

WP2

Executive summary

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Project acronym	FlexBeAn
Full title	Flexibility potentials and user Behaviour Analysis
Project start date	2022-05-02
Project duration	41 months

Work package 2	Behavioural aspects and energy literacy
Deliverable lead organisation	LIST
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Version	1.0
Status	Final
Dissemination level	PU: Public

This is the executive summary of FlexBeAn WP2, summarizing the goal of the workpackage, the different tasks executed, the achievements and conclusions. It links to WP2 deliverables for details.

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1. Introduction

1.1. Main objectives

The WP2 of the FlexBeAn project is dedicated to the customer side of Flexibility and the related human influential factors. It focuses on households, seeking as a first objective to understand their representative’s knowledge about the energy sector and its functioning (including the notion of flexibility), as well as the variables influencing their willingness to provide flexibility. This relates to customer (here household) energy literacy, and the modelling of customer flexibility from households and their representative characteristics (i.e., profile), including influential variables of flexibility. From the analysis and modelling of households, the second objective is to find incentives for providing flexibility and experiment strategies to upskill customers towards a better knowledge of the energy sector and increase their flexibility.

In short, the objective of WP2 was to analyse household energy literacy and behavioural drivers of flexibility, and to design and test strategies to improve customer engagement. More specifically, WP2 aimed to: (1) develop a theoretical model of household energy flexibility; (2) collect large-scale survey data to validate the model and identify influencing variables; and (3) design and evaluate digital tools and campaigns to upskill households and increase their flexibility potential.

1.2. Tasks

The work was divided into three tasks as illustrated by Figure 1:

- T2.1 Customers modelling and Energy literacy assessment: to gather data about customers, build and assess user models related to energy literacy and flexibility
- T2.2 Customer – Incentive mapping: to cluster users and map to incentives
- T2.3 Technologies for Energy upskilling of customers: to develop and test technologies for energy upskilling of customers to influence and increase their behaviour towards flexibility

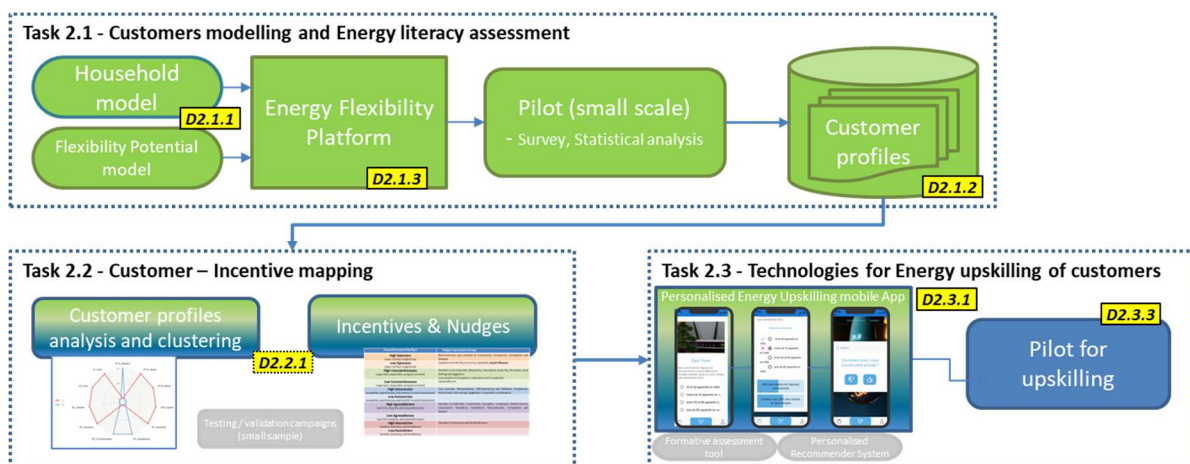


Figure 1. WP2 tasks details and structure

1.3. Methodology and Approach

WP2 combined quantitative survey research, behavioural modelling, clustering analysis, and a digital intervention campaign. The approach was structured into three main tasks:

- large-scale data collection and modelling of household energy literacy and flexibility (survey of 544 households in Luxembourg, development of a household flexibility model),
- clustering of households and mapping to incentives using statistical and medoid-based approaches,
- development and pilot testing of the One2Day mobile-first app, implementing a personalized nudging strategy for energy upskilling.

This mixed-methods approach enabled the identification of key determinants of flexibility, the segmentation of households into meaningful profiles, and the design of tailored interventions to foster behavioural change.

1.4. Overview of WP2 Deliverables

This executive summary introduces the final deliverables of WP2, which are aggregated versions of the deliverables initially foreseen when the project description was written. The initial deliverables have been revised during the project according to the progress, the evolving needs and the priorities. As a result, publicly available deliverables consist in the following set of reports, for which we kept the corresponding initial deliverable identifier as a reference (see FlexBeAn project description for details), detailed in the following in dedicated sections:

- Household's energy literacy and flexibility survey - flexibility model, survey design and conclusions (D2.1.1 - D2.1.4); Section 2.
- Household's energy literacy and flexibility survey - energy literacy platform and datasets (D2.1.2 - D2.2.1 - D2.1.3); Section 3.
- Household's energy literacy and flexibility survey - clustering of household profiles (D2.2.2); Section 4.
- Toolkit for energy upskilling (D2.3.1); Section 5.
- Upskilling campaign report (D2.3.3); Section 6.

2. Household's energy literacy and flexibility survey - *flexibility model, survey design and conclusions (D2.1.1 - D2.1.4)*

The report details the design of 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.

2.1. Energy literacy: state of the art and Household flexibility model

The review of the state of the art focused on energy literacy and factors impacting flexibility revealed three main determinants of flexibility: Ability (biographical characteristics, energy literacy, personality), Opportunity (socio-demographic aspects), and Motivation (personal

values, technology acceptance). From the analysis, we proposed a theoretical model of household energy flexibility, centred on these three variables, which provides a valuable framework for understanding the individual determinants influencing flexible energy practices.

2.2. Energy literacy survey

In 2023, Creos, LIST and SnT surveyed 544 Luxembourgish households to examine energy literacy and flexibility. The questionnaire covered socio-demographics, household characteristics, appliance ownership, environmental values, personality traits, technology affinity, openness to flexibility, and energy literacy.

The results showed that respondents were generally highly educated, with many early adopters of energy technologies such as EVs, PV systems and heat pumps. Energy literacy scores were relatively high overall and positively correlated with willingness to shift consumption or accept demand-side measures. Three literacy levels were identified, with higher literacy linked to greater openness to flexibility.

Behavioural drivers also played a significant role. Conscientious individuals and those with strong environmental values were more inclined to adapt consumption, while extroverted individuals responded well to gamified or competitive incentives. Women and tenants displayed higher sensitivity to social influence, suggesting the relevance of social comparison mechanisms. Older individuals were more likely to shift whiteware use, and households with EVs or heat pumps were more flexible than those with PV plus battery systems, who preferred self-consumption.

Financial incentives proved effective when perceived as fair and significant, whereas low incentives could discourage participation. Intrinsic motivations, particularly environmental concern, also strongly influenced willingness to provide flexibility.

Overall, the survey indicates that flexibility potential in Luxembourgish households is shaped by a mix of knowledge, socio-demographic factors, personality traits, and technology ownership. It underscores the importance of targeted communication, fair incentive design, and continued efforts to strengthen energy literacy.

3. Household's energy literacy and flexibility survey - *energy literacy platform and datasets (D2.1.2 - D2.2.1 - D2.1.3)*

The report documents the Energy Literacy Platform deployed as part of Task 2.1 and the anonymized user profiles collected with this platform during the energy literacy and flexibility survey conducted within WP2 of the FlexBeAn project (see D2.1.4). The platform is presented with its technical implementation. It supports the different methods of access to the Energy Literacy Assessment survey, and implements the data collection pipeline required in WP1 to gather smart meter data via the Smarty+ app.

4. Household's energy literacy and flexibility survey - *clustering of household profiles* (D2.2.2)

This report details the data analysis performed on the dataset obtained from the energy literacy and flexibility survey conducted in the WP2 of the FlexBeAn project, with the goal of finding clusters of households having different characteristics. It highlights the obtained clusters and their main characteristics regarding the household model (see D2.1.4), through the survey's questionnaire.

First investigations consisted in comparing respondent answers to the Energy literacy and flexibility study and detect any answering pattern. As a first step, an overall clustering algorithm was implemented on all categorical, ordinal and numerical features to detect any potential clusters. Then, the clustering analysis was focused on the features with Likert scale data (a Likert scale is a rating scale used to measure survey participants' opinions, attitudes, motivations, and more.).

As the first investigation did not provide any useful conclusions, advanced approaches were explored as a second step to get more significant and exploitable results. The goal was to uncover meaningful clusters among respondents based on their responses, using a medoid-based clustering approach. The methodology provides several advantages, enhancing the analysis and delivering valuable insights. The survey contained multiple questions, some of which were correlated. Therefore, the analysis prudently focused on reducing the number of features and highlighting key variables based on expert knowledge. This method aimed to uncover meaningful clusters within the data, which would be beneficial for understanding the survey results. The analysis presented here, supported by statistical and visual tools, confirms the presence of distinct clusters within the energy literacy and flexibility survey data. These results provide valuable insights into the diverse characteristics and preferences of the survey respondents, enhancing our understanding of the underlying patterns in the data.

From their answer to the survey, the participants sample could be grouped into two separated clusters of similar households having each their own unique characteristics. One category of households is represented by individuals with a higher emphasis on environmental issues, who are agreeable and conscientious, and most are not technology friends. The other category represents individuals who are less sensitive to environment, with a lower agreeableness and conscientiousness, but who are technology friends. They tend to be more literate and have a higher openness to experience (linked to their personality) than people from the first group, but the difference is not significant, and this remains to be confirmed. The other characteristics are mostly similar among the two groups, not statistically determinant. Overall, this analysis confirms the relationship between sensitivity to environment and conscientiousness, highlighting in addition the influence of agreeableness (which we know however is biased), and the affinity to technology interaction, which might also be a determinant.

5. Toolkit for energy upskilling (D2.3.1)

This report presents the toolkit for energy upskilling used for the pilot experimented in WP2 of the FlexBeAn project, seeking to upskill households' representatives towards more energy literacy and flexibility. The toolkit is implemented as a mobile-first application, One2Day, which delivers daily content related to energy flexibility to participants,

encouraging regular engagement to enhance their energy consumption behaviour. We document the development, implementation, and underlying software components of the One2Day app, and detail the specific approach driving the app behaviour, based on a personalised nudging strategy (from profiles following our household model – see D2.1.4) to encourage behaviour change. The application’s design adapts to individual users’ personality traits, as measured by the Big Five model, to provide personalized paths that support energy flexibility.

5.1. Energy upskilling toolkit: One2Day technical overview

The pilot led for household energy upskilling has been implemented as a mobile first app, named *One2Day*, that delivers to pilot participants one content related to the energy flexibility topic per day. Participants are expected to connect regularly (ideally every day) to consult the available content. A high-level technical overview of the different software components developed to implement the Upskilling Pilot is given, including details on the technology stack involved.

The One2Day App is designed to deliver to registered users a single daily content related to the energy flexibility domain. To implement this service, a typical cloud-native app architecture has been developed. The One2Day app itself is designed as a Progressive Web App² that can be accessed via a smartphone or a desktop computer. The content delivered by the app is encoded and managed via a dedicated CMS and served to the app by custom API. An internal service implements the app content selection algorithm used to personalize the users’ content feeds. Finally, a monitoring stack has been deployed to provide insight on the progress of the Pilot via pre-configured dashboards.

5.2. The App and its personalized nudging strategy

The One2Day App implements a nudging strategy based on persuasive design, which was found necessary to reach the expected level of flexibility, based on the consideration that energy flexibility is considered a necessary adaptation from the perspective of both electricity producers and consumers. For producers, it is defined as the ability to react to unexpected changes in electricity demand. For consumers, flexibility refers to the ability to adjust their own demand (and their energy production, if necessary) depending on the global demand on the electricity network and local conditions. Consequently, it is important to focus on the ways in which it is possible to change the attitudes and behaviour of consumers related to energy flexibility. The App design process including the persuasive strategies is detailed, highlighting the way in which the persuasion elements (the nudges) are chosen from the household profiles instantiating the household flexibility model (D2.1.4) and exploiting results from the survey analysis (D2.1.4 and D2.2.2).

6. Upskilling campaign report (D2.3.3)

This report presents the design, implementation, and outcomes of an energy upskilling pilot conducted as part of Work Package 2 of the FlexBeAn project, aiming to enhance household energy literacy and flexibility through a digital intervention. At the heart of the intervention is *One2Day*, a mobile-first application that delivers personalized daily content to encourage sustainable energy behaviours.

Three groups were studied: a *profile group* receiving personalized content based on psychological profiling and energy use characteristics; a *random group* receiving non-tailored content; and a *control group* with no access to the app. Over several weeks,

participants were exposed to thematic modules including quizzes, nudges, and informational prompts, with energy literacy and behavioural flexibility assessed at multiple stages.

The findings highlight several key insights:

- **App usage significantly improved energy literacy**, especially in the early stages of the intervention.
- **Personalized content enhanced both literacy and behavioural flexibility** more effectively than random or absent interventions, with the *profile group* showing the highest improvement rates.
- **Specific behaviours** such as voluntary delay of high-energy appliances (e.g., dryers, EV charging) were particularly responsive to targeted content, suggesting that **user-driven flexibility actions** are most effectively promoted through relevant, trusted messaging.
- **Psychological traits** (personality, environmental values, tech affinity) alone did not predict improvement but played a role when leveraged through personalization strategies.

The intervention proved effective in promoting learning and change among engaged users, despite decreasing participation over time. The results support the use of adaptive, psychologically informed digital tools to engage citizens in energy transition efforts. Recommendations include further tailoring of content, reinforcement of trust in grid actors, and prioritization of user-initiated flexibility behaviours.

7. Conclusion

Work Package 2 of the FlexBeAn project provided a comprehensive analysis of household energy literacy and flexibility. The theoretical household flexibility model (D2.1.1) framed the determinants of flexibility in terms of ability, opportunity and motivation. Building on this, the large-scale household survey (D2.1.2-D2.1.4) revealed high levels of energy literacy among early adopters in Luxembourg, and confirmed that knowledge, socio-demographic characteristics, personality traits and technology ownership are associated with flexibility intentions.

The Energy Literacy Platform and associated datasets (D2.2.1, D2.1.3) enabled robust data collection and integration with smart meter information, while the clustering of household profiles (D2.2.2) provided evidence of distinct household groups with differing openness to flexibility. These insights informed the development of the One2Day application (D2.3.1), which implemented a personalised nudging strategy to support behavioural change. The subsequent upskilling campaign (D2.3.3) suggested that targeted, tailored interventions can effectively raise energy literacy and increase willingness to adapt consumption patterns.

The main findings of WP2 can be summarized as follows:

- A theoretical household flexibility model was established, identifying Ability, Opportunity, and Motivation as key determinants of flexibility.

- The survey of 544 households revealed relatively high energy literacy in Luxembourg, positively correlated with willingness to shift consumption. Personality traits, environmental values and technology affinity also influenced flexibility potential.
- Clustering analysis confirmed the existence of distinct household profiles, differentiated by personality, environmental concern, and technology affinity.
- The One2Day application, designed with personalized nudging strategies, proved effective in enhancing energy literacy and flexibility during the pilot campaign. Personalized content outperformed random or non-personalized interventions.

Altogether, WP2 shows that flexibility cannot be fostered through a single instrument. Instead, a combination of education, incentives, and personalised engagement is required. The results highlight the importance of designing fair and motivating incentive structures, strengthening energy literacy across all population groups, and leveraging social and technological drivers to enhance household participation in the energy transition.