 

# Appendix C. Analysis for the selection of energy literacy questions

The document is 59 pages, therefore the interested reader can find the link below:

FlexBeAn Questionnaire_WP2-Survey.docx

# Appendix D. Are you flexible enough? The impact of energy literacy and environmental values on flexibility provision

## Are You Flexible Enough? The Impact of Energy Literacy and Environmental Values on Flexibility Provision

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***Abstract*— The residential sector plays a crucial role in the sustainable energy transition. By accepting direct load control, households can provide flexibility and contribute to stable energy systems where supply and demand are in balance. First studies indicate that when residential consumers are energy-literate, i.e., when they have a basic understanding of the use of energy and how it relates to their daily use of energy-related technologies, their willingness to provide flexibility increases. However, empirical confirmation is still scarce. Therefore, our study surveyed residential consumers in a European country ($n = 442$) to examine their understanding of energy use and their motivations for providing flexibility for heating and charging of electric vehicles (EVs). Results reveal that energy literacy and environmental values are key predictors for flexibility.**

***Index Terms*— Electric Vehicle Charging, Energy Literacy, Environmental Values, Flexibility Provision, Heating.**

### I. Introduction

Global strategies to combat climate change and reduce carbon emissions are manifold. One approach is to invest heavily in increasing the share of renewable energy. Another is to electrify certain sectors, such as mobility and heating [1]. However, these developments, especially increasing the share of renewable energy, present a major challenge to the power system [2]. This is because renewable energy sources (RES), such as wind and solar, are intermittent and less flexible at peak times [3].

To integrate RES and maintain grid balance, demand side management (DSM) can be applied. DSM refers to measures aimed to reduce consumers' energy use or shift it away from peak periods [4]. This encompasses demand response (DR) measures, which encourage consumers to change their energy consumption [5] based on grid conditions [6]. However, many DR programs require consumers to actively respond to price signals. Studies find that a large majority, more than 90% in Gohary's [7] study, lack an understanding of the impact of their behaviour on energy consumption. This means that most people lack the prerequisite knowledge to respond to DR price signals. Direct load control (DLC), which also falls under DR programs [6] might offer a more viable solution. With DLC, consumers authorize a third party (i.e., energy supplier, network operator) to remotely control specific household devices [8]. By giving control to a third party, consumers do not have to actively engage with energy price signals. Nevertheless, consumer preferences, such as when and at what percentage the electric vehicle (EV) should be charged, are considered by the third party. For example, DLC for EV charging means that consumers would give the energy supplier control over when to charge the EV, while still respecting charging preferences.

So far people are reluctant to accept DLC since they are afraid of losing control and comfort [5], [9]. Recent studies have begun to unravel the factors that motivate household consumers to provide flexibility. A first qualitative study suggests that energy literacy, or the lack of it, has a significant impact on consumption behaviours [10]. Energy literacy typically includes financial and energy knowledge as well as a general awareness of energy-related decisions and their impact on energy consumption and energy systems [11]. Other studies suggest that environmental considerations, such as maximizing the use of green energy, impact individuals' willingness to change their consumption habits [1], [12], [13]. What is still lacking, however, is a quantitative validation of energy literacy and environmental values in the context of flexible use of heating and charging. Thus, our research question is formulated as follows:

*RQ: How do energy literacy and environmental values influence the intention to provide flexibility for heating and charging?*

Combining the insights of previous qualitative studies, e.g., by Walker and Hope [10] as well as Martins et al. [11], we empirically examine the relationship between the provision of flexibility through the acceptance of DLC and energy literacy and environmental values. Our focus is on EV charging and heating, as they have the greatest potential for household flexibility [14]. Analysing survey data from 442 customers of a medium-sized European distribution system operator (DSO), our results indicate that the provision of flexibility varies across technologies. We find that environmental values and energy

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