

Final Year Project

Reduction of Personal Carbon Emissions Through Gamification

Simonas Ramonas

Student ID: 18763829

A thesis submitted in part fulfilment of the degree of

BSc. (Hons.) in Computer Science

Supervisor: Dr Gavin McArdle



UCD School of Computer Science
University College Dublin

December 3, 2021

Table of Contents

1	Project Description	3
1.1	Problem Statement	3
1.2	Proposed Solution	3
1.3	Related Work	4
1.4	Why Gamification?	4
1.5	Datasets	4
2	Related Work and Ideas	5
2.1	Calculating Carbon Footprints	5
2.2	Gamification	7
2.3	Existing Solutions	8
2.4	Background Research Summary	15
2.5	Technologies	15
3	Outline of Approach	16
3.1	App Features and Mockup	16
4	Project Workplan	19

Abstract

Provide a short description here (about 150-200 words) of your project. Do not go into fine detail, but offer a strategic overview of the project's aims. An abstract should whet the appetite for what comes next, not quench it with details.

Chapter 1: Project Description

1.1 Problem Statement

When we think about the actions in our day to day lives that produce greenhouse gases, what usually comes to mind is driving the car or heating our home and we often overlook how we may be contributing to climate change indirectly. For example, turning on the kettle, having steak for dinner or ordering something for delivery, all these activities produce emissions. All direct and indirect activities produce a range of greenhouses gases with varying degrees of potency for global warming but all can be represented as a carbon dioxide equivalent. In 2018 the average carbon dioxide equivalent emissions per person in Ireland was 12.6 tonnes which was the third highest in the European Union[1]. Ireland is committed to reduce its greenhouse emissions by 51% by 2030[2] but at the current rate it is likely to miss this target. That is why we all have to do our part. According to a survey of Generation Z carried out by Amnesty International based on answers of more than 10,000 participants questioned 41% ranked climate change as one of the most important issues facing our planet[3]. From this we understand that most people already understand that they need to reduce their emissions but the problem is how can we get people engaged and motivated to reduce their carbon footprints. What better way to get gen z involved in the race against global warming than with an app that has engaging gamification features to help track and reduce their greenhouse gas emissions. The technical challenge is how to develop an app to do this well.

1.2 Proposed Solution

Develop an app that aids one in lowering their personal greenhouse gas emissions while being entertained and engaged with the help of various gamification features (points, badges, leaderboards, streaks, loss aversion). The app would slowly ease the user into reducing their emissions so they are not overwhelmed. The user would first need to learn about why they need to take a certain action before they can take it so they would have an understanding why it is important. Each completed action would earn the user points and achievements. Every so often the app will prompt the user to fill out a survey which calculates their carbon dioxide equivalent emissions to plot a historical graph showing their progress in reducing emissions and to compare to the national average. To lessen the development workload and overhead all data would be stored on the phone and any multiplayer features would be handled by Apple's Game Center.

App Features

- Carbon footprint calculator
- Carbon footprint breakdown
- Carbon emissions tracker
- Engaging lessons on carbon emissions

-
- Quizzes on carbon emissions
 - Daily and weekly challenges
 - Leaderboards
 - Points, badges and Trophies
 - Stats and historical graphs
 - Friendly reminders and nudges

1.3 Related Work

After trying other available apps (Pawprint[4], eevie[5], EarthProject[6], Climate Court[7]) I found that most take a while to set up with long surveys and tedious sign up processes. Upon signing up you are greeted with an overwhelming amount of options and information. Thereafter, further looking into the reviews of these apps I came across conflicting opinions. Some mentioned that the surveys take too long but others wanted more options as they thought their carbon footprint calculation was inaccurate. Another problem with most of these apps is that they rely on the user to be truthful when entering their data so the leader-boards and other competitive aspects of the app can be easily manipulated. Furthermore, reading the findings of a research paper[8] I came to the conclusion that more gamification components lead to higher ratings. I also discovered that loss aversion is a gamification tactic utilised by many popular apps (Duolingo, HeadSpace, Snapchat) on the premise that sometimes the thought of losing something can be a greater motivator than gaining something[9].

1.4 Why Gamification?

Gamification is the strategy of adding entertaining game design mechanics to otherwise dull environments to boost engagement and motivation by creating experiences that are similar to those in real games. With the help of gamification we can make the act of becoming carbon neutral interesting[10], create a habit of reducing consumption and maybe even make the user addicted to the app while lowering personal carbon emissions.

1.5 Datasets

This project will require various datasets and user input for calculating the user's carbon footprint and tracking carbon emissions. These datasets include emissions by car model, electricity producer emission factors, airline emissions, emissions for different fuel types.

Chapter 2: Related Work and Ideas

Since the start of the Industrial Revolution, the most significant driver of climate change has been greenhouse gas emissions from human activity. As we burn more and more fossil fuels as well as continue mass deforestation all the greenhouse gases build up in the atmosphere and cause a "greenhouse effect". The "greenhouse effect" is what is making our planet warmer and is causing climate change. The most prevalent greenhouse gas is carbon dioxide. We may be contributing to greenhouse gas emissions without even knowing it as nearly everything we do or consume produces or has produced emissions in some way. We can see the impact that our individual lifestyle has towards contributing to global warming by calculating a Carbon Footprint which is all greenhouse gases represented as one value.[11]

2.1 Calculating Carbon Footprints

The easiest and most popular way to calculate one's carbon footprint is using a carbon footprint calculator, which is usually a lifestyle survey that uses the answers to estimate one's greenhouse gas emissions. There are many different calculators of varying length and detail. Some only require entering the most trivial of details from the main emission areas like transport, diet and home, whereas others go into more specific detail, this in most cases results in a more accurate carbon footprint.

2.1.1 International Student Carbon Footprint Challenge

One such calculator is the International Student Carbon Footprint Challenge (ISCFC)[12]. This calculator is interesting because it has a wide range of detailed input categories, there are clear explanations for how the answers to each of the questions are used to calculate the footprint. It is also made by a non-profit/charitable organization. The calculator has a lot of detail in the home energy category and has categories that set it apart from other calculators, for example, the water and wastewater category[13]. On the other-hand, it lacks detail in the transportation and diet categories which are main contributors of greenhouse gas emissions[14]. Furthermore, it has a lot of questions in areas that do not have a big impact on the carbon footprint, for example, how often does one use a leaf-blower.

Calculating Home Heating Emissions

To calculate the carbon emissions from home heating this calculator uses the number of occupants in the home, home size/area (m^2), number of months that heating is used and type of fuel. It assumes that 90% of the home's area is heated, this is based on a US census. The heated area is multiplied by the number of days that heating is used, this is the number of months that heating is used times the average number of days in a month. Then this is multiplied by kilowatt hours per heating day per square meter which is taken from data of the US Department of Energy.

$$homeSize * 0.9 * heatedMonths * 30.5 * kWhPerHeatedDayPerSqm \quad (2.1)$$

Now we have the total number of kilowatt hours needed for heating the home. This is multiplied by the amount of carbon emissions produced by the fuel type to generate a kilowatt hour of energy, this data is taken from the United States Department of Energy. This results in the total carbon emissions produced from heating the home. Which are then divided by the number of occupants to get the emissions per person.

$$\frac{kWhRequired * kgCO_2/kWh}{numberOfOccupants} \quad (2.2)$$

The average temperature at which the home is kept also has an impact on the carbon emissions and this is taken into consideration. The formula for this is based on heating costs/savings of 3% for every 1°C above/below 20°C, per the US Environment Protection Agency. Multiply the result from the previous equation by this factor to account for the costs/savings.

$$0.97^{\frac{20 - tempInHome}{0.56}} \quad (2.3)$$

Calculating Overlooked Emissions

One thing that this calculator does differently from other calculators is that it recognises the impact that water usage and wastewater have on a carbon footprint. The majority of calculators do not look at this even though it can have significance to the final carbon footprint. For example, washing dishes under constantly running water uses a considerable amount of energy-expensive heated water. This is calculated using 100l of water to hand wash a dish load and the carbon footprint of heating the water. If specified that the water is room temperature then it is assumed that 25% is hot and the rest is cold water. The total dish washing footprint for the household is divided by the number of home occupants to get the carbon emissions per person.

Another interesting thing that this calculator takes into consideration is mobile data usage as there is a significant amount of energy used to operate and maintain cell towers, servers and other infrastructure. The calculator uses an estimate of 10kWh per GB of data multiplied by the amount of data that is used and the electricity footprint in the locality to convert it to kilograms of carbon dioxide.

2.1.2 Carbon Independent Carbon Footprint Calculator

This calculator yielded one of the highest scores for number of categories and level of detail in a study that evaluated many different calculators[13]. It received a high evaluation because it allowed users to enter a wide range of data in detailed categories, especially in home energy and air transportation. It also has considerably less questions compared to the previously mentioned calculator (ISCFC). Although this calculator is made by a private entity it still has detailed explanations for how the answers to the questionnaire are used to calculate the carbon footprint. This calculator also has the top rating for takeaway of information as rather than just focusing on detailed calculations it motivates the user to change behaviour. There are a few drawbacks to this calculator as it is UK focused so it is not very suitable for residents of other countries because the assumptions and averages are based on UK data and it does not have a water usage and wastewater category which may lead to a less accurate carbon footprint calculation.

Calculating Transport Emissions

The air transportation category of this calculator is more detailed than in other calculators while still having a very simple way of calculating the carbon footprint of the flights. It asks the user to enter the number of return flights to various countries and then converts this to the total number of flying hours. The total flying hours are then converted to tonnes of CO₂ equivalent using the assumption that 250 kg of CO₂ equivalent are emitted per hour of flying.

$$totalHoursSpentFlying * 0.25tonnesCO_{2}e \quad (2.4)$$

The calculation of emissions from a car are not very accurate as it only requires the cars miles per gallon and annual mileage. It does not take into consideration how old the car might be and the fuel type it uses. All it does is calculate the amount of fuel that was used over the year and multiply that by an assumption of 14.3kg of CO₂ per gallon.

2.2 Gamification

Gamification is defined as the implementation of game mechanics and design elements in non-gaming environments as a tool to increase the engagement and motivation in completing tasks and activities that would otherwise be dull and unattractive[15]. The use of gamification is not limited to a specific area and can be applied in various fields. In particular, I am interested in using gamification in the context of improving one's behaviour towards the natural environment.

2.2.1 Effectiveness of Gamification

A study[16] that reviewed 31 gamification implementation papers found that gamification had a positive outcome in 18 of those applications, mixed results in 12 papers and negative outcome in only 1 paper but this outcome occurred on the removal of gamification as after removing it participation dropped. The most positive outcomes of gamification were found in the health and wellness domain. In the sustainability domain 2 out of 3 implementation papers had positive outcomes using gamification elements such as points, achievements, avatars, leaderboards and rewards. Application of gamification in the sustainability domain found improved awareness, high usability, high user experience ratings, increased usage rates and users preferred gamified products over their regular counterparts[16].

Another study[17] found similar outcomes as according to a majority of reviewed studies, gamification produces positive effects and benefits. However, it also found that the effects greatly depend on the context in which gamification is being used in, as well as on the users using it. It also found that the most commonly used gamification features are points, leaderboards and badges.

2.2.2 Types of Gamification Elements

There are many different gamification elements some more suitable for one application than others. One study[18] has grouped gamification elements into 5 dimensions (Fig. 2.1). The gamification elements from the performance dimension are related to environment response and provide the user with feedback for their actions. Without this dimension the user may feel lost. Elements from

Performance	Progression	Progress bars, steps, maps
	Level	Skill level, character level
	Point	Scores, experience points, skill points
	Stats	Information, data, dashboards
	Acknowledgement	Badges, medals, trophies, and achievements
Ecological	Chance	Randomness, luck, fortune, probability
	Imposed Choice	Choice, judgment, paths
	Economy	Transactions, market, exchange
	Rarity	Limited items, exclusivity, collection
	Time Pressure	Countdown timers, clocks
Social	Competition	Conflict, leaderboards, scoreboards, 1 vs 1
	Cooperation	Teamwork, groups
	Reputation	Classification, status
	Social Pressure	Peer pressure, guild missions
Personal	Novelty	Update, surprise, changes
	Objectives	Missions, side-quests, milestones
	Puzzle	Challenges, tasks, actual puzzles
	Renovation	Boosts, extra lives, renewal, upgrade
	Sensation	Visual and audio stimulation
Fictional	Narrative	Karma, implicit decisions
	Storytelling	Audio queues, text stories

Figure 2.1: Gamification Elements [18]

the ecological dimension are related to the environment within which gamification is implemented and they produce interactions with the user. The social dimension produces interactions between users. Gamification elements in the personal dimension motivate the user by providing meaning to the user. The fictional dimension provides meaning and context, and immerses the user in the environment.

2.3 Existing Solutions

In this section I will review existing apps that try to solve the problem of how to get people engaged and motivated to reduce their carbon footprints. The table below (Fig. 2.2) lists the features of multiple apps that are trying to solve the same problem but have different approaches of doing so.

2.3.1 Pawprint

This app has the most detailed carbon footprint calculator of all the apps I reviewed but its survey still lacks the ability to input data for some major carbon emitting fields. For example, it does not take into consideration whether the user has a clean energy provider or a heavy polluter. Moreover, while the app does require you to sign up it makes up for this by allowing the user to skip any questions that they do not wish to answer or skip the whole carbon calculator survey all together and get started tracking their carbon emissions right away. It can track carbon emissions in many different areas but the way it does this may seem cumbersome and overwhelming as there are many options and takes multiple pages to log a single piece of data (Fig. 2.5). Tracking actions earns the user points which can be used to donate to a charity or organisation (Fig. 2.4). Furthermore, education is left on the sideline as there is not much information presented about the data you are inputting and why its important. The app also does not give much insight into your improvement

App Feature	Pawprint	Eevie	EarthProject	Climate Court	Capture	EcoHero	joro*	Cogo*	Evocco*
Rating	3.8★ (22)	3.6★ (58)	3.8★ (18)	3.7★ (3)	3.7★ (264)	4.8★ (10)	4.7★ (85)	2.7★ (80)	3.5★ (13)
Sign up not required		✓		✓		✓			
Carbon footprint calculator	✓	✓			✓				
Quick survey		✓		✓	✓				
Detailed survey	✓								
Skip survey	✓								
Link bank account							✓	✓	
Carbon footprint breakdown	✓	✓			✓		✓	✓	
View history		✓				✓		✓	
Track diet	✓	✓	✓		✓	✓			
Track getting around	✓	✓	✓		✓	✓			
Track purchase habits	✓	✓	✓			✓	✓	✓	✓
Scan receipts									✓
Track waste management	✓	✓	✓			✓			
Track travel	✓	✓	✓		✓				
Track energy usage habits	✓	✓	✓				✓		
Weekly goals		✓				✓			
Create habits	✓	✓					✓		
Challenges	✓					✓			
Groups (Compete against others)	✓	✓	✓		✓				
Share your actions				✓		✓			
Social networking						✓			
Collect points	✓	✓							
Donates to charity	✓	✓							
Badges/trophies	✓					✓			
CO ₂ Saved	✓	✓	✓			✓		✓	✓
Offset emissions		✓			✓		✓	✓	✓
Learn			✓	✓	✓		✓		
Location tracking		✓			✓				
Health app integration					✓				

Figure 2.2: Existing Apps and Their Features

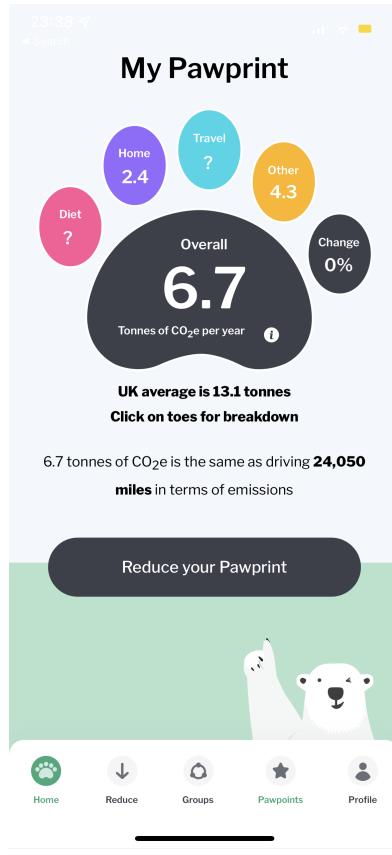


Figure 2.3: Pawprint App Home-screen Displays Carbon Footprint Breakdown

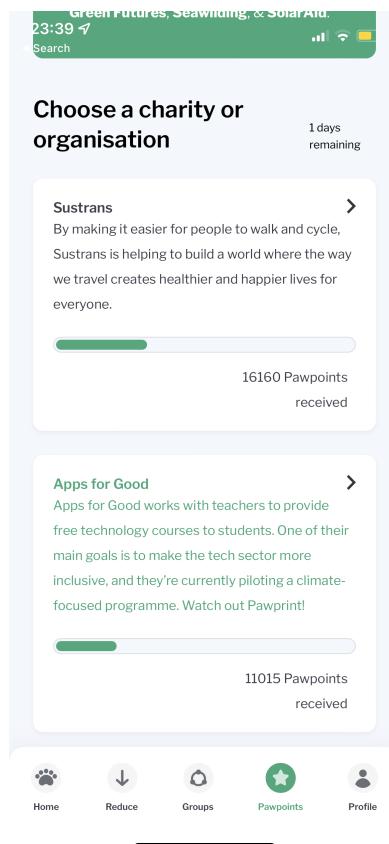


Figure 2.4: Pawprint App Donation Page



Figure 2.5: Pawprint App Action Tracker

as it only displays the total amount prevented carbon emissions and a simple carbon footprint breakdown (Fig. 2.3). Overall, this app is good for someone who is already knowledgeable in the area and has already started their journey on reducing their emissions but it may be overwhelming for someone who is just starting and may lack detail for someone who is already well on their way to carbon neutrality.

2.3.2 Eevie

Eevie has many features but all of them are very simple and seem to only scratch the surface. It has a very quick survey which does not require much input thus resulting in a semi accurate carbon footprint calculation. Furthermore, the way the user logs data is oversimplified because the user has to self evaluate by selecting 1 of 5 emojis indicating to what extent they did an action but there is little description for the action and the ratings are not precise. While it does have a historical graph of your carbon emissions and improvement it is missing a lot in regards to gamification. The app does have weekly goals and reminds you to log your actions everyday to build habits but this does not seem to do anything other than showing you how much carbon you saved/emitted. In conclusion, this app seems perfect on paper but is actually lacking in many areas and appears unfinished.

2.3.3 Climate Court

Climate Court takes a different approach to calculating your carbon emissions. Rather than having a traditional carbon footprint calculator it instead gives you a "verdict and sentence" based on

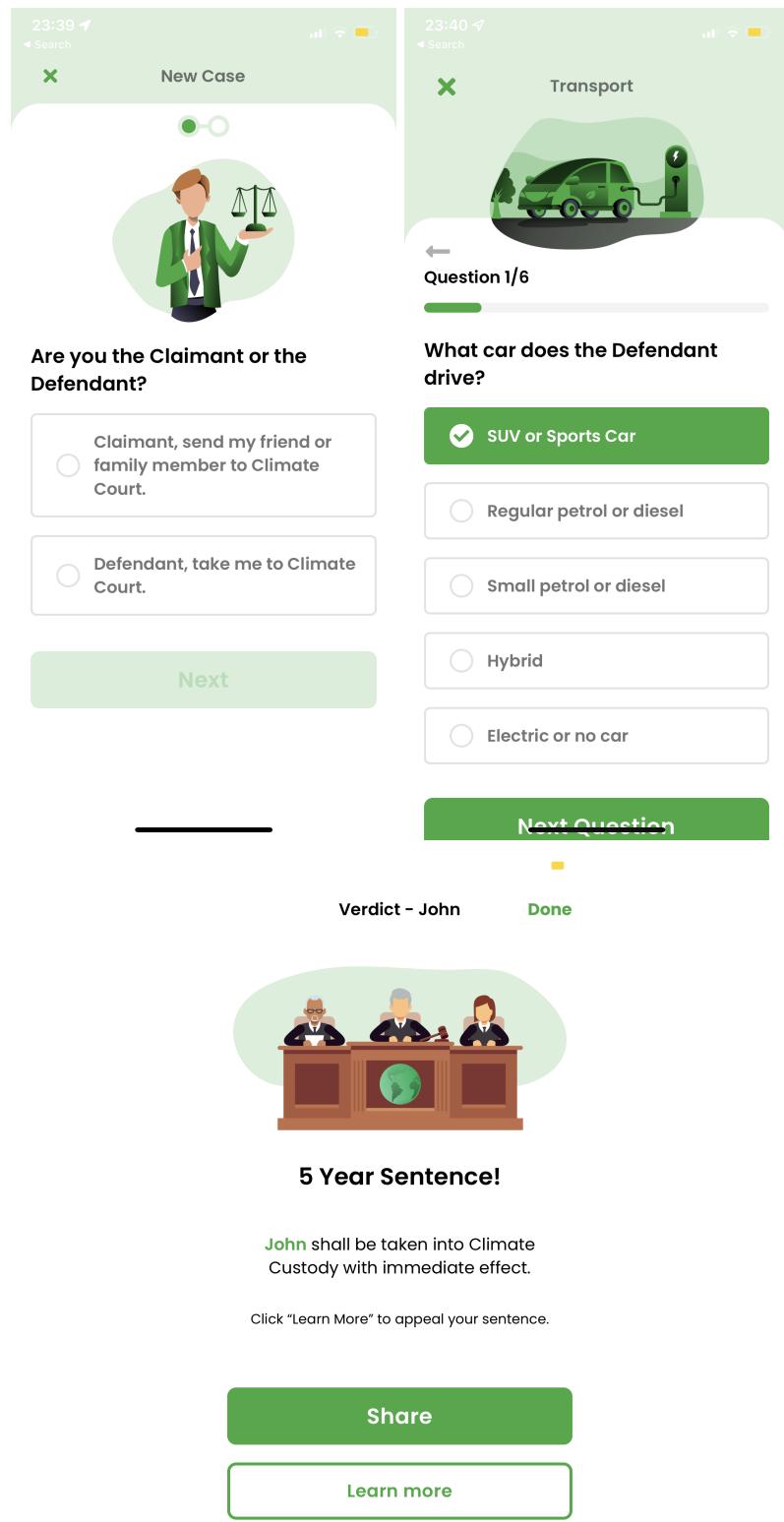


Figure 2.6: Climate Court App

just 6 questions (Fig. 2.6). It does not have any other features. This app is more about bringing awareness to the topic of carbon emissions and helps start a conversation about one's carbon footprint.

2.3.4 EarthProject

EarthProject is an app that is more geared towards school children. It does not have a carbon footprint calculator and does not let you track your carbon emissions, instead it lets you track the carbon emissions you have avoided. Besides that, it also allows for tracking plastic usage but again, similar to before instead of tracking the plastic you have used it tracks the plastic you avoided. For example, how many plastic bottles or bags you did not use. The learning aspect of the app is very disappointing considering it is intended for school students, there is 3 website links and 4 short paragraphs about carbon emissions. It has some gamification as you can form teams to compete against others and view your rank on the leaderboard.

2.3.5 Capture

This app has a lot of great reviews on the app store but upon using it I found that it is very limited. It is only possible to track emissions from two areas, transport and diet. It has a lot of options for inputting transportation data but, on the other-hand, the ability to track diet is very simple which most likely leads to an inaccurate carbon footprint calculation. Furthermore, this app is able to track your emissions using location tracking by automatically predicting your mode of transport and estimating your carbon footprint of each journey. Finally, this app also allows the user to donate to various projects that help offset one's emissions.

2.3.6 EcoHero

EcoHero is a social networking app for tracking and sharing environmentally friendly activities. The app does not limit you to only carbon emission reducing activities, you can also log if you have picked up trash or helped animals. When logging an activity you can add an image and a short message, after it is saved it is shared with your followers and other users of the app (Fig. 2.7). They can interact with your post by liking and commenting. As you log more activities and complete challenges you climb ranks and unlock achievements (Fig. 2.8). While this app does not have a carbon footprint calculator, it does let you view an overview of the impact your activities have made towards saving the environment.

2.3.7 Joro

Joro can be linked with a bank account to track your transactions. Using the transactions it categorizes purchases and estimates a carbon footprint for each. For example, if you pay for petrol it will find the average price of it in your area to calculate the amount of litres that were purchased. It then uses this data to estimate the carbon emissions for this transaction and the impact it has on your carbon footprint. It is then possible to offset your carbon footprint by donating to various carbon offsetting projects.

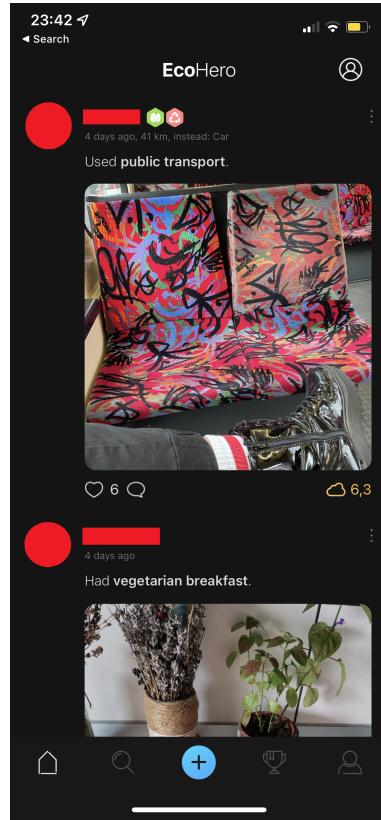


Figure 2.7: EcoHero App Feed of User Posts

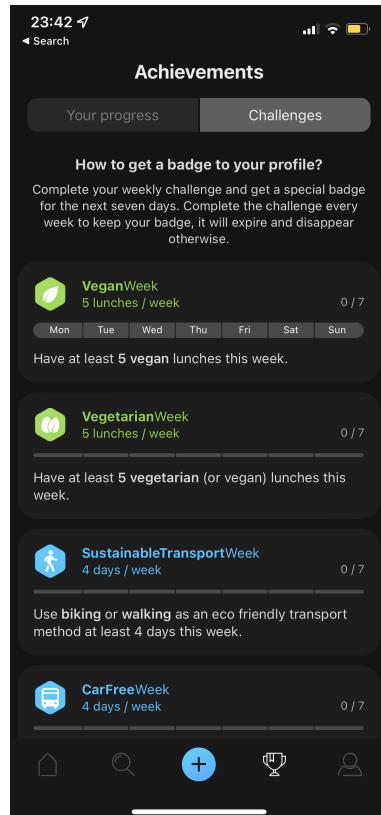


Figure 2.8: EcoHero App Achievements Page

2.3.8 Cogo

Cogo is a similar app to Joro as it also calculates your carbon footprint through bank transactions and lets the user offset their footprint by donating to carbon offsetting projects. It does not seem to have any other features that set it apart from the Joro app.

2.3.9 Evocco

Evocco is similar to Cogo and Joro by way of calculating the carbon footprint using transactions but instead of connecting to a bank account it uses receipts. The user can take a picture of a receipt and the app scans it to give it a carbon footprint score. The user can then reduce their carbon footprint by getting personalized tips to improve shopping habits. The user can also offset their emissions by donating money to plant trees.

2.4 Background Research Summary

After reviewing carbon footprint calculation, gamification and already existing apps I have gained insight for how to create an improved solution. I have learned how to calculate a carbon footprint and what data is needed to do so. Furthermore, I have found that there is no perfect carbon footprint calculator and that all of them excel some in areas but lack detail and accuracy in others. A better calculator would be a combination of existing calculators. Moreover, I found that gamification in general is an effective way to boost user engagement and motivation but that it cannot be applied to all contexts. Also, now I better understand the types of gamification elements and the impact they have on user experience. Lastly, after reviewing existing apps and their user feedback I now know which features I should implement in my app and what to avoid.

2.5 Technologies

I am planning to make my app for Apple's iOS mobile operating system because I use an iPhone myself and would like to learn how to develop app's for this operating system. There are many programming languages that can be used to develop iOS apps. The two most popular are Objective-C and Swift. I have chosen to use Swift as it was created by Apple in 2014 as a successor to Objective-C. Furthermore, while Objective-C is older, it is harder to learn and has low security, limited functionality, and lacks updates [19]. Whereas Swift is modern, fast, safe and regularly updated as well as easy to learn [19] [20]. Another benefit of using iOS is the ability to integrate Apple's Game Center which allows for easy implementation of multiplayer features like leaderboards, achievements and challenges [21]. This reduces workload and allows for the app to be self contained which reduces privacy and security issues as well as overhead costs.

Chapter 3: Outline of Approach

3.1 App Features and Mockup

Carbon Footprint Calculator

Calculate amount of all greenhouse gas emissions based on answers to a lifestyle survey and present the emissions as carbon dioxide equivalent where all greenhouse gases are rolled into one. Periodically prompt the user to retake the survey to draw a historical graph of their carbon footprint to see whether the app has had an impact on reducing the user's carbon footprint. Show a breakdown (Fig. 3.1) of the carbon footprint broken up into different categories so it is easy to see the main contributors to the footprint and problem areas.

Lessons

Before the user can start tracking their carbon emissions and reducing them, they first must learn about the importance and impact of the certain action. A lesson would consist of a few static/animated slides presented in a familiar "stories" format (Fig. 3.2) that is extremely popular on apps like Instagram and Snapchat. After viewing the slides the user would unlock new ways of tracking/reducing their emissions as well as earn points and a badge. There would only be a one lesson per week.

Quizzes

Along side the lessons there are quizzes (Fig. 3.3) that test the user's knowledge on carbon emissions and what cause them. Completing quizzes earns the user points to climb the leaderboard. The leaderboard would be integrated using Apple's Game Center. Integration with Game Center would allow the user to not only view leaderboards but also allow to challenge friends and show off one's achievements.

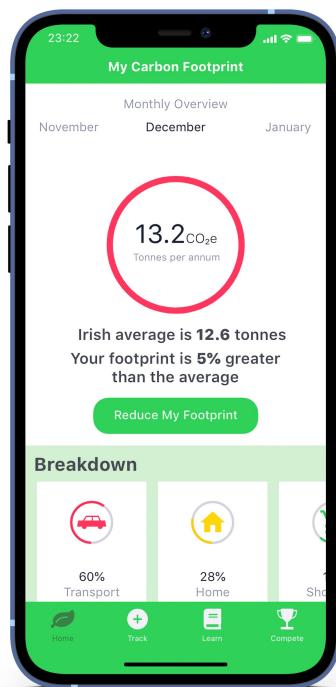


Figure 3.1: My App Mockup. Carbon Footprint Breakdown Page



Figure 3.2: My App Mockup. "Stories" Format Lesson

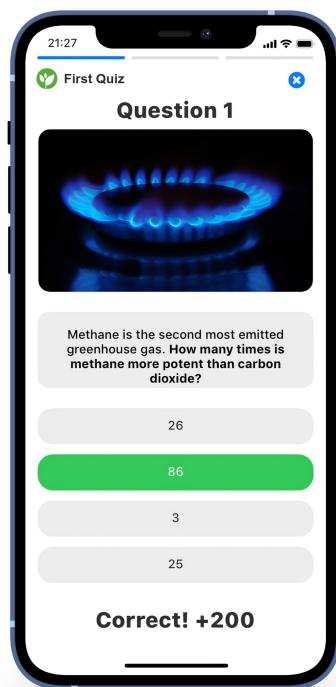
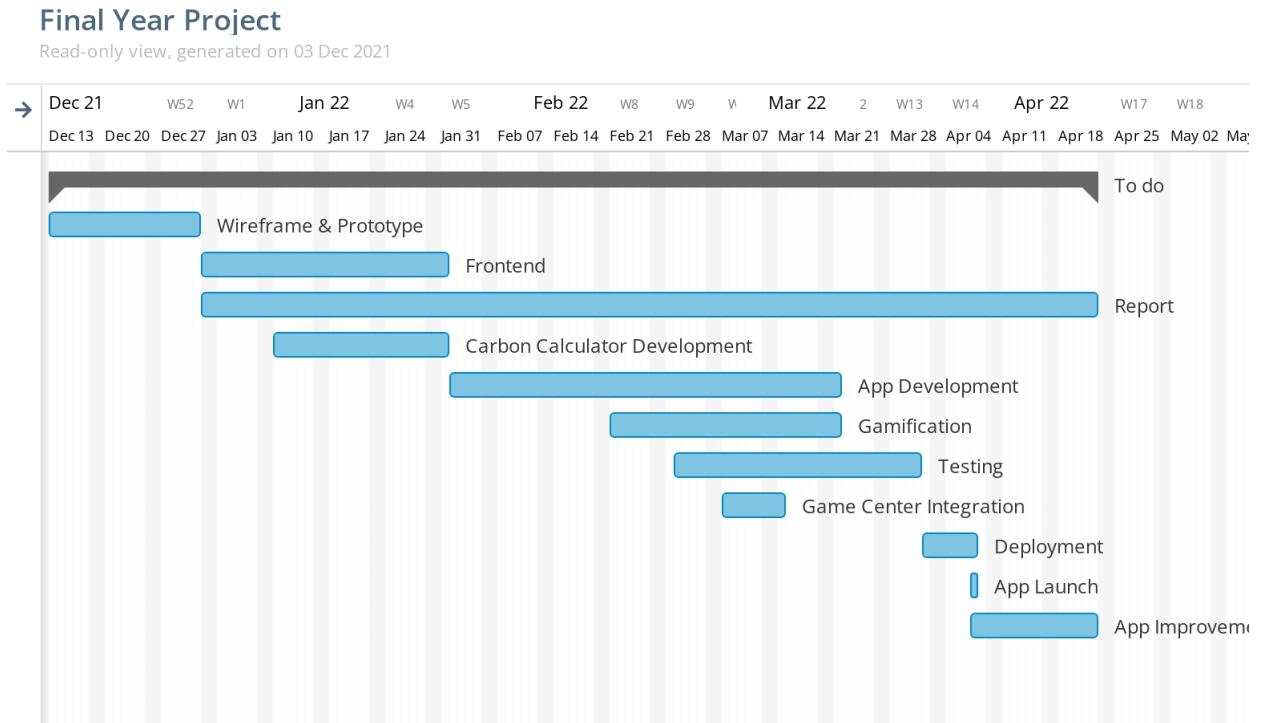


Figure 3.3: My App Mockup. Quiz Example

Chapter 4: Project Workplan



- **Wireframe and Prototype** - In this stage create wireframes for the application to better understand its navigation and the end-user's experience.
- **Frontend** - Create the user interface with the help of previously created wireframes.
- **Carbon Calculator Development** - Develop the carbon footprint calculator for calculating the user's carbon footprint.
- **App Development** - Develop the remaining features with gamification elements.
- **Integration** - Integrate the app with Apple Game Center to create a multiplayer experience.
- **Testing** - Test the app for technical flaws or bugs and correct them.
- **App Improvement** - Enhance the app using feedback from users.

Acknowledgements

In your Acknowledgements section, give credit to all the people who helped you in your project.

Bibliography

1. *Environmental Indicators Ireland 2020* Jan. 2021. <https://www.cso.ie/en/releasesandpublications/ep/p-eii/environmentalindicatorsireland2020/mainfindings/>.
2. Citizensinformation.ie. *Ireland's Targets to Reduce Air Pollution* July 2021. https://www.citizensinformation.ie/en/environment/air/ireland's_targets_to_reduce_air_pollution.html.
3. Barbiroglia, E. *Generation Z fears climate change more than anything else* Dec. 2019. <https://www.forbes.com/sites/emanuelabarbiroglia/2019/12/09/generation-z-fears-climate-change-more-than-anything-else/>.
4. Pawprint - Your Carbon Tracker <https://play.google.com/store/apps/details?id=eco.pawprint.app.twa&hl=en&gl=US>.
5. eevie: your climate guide to a sustainable life <https://play.google.com/store/apps/details?id=io.humbldt.eevie&hl=en&gl=US>.
6. EarthProject <https://play.google.com/store/apps/details?id=com.takeactionglobal.mobile&hl=en&gl=US>.
7. The Climate Court <https://play.google.com/store/apps/details?id=com.theclimatecourt.ClimateCourt&hl=en&gl=US>.
8. Beck, A., Chitalia, S. & Rai, V. Not so gameful: A critical review of gamification in mobile energy applications. *Energy Research Social Science* **51**, 32–39 (May 2019).
9. Burmester, N. *7 Best Gamification Examples 2021* <https://www.gamify.com/gamification-blog/7-best-gamification-examples-2021>.
10. Mattila, R. *MOTIVATING SUSTAINABILITY THROUGH GAMIFICATION: Expert Opinions on Inspiring Pro-Environmental Actions* <https://trepo.tuni.fi/bitstream/handle/10024/116979/MattilaRoope.pdf?sequence=2&isAllowed=y>.
11. Kenny, T. & Gray, N. Comparative performance of six carbon footprint models for use in Ireland. *Environmental Impact Assessment Review* **29**, 1–6. ISSN: 0195-9255. <https://www.sciencedirect.com/science/article/pii/S0195925508000929> (2009).
12. <http://web.stanford.edu/group/inquiry2insight/cgi-bin/i2sea-r2a/i2s.php?page=fpcalc>.
13. Mulrow, J., Machaj, K., Deanes, J. & Derrible, S. The state of carbon footprint calculators: An evaluation of calculator design and user interaction features. *Sustainable Production and Consumption* **18** (Dec. 2018).
14. CO2 footprint https://energyeducation.ca/encyclopedia/CO2_footprint.
15. Aparicio, A. F., Vela, F. L. G., Sánchez, J. L. G. & Montes, J. L. I. *Analysis and Application of Gamification in Proceedings of the 13th International Conference on Interacción Persona-Ordenador* (Association for Computing Machinery, Elche, Spain, 2012). ISBN: 9781450313148. <https://doi.org/10.1145/2379636.2379653>.
16. Seaborn, K. & Fels, D. I. Gamification in theory and action: A survey. *International Journal of Human-Computer Studies* **74**, 14–31. ISSN: 1071-5819. <https://www.sciencedirect.com/science/article/pii/S1071581914001256> (2015).
17. Hamari, J., Koivisto, J. & Sarsa, H. *Does Gamification Work? – A Literature Review of Empirical Studies on Gamification in 2014* *47th Hawaii International Conference on System Sciences* (2014), 3025–3034.

-
18. Toda, A. et al. Analysing gamification elements in educational environments using an existing Gamification taxonomy. *Smart Learning Environments* **6** (Dec. 2019).
 19. Kaczorowski, M. *Picking The Best Language For iOS App Development In 2021* <https://www.ideamotive.co/blog/picking-the-best-language-for-ios-app-development>.
 20. Inc., A. *Swift* <https://developer.apple.com/swift/>.
 21. *Game Center. GameKit.* <https://developer.apple.com/documentation/gamekit/>.