Final Year Project

Reduction of Personal Carbon Emissions Through Gamification

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A thesis submitted in part fulfilment of the degree of

BSc. (Hons.) in Computer Science

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Note: *A GitHub repository containing all project code can be accessed here: GitHub Link*

Abstract

The aim of this project was to develop an app for the Apple iOS operating system that would achieve the goal of reducing an individual's carbon emissions through gamification. The idea behind the project was to create an application that would help individuals understand their impact on carbon emissions and to help them realise how they as an individual can contribute to stopping global warming, instead of leaving it to governments and corporations. This project encompasses the research of what a carbon footprint is and how it is calculated, the research into the effectiveness of gamification and what gamification techniques exist, and the research of existing solutions. The project describes the finished application and its implementation, the features that were implemented and how they work, and the basics of the Swift programming language and the SwiftUI user interface framework. Implementing the solution entailed the learning of iOS development using the Swift programming language, the utilisation of various frameworks, tools and services. The project also included beta testing and a user survey of the app to find the areas in which the app is lacking.

Chapter 1: **Introduction**

Ireland has the third-highest per capita greenhouse gas emissions in the European Union[1] and is committed to drastically reducing them by 2030[2]. This is a huge undertaking and thus we need as many people to do their part as possible. Residents can help Ireland reach its targets by reducing their personal carbon emissions, but many believe that this is not their responsibility. What many people do not realise is that anyone can make a difference and contribute to the halting of climate change. Individuals can act now without waiting for governments or corporations to do so when it is too late. This project aims to find out how an individual can be encouraged and engaged in reducing their carbon emissions using gamification techniques and the solution is to develop an app that does that.

This project includes research about carbon footprints, what they are and what can they tell us. Furthermore, the project talks about the data that is required to calculate a carbon footprint and what is the best way of doing so. The project covers what gamification is, the effectiveness of gamification, what domains are best suited to the application of gamification, the type of gamification elements and techniques that exist and what effect they have on a user. The project also researches existing apps, the features they have and their advantages and disadvantages. The project contains a detailed description of my solution and its implementation. The implementation of the app also explains the basics of iOS development using the Swift programming language and the SwiftUI interface framework. The project also details the results which arose from user testing of the app.

The approach used to solve the problem included learning about carbon emissions, gamification, and calculation of carbon footprints. The approach required learning how to develop iOS apps, how to program using Swift, how to use SwiftUI to create a user interface, how to integrate the Game Center API, and how to test the app using Apple's TestFlight service and after-scenario questionnaires.

The outcome of the project is a fully functioning iOS app that has gamification features and aims to reduce personal carbon emissions. This project helped me gain a better understanding of carbon emissions, gamification and the development of iOS applications.

Chapter 2: Project Description

2.0.1 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 greenhouse 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 were the third highest in the European Union[1]. Ireland is committed to reducing 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 from 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.

2.0.2 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 of 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 for comparing 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

2.0.3 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 signup 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 leaderboards and other competitive aspects of the app can be easily manipulated. Furthermore, reading the findings of a research paper[8] I concluded 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].

2.0.4 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.

2.0.5 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, and emissions for different fuel types.

Chapter 3: 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 lifestyle has on contributing to global warming by calculating a Carbon Footprint which is all greenhouse gases represented as one value.[11]

3.1 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 lengths 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.

3.1.1 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 the main contributors to 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 (m2), 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 data taken from the US Department of Energy.

$$homeSize * 0.9 * heatedMonths * 30.5 * kWhPerHeatedDayPerSqm \tag{3.1}$$

Now we have the total number of kilowatt-hours needed for heating the home. This is multiplied by the number 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.

$$\frac{kWhRequired * kgCO_2/kWh}{numberOfOccupants} \tag{3.2}$$

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.

$$0.97^{\frac{20-tempInHome}{0.56}} \tag{3.3}$$

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 dishwashing 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.

3.1.2 Carbon Independent Carbon Footprint Calculator

This calculator yielded one of the highest scores in several categories 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 fewer 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 is emitted per hour of flying.

$$totalHoursSpentFlying * 0.25 tonnes CO_2 e \tag{3.4}$$

The calculation of emissions from a car is not very accurate as it only requires the car's 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.

3.2 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.

3.2.1 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 a 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, as well as on the users using it. It also found that the most commonly used gamification features are points, leaderboards and badges.

3.2.2 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. 3.1). 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 3.1: 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.

3.3 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. 3.2) lists the features of multiple apps that are trying to solve the same problem but have different approaches to doing so.

3.3.1 Pawprint

This app[4] 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 altogether 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. 3.5). Tracking actions earns the user points which can be used to donate to a charity or organisation (Fig. 3.4). Furthermore, education is left on the sideline as there is not much information presented about the data you are

App / Feature	Pawprint	Eevie	EarthProject	Climate Court	Capture	EcoHero	Joro*	Cogo*	Evocco*
Rating	**3.8★** (22)	**3.6★** (58)	**3.8★** (16)	**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 3.2: Existing Apps and Their Features

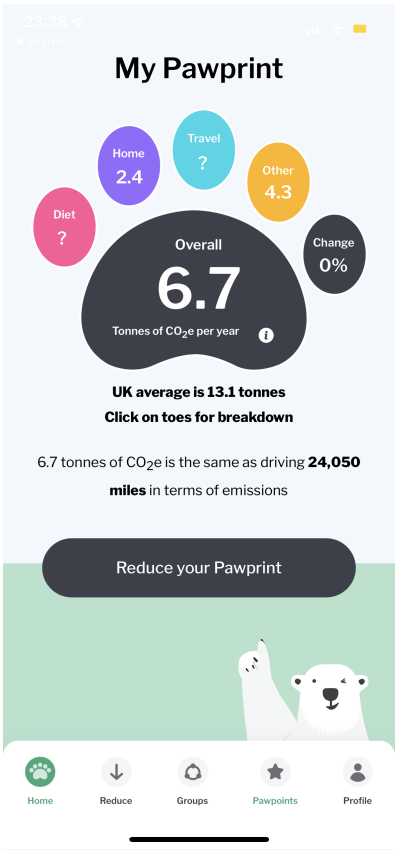


Figure 3.3: Carbon Footprint Breakdown

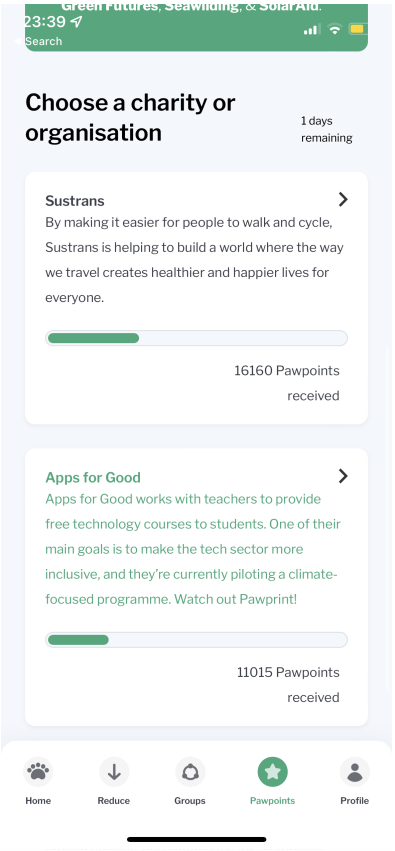


Figure 3.4: Donation Page

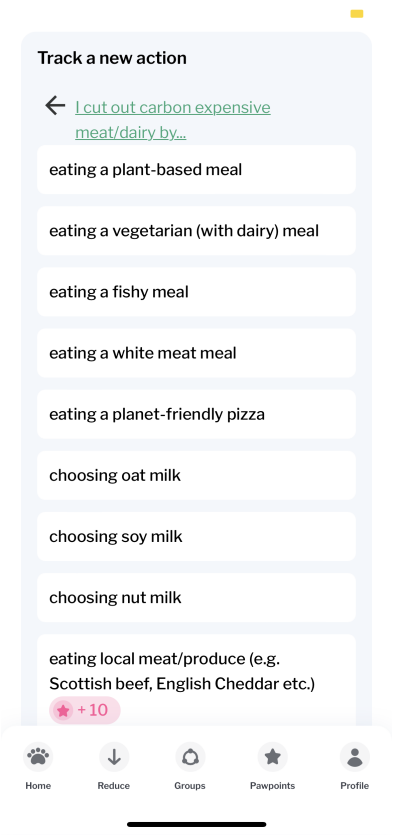


Figure 3.5: Action Tracker

Figure 3.6: Pawprint App

inputting and why it is important. The app also does not give much insight into your improvement as it only displays the total amount of prevented carbon emissions and a simple carbon footprint breakdown (Fig. 3.3. 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.

3.3.2 Eevie

Eevie[5] 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 every day 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.

3.3.3 Climate Court

Climate Court[7] 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 just 6 questions (Fig. 3.7). 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.

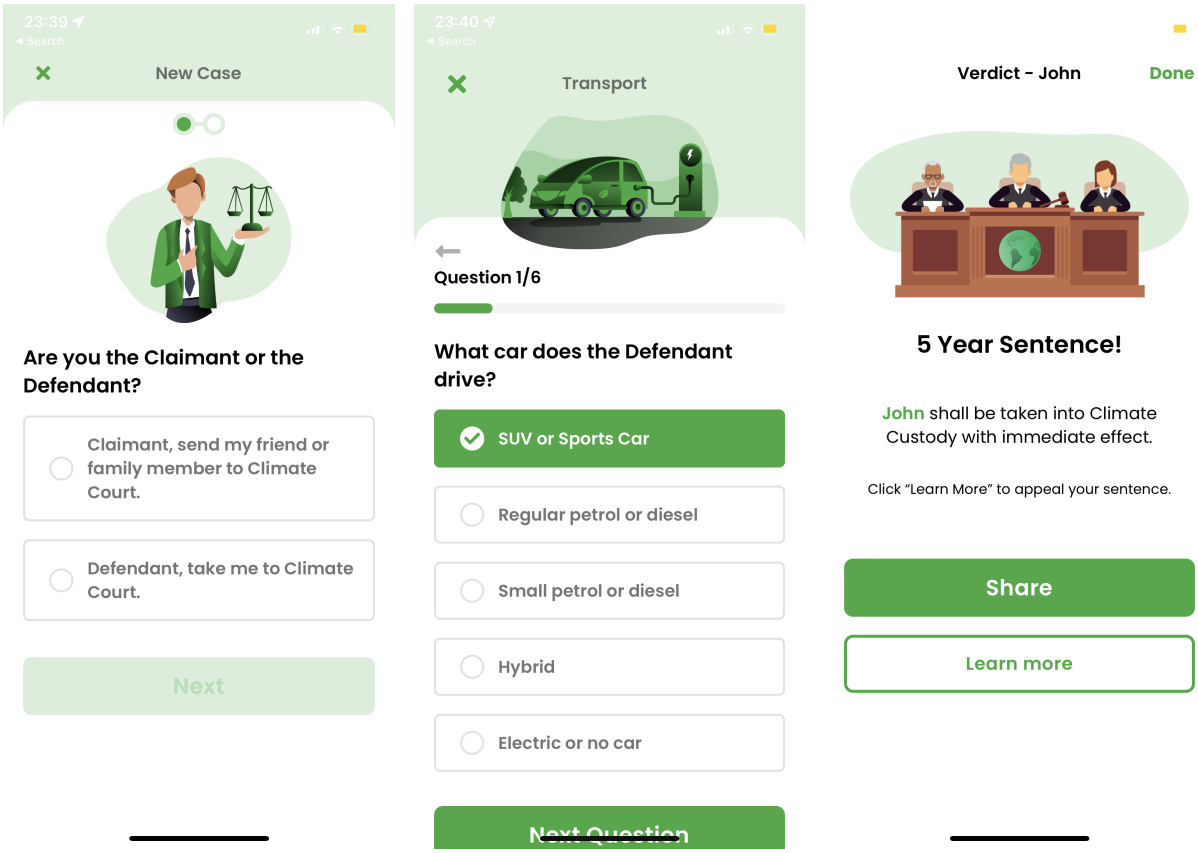


Figure 3.7: Climate Court App

3.3.4 EarthProject

EarthProject[6] is an app that is more geared toward 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 are 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.

3.3.5 Capture

This app[19] 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 can track your emissions using location tracking by automatically predicting your mode of transport and estimating your carbon footprint for each journey. Finally, this app also allows the user to donate to various projects that help offset one's emissions.

3.3.6 EcoHero

EcoHero[20] 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. 3.8). 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. 3.9). 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.

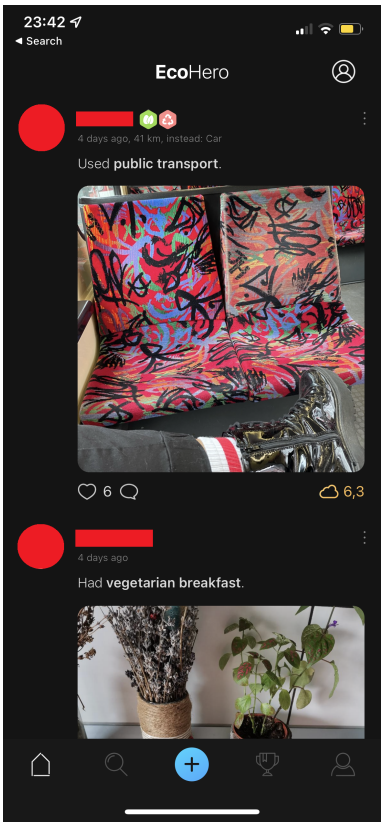


Figure 3.8: Feed of User Posts

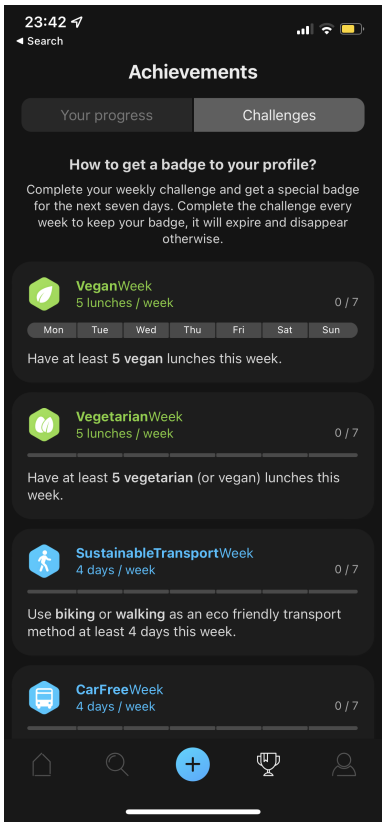


Figure 3.9: Achievement Page

Figure 3.10: EcoHero App

3.3.7 Joro

Joro[21] 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 number 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.

3.3.8 Cogo

Cogo[22] 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.

3.3.9 Evocco

Evocco[23] 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.

3.4 Background Research Summary

After reviewing carbon footprint calculation, gamification and already existing apps I have gained insight into 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.

3.5 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 apps 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 [24]. Whereas Swift is modern, fast, safe and regularly updated as well as easy to learn [24] [25]. 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 [26]. This reduces workload and allows for the app to be self-contained which reduces privacy and security issues as well as overhead costs.

Chapter 4: Outline of Approach

4.1 App Features and Mockup

Carbon Footprint Calculator

Calculate the 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. 4.1) 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. 4.2) 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 one lesson per week.

Quizzes

Alongside the lessons, there are quizzes (Fig. 4.3) that test the user's knowledge of carbon emissions and what causes 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 them to challenge friends and show off one's achievements.

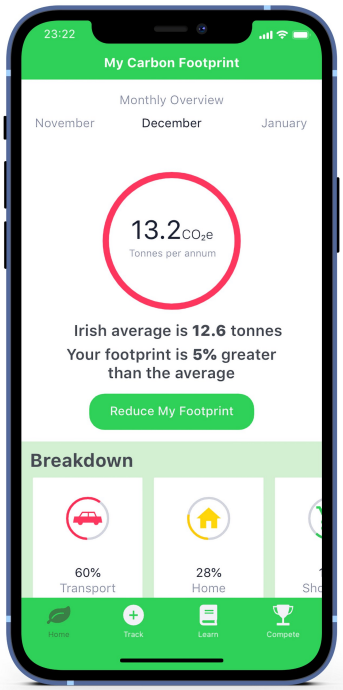


Figure 4.1: Carbon Footprint Breakdown Page

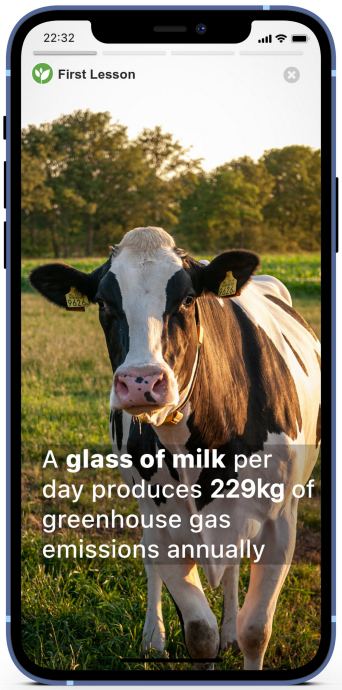


Figure 4.2: "Stories" Format Lesson

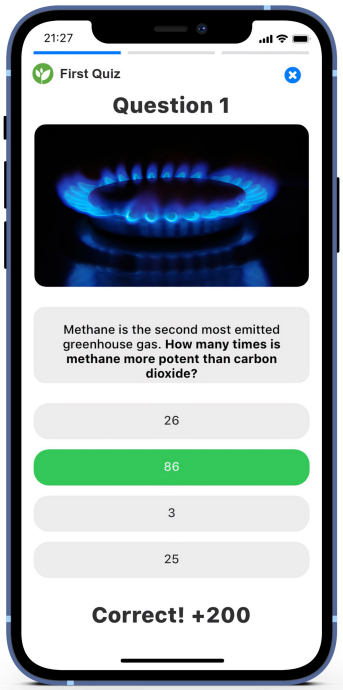
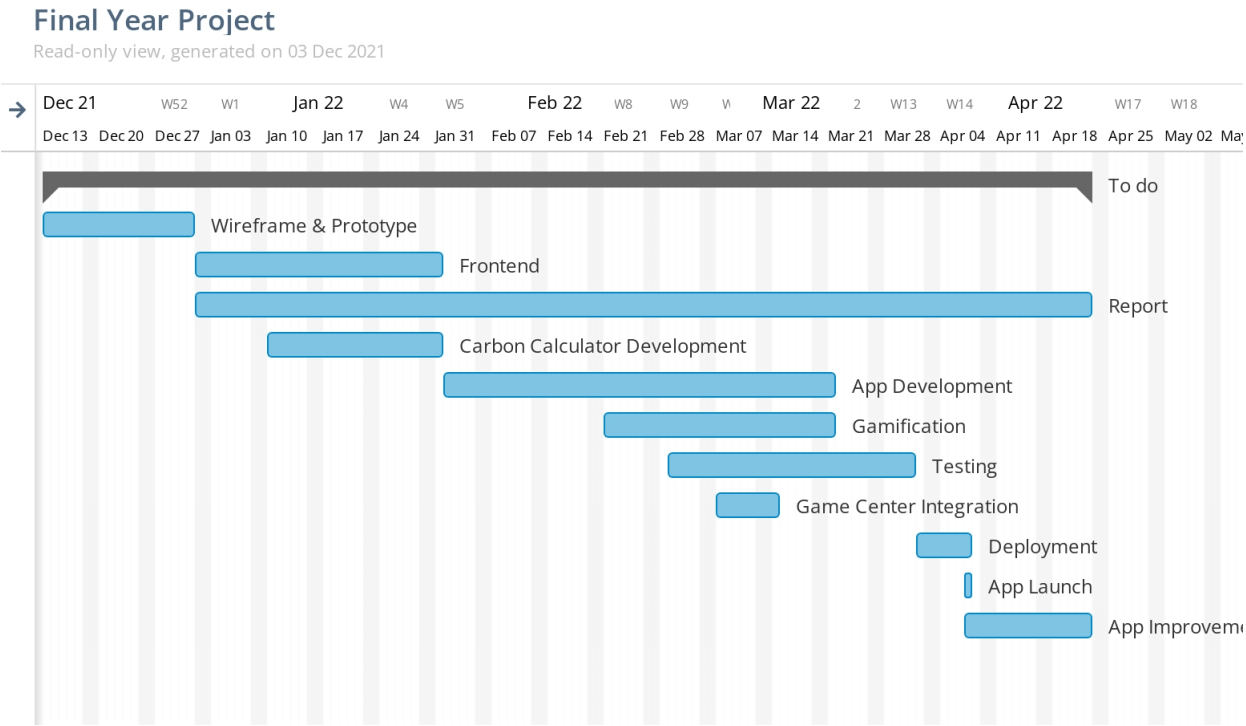


Figure 4.3: Quiz Example

Figure 4.4: My App Mockup

Chapter 5: Project Management Plan



- **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.

Chapter 6: System Overview

This is an iOS app that aims to reduce the user's personal carbon emissions through gamification. Using the app, the user can calculate their carbon footprint and view which areas of their day-to-day life contribute to their carbon footprint the most. Furthermore, the user can view a leaderboard of the lowest carbon emitters to understand how their own carbon footprint compares to the carbon footprint of other users of the app. Another feature of the app is the avoided emissions tracker, where the user can track actions that result in fewer carbon emissions. Lessons and quizzes provide an interactive and engaging way of learning how an individual can reduce their carbon footprint. While awards acknowledge the user's progress.

Hardware and Software Requirements

This app is compatible with Apple iPhone and iPod Touch devices running version 15 or later of the Apple iOS operating system. A beta version of the app can be downloaded from the following link (TestFlight app required): App Beta Download Link

6.1 Carbon Footprint Calculator

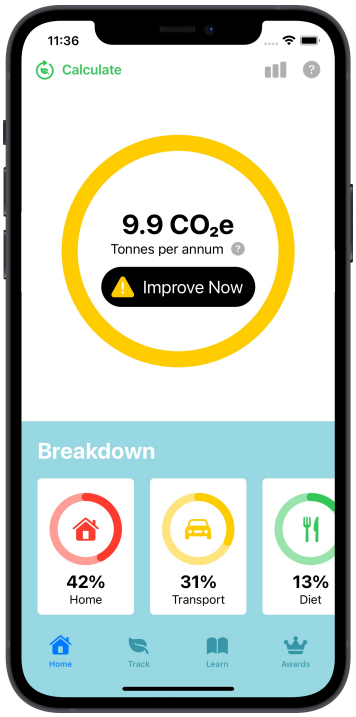


Figure 6.1: My App. Carbon Footprint Calculator

One of the main features of the app is a carbon footprint calculator. It lets the user get an estimate of their annual carbon emissions. This calculation is done using a series of questions regarding the user's lifestyle (See Chapter 3). The result is displayed on the main screen along with a circular

colour indicator that changes colour based on the result from green to yellow to red (Fig. 6.1). The result is also accompanied by a label that prompts the user to take action to reduce their carbon emissions and changes from "OK" to "Improve Now" to "Action Required". Below the colour indicator, the app provides a breakdown of the user's carbon footprint split into four parts: home, transport, diet and shopping. It shows a percentage of the total carbon footprint for each category. Clicking on one of the categories allows the user to update their answers to the carbon footprint calculator questionnaire.

Home Energy Footprint

The home category questionnaire asks four simple questions to calculate the user's carbon footprint for home energy usage. The first question asks the user to enter the number of people living in their household using a counter. This number is important for getting a more accurate individual footprint. Next, the user is prompted to select their energy supplier using a picker wheel (Fig. 6.2). The list contains all of the major Irish electricity producers. On the following page, the user must provide the amount of electricity their household consumes. They can enter their exact kWh usage or for the sake of simplicity their monthly billed amount(Fig. 6.3). If neither are available they can select to use the national average household electricity usage. Lastly, the user is asked to choose the type of their home heating system from a list of the most popular in Ireland.

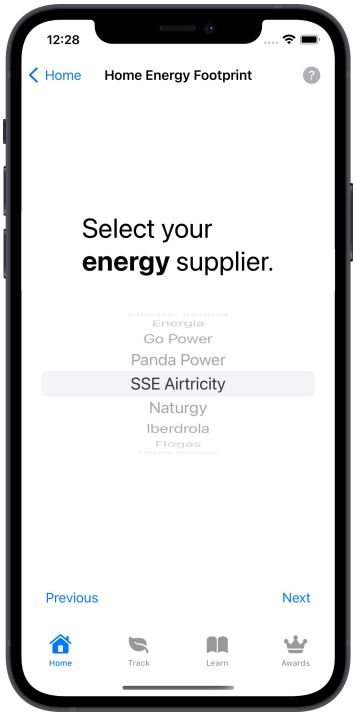


Figure 6.2: Electricity Suppliers

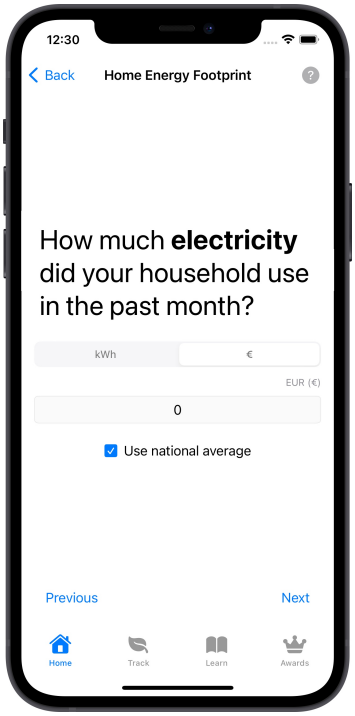


Figure 6.3: Electricity Usage

Figure 6.4: My App. Home Footprint Survey

Travel Footprint

In the transport category, the app only asks the user two questions. One is related to car usage, the other to air travel. I decided not to include public transport like buses and trains because these are alternatives to car travel and are considerably greener options. I felt that including them would unnecessarily penalise users of these transport methods as they are usually the only option. In the first question, the user has to fill in their weekly fuel consumption of petrol and/or diesel. Cars vary in metrics of miles per gallon or litres per 100 km but most cars have similar emissions

per litre of fuel. The next question prompts the user to enter all flights that they have taken in the past year. Instead of asking to enter the number of short, medium or long haul flights, the app asks to enter the exact departure and destination airports (Fig. 6.5). This results in a more accurate carbon footprint. The user can search (Fig. 6.7) from over 3000 airports worldwide, select whether it's a return trip and input the number of times the trip was taken which removes the burden of entering duplicate trips from scratch (Fig. 6.6).

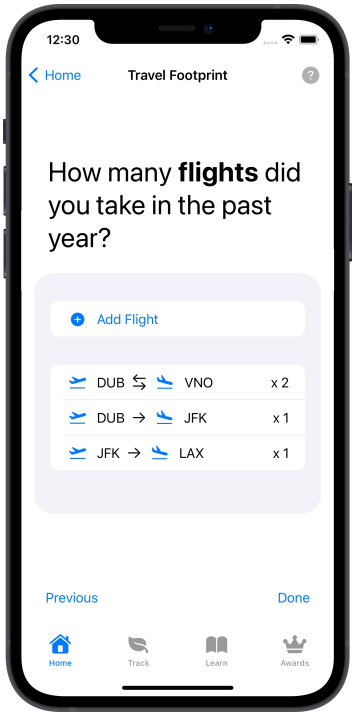


Figure 6.5: Flight Survey

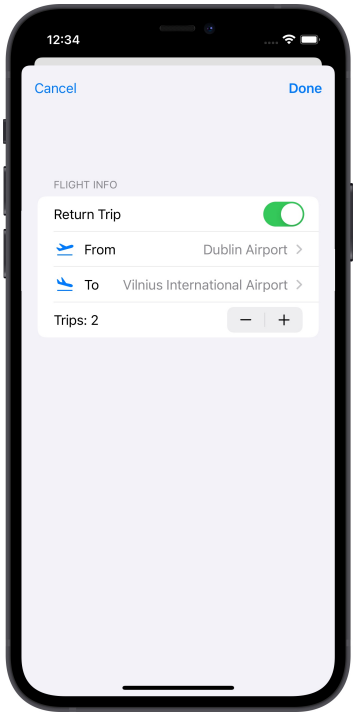


Figure 6.6: Add Flight

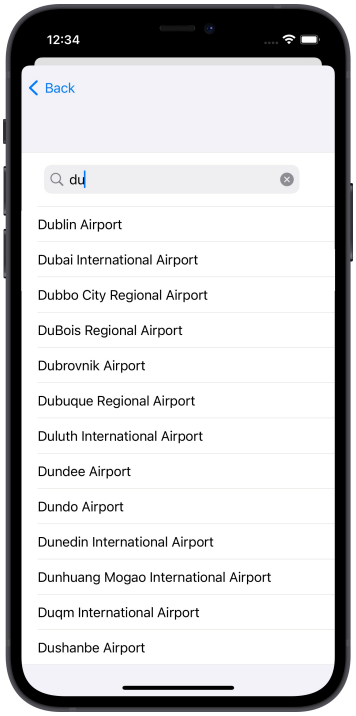


Figure 6.7: Airport Search

Diet Footprint

To calculate the carbon footprint of the individual's diet the user must answer a few questions regarding their food consumption habits. First, the user is asked whether they are a heavy meat eater, vegan or somewhere in between (Fig. 6.8). The next question follows up on this in more detail by requiring the user to enter the number of servings consumed weekly of high carbon emission foods(Fig. 6.9). Lastly, they provide the amount of food waste they have contributed in the past week.

Goods and Services Footprint

In this part of the survey, the user is asked about their shopping habits and how much they spend on various goods, as well as services. The user inputs the amount they spend on new electronics and new clothing. Followed by how much they pay for video streaming services each month. Finally, the last question asks for the user's monthly mobile data usage.

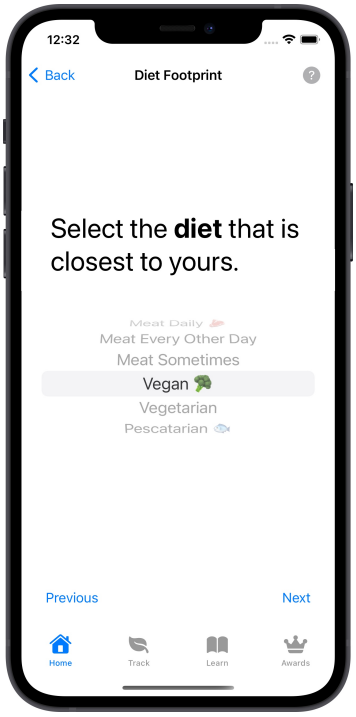


Figure 6.8: Diet Selection

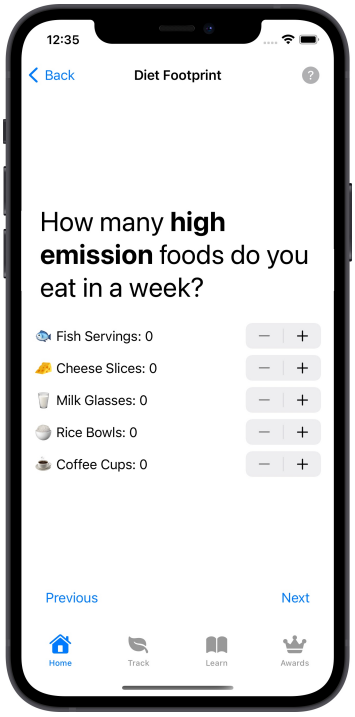


Figure 6.9: Pescatarian Diet High Emission Foods

6.2 Gamification

Stories

In the 'Learn'(Fig. 6.10) tab there are lessons which are presented in a format that should be familiar to most users. A 'Story' (Fig. 6.11) is essentially a slideshow. It consists of multiple images with overlaid text. Tap the right side to go forward or the left to go back a slide. Each slide is shown for a set amount of time, enough to read the text, and then moves to the next slide. Presenting otherwise mundane and boring information in such a format makes it interesting and engaging as they give the same satisfaction as 'Stories' on Snapchat or Instagram where they are extremely popular. The vibrant images and short text make it essentially effortless to consume the information.

Quizzes

Each story is paired with a quiz(Fig. 6.12) to create a lesson based on a certain topic related to greenhouse gas emissions. A quiz is a set of multiple-choice questions. The questions follow up on the knowledge gained in the story that is paired with the quiz. At the top of the view, there are progress bars indicating which question the user is on and how much time has passed. There is a set time limit to answer each question and the longer one takes to answer the fewer points they earn. Clicking an answer reveals the correct and incorrect answers and displays the points earned for the question. A user can earn up to a thousand points per quiz.

Game Center

Game Center is an Apple service that allows players to compare scores on leaderboards with friends or other players around the world, track achievements, and challenge others to earn an achievement or a place on the leaderboard. If the user is not signed into their phone with their Apple ID or if

Figure 6.10: Learn Tab

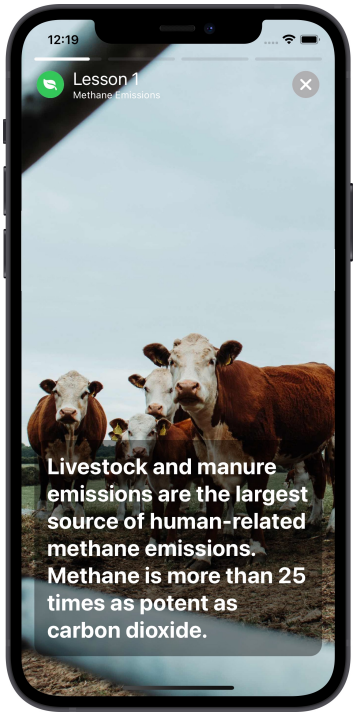


Figure 6.11: Lesson 'Story'

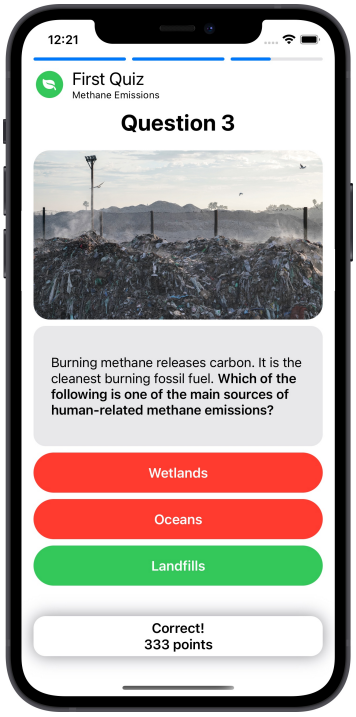


Figure 6.12: Quiz

Figure 6.13: My App. Lessons and Quizzes

they do not have a Game Center account, when they launch the app they will be asked to sign in or set up an account (Fig. 6.16). If the user already has a Game Center account, then when they launch the app they will be signed in automatically, this would be the case for most users.

Leaderboard

The leaderboard (Fig. 6.14) allows the user to see how their carbon footprint stacks up to that of other users on the app. It can be accessed via the home screen by clicking the icon in the top-right. A lower carbon footprint results in a higher place on the leaderboard and earns the user bragging rights. The leaderboard updates with the user's most recent carbon footprint calculation so if a user alters their answers to the carbon footprint survey their score on the leaderboard changes too. The goal of the leaderboard is to encourage users to compete for a higher rank on the leaderboard by reducing their carbon footprint.

Achievements

The 'Awards' tab (Fig. 6.15) showcases the user's earned badges, as well as ones that are yet to be unlocked, which are greyed out. Badges can be earned by achieving milestones and completing various tasks in the app. For example, viewing a lesson or completing a quiz earns the user a badge. A badge is simply a pictogram that attests to the user's achievement of an objective. Badges acknowledge a user's performance and motivate the user to collect them all. If a badge is unlocked, the user can click on it to view it in more detail. If the badge is locked, the user is presented with a pop-up that tells the user what task has to be completed to unlock the badge.

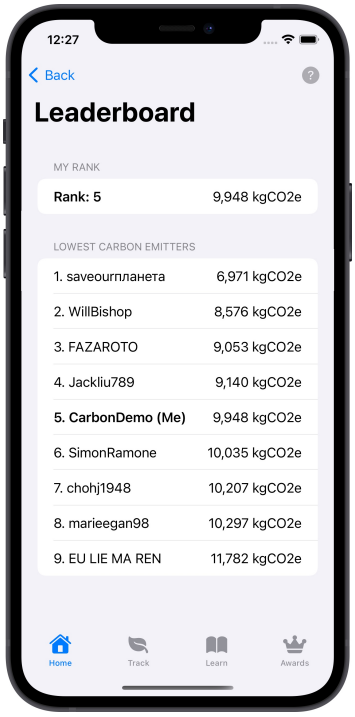


Figure 6.14: Leaderboard

Figure 6.15: Awards Tab

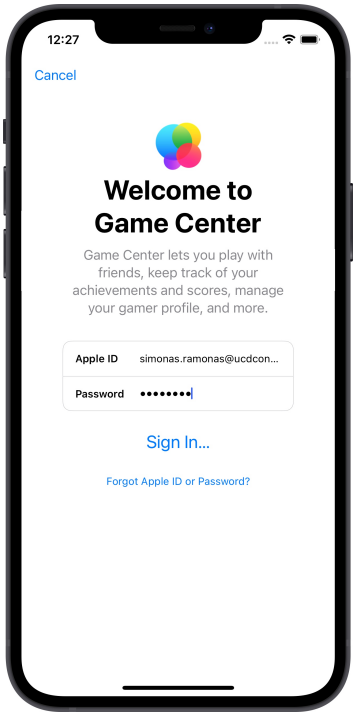


Figure 6.16: Game Center Login

6.3 Tracker for Avoided Emissions

In the 'Track' tab the user can keep track of avoided emissions (Fig. 6.17). For example, if the user usually commutes to work using their car, but today they decided to cycle to work instead they can track this activity in the app and view how many kg of carbon dioxide they saved from being released into the atmosphere. Tracking an avoided emission is effortless, all the user has to do is click the plus sign and choose from a variety of actions (Fig. 6.18) in categories such as home, transport, diet and shopping. At the top of the 'Track' tab, the user can view the total amount of carbon dioxide emissions they have avoided and just below this there is a bar chart of the emissions avoided in the current week. The user can interact with the bar chart by clicking a bar and viewing the amount avoided on the selected day. At the bottom of the 'Track' view is the history of all tracked actions.

6.4 Privacy

No personal data leaves the app unless clearly stated and explicitly accepted by the user. All data is stored locally in the app and if the user deletes the app all data stored in the app is deleted too. Calculations for estimating the carbon footprint are all done natively in the app and all information needed to complete the calculations are stored in the app, no API calls are performed. The sole personal information that is shared publicly is the calculated carbon footprint and only if the user accepts to do so. For instance, when the user opens the leaderboard for the first time the apps are displays a disclaimer(Fig. 6.20) stating that this feature shares their carbon footprint with other users.

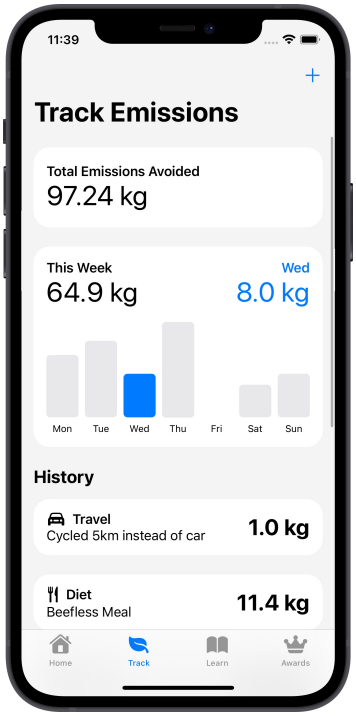


Figure 6.17: Avoided Emissions Breakdown

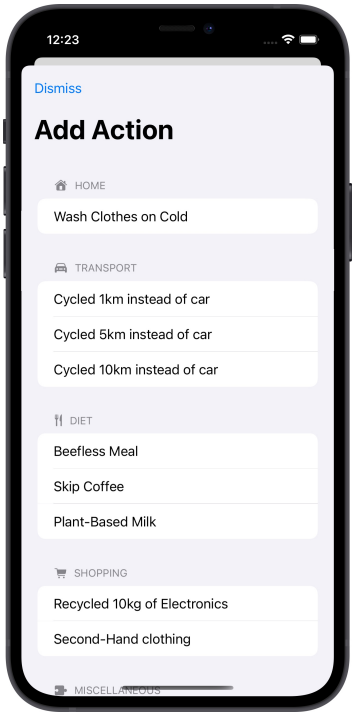


Figure 6.18: Add Action

Figure 6.19: My App. Avoided Emissions Tracker

6.5 Support Information

Support information can be found throughout the app (Fig. 6.21). All that the user has to do is look for the question mark icon. Clicking on it displays a window with information that should help the user navigate the app, understand how the app works, and help answer any queries that may arise. For example, the help icon appears for every question of the carbon footprint calculator and guides the user through the whole process, giving tips on what information to input to ensure a more accurate estimate or providing insight on how the information is used to calculate the footprint.

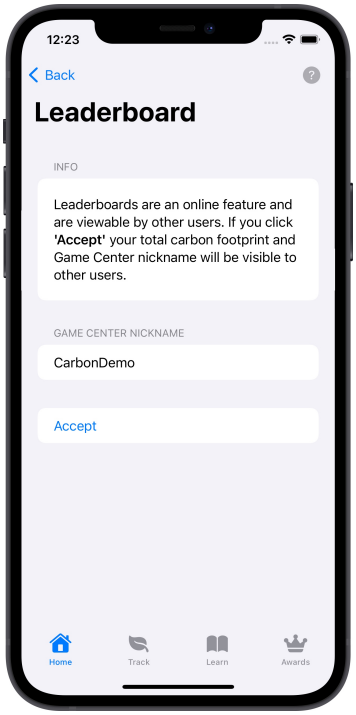


Figure 6.20: Leaderboard Disclaimer

Figure 6.21: Information Pop-up

Chapter 7: Implementation

7.1 Programming Language and Tools

Version Control

Git was the version control system used for the development of the app. All project code and files can be viewed on GitHub using the following link: GitHub Link

Swift

The application is implemented using the Swift programming language. Swift is a general-purpose, multi-paradigm, open-source programming language developed by Apple for Apple operating systems such as iOS, iPadOS, and macOS. Swift also has support for platforms not owned by Apple, for instance, Android, Windows, and Linux. It was released in 2014 as a replacement for Objective-C which is Apple's older programming language which was lacking many modern features due to being mostly unchanged since the 1980s. Swift's syntax is clear, concise, and intuitive which makes the code easy to understand and maintain.

SwiftUI

The application's graphical user interface was implemented using SwiftUI. SwiftUI is a declarative framework that provides views, controls, and layout structures for creating an app's user interface to work on any Apple platform. The framework also provides event handlers for handling taps and other inputs to the app. It is equipped with all the necessary tools to manage the flow of data from the application's models to the views that the user can see and interact with. SwiftUI has a declarative syntax which means that you define the views you want to appear on screen using Swift structures. Defining data dependencies for a view tells SwiftUI to update the view when the data changes.

Xcode

Xcode is the integrated development environment that was used to develop the application. Xcode is developed by Apple for the macOS operating system. It provides all the tools necessary for creating iOS apps, for example, a text editor, compiler, and an iPhone simulator for running the application. These tools help manage the entire development workflow, from creating the app to submitting it to the App Store.

7.2 Models and Views

7.2.1 Views

Complex views make up the user interface for the app. These complex views are composed of smaller and simpler views. Using VStack, Hstack, or Zstack (Fig. 7.1) smaller views can be grouped vertically, horizontally, or on top of one another to create complex combined or layered views. The appearance of views can be customised by using built-in modifiers. The app's root view is the MenuTabView.

Stacks and Modifiers

For example, the CircularProgressViews in the breakdown section of the home tab are two stacked Circle views(Fig. 7.1). The bottom circle has an opacity modifier while the top circle uses a trim modifier to have the length correspond to the percentage. The modifiers are the chained methods below the views, for example, .font() can be used to set a style for the text, whereas .frame() is used to set a view to a specific size.

```
VStack{
    ZStack {
        Group {
            Circle()
                .stroke(lineWidth: 10.0)
                .opacity(0.5)
            Circle()
                .trim(from: 0.0, to: CGFloat(min(percentage, 1.0)))
                .stroke(style: StrokeStyle(...))
                .rotationEffect(Angle(degrees: 270.0))
            Image(systemName: icon)
                .font(.title)
                .padding()
        }
        .foregroundColor(color)
    }
    .padding(.init(top: 10, leading: 10, bottom: 0, trailing: 10))
    Text(String(format: "%.0f", percentage*100)+"%")
        .font(.title2)
        .bold()
    Text(caption)
        .font(.subheadline)
}
```

Figure 7.1: BreakdownView.swift

Navigation Hierarchy

NavigationLink allows for the traversal of the views in a hierarchy(Fig. 7.2). NavigationLinks are defined by passing a view as the destination view in the initializer. When a user interacts with the NavigationLink element they are presented with the destination view from the navigation hierarchy.

Whereas, a Sheet can be used to present a modal view.

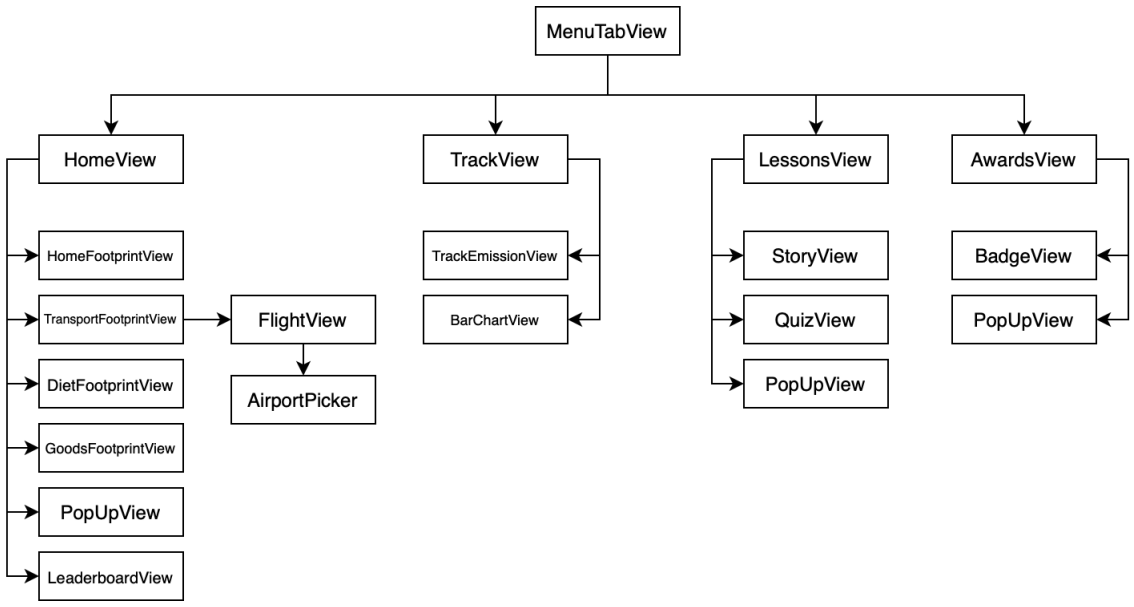


Figure 7.2: Navigation Hierarchy Diagram

Data Flow Between Views

State and Binding property wrappers allow for updating and passing data throughout the navigation hierarchy. The annotations ensure that the user interface always reflects the current state of the app's data. Declaring a property as a State creates a source of truth, the value is stored in one place and any number of views can access the same exact data. When the property defined as State is modified, for example by a user's interaction, the State property wrapper forces the system to re-render the views that are dependent on that property. If a property is declared with the Binding property wrapper, then it shares the read and write access with an already defined State property. Unlike State, the Binding property does not store the data directly instead it establishes a connection with the State property data. State and Binding establish the dependencies between the State data and the child view that contains a Binding. For example, the @Binding properties in AirportPicker(Fig. 7.3) are bound with the properties in its parent view called FlightView.

```
struct AirportPicker: View {
    @Binding var selection: Flight.Airport
    @Binding var airports: [Flight.Airport]
    @State var filteredAirports: [Flight.Airport] = []
    @State private var searchText = ""
    var body: some View {
        ...
    }
}
```

Figure 7.3: AirportPicker.swift

7.2.2 Models

There are many models defined for the app, for storing data, modifying data, completing various calculations, and saving data for persistency. A model for primarily carrying value data is declared as a struct (structure). A struct is a value type and can be used with State and Binding property wrappers which make binding user input possible. A model should be declared as a class when there is data coming from outside a view, this is because a class is a reference type and can be defined as an ObservableObject which triggers a view to refresh when a property that is wrapped with @Published property wrapper inside the class changes.

Structures

- Lesson
  - Quiz
  - Story
- Badge
- CarbonFootprint
- Constants
- Flight
  - Airport
- DataPoint
- User
- Action

Classes

- CarbonFootprintCalculator
- LessonTimer
- QuizScorer
- Leaderboard
- DataStore
- AchievementReporter
- EmissionsTracker

Figure 7.4: Models

7.3 Carbon Footprint Calculator

All the user input data necessary for calculating the carbon footprint is stored in the CarbonFootprint structure. Furthermore, all the calculations for calculating the carbon footprint are done using the CarbonFootprintCalculator class. The data that is stored in the CarbonFootprint structure can be modified through the carbon footprint calculator views: HomeFootprintView, TransportFootprintView, DietFootprintView, and GoodsFootprintView. When a view is closed the onDisappear event handler is called, this updates the data in the structure and recalculates the carbon footprint using the CarbonFootprintCalculator.

Home Footprint

The home energy carbon footprint is comprised of the emissions from heating and electricity usage. Heating emissions are calculated by multiplying the emission factor of the user's selected fuel type by the average Irish household's annual heating energy usage. Whereas the electricity emissions are calculated by multiplying the user's electricity supplier's emission factor (Fig. 7.5) by the amount of electricity used monthly times twelve. If the user has provided the bill amount paid instead of the kWh used, then the billed amount is divided by the average kWh price to get the total of kWh used. The heating and electricity emissions are divided by the number of people in the household

Data	Description	Source
Airport Dataset	A JSON file of over 3000 medium to large airports with scheduled services. Features available are airport name, airport code, longitude degrees and latitude degrees. Derived from a csv file.	[27]
12.6 tCO2e	Irish national average annual CO2 equivalent as of 2018.	[28]
4200 kWh	Average Irish household annual electricity usage.	[29]
11000 kWh	Average Irish household annual heating energy usage.	[29]
0.2396 Eur	Average price per kWh of electricity in Ireland 2021.	[30]
0.354 kgCO2/kWh	Emission factor of coal.	[31]
0.201 kgCO2/kWh	Emission factor of natural gas.	[31]
0.257 kgCO2/kWh	Emission factor of kerosene.	[31]
0.227 kgCO2/kWh	Emission factor of LPG.	[31]
0.382 kgCO2/kWh	Emission factor of peat.	[31]
0.395 kgCO2/kWh	Emission factor of coal.	[31]
2.35 kgCO2/l	Emission factor of petrol.	[32]
2.65 kgCO2/l	Emission factor of diesel.	[32]
0.09 kgCO2/pax/km	Emission factor of an average flight (kgCO2/passsenger/km) in 2019.	[33]
1.9 kgCO2e/kg	Emission factor of food waste.	[34]
3.486 kg	Average weekly food waste per person in the United Kingdom.	[35]
1058.5 kgCO2e	Vegan diet carbon footprint in the United Kingdom.	[36]
1390.65 kgCO2e	Vegetarian diet carbon footprint in the United Kingdom.	[36]
1427.15 kgCO2e	Pescatarian diet carbon footprint in the United Kingdom.	[36]
2624.35 kgCO2e	High meat diet carbon footprint in the United Kingdom. (>= 100 g/day of meat)	[36]
2054.95 kgCO2e	Medium meat diet carbon footprint in the United Kingdom. (50-99 g/day of meat)	[36]
1704.55 kgCO2e	Low meat diet carbon footprint in the United Kingdom. (< 50 g/day of meat)	[36]
11.44 kgCO2e	Per 115 grams raw beef.	[37]
1.42 kgCO2e	Per 115 grams raw pork.	[37]
1.14 kgCO2e	Per 115 grams raw poultry.	[37]
0.22 kgCO2e	Per 50 grams uncooked rice.	[37]
1.54 kgCO2e	Per 115 grams raw fish.	[37]
0.57 kgCO2e	Per 20 grams ground coffee.	[37]
0.72 kgCO2e	Per 30 grams cheese.	[37]
0.63 kgCO2e	Per 200 ml milk.	[37]
0.35 kgCO2e	Per 1 euro spent on clothing.	[38]
2.16 kgCO2e	Per 1 euro spent on electronics and appliances.	[38]
1.44 kgCO2e	Per 1 euro spent on video streaming services.	[38]
1.18 kgCO2e	Per 1GB of mobile data 5kWh per 1GB at 0.236kgCO2e per kWh.	[39]
0.328 kgCO2/kWh	Bord Gáis Energy emission factor in 2020.	[40]
0.179 kgCO2/kWh	Electric Ireland emission factor in 2020.	[40]
0 kgCO2/kWh	Energia, Go Power, Panda Power, SSE Airtricity, Naturgy, Iberdrola, Flogas, ElectroRoute, Arden Energy, Bright, BRI Green Energy Supply emission factor in 2020.	[40]
0.406 kgCO2/kWh	Glow Power and Prepay Power emission factor in 2020.	[40]
0.236 kgCO2/kWh	All-Island fuel mix emission factor in 2020.	[40]

Figure 7.5: Data Used for Calaculating a Carbon Footprint

to get the user's individual footprint.

Travel Footprint

The carbon footprint for travel and transport is calculated by summing car and flight emissions. Car emissions are calculated by taking the user input for the litres of petrol and diesel burned per week, multiplying the litres by 52 to get the total for the year and multiplying the result by their respective emissions factors, which is 2.35 kgCO2/litre for petrol and 2.65 kgCO2/l for diesel(Fig. 7.5). The flight emissions are calculated by first getting the distance of a flight. Each airport has its longitude and latitude degrees, using the haversine formula (Fig. 7.6) we can calculate the distance between two points on a sphere, in this case, earth. Once the distance is calculated, it is multiplied by the emission factor of a flight which is 0.09 kgCO2/passenger/km (Fig. 7.5). If the user has specified that it is a return flight then it is multiplied by 2 and then multiplied by the number of trips the user made. This is repeated for all flights to calculate the user's total flight emissions.

```
let dlon = longitude2 - longitude1
let dlat = latitude2 - latitude1
let a = pow(sin(dlat/2), 2) + cos(latitude1) * cos(latitude2) * pow(sin(dlon/2), 2)
let c = 2 * asin(sqrt(a))
let r = 6371.0 //Radius of earth in kilometres.
return c * r
```

Figure 7.6: Haversine Formula

Diet Footprint

The food-related carbon footprint is made up of food waste emissions and diet emissions. The diet emissions are calculated by taking the number of servings of different high carbon emission foods and multiplying them by their respective emission factors (Fig. 7.5). The weekly total is then multiplied by 52 to get the annual emissions. The footprint is then compared to the user's specified diet's average footprint. The greater footprint is used, this is because if the user underestimates the number of high emission foods they consumed, then their diet footprint will be too small. Food waste emissions are calculated by multiplying the total amount of food wasted annually by the emission factor of food waste.

Goods Footprint

The goods and services footprint is calculated by first taking the user's inputs and getting the annual totals for each. The resulting totals are then multiplied by their respective emission factors(Fig. 7.5). The sum of the products is the goods footprint.

7.4 Avoided Emissions Tracker

The avoided emissions tracker is comprised of the EmissionsTracker class and Action structs. An Action (Fig. 7.7) holds data for the action's name, category, value for the kg of avoided emissions and the date when the action was recorded. When the user tracks an action the details for the action and current date are added to the User struct. The EmissionsTracker has methods for calculating the all-time total of avoided emissions as well as a method for the totals for each day of the current week. The getThisWeeksData method places the calculated totals for each day into a DataPoint array.

Bar Chart View

A DataPoint is a struct that can hold a double value and a name for that value, for example, a string for the day of the week and a double for the number of avoided emissions. The DataPoint array is used by the BarChartView, where the name value of a DataPoint instance is a label for the bar and the double value determines the length of the bar.

```swift
struct Action: Identifiable, Codable, Hashable {
    let id = UUID()
    var name: String
    var type: String        // category: home, diet, travel, misc, goods
    var value: Double       // kg of avoided CO2 emissions
    var date: Date = Date()
    ...
}
```

Figure 7.7: Action.swift

7.5 Gamification

7.5.1 Lessons

The Lesson structure is comprised of a Story structure and a Quiz structure. Lessons are stored in a JSON file (Fig. 7.8). The JSON file is decoded when the user opens the Learn tab, an onAppear event handler is called which invokes the decode function. The stories and quizzes are then displayed on the LearnView.

```json
{
  "story": {
    "coverImage": "cows",
    "title": "Lesson 1",
    "subtitle": "Methane Emissions",
    "unlocks": [
      "Badge 1"
    ],
    "slides": [{
        "image": "lesson 1-1",
        "caption": "Livestock and manure emissions are ..."
      }]
  },
  "quiz": {
    "title": "First Quiz",
    "subtitle": "Methane Emissions",
    "questions": [{
        "image": "lesson 1-1",
        "prompt": "**What is the main source of ...",
        "answers": [{
            "text": "Fossil fuel production",
            "isCorrect": false
          }]}]}
}
```

Figure 7.8: Lesson JSON

Story

Stories are implemented with the help of a LessonTimer (Fig. 7.9) which is an ObservableObject. An ObservableObject causes SwiftUI views to update when changes occur inside the object. Using a publisher which repeatedly emits the current date and time at a set interval this updates a progress variable that can be at most equal to the number of slides. The floor value of the progress variable is used to determine which slide should be shown, whereas the decimal value is used for the progress bars at the top of the story. When a user clicks the right side to skip a slide then the skip function is invoked, and the progress variable is incremented by 1 and if the left side is clicked then progress is decremented by 1. At every, publish of the timer progress is incremented by the interval of the publisher divided by the duration the slide is set to be shown for.

Quiz

Quizzes work in an analogous way to the stories, as the LessonTimer class (Fig. 7.9) is used to iterate through the questions, but there is no ability to click the right or left side to skip a question. The QuizScorer class is used to keep track of the score when an answer is selected.

```
class LessonTimer: ObservableObject {
    @Published var progress: Double = 0.0
    @Published var isFinished: Bool = false

    private(set) var numberOfSlides: Int = 0
    private(set) var slideDuration: TimeInterval = 0.0
    private var publisher: Timer.TimerPublisher =
                        Timer.publish(every: 0.01, on: .main, in: .default)
    private var cancellable: Cancellable?

    func set(numberOfSlides: Int, slideDuration: TimeInterval) {...}
    func start() {...}
    func stop() {...}
    func reset() {...}
    func skip(by: Int) {...}
}
```

Figure 7.9: LessonTimer.swift

7.5.2 Game Center

Game Center features are implemented using the GameKit framework. GameKit enables users of the app to compare carbon footprints using the leaderboard and showcase achievements to other Game Center users. When the user launches the app an onAppear event handler in the MenuTabView invokes an authenticateUser function. If the user already has a Game Center account set up in their device's settings, then they are automatically signed in, otherwise, a sign-in screen is displayed which the user can dismiss. The user must be signed in to Game Center to view the leaderboard, but no other features of the app require the user to be signed in. If the user is signed in the app has access to the user's Game Center profile which allows the app to update the user's leaderboard score as well as report their achievements to Game Center.

Leaderboard

An onChange event handler in HomeView submits a new score to Game Center whenever there is a change in the user input data for the carbon footprint calculator. The score is submitted using GameKit's GKLeaderboard class with the method submitScore. Before the app could submit scores, the leaderboard was configured using App Store Connect. App Store Connect is an Apple website with tools for publishing, testing, and configuring apps. Once the leaderboard is configured, it is possible to submit and load scores. The Leaderboard class's load method loads the leaderboard from Game Center servers using the GameKit framework. The loadScores method then gets the top one hundred leaderboard entries which are displayed on the LeaderboardView.

Awards

When the user views a Story an event handler onDisappear adds the completed story and the unlocked badge to the User instance while the AchievementReporter class uses the GameKit framework to report the earned achievement to Game Center. In the awards tab when the badges are displayed the User instance is checked to see which badges are unlocked.

7.5.3 Data Persistency

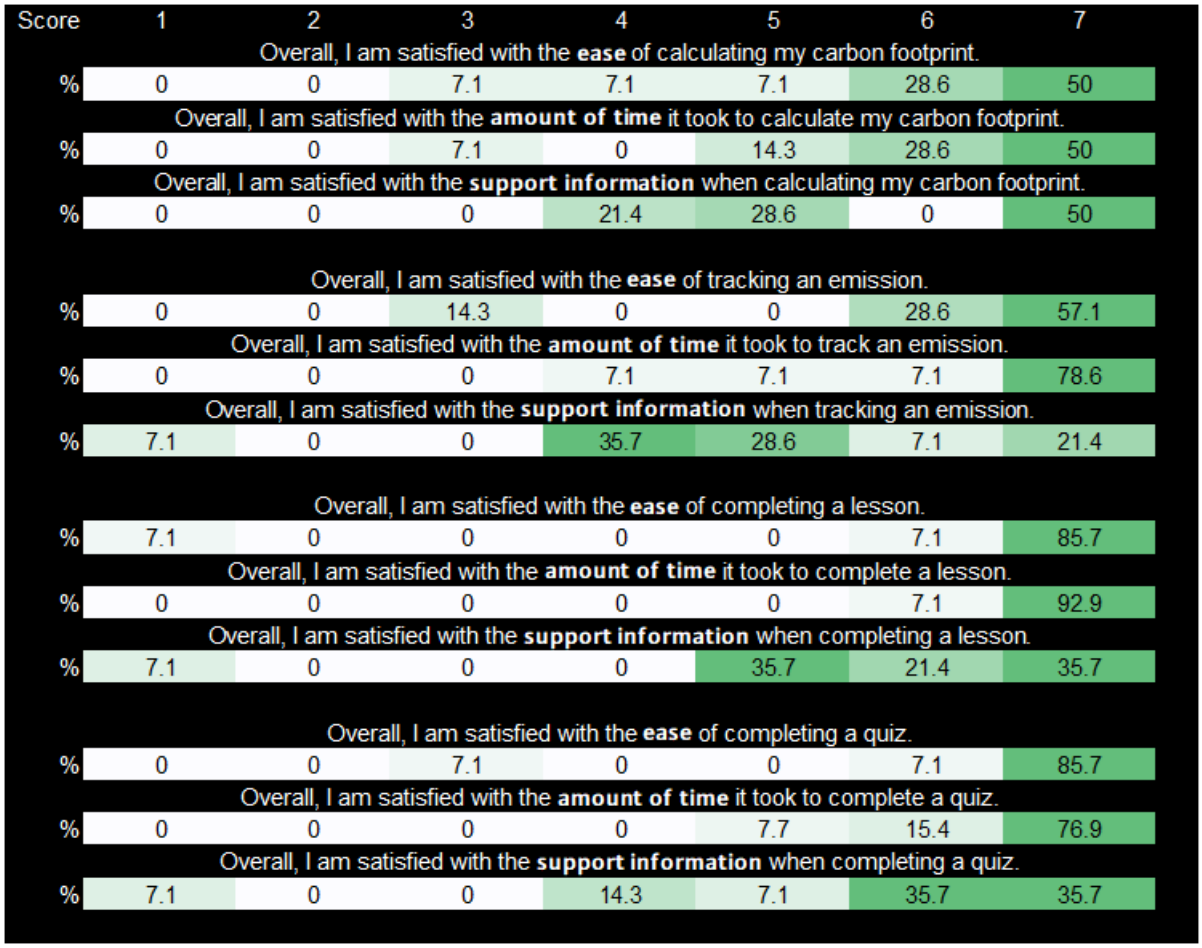
The DataStore class is responsible for data persistency between launches of the app. By adding Codable conformance to a struct, it is possible to serialize data to and from JSON using the Codable API. Codable is a combination of the Encodable and Decodable protocols. Protocols define blueprints of methods, properties, and other requirements that suit a specific task or functionality. In the app, all models that require data persistency conform to the Encodable and Decodable protocols. The User struct has codable conformance and stores all data associated with the user, for example, the lessons completed, unlocked badges, quiz scores, and all answers to the carbon footprint calculator survey. When the app is closed or if it enters an inactive state (Fig. 7.10), the User data is saved using the DataStore by encoding the data as a JSON file stored in the app's files. On the other hand, when the app is launched an onAppear (Fig. 7.10) event handler invokes the DataStore load function that decodes the JSON file and returns the User model.

```
...
MenuTabView(lessons: lessons, badges: badges, user: dataStore.user)
    {
        DataStore.save(user: dataStore.user) {...}
    }
    .onAppear {
        DataStore.load {...}
    }
...
```

Figure 7.10: Final_Year_ProjectApp.swift

Chapter 8: User Testing

Using Apple's TestFlight service I was able to perform a beta test of the app as well as carry out an after-scenario questionnaire [41] to determine the usability satisfaction of the app. TestFlight allows anyone with the unique link to download and install the beta version of the app on their own phone. There were 18 installs of the app and I received 14 responses to the after-scenario questionnaire. The questionnaire asked to complete a task in the app and answer three questions regarding the ease of completing the task, the amount of time it took to complete the task and the support information available to complete the task as well as an optional comment. In total there were four tasks: calculate carbon footprint, track an avoided emission, complete a lesson, and complete a quiz.



Score	1	2	3	4	5	6	7
Overall, I am satisfied with the **ease** of calculating my carbon footprint.							
%	0	0	7.1	7.1	7.1	28.6	50
Overall, I am satisfied with the **amount of time** it took to calculate my carbon footprint.							
%	0	0	7.1	0	14.3	28.6	50
Overall, I am satisfied with the **support information** when calculating my carbon footprint.							
%	0	0	0	21.4	28.6	0	50
Overall, I am satisfied with the **ease** of tracking an emission.							
%	0	0	14.3	0	0	28.6	57.1
Overall, I am satisfied with the **amount of time** it took to track an emission.							
%	0	0	0	7.1	7.1	7.1	78.6
Overall, I am satisfied with the **support information** when tracking an emission.							
%	7.1	0	0	35.7	28.6	7.1	21.4
Overall, I am satisfied with the **ease** of completing a lesson.							
%	7.1	0	0	0	0	7.1	85.7
Overall, I am satisfied with the **amount of time** it took to complete a lesson.							
%	0	0	0	0	0	7.1	92.9
Overall, I am satisfied with the **support information** when completing a lesson.							
%	7.1	0	0	0	35.7	21.4	35.7
Overall, I am satisfied with the **ease** of completing a quiz.							
%	0	0	7.1	0	0	7.1	85.7
Overall, I am satisfied with the **amount of time** it took to complete a quiz.							
%	0	0	0	0	7.7	15.4	76.9
Overall, I am satisfied with the **support information** when completing a quiz.							
%	7.1	0	0	14.3	7.1	35.7	35.7

Figure 8.1: After-Scenario Questionnaire Results. Based on 14 responses.

Usability of the Carbon Footprint Calculator

Most respondents found the carbon footprint calculator easy to use and were satisfied with the amount of time it took to calculate their carbon footprint (Fig. 8.1). Though some found that it lacks support information. One person mentioned that they would like more information on what the total carbon footprint number means, for example, whether it is good or bad. While another respondent found it tough to answer questions where consumption is being asked per time frame.

Usability of the Avoided Emissions Tracker

The majority found it easy to track an avoided emission and found it especially quick (Fig. 8.1). On the other hand, many respondents were not sure what exactly they are tracking and what is the correct way to track their actions. They hoped for more options for tracking avoided emissions and more supporting information to better understand how the tracker works. For example, whether they should track an action that they already do which is not in replacement of a carbon expensive action.

Usability of a Lesson

Overall, respondents were very satisfied with the ease of completing a lesson as well as the time it takes to complete one(Fig. 8.1). Although, some respondents did have concerns about the slides changing too fast and would have liked the ability to pause the slideshow. One respondent would have benefited from a tutorial before starting a lesson as they did not find the controls intuitive and struggled to discover how to return to a previous slide.

Usability of a Quiz

Similar to the lessons, most respondents found it easy to complete a quiz and were satisfied with the amount of time it took(Fig. 8.1). This was despite many respondents agreeing that the time given to answer a question was not enough. They would have liked more time to answer the questions and would have appreciated a heads up that the quiz is about to start. One respondent believed there was not enough information about the meaning of the points and felt they were random.

Summary of Results

Overall, the majority of users found the app easy to use and were satisfied with the amount of time it took to complete the tasks (Fig. 8.1). Many enjoyed the user interface of the app and noted that the design is pleasing and user friendly. From the user testing results, we can see that the greatest fault of the app is the lack of support information. A major limitation of an after-scenario questionnaire is that there is not enough context behind the scores. Although some users left comments, because the comments were optional not enough responses were received to understand the scores to a full extent.

Chapter 9: Conclusions and Future Work

Improvements Made Based on the User Survey

As a result of the survey, I discovered that there was not enough time for users to read the stories and quiz questions, so to rectify this issue I increased the duration of time that the stories and questions are shown. To provide more information on how stories work, I added a support popup in the learn tab. The user survey showed that many users would like more information about the avoided emissions tracker, so to help users better understand what actions should be tracked, I added a support popup in the track tab. The button for adding an action was also made more pronounced.

Future Work

In the future, I hope to implement the features I had planned from the very start but did not have the time for. One of these features is the daily and weekly challenges, where a user is challenged to complete a new task every day or to complete daily tasks to reach a weekly milestone. I also planned to add push notifications to remind the user to track actions, complete lessons or recalculate their carbon footprint. A major feature that was not implemented was the history of the user's carbon footprint, which would have let the user see how their carbon footprint has changed over time. Finally, after implementing all unfinished features and testing is complete, I aspire to have it published on the App Store.

Conclusion

This project has helped me gain invaluable insight into the development of fully-fledged iOS apps, the calculation of carbon footprints, and the implementation of gamification techniques.

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