AI Energy Sensor Interface for Google Home/Assistant

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***Abstract*—The climate crisis is pushing the requirements for more efficient energy management systems and increasing the introduction of renewable energies. These energy management systems are able to control the consumption and production of distributed households. For instance, some of these systems can measure the energy produced by solar panels, as well as the energy consumed by the multiple appliances used on a daily basis providing feedback and guidance. These systems are usually composed of smart meters, plug-level sensors, and other components that communicate with each other to provide reliable and real-time information about household energy. The project described here builds and extends on a previous system to control and provide feedback on a house's energy consumption and production, a small factory, and a restaurant. Here we improve on the previous system by introducing a scenario of a small-industry, and restaurant setting while also exploring how natural language assistants can improve the interaction with such systems. Given that, this project will integrate Google Assistant to deliver, through a natural language interface, all the information that the user needs about the energy consumption and production in their place. This solution will then be evaluated by a set of families in order to simulate the day to day life of a family, as well as in a restaurant and factory environment, where it will be evaluated qualitatively in terms of its performance and efficiency.**

Keywords: Energy Management System, Google Assistant, Artificial intelligence, IoT, NILM.

I. Introduction

The climate crisis and the ways to face it are a very debated subject nowadays. Are one of the biggest priorities of every country, and many solutions have arisen from many areas, such as engineering with systems that aim to increase energy consumption and production efficiency [1].

Countries, namely Australia, and Canada, among others, implemented regulatory mechanisms for the parties involved to meet the energy-saving targets [2]. These targets and rules make significant changes in the energy market, from implementing energy certifications on buildings, regular maintenance of the air conditioning and its certification for energy performance, to even the creation of financial incentives for energy efficiency in buildings [2]. On a big scale, smart cities, "high-tech intensive and advanced city that connects people, information, and city elements using new technologies in order to create a sustainable, greener city" [3], are implementing complex systems using new technologies into their smart buildings in order to measure and optimize the energy consumption and production.

These systems are part of smart-city projects that tend to incorporate sensors in order to get information from the electrical infrastructure. These sensors read and communicate through integrated apps, thus web dashboards, or even mobile applications to make this information available to the user.

A. Smart Energy Metering

There are many ways to retrieve information about energy consumption and production. The two most mentioned ones are the IAM (Individual Appliance Monitor), and the NILM (Non-Intrusive Load Monitoring) [4].

IAM is an often-used technique to get information from appliances and consists of having, as the name says, individual monitors for each appliance.

The NILM technique is now beginning to be more explored, and its measurement algorithms are being improved, as stated in some research [4], [5]. NILM is usually located in a central place and can provide information in real-time about various individual appliances, such as lights and machines, among others, using voltage measurements. Thus, this last approach has many advantages, for instance, with only one device is possible to get information from various electric devices about energy consumption and like so, and it helps people decide the matter to reduce energy costs.

B. Smart Metering Market

The urge to integrate smart meters is becoming very common as more people install solar panels in their homes. In this regard, some smart meters in the market do the job, by monitoring the energy consumption production. The majority of the meters solutions available provide an integrated system composed of the smart meter itself and an application, whether a mobile application or even a web platform, where the user can check their energy usage.

But just a few meters that their API available to developers to create their solutions, since most of them already have their own system. The best smart meters solutions available in the market are from the following companies: Sense [6], Emporia [7], and Smappee [8].

All of them can measure energy consumption and production, but they stand out from each other by their unique characteristics. The most sophisticated and innovative of these three meters is the Sense smart meter system [6]. Sense provides a complete system that integrates not just the smart meter but also many ways to visualize the information from their devices. Besides the ability to check information through their mobile application and even through their web app, Sense also integrates stand-out services, such as Google Assistant, Alexa from Amazon, and even Philips Hue, among others, that facilitate the user's day to day life of controlling their devices around the house.

C. *Internet of Things*

The urge to create ways to be more conscious of the environment is increasing in parallel with the IoT (Internet of Things). "It is estimated that the numbers of IoT users will improve massively where the economy grows significantly" [9].

The IoT stands for Internet of Things. These "things" or devices are designed to be convenient, easy to use, and seamlessly integrated into people's lives. Since old technology is decreasing in price without decrease its potential, it is becoming easier and more common to implement IoT devices. This technology makes day-to-day life easier, and its use is practical since it requires almost no human interaction [10] and some cases no human interaction at all, which is the case of the automation between IoT devices.

II. Home Assistants

With the evolution of technology, in the virtual assistant field, many home assistant solutions are being developed to bring people closer to this new technology, creating products that can be integrated into their homes. Home assistants have a large number of functionalities that allow users to automate their homes using smart devices, ultimately helping the user in their daily life. The most famous home assistants on the market are from the top three tech companies, Amazon, Google, and Apple. Each of them has its own virtual assistant, Alexa, Google Assistant, and Siri, respectively.

The home assistant market is continuously growing and is expected that this year, 2022, "123.5 million US adults will use voice assistants at least once per month, and that base will continue to increase over the next few years" [11]. This represents a great opportunity for systems to grow and extend their functionalities to home assistants.

Different projects emerged from multiple areas and explored the benefits of virtual assistants in fulfilling their objectives. In section V-B are described examples of project that implemented IoT and virtual assistants.

III. Objectives

One of the main problems stated in studies [12] is the availability of the user in their schedule to check data and its accessibility.

To tackle this problem is important to take into account the different ways to conveniently present information to the user and also use new technologies that are becoming part of day to day life of people. As mentioned above, IoT is nowadays a popular concept that is being applied to objects to automate tasks and make people's lives easier. When combined with virtual assistants, another popular technology, it makes every process much more smoothly, seamlessly and increases the interactivity with the users' houses.

This project aims to strengthen people's awareness of renewable energy solutions as well as the energy usage in their households by achieving the following goals:

- Develop a system composed of a smart metering solution and a Google Assistant application to check information about energy consumption and production in facilities;
- Test the Google Assistant application in domestic, small manufacturing, and restaurant scenarios and understand whether this type of application is more engaging.

With this approach is expected to fulfill the objectives of being easy to use, convenient, and also to be incorporated into the user's daily basis.

IV. Proposed System

Given the work objectives established, the proposed solution encompasses the development of an energy management system with interfaces and voice interactions for Google Assistant. For this purpose, will be developed a Google Assistant application and a web application to provide custom interfaces to the user.

The solution will be composed of a Google Action application, a Web application, and a Nodejs server. The Google Action application will be responsible for supporting voice commands and retrieving the Web application interfaces and will be the application with which the user will interact. As for the Web application it will integrate all the custom interfaces to show to the user and will be directly connected to the Google Assistant application and the server application. Finally, the server application will be responsible for the requests needed by the functionalities of the Web app and the connection to the SMILE API.

One of the environments of this project has the particularity of composing not just a household but also a small factory. This factory is focused on producing handbags, among other fashion products. In this way it has many machines that require a large power supply, supported by a triphasic power setup. It counts with more than eighteen machines, three fans, and a large amount of led lights. As for the house, it has a triphasic power setup, as well.

V. Related Work

A. *Power Share Project*

The previous projects' solutions, like most solutions in this field, were built with blockchain, a new technology with the objective to decentralize the process of transactions as we know [1].

a) Version 1: The first project aimed to test business models for the SMILE project (https://www.h2020smile.eu). The SMart IsLand Energy systems (SMILE) project involves three islands, and the main goal is to test technological solutions related with renewable energy and further replicate them for other parts of Europe.

The proposed solution in this project was to inform people about their energy consumption and allow prosumers - "i.e., households that function as both energy producers and consumers" [13] - to exchange their surplus energy with their neighborhood.

In order to achieve this goal, was created a mobile application (Android) using blockchain as a payment process and the Power Share Trading Management System (ETMS) to manage users' accounts. Related with the payment process, this app integrates IOTA technology [14] to perform payments, and it also solves problems of scalability that could occur.

The Power Share app shows real-time energy consumption and production and feedback. It has a settings page where users can change their buy/sell energy criteria. The historical page shows the data over time about consumption and production. Finally, the author found it interesting to create a page in which users could "compete" between them to engage them to use the app. So, the last page is the ranking of the neighbors based on their consumption of renewable energies.

b) Version 2: The latter project solution is an iteration of the previous one. It aimed to create a new version of the mobile app and even improve the project performance by integrating a new blockchain system [15].

This improvement was directed towards the integration of a new technology, the Hyperledger Fabric Blockchain Server. This network allows prosumers, consumers, electric vehicles, and utility companies to exchange energy [15]. The new version benefits from the main characteristics of Hyperledger by using a private blockchain for confidential transactions and smart contracts to run code in blockchain to automate the model, giving stability to the whole transactions model.

In conclusion, the transition from IOTA to Hyperledger Fabric was beneficial as it gives even more stability and the transactions run much more smoothly since it improved its performance. This new version of the Power Share project, as stated before, focused on increasing the performance of the transactions and the whole process while also trying to improve user engagement.

c) Other Versions: Besides these projects, other studies were made regarding the Power Share project, namely a study that aimed to develop and test Power Share in a Human Computer Interaction (HCI) perspective [12] and a study that created a gamified version of this previous one [13].

The Power Share P2P Energy trading project [12] started by choosing the technology to use in the platform, specifically for the energy trading system. The technology frequently referenced as revolutionary and a good choice for this purpose is blockchain. However, it also has some intriguing aspects that made the authors debate. One of those aspects is the trust given by the users since people tend to trust an entity to perform transactions. So, compared to a decentralized system, where there is no third-party handler involved, they choose not to trust. This was a very interesting aspect since the study is focused on the HCI perspective, besides implementing the platform.

Some important results noted throughout their investigation were the impact of the economic part of this matter, the transparency of the information about the billing, the sense of community and social comparison that led to the next iteration [13], and the trust that the majority of the users gave in this decentralized system.

The authors concluded that users were becoming more aware of their energy consumption and that it also created an interest in them. A particular feature that the users were looking forward to was the ranking, where they can see their position compared to the rest of the neighbors regarding "effective in fostering sustainable behaviors"[12]. The users reported that they checked the ranking regularly, and it motivated them to compete with each other.

This was an important aspect for the authors since the users felt motivated to be at the top of the ranking and also felt engaged to use the application even more.

Thus, this brings us to the next iteration of this project: Power Share 2.0 [13], the gamified version. This project aimed to explore further the game strand of the previous solution by creating challenges for users to surpass. The three main challenges consist of reducing energy consumption within the community, keeping the consumption below a threshold, and finally increasing the number of consumers of Renewable Energy Sources (RES). Whenever the community completes the challenges, they unlock a new level, and the app also helps users by giving them tips about ways to be energy efficient.

As a result of this study, they concluded that the design experience was very effective once the users were more engaged and felt that they were united in favor of a common objective. They also noted that users were much more interested in their energy consumption and production, and it gave them a new perspective on the environment and renewable energy matter.

This technology offers security, for example, in payments, it automates processes by using smart contracts and also ensures data integrity, among other features.

In addition to this project, blockchain technology is a success in many sectors. In the financial industry the blockchain is used in crypto services platforms and in the logistic sector in the digital ledger of shipments. The health care sector uses smart contracts platforms, such as BurstIQ company [16], to transfer sensitive medical information from doctor to patient and vice-versa.

B. Internet of Things and Virtual Assistants

Recently IoT is getting introduced into platforms that use blockchain, like the ones stated before. In the IoT for Efficient Energy Utilization [17] study, the authors had an interesting and a bit complex approach to energy-efficient systems for a proposed system. Considering all the benefits of IoT, the proposed system consists of a smart energy meter that controls energy consumption and helps detect power theft. The components that composed this solution were a Wifi module to manage the operations through the system, an OLED display that shows the operations' information and energy consumption, an energy meter, an optocoupler, and a current sensor.

With this solution, they were able to create an energy consumption pattern with the information retrieved, detect power thief, conserve energy, and have automatic control of the energy meter.

Vishwakarma et al. [18] developed, using IoT, home automation to efficiently control the energy around the house. The system involved an Arduino using NodeMcu, Adafruit, and IFTTT [19], a web-based assistant, and Google Assistant. The authors highlighted the evolution and importance of the new technologies in the IoT field, which now allows older people and people with some disabilities to interact with systems with the help of virtual assistants such as Google Assistant.

Keeping this in mind, they developed a prototype model with three light bulbs controlled by Google Assistant with voice controls and a web-based service. One of the reasons why it is possible to manage the smart home via a web-based service is because voice commands may not be well processed in the presence of background noises, which is one of the disadvantages of virtual assistants using voice commands.

With a similar perspective, Isyanto et al. [9] implemented a system for people with disabilities using Google's virtual assistant as well, where they can control the entire home simply with their voice. With this system, users were able to control the fans, lights, and even the TV using Google Assistant. Google makes its virtual assistant available on many devices, from its range of Google Nest products to even smartphones, whether they are Android or IOS. This was a very interesting aspect pointed out by the authors since it covers a great number of users, not restricting IOS devices, representing 42.7% of US smartphone users [9].

Many projects aim to control a certain place using just voice commands. Another example of that is the project of Poongothai et al. [20] which consists of automating a laboratory by using Google Assistant to control devices, such as lights, projectors, and AC among others. Their solution was based on a raspberry pi using NodeMcu, the usage of Blynk API, "a real-time state sensing IoT platform that helps in interfacing IoT hardware and Android or an iOS device" [20], also a Heroku Server and Google Assistant.

This proposed system not only controls the multiple devices in the laboratory but also monitors continuously their energy consumption, presenting the data to the users.

A closer solution to this document's proposed approach is the one described in the "Voice-Based Monitoring And Control System of Electronic Appliance Using Dialog Flow API Via Google Assistant" paper [21]. With the resource of Google's technology, such as Google Assistant and its development platform, the authors were able to create a system based on the voice that can control and monitor electronic appliances.

Google offers with their virtual assistant an API (Dialog Flow API) in which developers can create their applications with Google Assistant. Google Assistant incorporates Automated Speech Recognition and Text-to-Speech all in one, which facilitates developers' process of converting human language to information with their API.

All of these tools helped the authors to develop an application and tests that controls the aquaponic. The user is, by default, greeted by Google Assistant saying "Hello, how can I help?" [21]. Then the user makes a request, for instance, "How about the temp?" and the assistant captures the voice request, communicates with the different components such as database, and responds with "Current temp is "$temp" degree Celsius" [21]. This was one of the experiments that they did with their application with successful results.

Google Assistant has many advantages, among them the authors highlighted that it is not required memory to run such applications since all the process is made on the Google Assistant server's side. They also mentioned that the user experience is much more seamless since they don't need to interact with the application in the same way it is done in other types of applications.

With their solution, they stated that "the test outcomes demonstrating that creating electronic gadget application on checking and control dependent on voice had incredible potential. The accomplishment pace of talk affirmation structures is 75% of success rate" [21], which is a very positive point to proceed with developments in this area.

VI. System Design and Implementation

The main goal of this project is to develop a system composed of a smart metering solution and a Google Assistant application to inform the user about their energy consumption and production in their home or facility, bringing users closer to virtual assistants while making their interaction seamless and convenient daily. And finally, test the Google Assistant application in domestic, small manufacturing and restaurant scenarios.

One of the environments of this project is very particular, as it includes a house and a factory nearby. This factory is focused on producing handbags, among other fashion products. This way, it has many machines that require a large power supply, supported by a triphasic power setup. It counts more than eighteen machines, three fans, and a large amount of led lights. As for the house, it has a triphasic power setup, as well. This environment expands the initial functionalities thought for the system. It made us think about different environments that may exist and where this system could fit. Showing information regarding energy consumption, and in some cases, about energy production, among other helpful information.

Thus, this project counts on different test environments, namely the environment previously described, houses, and even restaurants. In this way, the system is thought to handle multiple types of facilities and energy configurations.

To develop this solution, we needed to divide it into two parts, the smart meters, and the application. The first part covers the installation of smart meters and raspberry pi in the electrical panel and their configuration. The last part describes the development of the Power Share app, including the Google Assistant application and its connection to the meters.

A. Smart Meter Solution

First and foremost, it is important to understand which technologies fit best in this solution, and smart meters are a crucial part of this project. The three leading smart meters with those characteristics are from Sense [6], Emporia [7] and Smappee [8]. These devices have some functionalities in common that are relevant for this project, such as monitoring in real-time the energy usage, more specifically consumption and production, and making this information available to developers to explore.

After analyzing the characteristics of each solution, it was possible to conclude which is the best option since each pro and cons have different weights.

a) Emporia's smart meter.: The biggest con that excludes Emporia's smart meter is that it does not provide an official API to make data from the electrical panel available to developers. Although it has attractive features, such as web and mobile apps with real-time information, not having an API makes it impossible to work with this meter.

b) Sense's smart meter.: Sense's smart meter has many advantages, making it one of the best choices to implement in this solution. In fact, the meter is very well developed, and it explores more strands than any other mentioned, namely IoT integration with Google Assistant and Alexa from Amazon and many more services.

The major con is that Sense is an American company, and their devices are designed for North American electrical panels, which differ in voltages from European electrical panels. This constraint makes it impossible to install the meters.

c) Smappee's smart meter.: The main advantage of this device is providing an official API to work with, as Sense does. It also offers an online dashboard to consult the data and does not incorporate features from the proposed solution.

The dark side of Smappee is the API access and the Data Usage License are limited, and even the API calls are limited to 1 per hour. Besides these restrictions, it is required too much equipment, and its price is too high.

B. Final smart meter solution

Since all previous devices had some major cons that made their implementation difficult in this project, a different approach was taken to solve this problem.

Given the previous successful experience with the Carlo Gavazzi smart meters [22], in the SMILE project [23], we chose the EM340 electricity meter to read the energy usage from the electrical panel. This meter is specific for triphasic power setups, which is the one present in the environment described.

The smart meters will be integrated into a system that also includes a Strato Pi [24], that inside has a Raspberry Pi 4. The Strato Pi will be responsible for processing the information received from the smart meters, and to send it to the SMILE API.

C. Design and User Commands

From the solution designed for this project, we started to structure the model of the application, specifying the user commands and the interfaces that are shown to the user.

In this process, we took into account the user needs, the helpful information that we can take from the smart meters, the information shown on previous projects [1], [15], and also how to conveniently show it to the user through the interfaces.

The design of the UI started by collecting the screens from the previous master thesis [1], [15], filtering the most important ones, and selecting the components related to this project. From those screens, we highlighted the energy usage graph, the feedback information, and the different types of views of the energy graph, from days to months.

The design of the interfaces faced some constraints, for which Google has guidelines with best practices on how to design them, in which is highlighted to "design with voice-first in mind" and also to "focus on one touchpoint at a time" [25].

With this process, we identified interfaces that were crucial to be implemented as well as features that were interesting to show to the user.

- **Home:** The home interface introduces the application to the user with a description. Has buttons suggesting commands to perform, and through Assistant's voice some other commands are recommended.

Each of the following interfaces encompasses two dashboards. That is, in each interface the user can choose to see the dashboard regarding the current or previous day/week/month.

- **Daily Dashboard:** The daily dashboard shows information about today's or yesterday's energy consumption and production of energy. It also presents a results card describing the peak and low values, as well as feedback for both production and consumption. The feedback for this dashboard is made by comparing today or yesterday with the same weekday of the previous week;
- **Weekly Dashboard:** The weekly dashboard shows this week's or last week's energy consumption and production. Similarly to the previous interface, here is presented a results card with the same type of information;
- **Monthly Dashboard:** The monthly dashboard provides an energy use overview throughout this month or last month. It also has a results card.

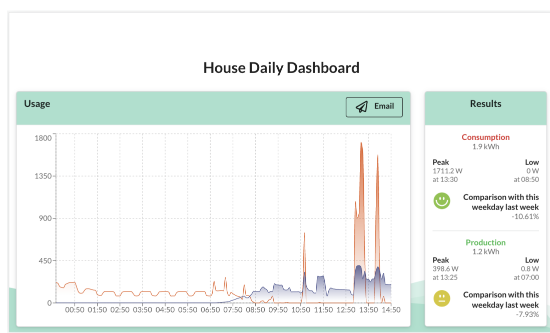

Fig. 1: House Daily Dashboard (with energy production)

The feedback of each dashboard is carefully calculated until the current hour. As a result of a preliminary test made with one family, specified in Section VIII, a new feature, initially implemented in a different interface, was also added to these interfaces. This feature has the purpose for the user to save this information and have it at any time. With the user's consent, an email is sent with information regarding the current dashboard. This email presents not just the results of the energy usage for the specific dashboard but also links to articles on how to optimize energy consumption, and a screenshot of the interface.

After defining these interfaces, we conclude that, in order to provide a summary of all that information to the user, and for them to check it quickly, we needed to create two more interfaces. These two interfaces contemplate a short summary of the ones mentioned above:

- **Complete Dashboard:** The complete dashboard provides a complete summary of the daily, weekly and monthly dashboards.
- **Latest Dashboard**: The latest dashboard shows an overview of the dashboard of yesterday and the dashboard of last week.

Considering the fact that in some environments there is no energy production, and the information presented to the user is only regarding energy consumption, we found it interesting to create a perspective of production, so the user would know how it could be in their house. For that matter, a special interface was designed to demonstrate a prediction of the energy production at the user's device location, together with the actual daily consumption.

When the user calls this dashboard, they will have an insight into the energy production if they install solar panels at their location. Similar to what users with energy production in their homes see in the daily dashboard.

Since these users do not have solar panels, we introduced a new feature, latter added into the detailed dashboards as specified above, to inform the user about energy production. Similar to those dashboards, an email is sent with information regarding energy production and solar panels, as Figure 2 shows. In the email are presented direct links to solar panel solutions from the largest energy companies in Portugal and a link to an article from the Portuguese consumer's defense company, which helps to choose the best solution. Additionally, a screenshot of the interface is attached to the email, so that the user has a reference of the consumption and the expected energy production.

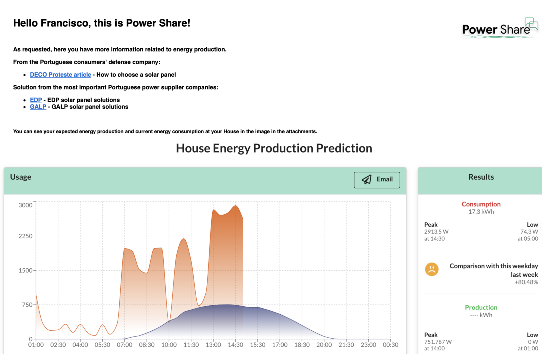

Fig. 2: Email about energy production

Finally, the last energy-related interface was developed to provide helpful and focused information on the most significant parts of the day, lunch and dinner. Similarly to the daily dashboard, it is possible to see information about energy consumption and production but filtered to mealtime. In the first graph, the time is filtered between 10:00 and 14:00 hours, showing the activity at lunchtime, and the time in the second graph is between 18:00 and 23:30 hours, representing dinnertime.

To complement it, we created a daily update notification feature. With this feature we intend to send daily notifications about the meals dashboard. Whenever the user calls this interface, they can decide whether they want to receive a daily update or not. If so, they can choose the hour to receive it.

After completion of the design of the main interfaces, we found it fundamental to have a help page to guide the user if they need it. Not only that, but given the fact that this application is voice-controlled, it emphasizes the need to help the user find the right commands to navigate through the app.

D. Google Assistant

Google, as referred to in the related work section V-B, offers a platform which allows developers to create their own Google Assistant applications. With this tool, it is possible to build an application that is supported not only on Google Nest products but also on any smartphone that has the Google Assistant app installed, with some limitations for IOS devices [26]. Another limitation of this tool, that affects the system testing, is the fact that it is not possible to create a shortcut, for instance an icon or an always-on-display functionality, to have better access to the application. The user is forced to invoked the app using their voice.

This type of application is commonly denominated Action, as is part of Google Actions, applications developed for Google Assistant. These applications have three to four intermediates or entities. These entities are the user, the Assistant itself, the conversational action, and finally, for applications that require it, the fulfillment service, which is the case of applications with custom interfaces. The process starts with the user requesting a command to Google Assistant using their voice. The assistant then sends the request for Google Home, i.e., to local devices to execute the commands much faster. After processing the request is sent to the correspondent appliances and fulfilled.

E. Smart Meters Solution Implementation

Given the smart meter solution, composed of two smart meters and a Strato Pi, we started configuring all the devices.

The configuration of the smart meters was simple, as it only required changing the identification of one of the meters.

As for the Strato pi, it needed more configurations. As mentioned in VI-B, inside the Strato pi is a Raspberry pi 4, responsible for processing the information received. First, was installed a fresh copy of the Raspberry pi OS image on the Raspberry pi, so we could start configuring it with the additional software needed to collect information from the meters, store it and send it to the SMILE API. With the installation completed, we passed the code implemented for the project SMILE to Raspberry, which reads the data from the meters. To this code, we changed some parts to adapt to the house/factory environment, in which both meters are used to read energy consumption from a triphasic power setup. After changing the code, we created a MySQL database so that the data read from the meters is stored locally to prevent data loss if the connection with the SMILE API fails.

At each second, the Strato Pi reads from the meters and stores the data in the local database. Parallel to this process, each minute, Strato reads from the database the data from the two meters, send it to the SMILE API. After completing these configurations, the devices were connected and mounted into the electrical panel, and the system started to read and send data.

F. Power Share Application

The Power Share application is designed to provide custom interfaces regarding energy use at the user's home. As described in Subsection VI-D, these applications are composed of an additional entity, the fulfillment service, in other words, a web application. Power Share is then split into two applications, a Google Actions application and a web application.

1) Google Actions Application: The Google Actions app comprises two other components, a Firebase project, and a Google Cloud project, linked to one another. Google Firebase offers many services, and in this particular project we used the hosting and functions services. In Google Actions platform, we have created a project for the application and started configuring it, giving it a name, and choosing the main invocation, which is how the user invokes the app. From here, we followed the architecture bottom-up, starting from the types moving to intents and finally to scenes.

According to the design, we divided the first energy interfaces into summary and detailed dashboards, which means we had to create two types. In the first type are specified the complete and latest dashboards, in a key-value structure, where the values are other possible ways to refer to the key. In the other type are specified the daily, yesterday, weekly, last week, monthly, and last month dashboards. Since this project has more than one environment, we needed to create one more type referring to the three facility options, house, factory, and restaurant.

For each type of dashboard (detailed and summary), we created an intent with training phrases composed of the dashboard and facility type.

For example, "Show me the house daily dashboard", and "What is the restaurant complete dashboard". This composition allows the user to vary the commands as it is only required to match these two key values.

With the intents implementation completed, we created a scene for each of them. In each scene we defined the conditions to show a specific interface. For instance, the conditions in the previous example phrases are that the facility type and the dashboard type must be present in the command given by the user. In addition, we also defined the paths for when the conditions are met or not. If they were met, the scene calls a webhook from the web app and shows the desired interface. Otherwise, it calls the *Match Any* scene, which is visually represented by the help page since the user asked for something the assistant does not understand. Finally, to finish the development of these scenes, we specified the commands available to go from the current scene to another. We made the same development process for the other intefaces.

For the production prediction dashboard, we need to have the device coordinates to present the expected energy production information.

As for the meals dashboard, we intended to send notifications for the user to check this particular dashboard. Curiously the Google API has a dedicated part for user notifications and daily updates. The latter has the particular aspect of sending notifications at a given hour of the day.

2) Web Application: As part of the Power Share application, a web app was developed to provide the interfaces designed previously for the user. This application was developed using JavaScript and React technologies, and the connection between the web app and the Google Actions app is made in this application.

The web application is composed of a control component and the components that represent the different interfaces. The control component, named Canvas, receives and processes the parameters from the user request and additional information provided by the Google API, such as the type of facility, the type of dashboard, and the user's email. In this application, we configured the screen size and rendered the components representing the desired interface.

The web app is also responsible for the rules of the Power Share application. It defines which users see each interface. For instance, users with energy production cannot see the production prediction interface, and users who do not own a factory cannot see information about this facility. To get the information needed to show in each dashboard, we created a Nodejs server.

3) Server: The server, an additional component of this solution, processes the information and makes it available for the web application to obtain. In this component, we defined the endpoints for each functionality of the application.

The daily, weekly, and monthly endpoints, and the meals endpoint, obtain information from the meters through the SMILE API.

On the other hand, the endpoint related to the prediction of energy production will make a request to the Solcast API. Solcast [27] is a company directed at developing tools for solar power systems. Solcast provides many resources related to solar data, from historical and Typical Meteorological Year to Photovoltaic (PV) live and forecast data. The Solcast resource chosen for this feature is the PV power, which provides live and forecast data for a given specific location in the world, which aligns perfectly with our goal.

As for the email endpoint, we created it with the help of the SendGrid API [28]. SendGrid is an email sender API, which allows us to send an email to any recipient, and is compatible with Nodejs, using its npm module. To send a specific email with energy production information, we created an HTML preset.

After making the requests, the data is filtered to the corresponding date and hour range, the low and peak values are computed, and feedback is provided by calculating the difference between the previous and current values.

In more detail, this information is calculated for the precise moment when the user visualizes the interface. For example, in the daily dashboard, the feedback is computed by comparing today's consumption and production at the current hour with the same weekday of the previous week until the same hour. The same happens if the user asks for yesterday's dashboard. The feedback in the weekly and last week's dashboard is obtained by comparing this week's energy values with those of the previous week up to the same day of the week and hour. The feedback in the monthly and last month's dashboard is done similarly.

VII. Methods

The evaluation of the Power Share system is divided into three main goals:

- **Evaluate the usability the system:** is intended to understand how users interact with the system;
- **Assessing the information of the system:** extract from the users assessment, what are the most useful information to be presented in the system;
- **Evaluate the users acceptance to virtual assistants:** understand the users perspective on virtual assistants, as well as their applications.

The evaluation process of the Power Share system was divided into two phases, a pre-test and a final test.

The pre-test was intended to assess the system in the environment specified before, which includes a house and a small factory. This test was performed by a family within a period of one month. At the beginning of the month, the family was presented with a consent form, and a general explanation about the system. To test the system, a Google Home Hub was provided, since the participants did not own one.

The final test was performed by a family in Madeira, in a domestic scenario, and a restaurant in Lisbon. The research team assisted in the acquisition and installation of meters in this family's house and with the communication with the system. The family, and the restaurant, similar to the pre-test, received a Google Home Hub, instructions, and a consent form. This final test had the same duration as the pre-test, one month, divided into two weeks for the assessments in the restaurant in Lisbon and another two weeks for the family in Madeira.

By having these three distinguished types of environments, it is possible to understand the differences in how the users interact with the system, and how it can be improved to fit best in each scenario.

VIII. Results

A. Factory with Domestic

The data collected after this assessment showed that the most called interface was the detailed dashboards, specifically the *house daily dashboard*. This dashboard shows the current energy consumption with real-time feedback and, as expected, was the most requested during this test.

The second most visualized interface was the one that shows the expected energy production, which was quite interesting. This dashboard was specifically thought for houses that do not have energy production. The information displayed on this interface informs users about how it would be if they installed solar panels to produce energy, as it overlaps, in a graph, the expected energy production with the current daily consumption. It is reported that at least 54% of the time users called this interface, they used the email functionality. This means that 54% of the time when the Assistant asked users if they wanted to receive an email about energy production they said *yes*.

Following the ranking, the factory-related interfaces were the next most viewed, and the weekly and monthly dashboards related to the home and factory were the least requested. This test had 367 interactions between the system and the users, having been most used around 12:00. These interactions, or so-called conversations, had an average duration of 1 minute and 47 seconds.

As mentioned before, whenever the user says a command that Google Assistant does not understand, the scene *Match Any* is called. During this test, the *Match Any* scene was called 25 times, which can be seen as a failure using the system. Thus, the success rate was 93.19%, as 342 interactions out of 367 were successfully fulfilled.

B. Restaurant

The restaurant differentiates itself from the other two environments by being only a workplace. This difference is reflected in the data collected during the system tests, for example, the interfaces that were called to show information about energy consumption. And most importantly, in fewer interactions with the system due to user availability during working hours.

It is essential to take this last statement into account because in professional environments, it is especially challenging to have time to perform tests with users, and therefore it influences the data collected.

Nevertheless, the results showed that the most called interface was the *restaurant complete dashboard*. In this interface, the user can see the energy consumption peaks and lows during the month, the week, and even the day, all at once.

As expected, the *restaurant daily dashboard* was one of the most visualized since this dashboard details the consumption throughout the day. The data displayed here also inform the user about their consumption on the same weekday in the previous week by comparing it with the current day. This information can be relevant for this specific environment as the number of clients and working machines varies daily.

Continuing the ranking, the *restaurant weekly dashboard* and the *restaurant monthly dashboard* were the following most preferred dashboards. These two interfaces can be particularly helpful for tracking energy usage variations and habits in the restaurant since they present the data from a more summarized perspective. Furthermore, the user can even compare the data to the previous week and month.

It is reported that the other functionalities were not used, suggesting a lack of availability to explore the rest of the system. This fact is justified by the type of establishment in which the test was performed. Interestingly, some of the not-accessed interfaces require, in fact, some time for the user to interact with the system and fully understand the given results. In fact, the most called interface is the one that shows all the information in a summarized form to be easily visualized. With the data collected in this test, it is possible to conclude that the user was more interested in seeing information in real-time than information about the last days, weeks, and months.

The results of this test show that the interactions between the user and the system had an average duration of 1 minute and 7 seconds and were made around 14:00, which is when the restaurant closes after serving lunch. The success rate, measured by the number of times the scene *Match Any* was called, was 88.57%.

C. Domestic

Following the same procedure as the previous assessments, the data collected by Dashbot.io allowed having a clear perspective of the most used features. The dashboard that showed the most interest on the part of the user was, as expected, the *house daily dashboard*. As mentioned above, this interface shows real-time energy consumption and production. It also provides continuously updated feedback by comparing the data with those of the same day in the last week. This feature is commonly the most desired one, as it gives the perception of the current energy values, which users often do not know.

Interestingly, the second most asked dashboard was the *house latest dashboard*. This action can be seen as a complement to the previous feature, as this dashboard gives summarized information regarding the last day and week's energy consumption and production.

The next data reveals a surprise since this specific functionality was suggested by the other family in the pre-test. In the pre-test, the users frequently asked the assistant to show the prediction of the energy production at their location, and when they got the data, they had the possibility to receive it in their email. The email feature was so well received that the family suggested amplifying it to the other dashboards. As a result, this feature was included in the detailed dashboards and was made available during the final test. And it was one of the most used features during this family assessment.

While users were very interested in seeing the information from a closer perspective, that is, at the day level, they also explored other interfaces where the data is displayed differently. They chose to consult the *house complete dashboard* and the *house weekly dashboard*.

The data shows that the interactions with the system lasted an average of almost 1 minute and were mainly performed around 10 p.m. As for the well-interpreted commands, is stated a success rate of 76%, measured by the calls made to the *Match Any* scene.

The results of this family test lead to the conclusion that the users were more concerned about the real-time energy information. This assertion is, in fact, applicable across all of the system tests. Users tend to be more interested in current values, whether they are daily, weekly, or monthly data.

IX. Conclusions

Power Share is an integrated system that comprehends a smart meter solution, a conversational Google Assistant application, a web application, and a server. The solution was envisioned to raise people's awareness about energy, informing them about its use by using a virtual assistant and seamlessly integrating it into their daily lives. Power Share provides attractive interfaces regarding facilities' energy consumption and production while offering an engaging virtual assistant experience. These interfaces include a variety of dashboards in which users can see historical and real-time data from different perspectives and even compare them to understand their energy use habits.

The system was successfully tested in three distinguished environments with different types of energy use, namely, houses, houses with a factory, and a restaurant, demonstrating its versatility in different scenarios. Power Share receives this characteristic by not only being adaptable to various facilities but also by being available across multiple platforms, such as Google Home Hub and Android smartphones.

The tests were split into a pre-test and a final test, in which were conducted quantitative and qualitative assessments to understand the user experience. The house with the factory was included in the pre-test that lasted a month. The houses in Madeira and the restaurant in Lisbon were part of the final test and lasted two weeks each.

From the data collected by Dashbot.io [29], the interactions were short-lived as the system has a fast response rate, and the dashboard displays information efficiently, allowing it to be integrated into work environments such as restaurants and factories, where time is scarce. In this type of environment, was preferred the summarized dashboard since the data is more consolidated and embraces more than one scope.

Moreover, the data shows that the real-time comparison between days, weeks, and months was one of the most praised functionalities, as it allows users to implement new measures to reduce their energy consumption and improve production. Users even expressed a tendency to prefer real-time information over data about past days, weeks and months. Finally, the tests characterized the system as a system of long-term use, as people use it over time and not exhaustively over a short period of time.

Testing the system resulted in monitoring energy use habits and creating effective ways to mitigate unnecessary energy consumption. It even boosted users' curiosity to start producing energy and finding the best solar panel solutions. Finally, the adherence to testing the system, as far as the number of interactions, aligns with the previously made studies and with the literature.

This work contributed to bringing users closer to virtual assistants and taking advantage of them while keeping them informed about their energy use in their facilities. Users found functionalities that helped them to manage their energy and even explore ways to produce it by installing solar panels. And are even willing to use the system in the future for the same purposes. Ultimately, it contributed to leveraging the research on home assistants and their potential in the energy field, as we believe that it can be further explored in future investigations.

X. Future Work

Power Share was built with new technologies and procedures, namely Google Actions, which consequently gives opportunities for improvements in its various parts. The Google Assistant application was developed with the latest technology and Google's latest platform, the Google Action platform. However, due to Google's decision to make its assistant only available through Android apps, the conversational application must be transformed into an Android application and consequently integrate the Google Assistant.

With the analysis of the test results, the interfaces can be improved to fit best the type of information that users want to see the most. Moreover, it is possible to understand which functionalities could be improved or added to provide a better experience.

In addition to the functionalities, the smart meter solution could be enriched by exploring the NILM integration and delivering specific information regarding each active appliance. With live data about the appliance, it is possible to create warnings to turn them off and notifications to inform them about their activity throughout the day, week, and month.

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