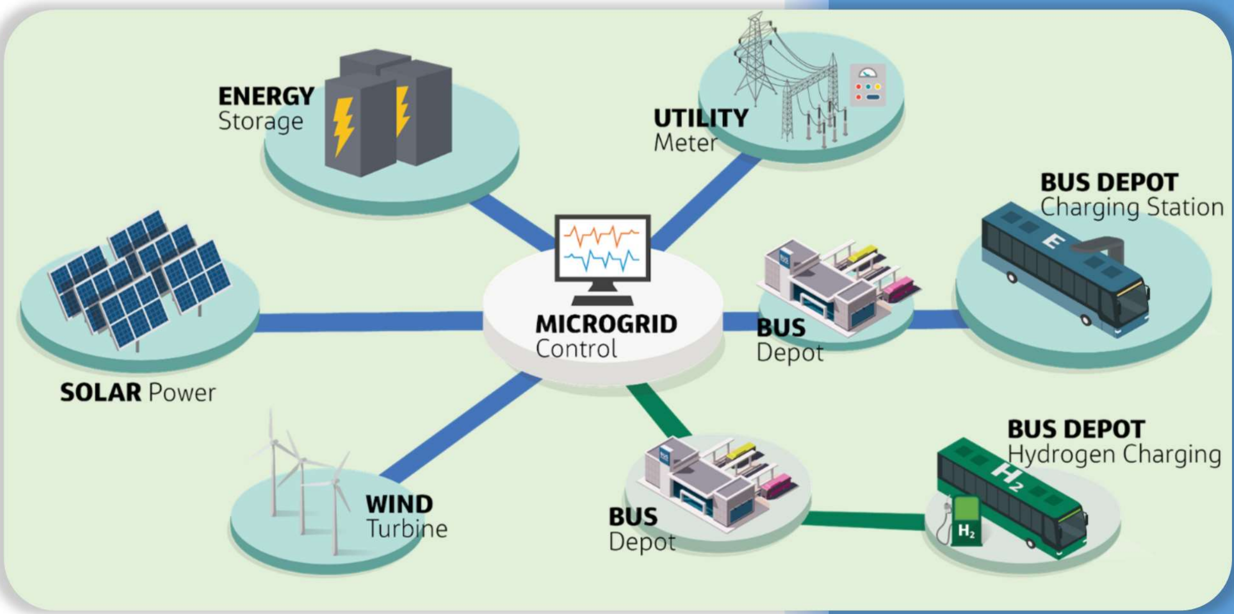
Team Guinness

CleanerGrid Competition



Team Members: Aleksandra Dozorova, Jack Brady and Ugochukwu Uzoukwu

College: TU Dublin

Team Guinness

Table of Contents

Table of Figures

Table of Tables

1. Introduction

1.1. Objectives

The aim of our team was to extract data from **EirGrid's Smart Grid Dashboard** and/or from the **Single Electricity Market Operator (SEMO)** website to create a digital prototype of a website and dashboard. The primary objectives were to retrieve and process the data using the EirGrid Dashboard and SEMOpx API's, import the data to Power BI, and display the information in a meaningful way which encourages consumers to be more mindful of energy consumption during periods of peak demand. The ultimate goal of our team was to take a simplistic and straightforward approach towards the creation of a website and a dashboard. Our solution embraces the idea that most consumers may not have the engineering or scientific knowledge to understand the relevance of this data. Our dashboard ensures that all consumers understand what it means to be conscious of energy consumption and have the capability to adopt a cheerful outlook towards energy conservation.

2. Development/Methodology

2.1. Research

Research was conducted in order to identify and understand techniques which could help consumers to adopt sustainable energy usage practices and apply the methods which were statistically proven to have the highest success rates. A study from March 2007 explored the various behavioural change models which were successful at affecting consumer behaviour on energy demand [1]. A comparative analysis was conducted on various methods such as the ***Rational Choice Theory***, the ***Persuasion Theory*** and ***Community-Based Social Marketing Tools***.

Whilst all models had conceivable advantages, it was established that the ***Triandis' Model*** was the most effective at improving consumer behaviour on energy demand as it took into consideration *"internal and external factors influencing behaviour, but also includes the most complicated parts of peoples behaviours, much of which are based on routine and habit"* [1, p. 24]. Figure 1 below highlights the concepts included in the Trandis' Theory and shows how each element combines to produce the desired impact on consumer behaviour. Behaviour is a concept comprised of many traits, so a multifaceted approach is needed to target each trait in order to positively change consumer behaviour. This model looks at the wider societal contexts in which people live and how behaviour is affected by societal and economic issues as well as internal and external factors.

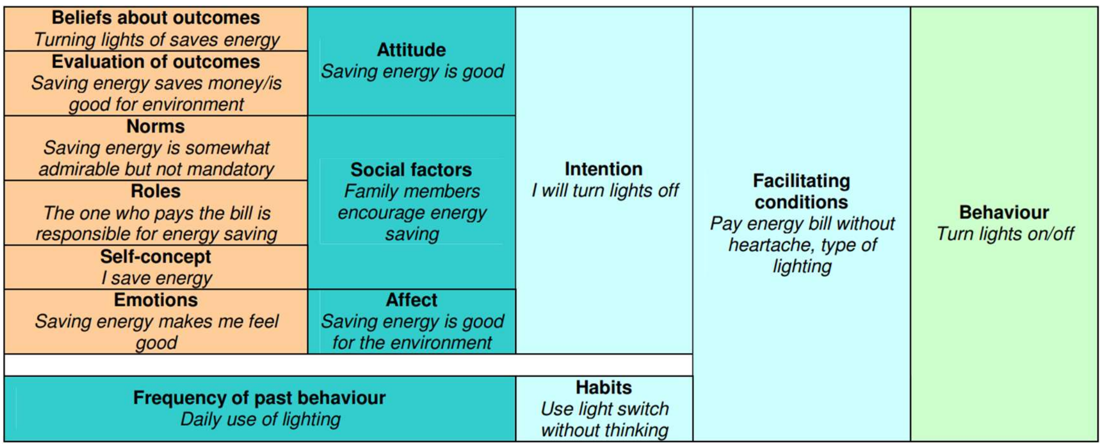


Figure 1 Tabular summary of the Trandis' Behavioural Model. [1]

2.2. Our Model

2.2.1. Targeting Behavioural Aspects

Our model was formed by selecting what we perceived to be the most effective methods at improving consumer behaviour towards energy conservation. We focused on the following areas: direct data feedback, community involvement, competition, and monetary benefits.

- **Direct Data Feedback:** Direct data feedback ensures that information relating to demand and wind generation is continuously displayed to establish the consistency that a consumer would need to make decisions based on energy consumption.
- **Community Involvement:** The previously mentioned study has shown that community involvement has positive impact on consumers' behaviour when it comes to energy conservation [1].
- **Competition:** It was found that gamification of the process can have a positive impact on consumer's awareness of energy conservation [2]. A competitive element could be added to the project by including an "Interactive EirGrid Quiz" which prompts the user to answer a 10-question quiz with questions based on energy conservation.
- **Monetary Benefits:** The reality for a lot of consumers is that they are more likely to actively change their energy consumption behaviour if they are aware of ways that they can save money by doing so. An "Energy Saver" application was included on the website to achieve this.

2.2.2. Data Selection

Data was retrieved using APIs. By conforming to the objective we had to provide a simple and straightforward dashboard, not all of the data retrieved is shown to the consumer. Instead, only the vital information is displayed as we tried to limit the possibility of confusing the user or giving them contradictory signals. From the "EirGrid SmartGrid Dashboard" data sets from overview, demand, generation, wind generation, interconnection, and frequency were retrieved. From the "SEMOpx" website, data from market results was retrieved. After much discussion it was decided that **Wind Generation** and **Energy Demand** were the two primary data sets to concentrate on.

Wind Generation: Due to wind's unpredictable nature, there are often serious implications associated with storing it when there is an excess supply. Grid stability can be improved, and energy conserved by ensuring that the energy produced from wind is consumed during periods of excess generation. In our dashboard and website, the underlying message was to **encourage** energy consumption during periods of high wind generation.

Energy Demand: This refers to the amount of energy that the consumers are using at a specified period in time. High demand puts a significant strain on the grid and under extreme circumstances could even instigate a black out or brown out. In our prototype, the underlying message was to discourage energy consumption during periods of high demand.

A **Traffic Light System** was created to tell the consumer that high demand is bad and high wind generation is good ("Low D" = low demand and "Low WG" = low wind generation).

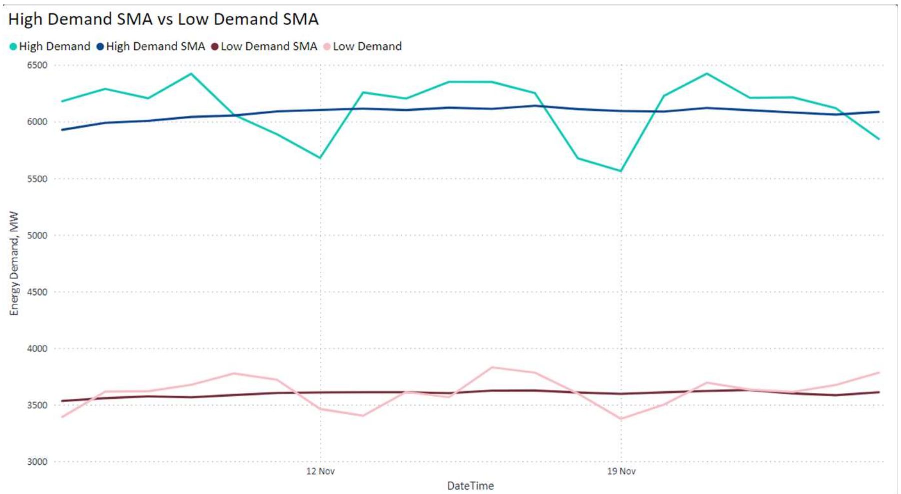
Low Demand, High Wind Generation	**Low Demand, Low Wind Generation**	**Mix**	**High Demand, High Wind Generation**	**High Demand, Low Wind Generation**
Strongly Encourage Consumption	Encourage consumption	Consume with Caution	Discourage Consumption	Strongly Discourage Consumption

Table 1 Proposed Traffic Light System.

Although data sets from **Generation, Exports/Imports, Frequency, and Day-Ahead Market Results** were retrieved, they were not used in our dashboard as it added too much complexity to our prototype. As our prototype is easily expandable, in a future revision we could utilize this data in some way.

2.2.3. Simple Moving Averages and High-Low Ranges

In order to establish when the demand was high or low or when wind generation was high or low it was obvious that we needed something to compare it to. For example, saying that the "demand is high" means nothing if there is no prior data to compare it to. This is why the implementation of Simple Moving Averages (SMA) and High-Low Ranges were ideal for our dashboard. By calculating what the 7-day Simple Moving Average was we could use it as a reference point to compare with the current demand. For example, if the 7-day moving average of a grid was 1,200 MW and the current demand was 1,250 MW, this is a strong indicator to discourage energy consumption as the demand is high relative to the average demand over the past week.



Graph 1 Graphical representation of Simple Moving Averages for Demand.

Taking this one step further, now let's say we found the **maximum** demand for each day and calculated the SMA for the past 7 days and let's say we did the same for the **minimum** demand, this presents an ideal opportunity to establish a window where we can not only tell consumers when demand is high, but we can also tell them when it is low. The same method was applied to wind.

2.2.4. Multi Criteria Decision Matrix

A Multi Criteria Decision Matrix is a simple, yet effective method used to make decisions in scenarios where there are multiple data sets. This was an ideal method for processing our data as we needed a way of combining multiple data sets to influence decisions made by the consumer.

	Demand (MW)			Wind Generation (MW)		
Weightage	**0.75**			**0.25**		
SMA	**Low**	**High**	**Range**	**Low**	**High**	**Range**
Day 1	1,800	4,300	2,500	400	1,400	1,000
Day 2	1,700	5,100	3400	700	1,400	700
Day 3	850	4,750	3900	760	1,250	490

Table 2 Multi Criteria Decision Matrix.

Our Multi Criteria Decision Matrix works in the following way:

1. **Step 1:** Consider Day 1 for wind generation. The range for this day was calculated by subtracting the High Simple Moving Average from the Low Simple Moving Average.
2. **Step 2:** A Traffic Light System for Wind can be created by dividing the range for each day by five. This range is the difference between the high moving average and the low moving average. This establishes five different ranges, one for each colour of the Traffic Light System.
3. **Step 3:** The size of each range is calculated by finding the total range and dividing by five $\left(\frac{1{,}000}{5} = 200\right)$. The table below shows what the five ranges for wind would be.

Range	**400 - 600**	**600 - 800**	**800 – 1,000**	**1,000 – 1,200**	**1,200 – 1,400**

Table 1 Five Ranges for Wind Generation.

4. **Step 4:** Now let's assume that the current value for wind generation is 1,150 MW. To assign a "score" or "rating" to this which tells us how confident we are that the consumer should/should not consume, the formula below was used. The results means that we are 75% confident that the user should consume electricity at the current moment.

$$R = Range = 1{,}000\ MW$$
$$HLW = High\ Limit\ for\ Wind = 1{,}400\ MW$$
$$LLW = Low\ Limit\ for\ Wind = 400\ MW$$
$$CV = Current\ Value = 1{,}150\ MW$$
$$X_1 = CV - LLW = (1{,}150 - 400) = 750\ MW$$
$$a = \left(\frac{750}{1{,}000}\right)(100) = 75\%$$

5. **Step 5:** Now let us say we repeated steps 1 – 4 but for demand instead. The implementation of the Traffic Light System would be the same, except the colours should be inverted. The reason for this is that a high demand value is bad (red) meaning "don't consume" but a high wind generation value is good (green) meaning "consume". Assuming the current demand to be 2,100 MW the Traffic Light System would look like the table below.

Range	**1,800 – 2,300**	**2,300 – 2,800**	**2,800 – 3,300**	**3,300 – 3,800**	**3,800 – 4,300**

Table 2 Five Ranges for Demand.

6. **Step 6:** Like before, we can assign a score to the current demand value.

$$R = Range = 2{,}500\ MW$$
$$HLW = High\ Limit\ for\ Wind = 4{,}300\ MW$$
$$LLW = Low\ Limit\ for\ Wind = 1{,}800\ MW$$
$$CV = Current\ Value = 2{,}100\ MW$$
$$X_1 = CV - LLW = (2{,}100 - 1{,}800) = 300\ MW$$
$$b = \left(1 - \frac{300}{2{,}500}\right)(100) = 88\%$$

Keep in mind that because the colours (signals) are inverted for demand, we need to subtract the final result for 1. Our calculation here tells us that we are 88% confident that the user should consume at the current demand.

7. **Step 7:** Finally, the scores for wind and demand are combined using a weighted average formula. Our weighting for wind is 0.25 and for demand it is 0.75 which means that we consider demand to be 3 times more important than wind in our calculations (the weightings used for wind and demand here were not the actual ones we used and were only used for the example). An additional weighting was added for wind to prevent misleading scores. For example, if the wind was low all day but was creeping higher than the day's high moving average, the score would be high, however the wind generation is still low, and the score should be low. The weighing was found by dividing the current wind by the max all-time wind. In our example, this was 0.7.

$$cr = Confidence\ Rating$$
$$w_1 = weight\ for\ wind$$
$$w_2 = weight\ for\ demand$$
$$w_3 = second\ wind\ weighting$$
$$a = score\ for\ wind$$
$$b = score\ for\ demand$$

$$cr = a.w_1 + b.w_2.w_3$$
$$cr = (0.75)(0.25) + (0.88)(0.75)(0.7) = 0.6495 = 64.95\%$$

8. **Step 8:** In conclusion, our final value indicates that (combining the data sets for wind and demand), we are 64.95% confident that the user should consume. This is a mildly strong signal as it falls into the light-green range of our original Traffic Light System. The underlying message for the consumer here is "Encourage Consumption".

2.2.5. Consumer Meter

The Consumer Meter or **"Consumeter"** is the central idea behind our dashboard. Our goal was to provide a visually descriptive and aesthetically pleasing meter/gauge.

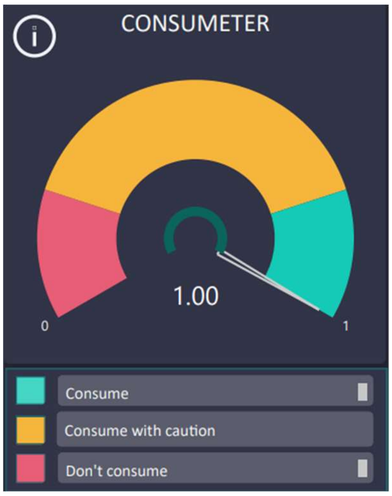


Figure 2 Consumer Meter or "Consumeter".

The Consumeter takes the Confidence Rating (cr) displays this on a meter with a score of 0 (red) indicating **“Strongly Discourage Consumption”** and a score of 100 (green) indicating **“Strongly Encourage Consumption”**. The score range 20 – 80 represents the yellow area indicates that the user should **“Consume with Caution”**. We hoped to include five colours on the meter (red, orange, yellow, light-green, and dark green) but we were limited by the settings of the chart that we used in Power BI.

3. Implementation

3.1. Website

The website was coded using HTML, CSS, and JavaScript. The HTML gave a structure to the webpage, CSS was used for styling and providing it with a suitable colour scheme (similar to the Smart Grid Dashboard and the turquoise colour of the EirGrid logo), and JavaScript was used to provide dynamic functionality to the key features of the website.

Using JavaScript, the “document.getElementById()” function was repeatedly used to target a specific HTML element such as a button “<button>” or an input “<input>” and assign a variable to it. An event listener could then be added to a button so that once clicked, it performed a certain task. This was repeatedly done in the code and was used to implement the “EirGrid Quiz” and “Energy Saver.”

3.2. Data Collection and Processing in Python

Python was used to communicate with EirGrid’s API and get the information needed, organise it and perform some calculations before using the tables in the Microsoft Power BI visualisation tool. To run the code, python 3.12 must be installed on the machine, as well as the ‘request’ and ‘pandas’ libraries. The code was divided into regions to help with organising it. The regions and comments clearly state what is being performed in each section of the code. The following calculations and transformations were performed in the code:

- Forming of DataFrames (tables) for demand and wind data from EirGrid’s dashboard
- Calculating minimum and maximum values for a day and for an hour – refer to **Error! Reference source not found.**
- Calculating the moving average for a specified window of time – refer to **Error! Reference source not found.**
- Filtering and preparing DataFrames to be used in Power BI report.

The code is easily adaptable to analyse data for different date and time ranges, and data from different websites, provided they have a field with date and/or time.

3.3. Dashboard

The dashboard was developed in Microsoft Power BI. By embedding the python script, “PBI_scrapingAndProcessing.py” that we created already we were able to import all the tables that were created with the prefix ‘PBI’. Before analysing the dashboard, data must be refreshed by using the “Refresh” button in the top ribbon under “Queries” section.

Some of the tables had more manipulation done to them using Power Query (PBIactual_days, PBIactual_hours, forecast tables for today and tomorrow) to add a difference between low moving average and high moving average for demand and wind, and to add the coloured zones between wind moving averages. Finally, necessary calculations were performed for tables PBIactual_hours, PBIforecast_hours and PBIforecast_tomorrow to calculate the consumption score for hours of today and tomorrow – refer to steps in **Error! Reference source not found.**.

It is possible to refresh the report automatically if it is published to Power BI Service or Server. To set up automatic refresh in Power BI Service, On-premises gateway must be used. Once the report is published on either of these services, it is possible to embed the dashboard into a website to be used by end users.

4. Consumer Interaction

4.1. Website

Navigating through the website is simple and is done by selecting any of the five buttons at the top of the page which are **Guide, Dashboard, EirGrid Quiz, Energy Saver, and Community**.

Guide: The initial content that the consumer sees is the "Four Step Guide" provided under the Guide Section. Each step outlines how the user should interact with the website in order to gain access to the Dashboard where the critical energy data is displayed.

Dashboard: This is where the dashboard could be displayed had it been embedded on the website. Unfortunately, we could not do this due to account limitations on Power BI.

EirGrid Quiz: The EirGrid Quiz is a fun and interactive quiz where users answer ten questions with topics relating to data from the Smart Grid Dashboard and SEMOpx website. The questions and answers are retrieved from a Firebase database where they are stored and each time the quiz starts the questions are randomly shuffled to provide a unique quiz each time! When the user finishes the quiz, their score is displayed. This targets the "Competition" element of our model so that users can compete with each other to gain a higher score whilst also educating themselves about energy.

Community: The Community Section of the website was designed to give users an opportunity to interact with other consumers to share advice/tips for energy conservation. Research has shown that users are more likely to be conscious of their energy consumption and take action if they participate in local community groups. The user interacts with this part of the website by subscribing to their local area/county (Dublin, Wicklow, Kildare, etc) and publishing a post to an MQTT broker so that other people from their community can see it.

4.2. Dashboard

The consumer navigates through our dashboard by selecting one of the five tabs which are: Today, Forecast for Tomorrow, Renewables, Visit EirGrid Dashboard, or Visit our Website. Each page contains a navigation panel on the left (to navigate between tabs in Power BI Desktop, hold Ctrl + Click, when using dashboard from embedded solution, just clicking will take the user to the desired tab). Last refresh field was added to indicate when the dashboard was last refreshed.

Today: This is the central section of our dashboard as it provides the user with the most vital information they need relating to the consumer score, demand, and wind. The data is displayed in a practical, simplistic, and visually attractive way so that even a quick glance at the dashboard can inform the consumer on whether or not it is currently a good time to consume.

Forecast for Tomorrow: The consumer score forecast for the following day can be viewed here, so that the consumer has an idea of what to expect in the near future. Figure 3 below shows this, where the consumer score is in the red zone for the hours of peak-demand and transitions to the green zone when demand is low.

Renewables: It is important to us that the consumer has a clear understanding of the unpredictable nature of wind, and this was done by showing past fluctuations of wind generations as it transitions in and out of different coloured zones. On the right-hand side users can view the location of wind farms in Ireland and also the portion of the fuel source that is taken up by renewables.

Visit EirGrid Dashboard: By clicking this tab, users can link back to the Smart Grid Dashboard should they seek any additional information.

Visit our Website: By clicking this tab, the consumer can gain access to our website.

A user survey was conducted to analyse the accessibility of the dashboard. Responses were collected from five people from different age groups and backgrounds.

Table 3: Survey Results [3]

Clarity	3.5/5
Visual attractiveness	4.5/5
Abliity to influence energy consumption	3.5/5
Overall experience with the dashboard	4.3/5

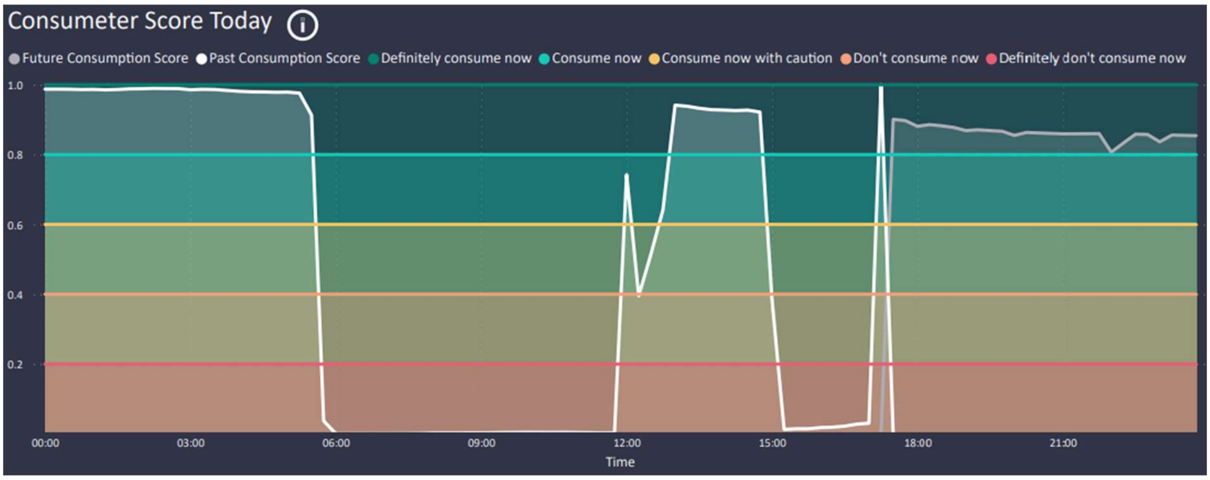


Figure 3 Graphical Representation of Consumer Score.

5. Conclusion

5.1. Achievements

We have achieved most of the objectives that we set at the beginning of the competition. We have created a dashboard that allows the consumer to make an informed decision about whether they should be consuming energy now, whether they should postpone it to later today or tomorrow. Moreover, the dashboard gives the user some extra information on why the score is the way it is. From the survey, it was found that most users found the dashboard clear and able to influence their energy consumption behaviour in some way.

The website added more elements that help to influence consumer's behaviour by the addition of the quiz, energy saver calculator and a community element.

5.2. Improvements

There were certain features which we wanted to implement in our prototype but could not due to time constraints. For example, we hoped to include a "Reward System" similar to the feature included in an Apple Smart Watch. The idea behind this was that users could make a record each day they reduced their energy consumption. If they reduced their consumption by 10% seven days in a row, they would receive a badge as an emblem of accomplishment. We also hoped to include "low margins" in the calculation for the consumer score. Margins ensure that we are generating extra energy (e.g., 10% more than we need) so that in the case of a generator failing or a blackout, we will have the additional energy needed to keep the system running. This would be a valuable metric to include in our consumer score as it could be used to bring the score down when margins are low, indicating that we are strongly discouraging consumption. Unfortunately, we do not have access to electricity margins information. Lastly, we hoped to include a hardware component (turning on a light on an LED when a message was published to the MQTT broker indicating that demand is high), but this was not done due to time constraints.

5.3. Final Word

In conclusion, this competition proved to be very insightful, and although the process was as difficult as we had anticipated, we nevertheless enjoyed every moment of it! There is obviously room for improvement in certain areas of our dashboard and website and if there had been more time, a more refined and accurate approach could have been taken for analytical aspects and calculations for the Dashboard. Overall, we hope he value of our prototype and how our prototype is capable of helping consumers be more mindful of their energy consumption at certain times of the day is apparent.

6. References

[1] M. Martiskainen, "Affecting consumer behaviour on energy demand".

[2] M. Casals, M. Gangolells, M. Macarulla, N. Forcada, A. Fuertes, and R. V. Jones, "Assessing the effectiveness of gamification in reducing domestic energy consumption: Lessons learned from the EnerGAware project," *Energy Build.*, vol. 210, p. 109753, Mar. 2020, doi: 10.1016/j.enbuild.2019.109753.

[3] SurveyMonkey, "Survey Results." Accessed: Nov. 30, 2023. [Online]. Available: https://www.surveymonkey.com/results/SM-ftlYZoNlqPzUyRatLEEoVA_3D_3D/