Visualization of energy consumption and development of an energy consumption optimization strategy with measurement data of smart sockets

AL1523 Group 7

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Abstract

Over the last few years, the use of ICT has increased around the world. The increased demand for energy has caused energy consumption to rise. Energy consumption is something that contributes to higher amounts of emissions as well as the depletion of resources. Because of this, it has become relevant to develop a tool to minimize consumption. This report describes a project aimed at developing a web application that visualizes energy consumption data collected from smart sockets where users can study their household energy consumption. The research question that the report tries to answer is if a platform that visualizes energy consumption data is possible to create and what conclusions can be drawn from the visualized consumption data. The result of this project is a tool that could raise awareness of energy usage among people. With different sockets recording different devices in a household, the data provided by the sockets can be visualized in graphs which are done in the web application that has been developed throughout the duration of this project. This enables the user to study how different devices consume different amounts of energy during a period of time. Additionally, the report describes limitations and issues encountered during the project, including data availability and quality issues, and time constraints. Finally, the report offers suggestions for future development of the web application, including incorporating features that promote sustainable energy consumption practices such as live view and gamification.

Contents

1 Introduction

1.1 Background

Electricity contributes to 25% of the global greenhouse gas emissions[1] today and lowering energy consumption is a vital aspect of sustainable development due to the environmental impacts of energy usage. The increased adoption of ICT systems naturally results in increasing demand for energy which has made energy-efficient practices more important than ever within the field. This project focuses on how energy consumption can be minimized using data gathered by smart sockets. This will be achieved by visualizing energy usage strategies that enable the consumer to reduce energy consumption and minimize energy waste. The plan is to create a platform that can increase consumers' awareness of their own consumption such that said users can use energy more efficiently.

1.2 Problem Formulation

The use of electricity has increased significantly over the last century and it keeps increasing [1]. While the ICT sector has contributed to this trend, it only accounts for a small portion of the total electricity usage globally [2]. Nonetheless, it's essential to reduce wasted energy and improve efficiency in all sectors, including the ICT sector. ICT systems have been mostly something that we use in work up until quite recently but now more products are connected and digitalized in our homes as well which means that the amount of energy we use in our homes is on an upswing right now. This means that we are in dire need of more energy but also of reducing wasted energy. One common use of ICT is to collect and analyze data to help improve efficiency in different scenarios, in this case, the energy consumption in our homes. Collecting the energy consumed, at what time, and from which products might be able to guide homeowners to a more efficient and cheap household that would benefit the individual and environment at the same.

1.3 Sustainability Aspects

With households being unaware of their own consumption, it might cause consumption to rise more than necessary. Higher energy consumption is something that affects global goals due to the fact that higher demand requires higher energy production. The 11th global goal is sustainable cities and communities which includes reducing the environmental impact of cities. By providing knowledge of energy consumption in households, the consumption could reduce and can therefore facilitate achieving this goal[3]. Energy consumption contributes to higher levels of greenhouse gas emissions and today electricity contributes to 25% of the global greenhouse gas emissions[1]. This is mainly due to the process of burning different kinds of fossil fuels [1]. This process also contributes to air pollution which affects some of the global goals. For instance, the third global goal is about good health and well-being. With people being exposed to polluted air, achieving this goal will become more difficult. Target 3.9 of this goal includes reducing illnesses and death from hazardous chemicals and pollution [4]. The fact that energy usage contributes to air pollution will therefore jeopardize achieving this target.
Letting households access their energy consumption can lead lead to cost savings for the households. This can then help to reduce financial burdens and improve overall economic sustainability. Low-income households are the most affected by energy poverty and lack of access to energy-efficient technologies. This project could help to address these equity issues by showing where there is room for energy efficiency.

2 Aim and objectives

2.1 Purpose

The short-term purpose of this project is to aid Vattenfall in their research regarding the development of a visual interface and the strategies said interface will employ in order to convey a deeper understanding of energy usage to their customers. However, there is another bigger problem that this paper covers as well and that is how to increase the consumer's energy consumption awareness. Today it is very hard for consumers to track their energy consumption and this in the long term will make it much harder for consumers to spend energy in a sustainable manner. Our solution for increasing customer energy consumption awareness is to create a platform that visualizes the energy consumption data and creates an easy way to access and track energy consumption data. This project will also cover strategies based on the data that could lower energy consumption and theoretical solutions that build upon this project that Vattenfall could implement in the future.

2.2 Objectives

The project focuses on visualizing consumer data as well as finding a way to make the data accessible to consumers. Our solution to this is to create a web application that can be used to access the user's energy consumption data. The app should visualize the data in a way that is easy for the user to understand. Moreover, the data received from Vattenfall is recorded with different kinds of smart sockets in their energy lab. Hence, the application should illustrate the energy usage of the different devices that have been recorded. The main purpose of the application is to enable the user to study the energy consumption in the home. This will give the user a greater understanding of its own energy consumption and it might affect the choices of the user moving forward with its energy usage. In this way, the project aims to provide an opportunity for a more sustainable home.

3 Project Design

The resulting outcome of the project is a web application that can visualize the data. For this to be possible, an algorithm is developed as a compression script to be able to handle the input data since it originally is too big. The compressed data is then loaded into the web application with the purpose to visualize the data in a way that is easy for the user to understand. The user is able to look at the overall energy consumption over a period of time, but can also filter on one of the devices that have been recorded by one socket.

3.1 Energy data

3.1.1 Data File

This file was sent by Vattenfall and contained all the recorded data from 23 different sockets. The file was of type CSV and contained over seven million rows which made the file size around one gigabyte. Most of the columns were not used in this project but we used the Entity id, Power, and the date and time of the recording. The unit of power is watt. The number of recordings was unevenly distributed between the different types of sockets and some of the sockets had missing data. The data was collected in a lab created by Vattenfall to better understand their consumer's consumption of energy.

3.1.2 Entity Table & the sockets

This file was only a table that mapped the different sockets' entity ids to their respective name device name. This table is later used to identify what device is drawing current. There were three different types of sockets that gathered data, Home Wizard, Shelly Plug, and Philips Hue. Philips hue gathered data from a motion sensor, plant lamp, and Philips Hue bridge. The Shelly plugs gathered data from the microwave, fridge, Nespresso, iPad, toy car, water boiler, two TV screens, Nest, google speaker, Amazon Alexa, laptop charger, and two dishwashers. The home wizard sockets collected data from an offline dishwasher, Socket boiler, and an AC unit.

3.2 Data compression algorithm

In order to be able to load the entire file into the web application we need to compress the data in order for the file to take up less space. In order to achieve this we compromise it using a python script. The script is divided into multiple tasks successively reducing the about of data used. The script deletes all unnecessary columns and all duplicates. It also maps the corresponding names to the entity_ids and averages the state based on each minute instead of every five seconds. The columns that we are interested in are entity_id, state, and last_updated.

3.3 Web Application

The web application is written in ReactJS and libraries such as d3 are used to read CSV files and Dychart is used to display the data in graphs. These tools were chosen because they complement each other and work very well for our purposes. ReactJS is a library that made building user interfaces effective and easier. ReactJS allowed us to create reusable components which were good in our case since we had to create elements for each graph otherwise. Future implementations were also taken into mind then ReactJS was chosen since it is well-suited for web applications that have features that need real-time updates. D3 is another library that is used for data visualization and it provides tools for manipulating data and rendering the data as visual elements. The meaning behind the web application is to have one place for all data. Making it easier for the customer. It is also standardized so the customers don't need to switch between different apps for different adapters.

3.4 Visualization

The visualization is based on the data state from the CSV file and time. Writing up graphs based on these data points. It reads all data it gets but has a range selector making it easy to set intervals by your own interest and get details. Each adapter has its own chart as well as a total graph which shows the total amount of energy used based on the sum of all the adapters.

3.5 Flow of the application

This flow chart describes the entire flow of the web application meaning it represents the steps that the application takes when the website is first loaded in the web browser. When the web application 3.3 opens it starts by requesting data from the CSV file 3.1.1 containing the energy consumption data. Before the data returns to the application the data goes through the data compression algorithm 3.2. When the data has been compressed to an appropriate size the data is then sent back with the entity file 3.1.2 so that the data from individual sockets can be separated. Then lastly the application works with the data to create graphs for the overview and the individual sockets.

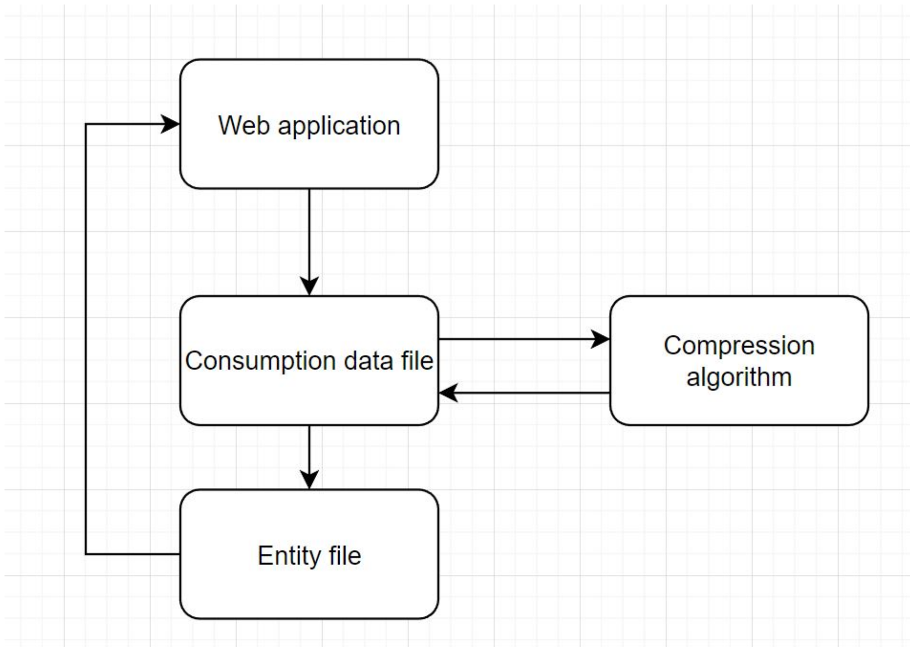

Figure 1: Flow chart

4 Results

The group managed to successfully create a basic web application that could take in energy consumption data collected from the smart sockets and visualizes the data. The application serves as proof of concept to Vattenfall and was made to enable users to access and understand their energy usage. This will then increase their awareness of energy consumption and promote more sustainable energy usage practices. Below are all parts of the web application

4.1 Front page

The application interface is simple and gives the user an overview of their total energy consumption. When the website is loaded it shows an overview of the household's entire energy consumption 2. This page allows the users to see their total energy consumption for the day, week, and month and get the average kilowatt hour based on the selected time period.

Figure 2: Front page of website

4.2 Socket visualization

When scrolling down below are all the visualized individual socket data and the time frame for all sockets is from the first recording to the last recording so the users can see the entire socket lifespan. The x-axis is time and the y-axis is Watt.

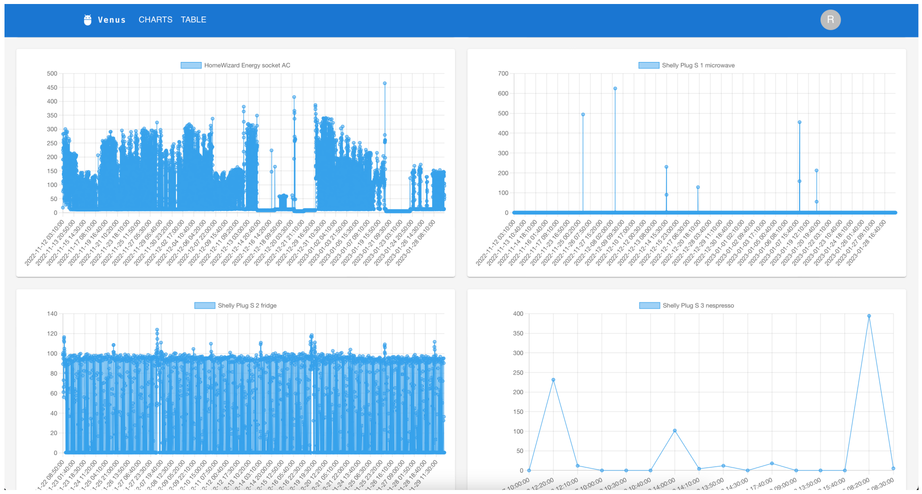

Figure 3: Front page of website

Figure 3 displays data pertaining to the energy usage of four household appliances: the air conditioning unit, microwave, refrigerator, and Nespresso. These machines all utilize energy in entirely different ways, the compressor in the fridge always needs energy to keep the fridge cold, while the other devices share a similarity in drawing energy only when they are turned on.

Figure 4: Front page of website

Figure 4 displays data on the energy usage of one TV screen and two dishwashers. The TV screen exhibits consistent and stable energy usage throughout the entire duration of the experiment, suggesting that the TV remained on throughout the entire testing period. Dishwasher 13 only spikes at the end of the time frame and was on max power for a couple of days. Dishwasher 14 was monitored for only a brief period of time and recorded a single usage cycle of the appliance.

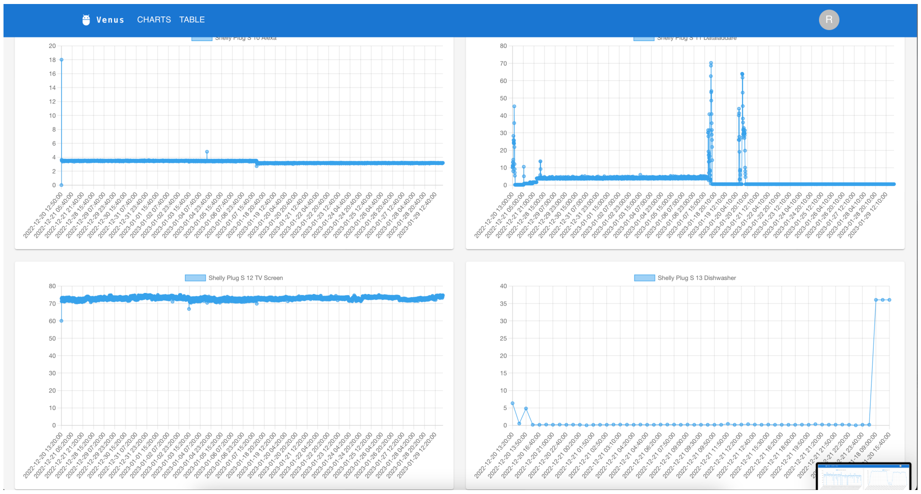

Figure 5: Front page of website

The figure 5 portrays the energy consumption data of a laptop charger and an Amazon Alexa. Over the course of a month, the laptop charger shows sporadic energy spikes while simultaneously drawing a consistently low level of power. The Alexa consistently draws a steady level of power and appears to be on standby for the majority of the time.

Figure 6: Front page of website

Figure 6 depicts the energy consumption data of four electronic devices, namely a water boiler, a TV, a Google Nest, and a Google speaker. The water boiler recorded data for over a month and shows a wide variety of energy consumption. The TV also recorded data for around a month and was used most of the time, with the exception of a few days during the testing phase. Similarly, the Google Nest was monitored for a month, and its energy consumption Oscillated a lot during this period, indicating the presence of some power-saving functionality. Lastly, the google speaker was also recorded for a month and had constant use of energy during the whole monitoring period. There are also two spikes in the graph.

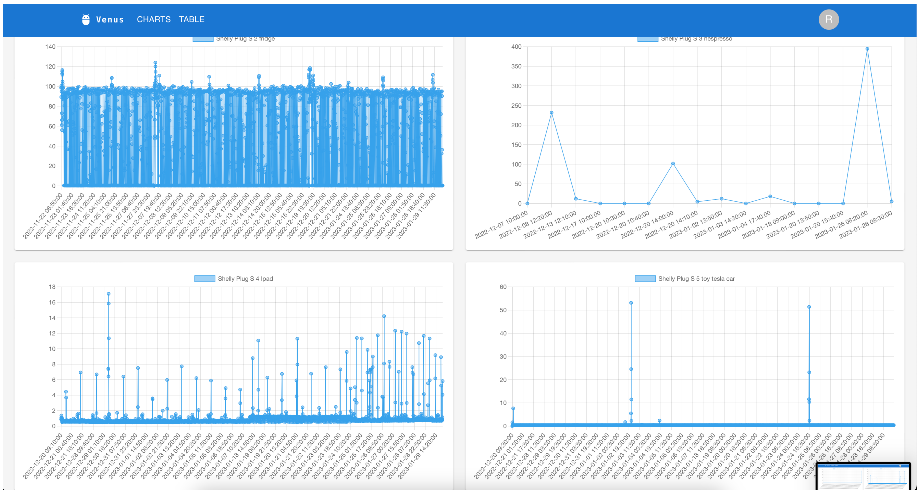

Figure 7: Front page of website

Figure 7 shows the consumption data of an Ipad and a Tesla toy car and the test period for these devices was around a month. The group did not receive any information about how the device's energy consummation was recorded but we assumed since all records came from the sockets that the spikes in the graph comes from when the devices were being charged and not just being used. The Ipad shows varied energy consumption with a lot of spikes. There is also no time in the test period that the Ipad used zero energy. The toy car only showed two energy spikes indicating that the toy car only needed energy when it needed to charge which happened once in a couple of weeks.

5 Discussion and Conclusions

5.1 Discussion on aim and results

The goal of this project was to create a web application that visualizes energy consumption data and creates an easy way to access and track energy consumption data. This goal was reached and the web application creates graphs on the total consumption and graphs for all the individual sockets as well.

The results showed two types of sockets in the household, some sockets always consume energy, and some only draw current for a small time period and spikes in energy consumption. The TV 4 for example was using power throughout the entire testing period and the Amazon Alexa 5 also consumed current during the entire testing period regardless if someone was using it or not. The application shows the users where the energy is being used in the house and the TV and Alexa are perfect examples of a situation where the user is now aware of their energy consumption and can now decide if having the TV on all the time is the optimal choice. The consumer can also see what brands have more energy-efficient products. In the future, this is something that could share and receive information on products that have similar usage but require different amounts of energy. In figure 5 the dishwashers use a vastly different amount of energy on each washing cycle. This is an indicator that one is more energy efficient than the other. If this information was shared between households it would promote product owners to create more energy-efficient products. The application should try to implement these sorts of features because it puts more pressure on companies to be more aware on how their products use energy.

5.2 Sustainability Aspects

As mentioned, the resulting outcome of the project is a web application that visualizes energy usage in a household. This provides an opportunity for users to get a better understanding of their energy consumption and how different devices in the home consume more energy than others. People having access to this information can use this in order to decide how to move forward regarding their consumption. For instance, if there would be a device consuming large amounts of energy, one might consider choosing a more electricity-efficient device in order to lower the consumption. Perhaps a user can see that a specific device consumes large amounts of energy because of the way that it is used and therefore decides to change how to use the device more efficiently. For instance, when looking at Figure 5 and Figure 6 it appears that Google Nest uses less energy compared to Alexa. This is a good example of how the user can study the energy consumption in the household in order to make the home more electricity-efficient. Alexa and Google Nest provide very similar functions, however, the results show that Google Nest is consuming less energy performing similar tasks. In this case, the user could decide to use Google Nest instead of Alexa in order to save energy. Moreover, certain devices might consume energy differently. For instance, in figure 4 the energy usage from a dishwasher is illustrated. However, when studying the energy usage it appears that it only consumes energy in specific time frames 5. The user would probably make the conclusion that it only consumes energy while washing. In order to save energy, the user then might decide to minimize its usage by only washing when the washer is full. In this way, the dishwasher won't need to run as many times. In conclusion, energy consumption patterns can change with the use of this developed web application. When studying the framework from Hilty and Aebischer it appears that this application has a sustainability impact. ICT as a part of the solution requires an application that enables impacts as well as a structural change [5]. In this case, the application is the web application that visualizes the data. This enables the user to study its energy usage making it possible for the user to reconsider its usage. Moreover, with the user changing its behavior, we will see structural changes due to the new patterns of energy consumption.

Currently, Energy consumption contributes to 25% of the global greenhouse gas emissions[1]. As discussed in the introduction, high energy usage is something that has a negative environmental impact and prevents being able to fulfill some of the global goals for sustainable development. However, with a structural change regarding energy consumption patterns, there is a chance for the environmental impacts to decrease and the possibility of meeting these goals will become more realistic.

5.3 Discussion on Product design

This project only explored a visualization application and the data used was lab data from a file but to use such an application in the real world data needs to be collected and stored. For live view, data is collected often and displayed in the app, however, if the live view is not used data only needs to be collected at intervals of one or five minutes to be able to see trends and patterns in the data as well as getting good statistics such as an average of total consumption per day. This implies that the smart plugs are connected at all times, measuring data at the chosen interval but also that the database is up and running at all times as well.

It is also possible that the solution, including the website and the smart plugs, takes more energy to preserve than it saves for the consumers. The amount of energy required to implement this kind of project in multiple households would require a substantial amount of energy. The energy consumption of the system depends on several factors and the system is dependent on the sockets as well. There are no data on how much energy a single smart socket requires to gather the data. Moreover, the amount of data that the sockets have to be stored and manipulated and the amount of energy that storage will take is also difficult to calculate since the energy consumption for storing data is dependent on the storage type e.g Solid-state drive, cloud storage, and the efficiency of the specific hardware. However, if we assume that each household records a similar amount of data that we received from Vattenfall (one GB) and that cloud storage is used a rough estimate would be that one GB would take between 0.2 to 0.5 KWH according to Arman Shehabi et al [6]. This is not a lot of energy and it is equivalent to the amount of energy it takes for a light bulb to be on for a couple of hours. This means that if a user saves a couple of KWH the system would be net positive. However this is only to store the data, further energy analysis has to be made on how much energy the sockets require, and how much energy it would take to execute the data manipulation and run the web server. The system could very easily have a negative impact on the environment if the system uses more energy than it saves. Nonetheless, an argument for this is that energy awareness is a vital part of more sustainable practices in consumer households. Even if it becomes a net negative system if the consumers don't have this data it becomes substantially harder to track energy usage and reduce energy waste.

To make sure that this solution is sustainable in itself the power consumption of the database needs to be explored as well and the total consumption of the smart plugs and the database has to be compared to the expected savings of helping people understand their consumption. Buying smart plugs for every socket in the house is also a negative thing for an individual as it will cost quite a lot, and it will also increase consumption which is negative from a sustainability perspective. Therefore an alternative solution could be a subscription with the application and smart plugs included, and the smart plugs are returned upon cancellation of the subscription. This way the smart plugs can be reused and there won't be masses of unused smart plugs in different homes.

From an information perspective, the use of smart sockets could be controversial regarding privacy. Smart sockets rely on the collection of data, which may need to be accessed by other people than the consumer if smart sockets are the way that energy consumption is going to be measured. As a result, consumers must consider the potential for energy companies to have access to their consumption data on a device level, which could be potentially harmful if not handled properly. For instance, energy companies may choose to sell the data to marketing firms seeking to gather information about consumers' energy consumption habits. This could be seen as a violation of privacy, and raise ethical concerns about the use and sharing of such data.

5.4 Limitations & issues

This project was limited by several factors that impacted its scope and effectiveness. One of the primary limitations was the availability of data received from the lab at Vattenfall. While this data was sufficient to create a proof of concept for the web application, it was only from one single user. As a result, the web application was designed to work for a single user, and there is currently no way for multiple users to use the application simultaneously. However, the web application still shows that it is possible to visualize energy consumption data and make it accessible.

In addition to data availability, data quality issues showed further constraints. Some of the smart sockets had missing data, while other recordings were inconsistent with expected values. To address these issues, graphs were generated using average values, which allowed the overall consumption to be approximated even though the accuracy of the graphs was compromised. This also had to be done because of the size of the file and the file was too big to be opened. Future work could involve better equipment that could handle the vast amount of data, this would improve the accuracy of the graphs.

Other than this, the assignment was time limited causing the functionality of the web applications to be limited. Because of the lack of time to develop the application, the most important functions were prioritized. However, to improve the application, there are some suggestions that could have been implemented but would require more time. Functions such as live view and gamification are described in chapter 7 6.

Finally, while the web application was successful in its aim to increase user awareness of energy consumption patterns, it does not provide guidance for users to make more sustainable energy consumption choices. Rather, the application only served to raise user awareness of their energy consumption. In future work, the web application could be enhanced with more interactive features, such as personalized energy-saving tips and recommendations, that can help users make more sustainable energy choices. This would expand the utility and effectiveness of the web application and could provide a more comprehensive solution for reducing energy consumption and promoting sustainability.

5.5 Conclusions

In conclusion, the goal of this project was to create a web application that visualizes energy consumption data and creates an easy way to access and track energy consumption data. This goal was achieved, and the web application creates graphs on the total consumption and graphs for all the individual sockets as well. The web application has the potential to enable users to reconsider their energy consumption and make changes to reduce their energy usage. The application's impact on sustainability is clear since it provides an opportunity for users to get a better understanding of their energy consumption and helps them move towards more sustainable practices. The results showed two types of consumption patterns which are sockets that always consume energy and sockets that draw energy for a small time period and spikes. The web application shows users where energy is being used in the house and enables users to change their energy consumption. However, the project faced several limitations, the quality of the data and the time constraints made the functionality of the web application limited. Despite of this the project works and serves as a proof of concept. Overall, the project demonstrates how digitization can promote or provide the opportunity for sustainable practices. The application could have an impact on sustainability as it lets users reconsider and study their energy consumption. Nevertheless, the impact of the application is dependent on the consumer's willingness to make changes to their energy usage.

6 Future development

6.1 Tips

In addition to providing users with access to their consumption data, the application should have features that encourage more sustainable energy usage practices. For example, users can set energy usage goals and track their progress toward achieving them. The application could also provide users with personalized energy-saving tips and suggestions for reducing energy consumption.

6.2 Database

The web application that was created only read the data from a singular CSV file. This made it hard to load a large amount of data into the website. A solution to this is to create a SQL-based database that could handle all data entries from all the different sockets. Databases also make data sharing easier and allow multiple users to access and share data simultaneously, which is something that is going to be needed if the platform will allow the visualized data to be shared with multiple households. Lastly database would also be more secure since it also provides security features and has backup and recovery.

6.3 Live view

Live view is a tool that can be used for many things by the user. It could be used to confirm the power consumption of a specific thing by using it while watching the live view. If electricity prices are very expensive during periods of time one can use live view to check that nothing unexpected is using large amounts of power. Live view's greatest benefit is probably the fact that real-time monitoring allows users to see how much their behavior can change the power consumption, for example by shutting down a computer instead of letting it idle. This feature could also let users turn off their smart plugs where ever the user is.

6.4 Gamification

There are many information and communication technology (ICT) tools available that promote sustainable practices. Some of these tools use gamification to encourage users to become more engaged in the Tool. Gamification is the use of game design principles and techniques in non-game contexts to make users more engaged and make the user experience more fun [7] [8]. This approach could be applied to the present project to incentives users to lower their energy consumption. For example, a point system could be implemented, in which users earn points for meeting their weekly energy consumption goals. Furthermore, the point system could be extended to a neighborhood or community level, allowing users to compete for rewards based on their energy consumption patterns. There exists evidence that gamification provides positive results if the context is right [9] and it could be an effective way for users to become more conscious about their energy consumption without it feeling like they have to use less energy.

In future work, gamification could be further explored as a strategy for promoting sustainable energy consumption practices in the application. This should involve conducting user testing and evaluation to determine the most effective gamification strategies for motivating users to reduce their energy consumption since the context has such importance in gamification.

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