POLITECNICO DI TORINO

Master's Degree in Energetics and Nuclear Engineering

Master's Degree Thesis

Design of User Interface(UI) for participatory Science Experiment in Energy Environment

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Summary

The thesis titled "Design of User Interface (UI) for Participatory Science Experiment in Energy Environment" focuses on enhancing energy savings in the building sector by improving user engagement with energy consumption data. The goal is to develop a dynamic, intuitive dashboard that allows users to monitor and manage their energy usage effectively, fostering energy-saving behaviors.

The study is part of the xKy Project, which utilises the Linky smart meter from the French energy provider company ENEDIS, along with the Winky gateway, to deliver real-time data on household energy consumption.The project aims to bridge the gap between innovative technology and user engagement by creating a user-friendly interface for visualizing energy metrics. This interface helps users better understand their electricity consumption and make informed decisions, thus promoting energy savings.

The dashboard design leverages principles of visual hierarchy, ensuring that key metrics are prominently displayed, and is built using the Grafana platform in conjunction with the InfluxDB database. Real-time data visualization is enhanced through interactive and customized features, such as displaying energy costs and consumption patterns. The work also integrates demand response mechanisms, encouraging users to shift energy use during off-peak hours.

Key achievements include the development of a prototype dashboard and the successful integration of real-time energy data for 45 participating households. The study emphasizes the importance of clear insights and user-friendly designs in motivating energy-saving behaviors.

The long-term aim is to deploy the dashboard in real-life settings, evaluate its impact, and refine the design based on user feedback, ultimately contributing to a more sustainable and efficient energy future.

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Acronyms

ASI
Appliance Specific Information

CNRS
Centre Nartional de la Recherche Scientifique

G2ELab
Grenoble Electrical Engineering Laboratory

GAI
Group Appliance Information

GreEn-ER
Grenoble énergie - enseignement et recherche

INP
Institut National Polytechnique

MAGE
Models, Methods, and Methodologies Applied to Electrical Engineering

OTE
Observatoire de la Transition énergétique

PREDIS
Production Réseau Energie Distribuée

TIC
Télé information client

UGA

Université de Grenoble Alpes

Chapter 1

General Introduction

1.1 Context of the study

The transition to a low-carbon economy is one of the most pressing challenges of our time. The 2015 Paris Agreement on climate change sets global expectations for this transition, emphasizing the need for a low-carbon future [1]. The urgency of this challenge is well understood, and there's a global commitment to being part of the solution. Furthermore, the International Energy Agency highlights the critical role of energy efficiency in achieving significant reductions in greenhouse gas emissions. Energy efficiency improvements can contribute around 40 percent of the necessary emissions reductions to meet international climate targets, such as keeping global temperature increase below 2°C [2]. The increase in electrification is evident across all end-use sectors, with the greatest potential in buildings. By 2050, at least half of the final energy demand in buildings is expected to be electrified, mainly due to the massive integration of electric vehicles and heat pumps [3]. The buildings sector, which includes energy used for constructing, heating, cooling, and lighting homes and businesses and the appliances and equipment installed in them, accounts for over one-third of global energy consumption and emission [4]. In France, many companies are investing significant effort in enhancing energy efficiency in the building sector, especially in homes [5]. At G2Elab in Grenoble, a team of researchers called MAGE is working on smart grid modelling, specifically focusing on the Linky smart meter to enable users to better understand their electricity consumption and adopt energy-saving habits and behaviors. One project, the xKy Project, is open to everyone as it is available in Open Source. It is an ongoing project in the team MAGE at G2Elab and my work is involved in the xky project.

1.1.1 Problem Statement

There is a significant socio-technical gap in the current energy management in the building sector. The gap is characterized by a disparity between innovative technology and the engagement of users with these technologies.

The first problem encountered is the lack of knowledge among users about their energy consumption which leads to energy waste and the absence of energy-saving habits. Many users receive their electricity bills that provide minimal insights into their actual consumption patterns, leaving them unaware of how to adjust their behaviors to save energy.

The second issue concerns the time granularity of harnessed data. The current energy data collection methods, such as electricity bill and Linky meters, do not provide real-time data. Electricity bill offer a retrospective view of consumption without detailed breakdowns. Linky meters although an improvement, only provide data in 30-minutes interval, and this data is typically available the day after consumption.

This delay and lack of a finer time granularity in the data makes it difficult for users to make timely and informed decisions about their energy use. For example, users can not see the immediate impact of turning off an appliance or adjusting their heating settings, which limits their ability to adopt energy-saving habits effectively.

With Linky meter, only 48 row data are provided per day and the readings are seen the day ahead which is not real-time data. This issue is addressed by Jérôme Ferrari, a CNRS engineer affiliated with G2Elab. He has developed a device called WinKy that can be connected to the TIC port (tele information client gateway) of the Linky smart meter[6] and allows the recovery of 2880 data per day with a time step of less than one minute. The Linky meter equipped with winky gateway in the xky architecture, allows the Grenoble scientific community and OTE (Observatoire de la Transition Énergétique) to obtain all users' electricity consumption data in real-time—including all energy related metric data and send it to OTE servers. With this data it is possible to have the baseline of electricity consumption of each household therefore visualise it and optimize the appliances' energy use per household to incite users to energy-saving habits.

To bridge the gap between innovative technology and user engagement with the technology, my research focuses on developping a user-centric interface. The goal is to create an intuitive real-time data visualization tool based on users preferences and needs enable them to visualise their electrical energy consumption metrics actively.

1.2 Importance of the study

The work aims to design optimal user interface for users having a Linky smart meters in their houses in order to help them reducing their energy consumption. This project aligns with the commitment to reducing emissions and promoting energy savings in the building sector. By focusing on developing a user-centric energy data visualisation and monitoring interface for users having Linky meters, individuals and organizations can be empowered to make informed decisions about their energy usage, promoting change of use of appliances.

1.2.1 The XKY project

My internship is part of the XKY project, aligned with the research efforts of the Energy Transition Observatory (OTE) of Grenoble. This observatory brings together over a hundred researchers from 11 scientific fields across 20 public laboratories of the University Grenoble Alpes. The program aims to observe and understand potential changes to achieve a decarbonized energy transition that is "Efficient, Simple, Sustainable, Desirable, and Flexible." The primary goals of the observatory are to contribute to the emergence of a low-carbon society, conduct in-depth scientific research on energy transition, develop future technologies and materials used at all stages of energy systems, widely disseminate results to maximize impact and promote a participatory and open scientific approach.

The OTE employs a unique approach called “participatory science,” where the non-scientific public actively participates in data collection, analysis, and even the formulation of research questions. This approach aims to involve individuals, community groups, and society as a whole in the production and dissemination of scientific knowledge, fostering a two-way relationship between novices and experts. By uniting researchers from various disciplines, the OTE plays a key role in promoting solutions for a sustainable energy future.

The goal of the XKY project

The main goal of the xky project is to create an Open Source gateway for retrieving data from the Linky meter. Utilizing three communication technologies (LoRa, WIFI, and Ethernet), auto-powered via the TeleInfoClient socket of the Linky meter, and receiving data transmitted by the meter every minute, this device can collect real-time electricity consumption information of a household.

The primary objective of xky is to securely collect this information to meet the various needs of research teams during their experiments. It also aims to make the technology accessible to individuals wanting to understand and reduce their energy consumption through the open-source plan and code of the solution. This device is part of a study covering several themes such as the role of Open Source in the energy sector, disaggregating appliance data, understanding household energy consumption, and potentially many other interdisciplinary studies. It is developed through participatory sciences.

Phases of the xKy project

The study is conducted in three major phases:

- Preliminary Questionnaire and Data Access: Respondents complete a preliminary questionnaire and grant access to their consumption data from ENEDIS servers.
- Receiving and Connecting the Winky Gateway: Participants receive and connect a free Open Source Winky gateway to their Linky meter.
- Connecting Communicating Plugs: Depending on the profile, participants receive and connect four free communicating plugs to measure and control the consumption of certain appliances.

1.2.2 Objective of the study

The primary objective of the xKy study is :

- Facilitate Scientific Publications: Provide a standardized, intuitive platform that enables researchers to collect, analyze, and publish energy consumption data more effectively.
- Enhance Understanding of the Electrical Domain: Create a user-friendly interface that helps non-expert users visualize and comprehend their electricity consumption patterns, empowering them to make informed decisions.

1.3 Objective of my internship

For my master's thesis, I am carrying out an internship at G2Elab, focusing on the design of User Interface (UI) for participatory science experiment in the energy environment. To achieve the main goal, the internship focuses on the following specific objectives over six months:

1. Understand the Existing Solution: Gain a comprehensive understanding of the current xKy solution developed by Jérôme Ferrari and how it integrates with the Linky smart meter.

2. Analyze User Feedback: Review and analyze initial feedback from participants using the xKy device to identify areas for improvement in the user interface.

3. Design and Prototype the Interface:

    - Develop a self-configurable, user-friendly interface that visualizes real-time energy metrics in a meaningful way.

    - Ensure the interface adapts to different user profiles and energy consumption patterns.

4. Prototype and test questionnaires to gather additional feedback on interface design and usability.

5. Implement Experimentation Phase:

    - Assist in implementing the second phase of the xKy experimentation.

    - Collaborate with the scientific community and OTE (Observatoire de la Transition Énergétique) to refine the data collection and visualization process.

6. Conduct User Interviews:

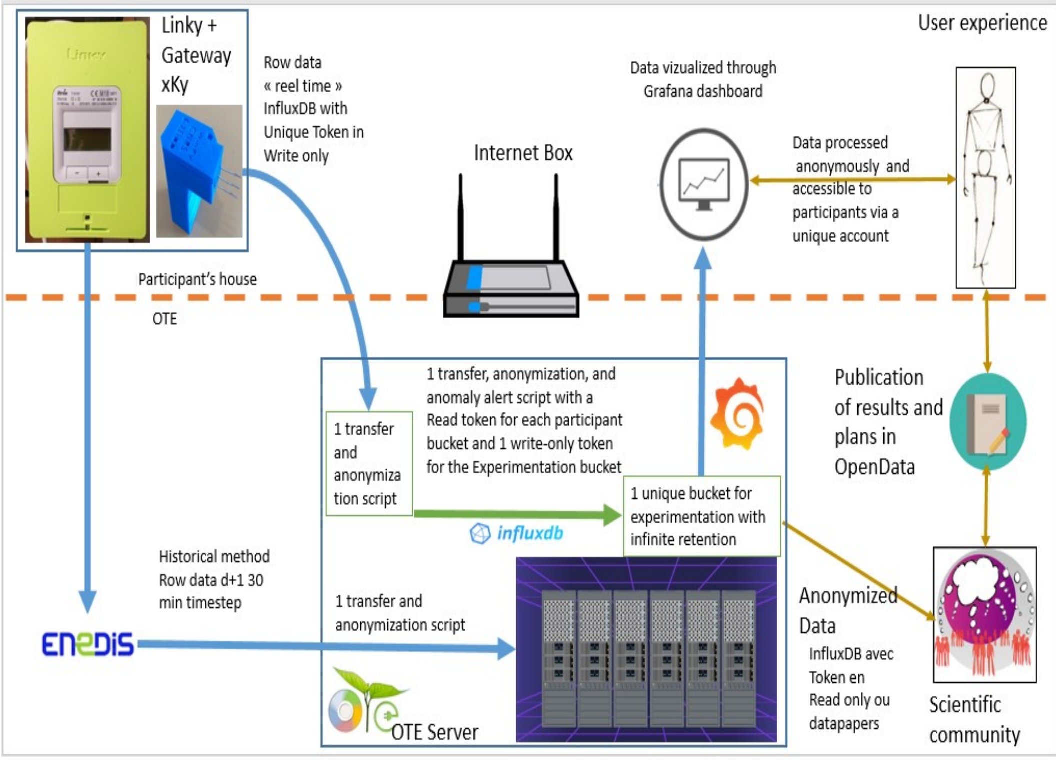
    - Design and conduct interviews with participants to understand their experience with the xKy device and identify further improvement opportunities.

7. Develop the Universal Interface:

    - Code and implement the universal interface to enable users to visualize and understand their energy consumption.

    - Incorporate feedback and interview insights to create a robust, intuitive, and self-configurable user interface.

By achieving these objectives, users will be significantly empowered to monitor and manage their energy consumption more effectively, ultimately promoting energy savings and contributing to a cleaner environment.



[7]

Figure 1.1: Architecture xky project

1.4 Company presentation:Grenoble Electrical Engineering Laboratory(G2ELab)

Electrical Engineering plays a pivotal and unifying role in modern society, particularly in addressing the major societal challenge of energy. The flexibility and performance offered by electricity across industrial systems, transportation, and housing underscore the importance of this field. Within this context, the Grenoble Electrical Engineering Laboratory (G2Elab) stands at the forefront of innovation, covering a scientific spectrum ranging from materials and components to the design and control of electrical energy systems. [6].

Key Focus Areas: G2Elab's activities can be summarized by the following keywords:

- Electrical Energy
- Materials for Electrical Engineering
- Innovative Processes and Systems

- Modeling and Design

Research Overview:

- Permanent Staff: Approximately 100 members
- Doctoral Students: Around 100 researchers
- Students and Visitors: Over 70 master's students, post-doctoral researchers, and visiting professors

Structure and Supervision:

G2Elab is a joint research unit of the CNRS (French National Research Organization), supervised by:

- CNRS(Centre National de la Recherche Scientifique)
- University of Grenoble Alpes (UGA)
- Grenoble INP (National Polytechnic Institute)

Research Teams and Groups

The laboratory comprises five core research teams and two specialized research groups:

Research Teams:

- Power Electronics
- Material Machine, and Advanced Electromagnetic Devices
- Model Methods Methodology Applied to Electrical Engineering
- Dielectric and Electrostatic Materials
- Power Systems and Electrical Networks

Research Groups:

- Micro Magnetic Systems
- Low Magnetic Field

Facility Overview:

In the summer of 2015, G2Elab relocated to its new premises within the "smart building" known as GreEn-ER (Grenoble Energy - Education Research). This state-of-the-art facility spans 23,000 m^2 and houses:

- Engineering School Ense[3]
- Undergraduate and Master's programs from the Université Grenoble Alpes
- G2Elab Laboratory
- Training/Research Platforms (PREDIS)

Innovation Hub:

A notable feature of GreEn-ER is a 500 m^2 "living laboratory," which enables students and researchers to test energy management strategies on a real scale.

Technical Platform:

I am integrated within the shared technical platform, specifically in the Industrial Computing department.

To conclude, G2Elab has firmly established itself as a leader in energy efficiency for components and systems, playing a significant national and international role.

The structure of this work will be as follow:

- Chapter 1: General introduction
- Chapter 2: Literature Review
- Chapter 3: Methodology
- Chapter 4: Analysis and implementation
- Chapter 5: Conclusion

Chapter 2

Litterature Review

2.1 Designing User Interfaces for Energy Consumption Management

2.1.1 Introduction to Smart Meters and User Interfaces

The increasing global energy demand and environmental concerns necessitate innovative approaches to energy management. Smart meters, capable of providing detailed real-time data on energy consumption, represent a critical tool in managing energy use in residential and commercial settings. Articles by Wood and Newborough (2007) [8] and Weiss et al. (2019)[9] emphasize the potential of smart meters to influence consumer behavior by providing immediate feedback and detailed consumption data, which can encourage energy-saving behaviors.

Effective User Interfaces: Effective user interfaces in smart meters are crucial for facilitating user interaction and comprehension. Perekalskiy and Kokin (2020)[10] highlight the development of a smart meter that integrates seamlessly with existing household infrastructure, offering features like theft detection and real-time quality monitoring accessible via an intuitive user interface. This approach underscores the importance of designing interfaces that are not only informative but also engaging, promoting regular interaction and behavior change.

2.1.2 Previous Studies on Designing User Interfaces for Energy Management

Visualization of Energy Data: The visualization of energy data plays a vital role in how consumers perceive and react to information. Dressel and Peinl (2018)[11] discuss an app that centralizes data from various smart home devices into a single interface, providing a comprehensive view of energy flows. This integration helps users see the connection between different energy sources and uses, facilitating a deeper understanding and more informed energy decisions. Similarly, Sayed et al. (2019) [12] present a modular smart meter project that aids educational efforts and enhances user understanding through practical application, further illustrating the educational benefits of effective data visualization.

2.1.3 Feedback Mechanisms

Feedback mechanisms are instrumental in promoting energy conservation.Wood and Newborough [8], Weiss et al. (2019)[9] introduce a smartphone application that centralizes data from multiple devices, offering users a unified view that can prompt behavior change. This aligns with findings by Dressel and Peinl (2018) [11], who note that user-friendly visualizations and consolidated information can significantly influence user behavior by making them more aware of their energy consumption patterns.

2.1.4 Integration with Broader Smart Home Systems

The integration of smart meters with broader smart home systems is discussed by Perekalskiy and Kokin (2020) [10], who explore the practical implications of implementing advanced meter displays within homes. This integration allows for sophisticated home energy management systems that not only track energy use but also automate certain energy-saving tasks, further enhancing the potential for energy efficiency.

2.1.5 Challenges and Future Research

Despite the progress in smart meter technology and interface design, challenges remain, particularly in terms of user engagement and the technical integration of diverse devices within a unified system. Future research could focus on developing more adaptive interfaces that cater to individual user preferences and enhance the ability to manage and predict energy use more effectively.

2.1.6 Conclusion

The literature underscores the critical role of user interface design in the effectiveness of smart meters to promote energy conservation. By improving how energy data is visualized and interacted with, designers can significantly enhance user engagement and users participation in demand response and foster sustainable energy consumption behaviors. Future developments should continue focus on integrating advanced technological features with user-centric design principles to maximize the impact of smart meters on energy conservation efforts.

2.2 Important concepts

2.2.1 Flexibility in energy in building sector

2.3 Definition of energy flexibility on the demand side

Demand-side flexibility can be achieved by using components that can adapt their operation and shift their consumption to different time intervals. The energy flexibility of a building is the ability to manage its demand and generation according to local climate conditions, users' needs, and energy network requirements[13].

The definition of the terminology flexibility varies from sector to sectors and from authors to authors. In the energy sector especially in the building sector,it can be defined as ability of a user or an energy consumer or a prosumer to deviate from its normal electricity consumption profile in response to price signals. It can also be defined as the ability that a user has to shift its energy consumption hours during off peak hours. In the context of this thesis, this concept plays a key role because the selection of participants will be influenced by the flexibility potential of their appliances. Appliances with high flexibility can adjust their operations such as delaying, reducing, or increasing energy consumption without affecting the comfort or functionality of the building occupants.

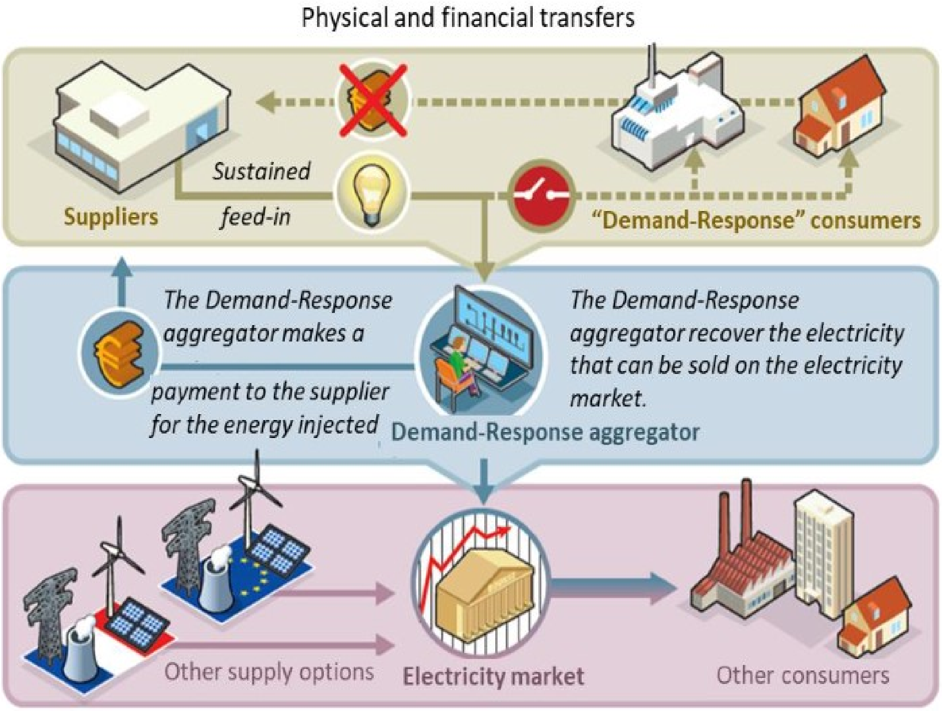
2.3.1 Demand Response program in France

The concept of demand response can be seen as the variation in the user's consumption with respect to their consumption in normal conditions in response to a price signal. Demand response can also be defined by voluntary adjust or change the use of electricity in the way that increases system efficiency and security. This concept is very important since the work also aim to incite electricity consumers to change their energy consumption behaviours.

2.3.2 Participation of Demand Response in French electricity market

If we consider an aggregation of 45 households, each participating in a demand response program by adjusting their energy consumption patterns specifically by reducing their usage they can collectively contribute to demand response participation in the French electricity market. By shifting or lowering their energy demand during peak periods, these households help alleviate pressure on the grid and support more efficient market operations, enhancing grid stability and potentially lowering energy costs for all participants

In France, there is a demand response program called NEBEF(Block Exchanged Notification of demand Response) mechanism, a plan in France to engage participants in energy flexibility. The level of aggregation required for participating in the NEBEF mechanism is a minimum load reduction of 100kW[14].



[14]

Figure 2.1: How Demand Response can take part in the electricity market

The demand response aggregator recovers the electricity that can be sold in the electricity market,a place where transactions involving electricity are conducted.

In Italy, the electricity market is divided into:

1. Day-Ahead marked
2. Intra-Day Market
3. Dispatching Services Market

In the Day-Ahead market and Intra-day market, users buy and sell wholesale quantities of electricity for the next day. These market define system marginal prices at which the energy is traded.

In Dispatching Services Market, Terna, the distribution energy company in Italy procures the ressources it needs to manage and control the system.

In France, the electricity market is similarly divided into several key segments:

Day-Ahead Market (Marché Spot or Marché de J-1): Like in Italy, the French

Day-Ahead market allows participants to buy and sell wholesale quantities of electricity for the next day. This market is operated through the European Power Exchange (EPEX SPOT), and the prices are determined by the intersection of supply and demand bids submitted by market players. The system marginal price (SMP) is set based on the most expensive accepted bid to meet the demand.

Intra-Day Market (Marché Intrajournalier): The Intra-Day market operates continuously, allowing participants to adjust their positions by buying or selling electricity closer to real-time, typically to correct any imbalances or take advantage of new information. This market also helps in responding to unexpected changes in supply (e.g., renewable energy fluctuations) or demand. Prices are similarly based on the marginal cost of the last trade executed.

Balancing or Dispatching Services Market (Marché des Services d'Ajustement): This market is managed by the French Transmission System Operator (TSO), RTE (Réseau de Transport d'Électricité). It ensures the balance between electricity supply and demand in real time by calling on participants to adjust their production or consumption. This includes balancing energy markets, reserve markets, and frequency control services to ensure grid stability.

In both the Day-Ahead and Intra-Day markets, electricity is traded on a wholesale basis, and system marginal prices are established based on market dynamics, similar to the Italian market structure.

2.4 Appliance Classification and Flexibility Analysis

Home appliances characterization

Home appliances can be classified into five categories according to the appliance type and the consumer's preference[15]:

2.4.1 Deferrable Appliances

It includes all appliances whose starting time can be shifted across the day in response to price variations while achieving the required energy use within a single day. These appliances can also be broken into two technology groups: a) Non-flexible b) flexible

i) Non-flexible Deferrable Appliances

It includes all appliances that have to follow a predefined power profile during the operation cycle and cannot be interrupted. For example, laundry appliances such as washing machines must complete a 120-minute operation cycle during rinse mode. Each non-flexible appliance has to complete several cycles of sequential operations within a day, with each operation following a predetermined power profile. • Washing Machines (WMs): Must complete their cycles within a set time, e.g., 120 minutes for a rinse cycle. • Dishwashers: Generally follow a predefined cycle that cannot be interrupted. • Electric Oven: It needs to complete its heating cycle per the cooking requirements.

ii) Flexible Deferrable Appliances

It includes deferrable appliances whose power profile can be managed during the operation, either by interrupting it or reducing its power usage. For instance, the charging rate of a plug-in electrical vehicle (PEV) can be flexibly controlled. b) Flexible Deferrable Appliances • Plug-in Electric Vehicles (PEV): The charging can be paused or the power level adjusted. • Smart Refrigerators: While their cooling function is critical, their defrost cycle can sometimes be managed or delayed. • PV batteries, which are typically used in conjunction with solar photovoltaic (PV) systems to store excess electricity generated during the day for use during periods of low sunlight or at night, would typically fall under the category of "Flexible Deferrable Appliances" in the classification system provided earlier. Here's why: PV batteries are flexible in the sense that their charging and discharging cycles can be managed according to the user's preferences or system requirements. Users can adjust the charging and discharging schedules based on factors such as electricity prices, energy demand, or availability of solar energy. Therefore, PV batteries can be considered as part of the "Deferrable Appliances" category, specifically within the subset of "Flexible Deferrable Appliances," since their power profile (charging and discharging) can be controlled and managed based on user preferences or system needs.

2.4.2 Thermal Appliances

The power consumption can be controlled to maintain the temperature within the preferred dead band, for example, space heating. • Space Heaters: Their power consumption can be adjusted to maintain a temperature within a certain range. • Water Heaters: Can adjust the heating cycle to operate during off-peak hours while maintaining the desired water temperature. • Air Conditioners: Power usage can be controlled to keep the temperature within a preferred comfort zone.

2.4.3 Curtailable Appliances

This type includes those appliances that can be switched off without turning them on later. The consumer can assign the priorities to operate those appliances. •

Lights: Can be turned off completely with no requirement for immediate restart. • Television: Can be switched off anytime without impacting functionality. • Sound Systems: Similar to televisions, these can be turned off as needed without any need to resume operation later.

2.4.4 Critical Appliances

The operations of this type of appliance are uncontrolled and have to be preserved without intervention. They represent those appliances that need to be operated without restrictions. • Medical Equipment (like CPAP (Continuous Positive Airway Pressure) machines): Operations of these appliances are critical and should not be interrupted. • Security Systems: Including alarms and monitoring systems that must remain active for safety. • Refrigerators and Freezers: Generally need to run continuously to preserve food safety.

By categorizing appliances in this way, consumers can better understand how to effectively manage their electricity usage, especially in response to dynamic pricing or peak energy demand periods. This can lead to cost savings and help manage the energy grid more efficiently.

Chapter 3

Methodology

3.1 Work done at the first phase of the project

The aim of this study is to develop a human-machine interface (HMI) for visualizing real-time electrical data, tailored to the needs and preferences of users, and to enhance their understanding of their electricity usage. To accomplish this aim, it is crucial to understand the actual desires of potential users.

To gain a broad view of preferences and trends while also enabling an in-depth understanding of individual motivations and experiences, two methods were used to explore this issue: questionnaires and interviews, known as a mixed approach. Bioy, A. (2021). Indeed, the methodology of this study is based on a mixed approach, combining both quantitative and qualitative methods for a comprehensive exploration of users' needs and preferences regarding the human-machine interface (HMI) for real-time electrical data visualization. As Creswell (2014) states, this approach leverages the strengths of each method: "the quantitative approach describes what is, while the qualitative approach explores the meaning of what is."

3.2 Interviews

3.2.1 Goal and prerequisites

In this phase of the study, a semi-structured exploratory interviews is engaged to gain thorough insights into the expectations, perceptions, and potential requirements of users regarding an interface for visualizing electrical data. Typically, interviews delve deeply into the attitudes, opinions, preferences, beliefs, and even the mental representations of the interviewee (Lallemand and Gronier, 2015). This qualitative method allowed us to fully grasp the viewpoints of participants who hadn't yet experienced the application. The primary aim here was to examine participants' responses during one-on-one interviews, focusing on their understanding of energy consumption, expectations regarding the user interface, preferences for displaying electrical data, needs for personalized features, and their viewpoints. Incorporating interviews in this study is crucial for thoroughly exploring participants' perceptions, experiences, and motivations regarding HMI design. As stated by Lallemand (2018), "Interviews serve as excellent platforms for innovation. The personal and significant details shared by participants serve as sources of inspiration." This qualitative approach provides a dynamic framework for capturing nuances, contexts, and rationales often missed by quantitative methods. These interviews encompassed behavioral queries: what actions do they take? Opinion-based inquiries (attitudes, beliefs, or motivations): what are their thoughts? Knowledge-related questions: what do they understand? Demographic and factual inquiries: who are they?

3.2.2 Participants Recruitment

Thirteen participants were recruited for this interview, all of whom had never used the developed electrical data visualization application before. However, it should be noted that this sample, while informative, is not entirely representative, as the participants were sourced from the laboratory and were already sensitized to the situation. Some had brief knowledge of the xKy project, while others had advanced training in the field of electricity or energy consumption, which could bias the results. However, it was decided to retain all participants to preserve a diversity of opinions and perspectives. Participants were recruited through an announcement made via the building's mailing list, and they were required to register on a Doodle platform to confirm their participation in the study.

3.2.3 Equipment

Design of the questionnaire

A semi-structured interview guide was developed to guide discussions with participants. This guide included open-ended questions aimed at exploring various aspects related to understanding energy consumption, expectations towards the user interface, preferences for data visualization, and needs for personalized features.

The questions were structured around three themes:

- Use of reporting tools
- Knowledge and experience regarding their electricity consumption
- Discussion around a prototype developed based on scientific literature

Sample interview questions

- Do you use any reporting tools (allowing analysis and dissemination of your own data), for example, to track your consumption and monitor your expenses?

- Has access to data from your daily life had an impact on your actions? Has it influenced how you manage your daily tasks?

- How do you currently manage your electricity consumption? Do you use any tools?

- What do you hope to achieve by using a real-time visualization interface for your electrical data?

- Describe, in your opinion, what would be the ideal system for better understanding your electricity consumption.

3.3 Questionnaire

3.3.1 Goal and prerequisite

The integration of a questionnaire allows for obtaining an overview of participants' preferences, behaviors, and trends. Questionnaires provide a structured approach to collect data from a representative sample, enabling the identification of emerging patterns and general trends across a broader spectrum. Therefore, in addition, we developed a questionnaire to understand users' viewpoints and preferences regarding the interface and their knowledge. The quantitative approach following the qualitative approach is an exploratory design. According to Bioy, A (2021), this is a commonly used method in exploratory studies or when the study domain is unfamiliar or requires further clarification. The qualitative approach provides initial comprehensive data, which will later be used to identify consistent elements or specific items related to the study object. This will then be done using quantitative methods. However, due to project delays, the questionnaire could not be launched, so we do not have any results yet by the report submission dates. Nonetheless, we will still detail the procedure, the planned recruitment, and the materials used.

3.3.2 Participants and procedure

Following registration on the OTE platform, participants recruited through word-of-mouth will have the opportunity to learn about the study and participate by initially responding to a questionnaire regarding their electrical setup. Subsequently, they will be invited to complete two additional questionnaires, one concerning the

HMI and the other on open-source. There are no specific controls, except that participants must possess a Linky meter and be of legal age. This questionnaire will provide better insights into the users and determine which study group they will be assigned to, constituting the first phase of the protocol. The second phase will involve receiving and connecting a free OpenSource Winky gateway to their Linky meter, and the third phase, based on their profile, will involve receiving and connecting four free smart plugs to control and measure the consumption of certain appliances

3.3.3 Materials

The goal is to understand users' expectations and preferences regarding the human-machine interface for visualizing their electricity consumption. It comprises a mix of closed-ended, open-ended, and Likert scale questions, divided into three parts (APPENDIX):

- Understanding and knowledge about energy: This section assesses users' level of knowledge about electricity consumption. The aim is to better understand what they already know to determine what details need to be highlighted in the interface. This part also aims to understand how they currently manage their consumption, whether other tools are used, and to gather feedback on their past experiences.

- Preferences for visualization: This part aims to understand users' visual preferences. Participants are asked to indicate their preferences regarding the types of graphics and visual representations they find most intuitive and informative for visualizing their electricity consumption data.

- Expectations in terms of features: The goal of this section is to identify the features that users want or do not want.

3.4 Development of a dashboard

The design of the tool for visualizing electrical data in the residential sector must consider user needs, ergonomics, and best design practices. It was decided to use Grafana, an open-source platform, in line with the project's visualization and data monitoring objectives, which allows for creating interactive and informative dashboards. This technology offers freedom and flexibility for rapid and straightforward development. Grafana is used with a database system, and for this project, we are using InfluxDB. InfluxDB is a time-series database specifically designed for storing and querying temporal data, such as performance metrics, system metrics, or sensor data, making it perfect for our case of analyzing electricity consumption data. To create this dashboard, I developed it using InfluxQL (a language specific to the database InfluxDB).

3.4.1 Design of the dashboard

What is the goal of a dashboard?

To design a dashboard, it is important to know that every dashboard has a goal or a purpose, a target audience(who the dashboard is built for), it is important to see it as an empty piece of paper that has to be filled. to design good dashboards, we must primary understand people, not computers.Someone will look to the dashboard to answer problem.To fill it, it is important to know the variable to be represented, the units of measurement, the type of representation, and where the visualization should be placed. The quality of a successful dashboard is depends on how quickly and accurately the dashboard can deliver information.

How to convey information must efficiently and most effectively?

1) Visual Hierarchy: The visual properties of an object suggest its level of importance. There is a field of psychology dedicated to understanding visual hierarchy called Gestalt psychology. This field explores how humans perceive entire patterns rather than focusing on individual components. Essentially, the whole is greater than the sum of its parts.

Gestalt psychologists emphasize the importance of visual hierarchy. This principle explains why some elements naturally stand out and attract attention, creating a sense of importance. By leveraging visual hierarchy, we can guide users' attention to the most critical information.

One key aspect of visual hierarchy is the alignment of content. Studies have shown that in most countries, people scan page content in a similar way to how they read books. On websites, this often follows a Z-shaped pattern: left to right, top to bottom. This pattern can be used strategically when designing dashboards. Not only are the top elements typically the most important, but users also tend to skip the middle row and jump from the top directly to the bottom. Therefore, placing key information in the top row, especially in the corners, increases the likelihood that users will notice it.

2) Size: Larger elements naturally convey a sense of greater importance. For instance, bigger charts draw more attention and suggest higher significance.

3) Color: Color is a powerful driver of visual hierarchy. Objects with high contrast to their background tend to attract the eye more quickly, making them stand out as more important.

4) Shapes: Different shapes can also influence the way information is perceived, though this may vary based on context.

To design an effective dashboard, it's essential to recognize that while all the information on the dashboard is important, not all elements hold equal importance. Key metrics should be placed at the top and made larger to attract attention, while secondary information can be positioned accordingly.

3.5 Work done for the internship

After the first phase of the project that consists recruiting participants and gathering data about their needs through questionnaires and interviews, participants' suggested questions were categorized and their feedbacks were taken into account for the design of their interfaces. The questionnaire consists of 153 questions suggested by 38 participants. The questions were grouped into YES or NO answer questions, open answer questions, and multiple choice answer questions. A sample of the questionnaire is available in the Appendix.

The next step was to get familiar with the tool Grafana. Grafana is an open source platform for visualization of data in real time and has been chosen because it allows the creation of interactive and informative dashboards. The task was well performed and I had the feedback of participants regarding their household appliances and some other energy details. With the help of Olga, a PHD researcher in the team MAGE, flexibility assessment of each household based on the appliances each participant has was done. The state of flexibility was indicate by 1 or 0. 1 indicates that the appliance is flexible and 0 stands for not flexible appliance. With this assessment, I was able to select the 45 most interesting participants to continue the study with them. Then, 180 NOUS A1T Smart wallplugs were bought. The NOUS A1T smart Wi-Fi socket with Tasmota open software installed (hereinafter – the smart socket) is designed to organize automatic and manual shutdown of electrical appliances in the room, through remote access via a Wi-Fi network, using a smartphone or from a personal computer via the Web interface. Communication with the smart outlet is configured via a Wi-Fi network, for which a wireless Wi-Fi adapter is used. The smart socket is equipped with a mechanical button and a global indication of the device's status. The smart outlet is equipped with an electromechanical relay with a throughput of 16A . The device has the function of energy monitoring and recording of consumer electricity. One NOUS A1T box consists of four wallplugs. I proceed by identifying the 180 wallplugs. For each participant, the 4 wallplugs were labeled from XKY0A, XKY0B, XK0C, XKY0D....to XKY45A, XKY45B, XKY45C, XKY45D.

The Local area wifi network(openWrt-xky) for the smart wallplugs were created and all the 180 wallplugs were added to the network. This means that the computer and wallplugs can communicate one another. Each wallplug connected to the local area is attributed a unique IP address for the open-wrt router. The address allow the wallplugs to be identified and to communicate among them in the network. The wallplugs function with a firmware called Tasmota,a software integrated in each wallplug to enable the control of it functions.It is a permanent program that gives useful instructions for the appliance to operate well.Tasmota is also a web interface which can be accessed through a web navigator.

After on, the wallplugs were calibrated and configured.The process was to plug each wallplug on the electrical measurement device Voltcraft, find the IP address of the wallplug, have access to the TASMOTA interface, upgrade the firmware and open the console to program it. The voltage was set to 240 volts and the active power to 43 watts. After the completion of this task, I decided to build my own winky gateway, the famous device that, connected to the Linky meter, improves the quantity and quality of harnessed energy consumption data. The winky was distributed to participants and their desegregated energy consumption data could be retrieved and available in the OTE server. I was able to display the desegregated load curves of users on grafana dashboard.

Once I mastered how to handle the tool grafana, I it time to choose what relevant data has to be presented on the dashboard. Th dashboard has to be simple to understand, intuitive, informative, user friendly and interactive.

It was decided to display the active power consumed by the user in real time and the monetary value of the energy consumption, that is the the cost of consumption in real time. I was given electricity users' consumption and tariffs file names accessible in INFLUXDB data base of OTE server. I was able to create a visualization of the energy consumption in monetary form.The type of visualisation chosen is the statistic visualisation. It has been chosen because it is simpler to understand compared to the other types of visualisation graphs. Users can see the price of their electricity consumption in real time.

It is important to note that each user has a different electricity supplier company and a different subscription type. All these data are taken into account while designing the dashboard.

Chapter 4

Results

4.1 Data Visualization and Insights

My first dashboard was created on Grafana. We displayed some energy and financial metrics using data available in the INFLUXDB-OTE server.

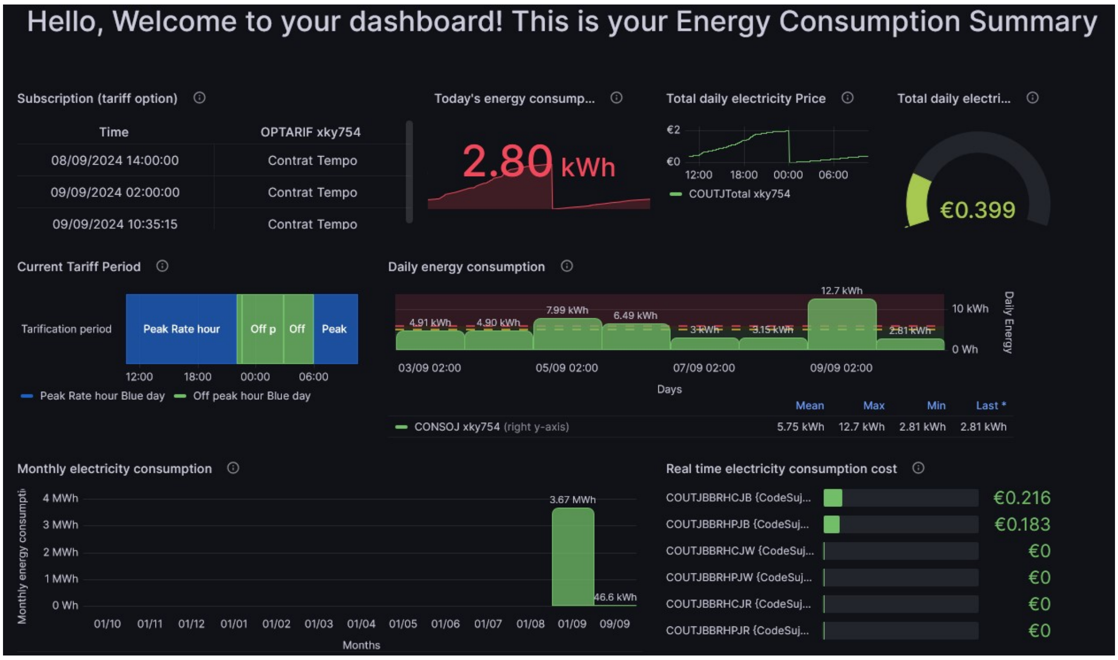


Figure 4.1: First dashboard

This dashboard shows the representation of energy summary of the participant xky754. Several metrics can be displayed in different visualisation. The first panel shows the energy subscription tariff of user xky754. The consumer has subscribed to the "Peak hours/off Peak hours" and "Tempo" options. the time and the tariff option of the user xky754; The energy consumption of the day is shown using a statistic representation 2.80kWh. The third panel shows the time series evolution of price. The fourth panel is a gauge representation of the the total daily energy consumption price in euro. The fifth panel is a state timeline representation of the current Tariff Period. The sixth panel is a bar chart representation of the daily energy consumption of the previous seven days in kWh. There are two limits, 5kWh and 6kWh represented by red and orange dashed line respectively. The fifth panel displays the monthly energy consumption bar chart. The seventh representation is the bar gauge representation of the cost of energy consumption according to the type of day.

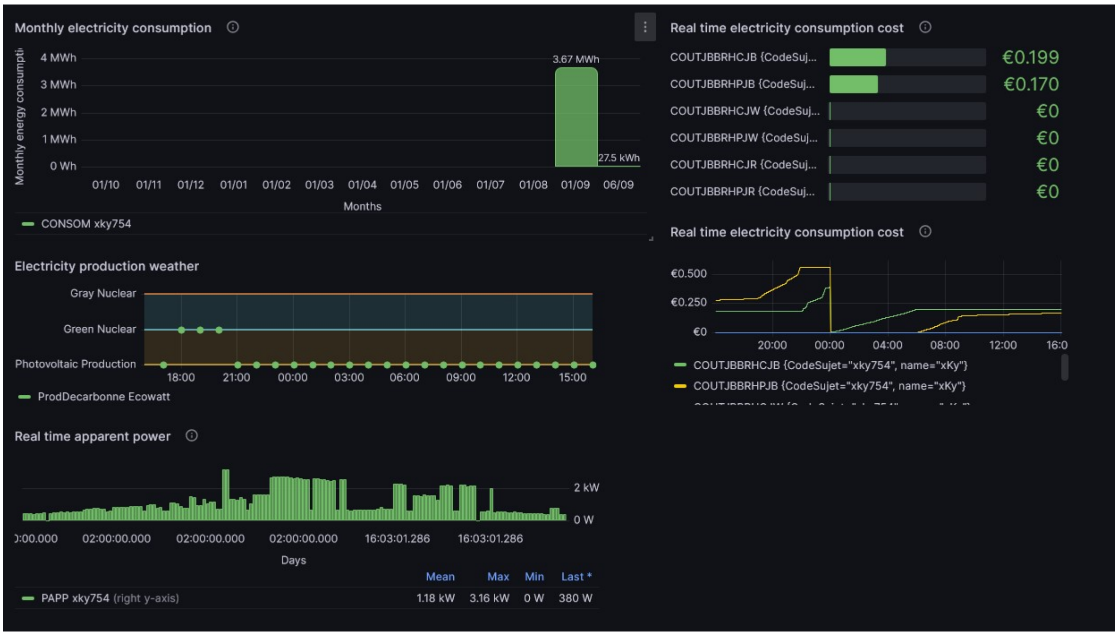


Figure 4.2: Instantaneous power withdrawn from the grid

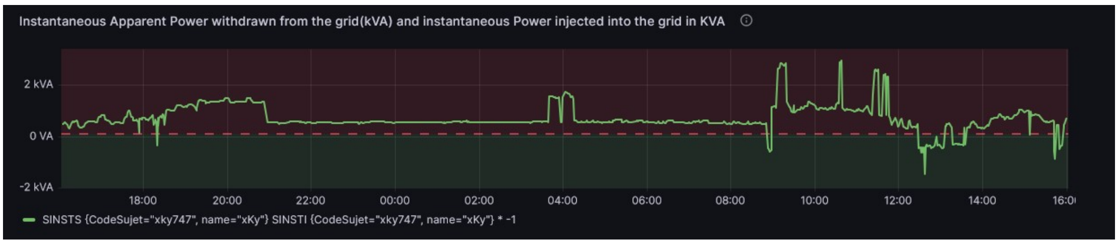
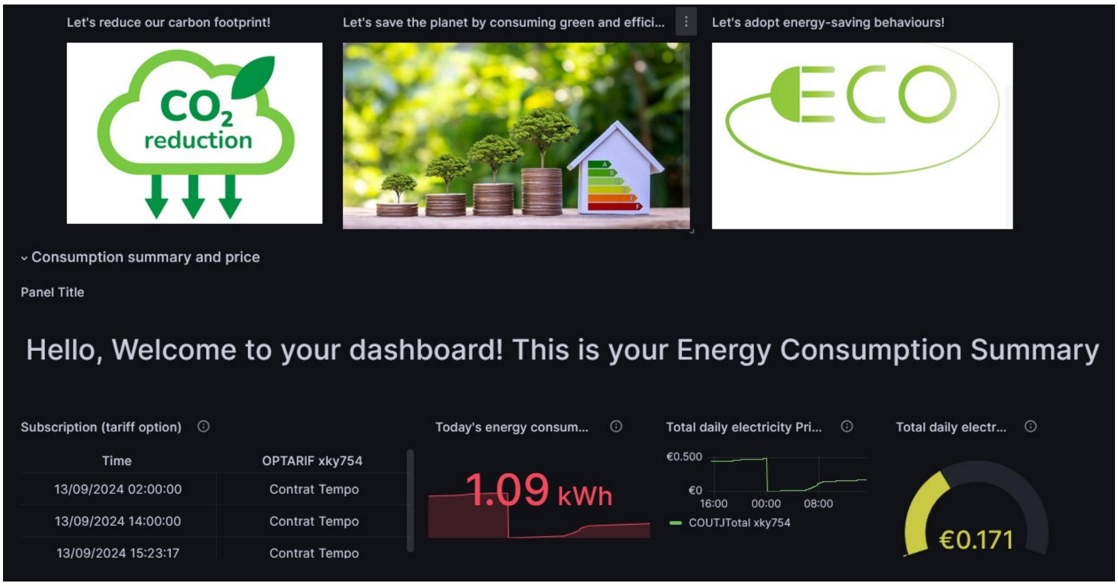


Figure 4.3: Apparent power withdrawn and injected into the grid

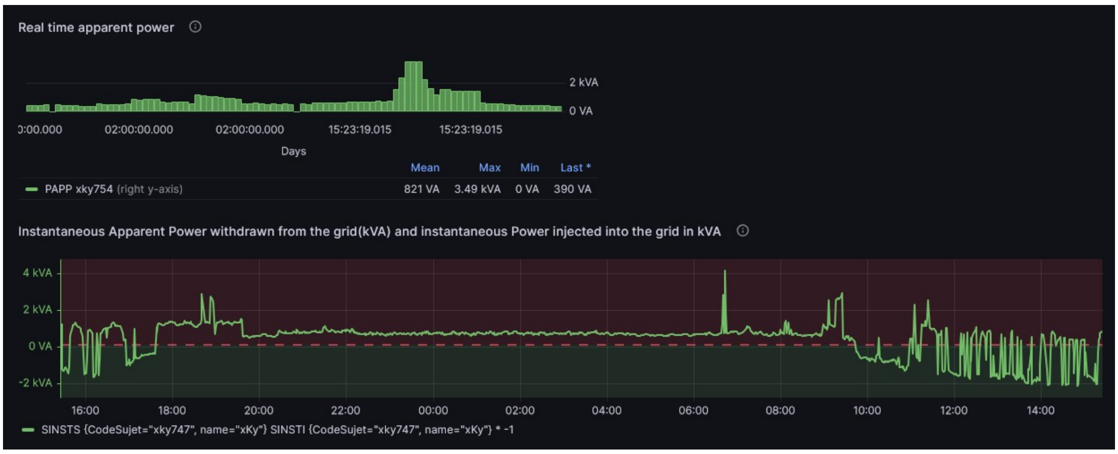
The sixth panel is the electricity production weather according to time.0(first level)represents the photovoltaic production, 1(second level) signifies that the Green nuclear power plants are launched, 2(third level) is when electricity is produced by gray nuclear power plant. The fifth panel is the time series representation of the energy consumption cost based on the type of day and hour. The sixth panel is the real time apparent power bar chat representation of the user xky754 in kVA.

The seventh panel is the time series representation of the apparent power withdrawn from the grid and the apparent power injected into the grid. There is a threshold dashed line under which the graph represents the Photovoltaic production.

You can access the Grafana dashboard here.




Current Tariff Period
Tarification period
Peak Rat
Off peak h
Peak R
Peak
12/09 16:00
13/09 00:00
13/09 08:00
Peak Rate hour Blue day
Off peak hour Blue day
Daily energy consumption
12.7 kWh
8.42 kWh
4.77 kWh
12.2 kWh
3.42 kWh
1.09 kWh
3.15 kWh
10 kWh
0 Wh
Daily Energy
07/09 02:00
09/09 02:00
11/09 02:00
13/09 02:00
Days
Mean
Max
Min
Last *
CONSOJ xky754 (right y-axis)
6.10 kWh
12.7 kWh
1.09 kWh
1.09 kWh
Monthly electricity consumption
4 MWh
3 MWh
2 MWh
1 MWh
0 Wh
3.67 MWh
73.7 kWh
01/10
01/11
01/12
01/01
01/02
01/03
01/04
01/05
01/06
01/07
01/08
01/09
13/09
Months
CONSOM xky754
Real time electricity consumption cost
COUTJBBRHCJB (CodeSuj...
€0.0198
COUTJBBRHPJB (CodeSuj...
€0.151
COUTJBBRHCJW (CodeSu...
€0
COUTJBBRHPJW (CodeSuj...
€0
COUTJBBRHCJR (CodeSuj...
€0
COUTJBBRHPJR (CodeSuj...
€0
Real time electricity consumption cost
€0.200
€0
16:00
20:00
00:00
04:00
08:00
12:00
COUTJBBRHCJB {CodeSujet="xky754", name="xKy"}
COUTJBBRHPJB {CodeSujet="xky754", name="xKy"}
Electricity production weather
Gray Nuclear
Green Nuclear
Photovoltaic Production
18:00
21:00
00:00
03:00
06:00
09:00
12:00
15:00
ProdDecarbonne Ecowatt


Real time apparent power
2 kVA
0 VA
02:00:00.000
02:00:00.000
15:23:19.015
15:23:19.015
Days
Mean
Max
Min
Last *
PAPP xky754 (right y-axis)
821 VA
3.49 kVA
0 VA
390 VA
Instantaneous Apparent Power withdrawn from the grid(kVA) and instantaneous Power injected into the grid in kVA
4 kVA
2 kVA
0 VA
-2 kVA
16:00
18:00
20:00
22:00
00:00
02:00
04:00
06:00
08:00
10:00
12:00
14:00
SINSTS {CodeSujet="xky747", name="xKy"} SINSTI {CodeSujet="xky747", name="xKy"} * -1

Chapter 5

Conclusion

5.1 Summary of Objectives and Progress

The objective of this work was to design a user interface for participatory science in an energy environment. The study was carried out using a set of 45 participants or 45 houses in Grenoble. A winky gateway device was distributed to them and they equipped their Linky meter with it. We were able to recover their energy consumption data and this was gathered in the OTE server. The wallplugs were configured and distributed to the users and I was able to recover the desegregated load data for each house. A prototype dashboard was designed to show the real-time active power consumed by the user, and its consumption according to different tariffs. An active user can also visualize his renewable electricity production.

5.2 Significance of Findings

The choice of the type of data representation is very crucial to have meaningful representations.

5.3 Final Thoughts

The accessibility and availability of data was a crucial point in designing the visualization and monitoring energy consumption dashboard. Without data, nothing is possible. Special thanks go to Jerome Ferrari, who always ensures data availability, by creating databases, thanks to the winky gateway that helps in retrieving precise data with a finer time granularity from the smart meter to the OTE database.

5.4 Future works

1) User Feedback and Iteration

We recommend to have an ongoing user testing and gather feedback to continuously improve the dashboard's design and functionality. User needs and behaviors may evolve, so it's essential to iterate on the design based on real-world feedback. This ensures that the dashboard remains intuitive, effective, and adaptable to different user profiles and energy consumption habits.

2) Demand Response Program Participation

We recommend to actively promote the use of the dashboard for participating in demand response programs to encourage energy consumption shifts during peak hours.

By allowing users to easily participate in demand response programs, energy-saving behaviors can be encouraged that benefit both the users and the grid. This will help alleviate grid strain during peak hours and potentially reduce costs for consumers.

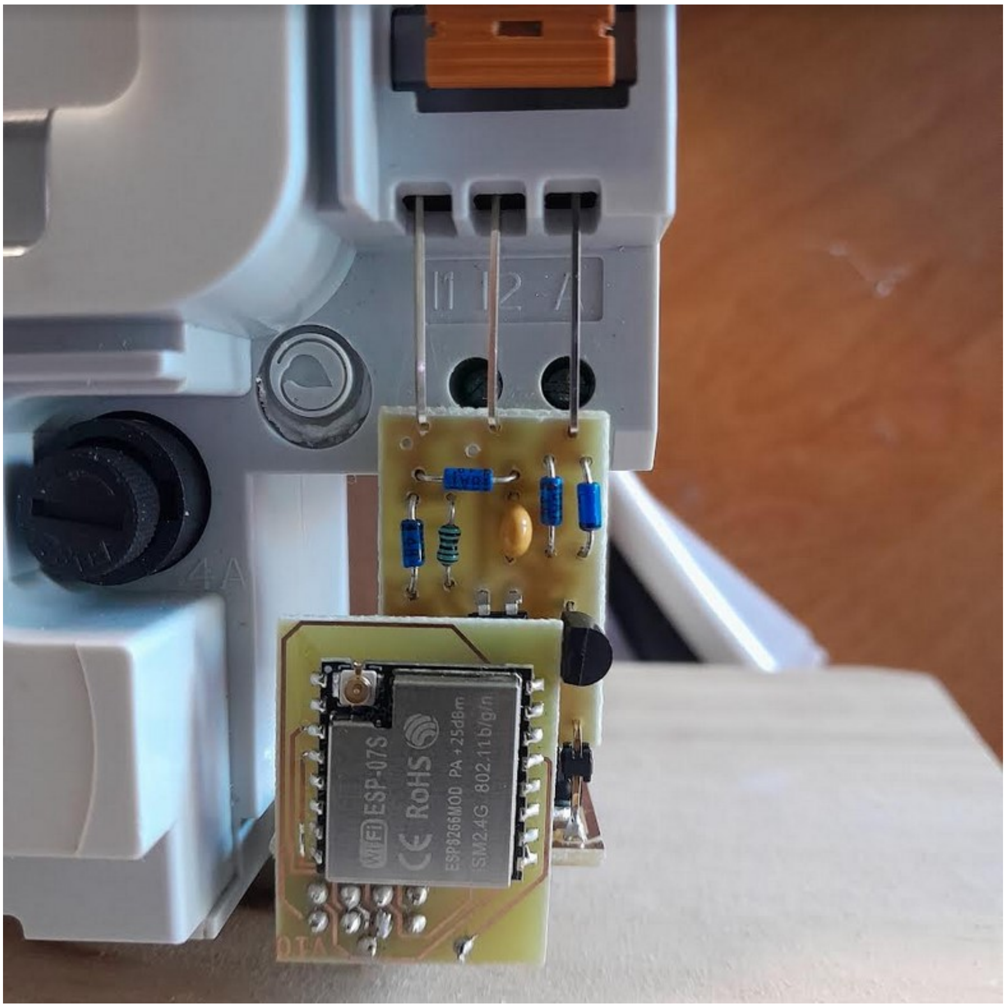


Figure 5.1: Linky smart meter equiped with winky gateway

Appendix A

Chapter 1

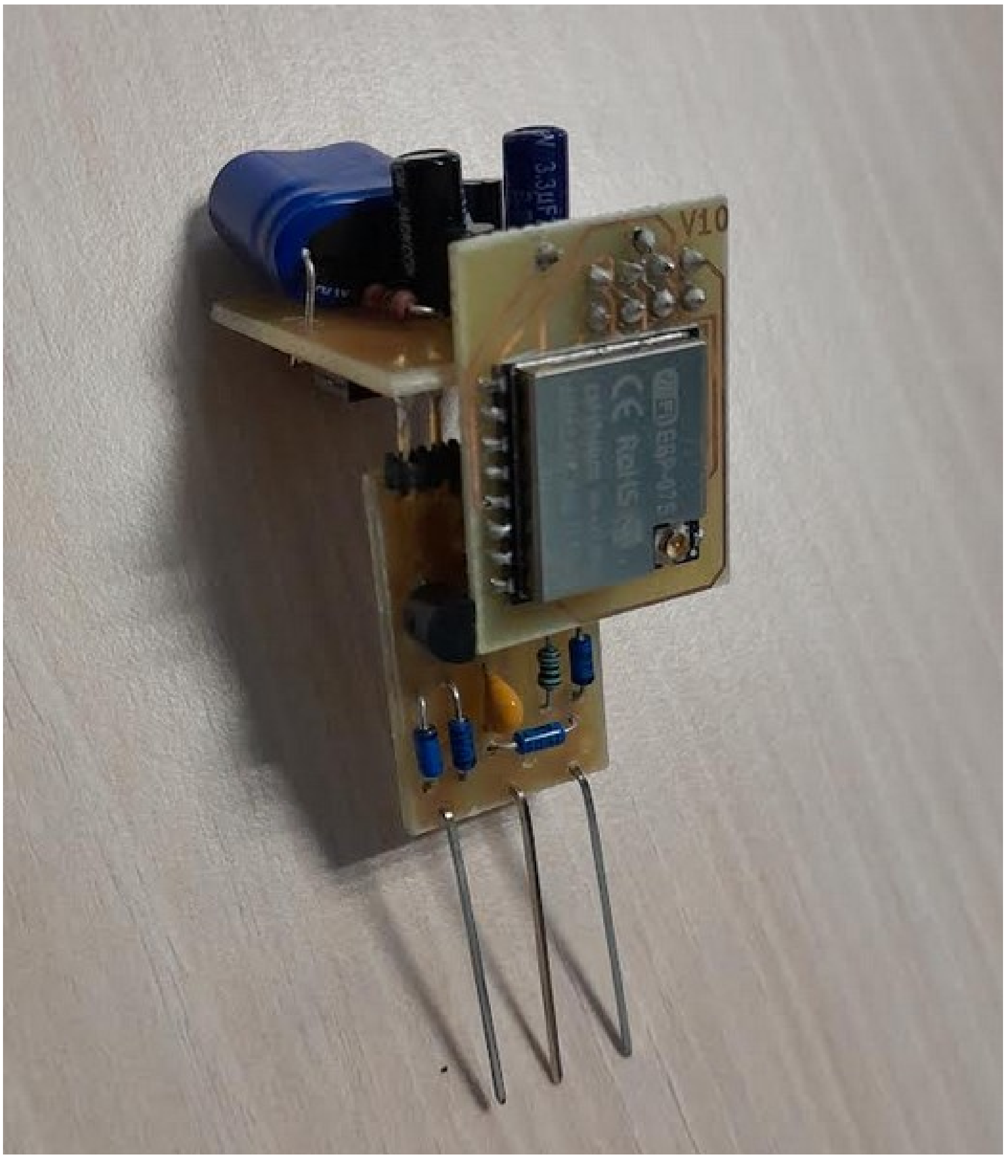


Figure A.1: Winky gateway a

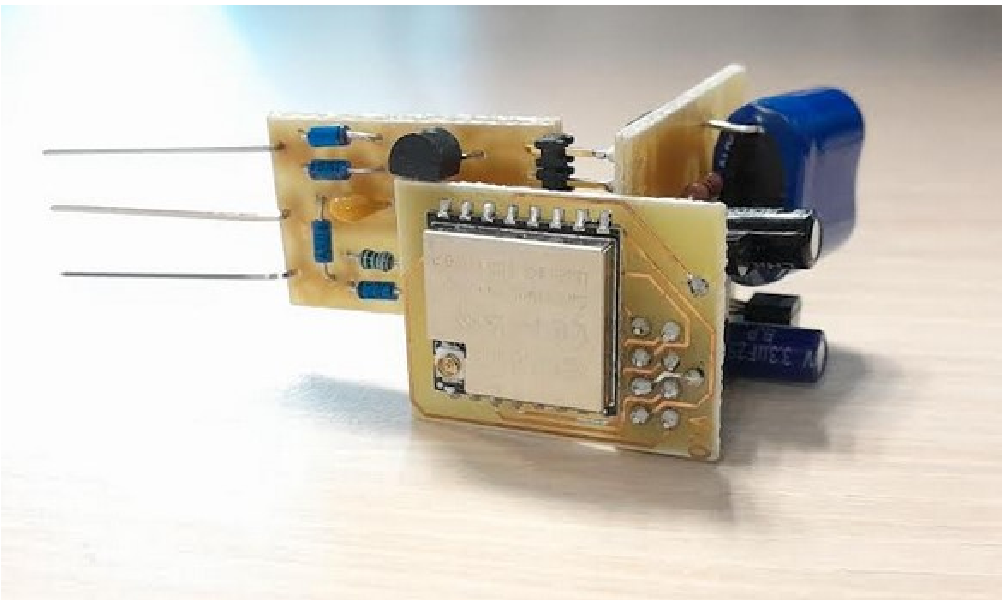


Figure A.2: Winky gateway b

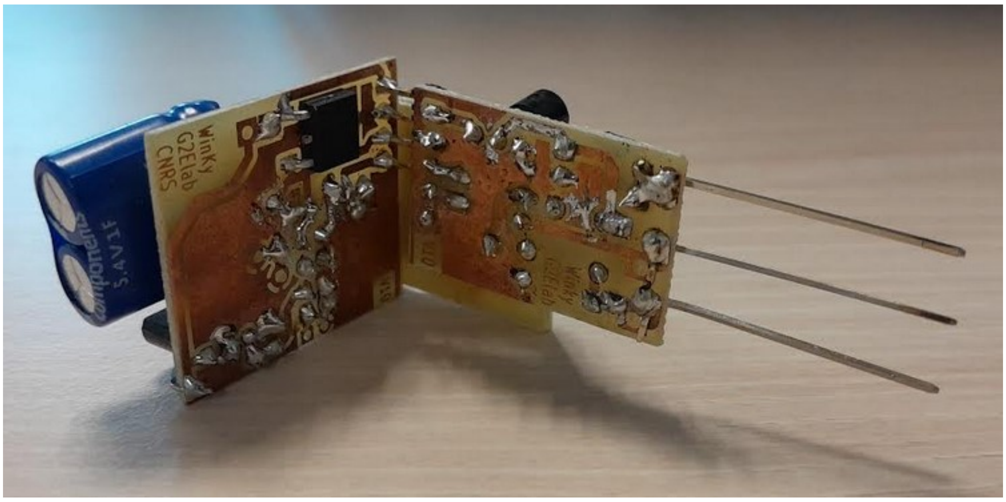


Figure A.3: Winky gateway c

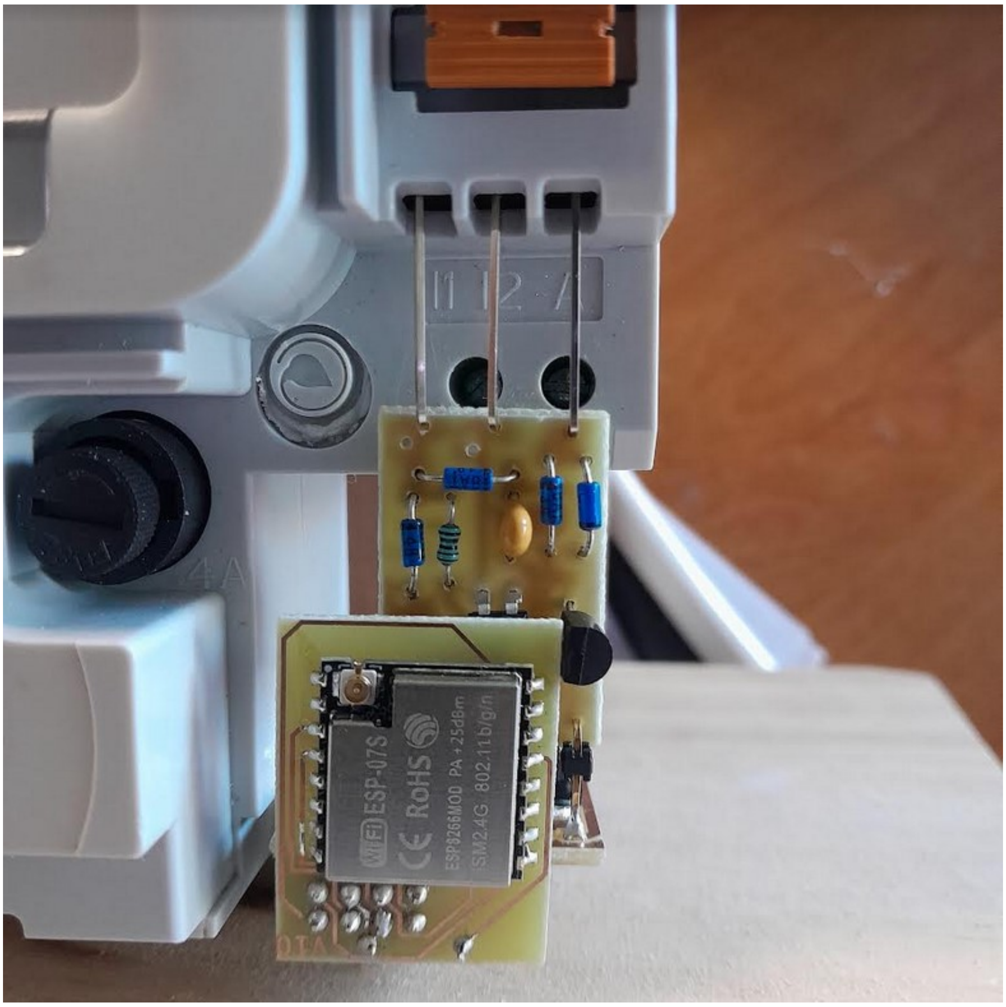


Figure A.4: Linky smart meter equiped with winky gateway

Figure A.5: Nous AT1 Wallplugs

Figure A.6: 4 Nous AT1 Smart Wallplugs

Figure A.7: Poster for the recruitment of participants

User ID	Flexible (%)	Non-Flexible (%)	Unknown (%)
880	46.34	17.07	26.83
1259	43.90	7.32	41.46
902	43.90	14.63	34.15
927	43.90	14.63	31.71
881	41.46	9.76	39.02
952	41.46	12.20	39.02
870	41.46	17.07	34.15
898	41.46	14.63	36.59
942	41.46	12.20	39.02
866	39.02	12.20	41.46
877	39.02	9.76	43.90
948	39.02	12.20	41.46
949	39.02	7.32	46.34
953	39.02	9.76	41.46
992	39.02	12.20	41.46
983	39.02	9.76	43.90
846	39.02	12.20	39.02
1052	36.59	9.76	46.34
910	36.59	7.32	48.78
879	36.59	12.20	43.90
815	36.59	7.32	46.34
981	36.59	7.32	48.78
842	36.59	12.20	43.90
861	36.59	17.07	39.02
801	36.59	12.20	41.46
1265	36.59	12.20	43.90
1007	36.59	12.20	41.46

Figure A.8: Selected Users based on percentage of possession of flexible devices at their home

Appendix B

Chapter 4

Figure B.1: Home page

```
  from(bucket: "otexky")
 |> range(start: v.timeRangeStart) // Sélectionnez une période plus
   large pour vous assurer davoir suffisamment de données
 |> filter(fn: (r) => r["_measurement"] == "xKy")
 |> filter(fn: (r) => r["CodeSujet"] == "xky747")
 |> filter(fn: (r) => r["_field"] == "CONSOJ")
```

```
import pandas as pd
def load_and_process_data(file_path):
     data = pd.read_excel(file_path, header=2)
     equipment_data = data.drop(columns=['User ID']).applymap(lambda x
    : 1 if x == 'x' else 0)
     possession_percentages = equipment_data.mean() * 100
     return possession_percentages
file_path = 'C:/Users/Admin/OneDrive/Desktop/Python_Projects/clean.
    xlsx'
percentages = load_and_process_data(file_path)
print(percentages)
```

Note d'information en vue de l'habilitation d'accès aux données personnels de l'étude xky

Cette note vise à vous informer des enjeux et contraintes liés à la protection des données personnelles dans le cadre de l'étude xky. Merci de prendre le temps de la lire et de la compléter.

En cas de question relative à cette note, vous pouvez contacter le (ou les) responsable(s) de l'étude xky à l'adresse suivante : ote-etudes@univ-grenoble-alpes.fr

DEFINITIONS

Donnée personnelle (définition de la CNIL[1])

Une donnée personnelle est toute information se rapportant à une personne physique identifiée ou identifiable. Mais, parce qu'elles concernent des personnes, celles-ci doivent en conserver la maîtrise.

Une personne physique peut être identifiée :

- directement (exemple : nom et prénom) ;
- indirectement (exemple : par un numéro de téléphone ou de plaque d'immatriculation, un identifiant tel que le numéro de sécurité sociale, une adresse postale ou courriel, mais aussi la voix ou l'image).

L'identification d'une personne physique peut être réalisée :

- à partir d'une seule donnée (exemple : nom) ;
- à partir du croisement d'un ensemble de données (exemple : une femme vivant à telle adresse, née tel jour et membre dans telle association).

RGPD

Règlement Général sur la Protection des Données, accessible sur le site web de la CNIL : www.cnil.fr/fr/reglement-europeen-protection-donnees

Consentement

Le consentement est défini par le RGPD comme « toute manifestation de volonté, libre, spécifique, éclairée et univoque par laquelle la personne concernée accepte, par une déclaration ou par un acte positif clair, que des données à caractère personnel la concernant fassent l'objet d'un traitement ».

CONTEXTE

L'étude xly est une étude de l'Observatoire de la Transition Energétique (OTE) portée par le laboratoire G2ELab dans lequel j'occupe actuellement la fonction de (*rayer les mentions inutiles)* :

- ~~Chercheur~~
- ~~Chercheur invité (doctorant, post-doctorant, titulaire ...)~~
- ~~Ingénieur~~

[1] www.cnil.fr/fr/definition/donnee-personnelle

1

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- ~~Chercheur invité (doctorant, post-doctorant, titulaire ...)~~
- ~~Ingénieur~~

[1] www.cnil.fr/fr/definition/donnee-personnelle

1

- Stagiaire

Dans le cadre des missions qui me sont confiées, j'ai besoin d'accéder aux données personnelles des participants à l'étude xky.

Données énergétiques du compteur Linky de chaque participant, ensemble d'appareillages de chaque participant ainsi les équipements énergétiques.

Ces données seront employées pour développer une interface homme-machine optimale. Cette interface permettra aux participants de mieux comprendre et visualiser leur consommation énergétique quotidienne, et les encouragera à utiliser leur énergie de façon plus économe. C'est en fait l'objectif principal de mon stage.

Ces données personnelles font l'objet d'un recueil de consentement explicite auprès des participant.es à l'étude xky précisant la finalité du traitement et les personnes susceptibles d'y avoir accès.

ENGAGEMENTS

Afin de respecter les engagements pris auprès des participant.es à l'étude xky dans le cadre du RGPD, j'ai compris que je ne pouvais en aucun cas partager de donnée personnelle de ces participant.es en dehors des personnes explicitement habilitées à accéder à de telles données (liste accessible auprès du ou des responsable(s) de l'étude joignable(s) à l'adresse ote-etudes@univ-grenoble-alpes.fr).

☑ J'ai lu et compris cette note d'information.

☑ Je m'engage à respecter les engagements pris envers les participants à l'étude xky en matière de protection de leurs données personnelles. En particulier je m'engage à ne pas reproduire,ni diffuser ces données, et à ne les manipuler que dans les espaces de travail sécurisés et protégés.

Date et signature :

Jeudi 2 mai 2024

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