University of Glasgow | School of Computing Science

Honours Individual Project Dissertation

Envirofy 2.0 : A Web Extension Promoting Sustainable Shopping

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April 2nd, 2021

Acknowledgements

I would like to thank my supervisors, Professor Stephen Brewster and Dr. Gözel Shakeri for their invaluable support and guidance throughout the year. I would also like to thank the user evaluation participants for their time and input, which was extremely valuable.

Dedicated to my parents, who supported me through my four years of undergrad at the University of Glasgow and who always pushed me to achieve the best I can.

Abstract

Global warming is a critical issue affecting humanity, which if not addressed, will have disproportionate consequences on energy and water availability. Policies put in place by governments and internationally recognised organisations to help tackle global warming were found to be slow-acting and will need years before development and global deployment. Rather than focusing on altering industrial behaviour, focusing on individual consumer behaviour provides a faster way of reducing the carbon emissions. One way to achieve this is through educating users about the impact of their food consumption. Envirofy 1.0 is a browser extension that aimed to educate its users about the environmental impact of their food choices when shopping on Tesco.com, however, it was found to have severe issues (high latency, high carbon footprint, low flexibility and modularity) that hindered its usability and credibility. This paper discusses the development of Envirofy 2.0, which is a second, fundamentally different, version of Envirofy 1.0 that aims to address the issues identified in Envirofy 1.0. Envirofy 2.0 will extend its coverage of supermarkets to become compatible with Waitrose.com as well. In this paper, Envirofy 2.0 undergoes user and performance evaluations in which the findings indicate the Envirofy 2.0 offers better usability, lower latency and lower carbon footprint.

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1 Introduction

This chapter introduces the goals of the Envirofy project and the motivations behind it. Envirofy is a web browser extension that aims to guide consumers into making more environmentally friendly shopping decisions. This is achieved through the use of behavioural change intervention techniques that are displayed on the user interface.

1.1 Motivations

Global warming is a critical issue affecting humanity, which if not addressed, will have disproportionate consequences on energy and water availability (WWF 2021). Policies have been developed by governments and internationally recognised bodies to help decelerate the alarming rate at which the global greenhouse gas (GHG) emissions are increasing. However, most of these policies are considered long term and slow-acting as major new technologies for low-carbon energy supply, carbon capturing and higher energy efficiency must overcome several technical and economical obstacles, which might take years or even decades before development and global deployment (Dietz et al. 2009).

Another issue related to tackling climate change is that most efforts are focused on analysing and changing industrial behaviour (e.g. improving production and transportation processes), which often presents a conflict of interest as businesses' main objective is profitability. This is apparent as companies' financial performance was proven to decline under the introduction of climate change legislation (Delmas et al. 2015). Dietz et al. (2009) argued that focusing efforts on individual consumer behaviour (e.g. recycling, diet change) can provide a much faster way of significantly reducing carbon emissions, which can help provide the additional time needed for the longer-term industrial changes and the transitions towards a greener industrial system.

The food supply chain is responsible for a third of the global greenhouse gases emissions (Vermeulen et al. 2012), which are considered one of the main contributors to global warming and hence climate change. Yet, most consumers are unaware of the impact that food consumption has on climate change (Macdiarmid et al. 2015). This is mainly attributed to the lack of consumer knowledge in relation to the environmental impact of the food being bought and consumed. With a lack of the necessary knowledge, the consumers' ability to make an educated choice even in the presence of the inherent intention of making environmentally friendly shopping decisions (known as "behaviour intention gap") is hindered (Macdiarmid et al. 2015; Nguyen et al. 2019; Vermeir and Verbeke 2008).

This gap in the knowledge of the environmental impact of food consumption could be addressed by educating consumers on their food-shopping's carbon footprint. This will allow them to make better-informed decisions (Gerbens-Leenes and Nonhebel 2002; Poore and Nemecek 2018), which could help decrease greenhouse gases emissions (Dey et al. 2007).

Envirofy aims to address the behaviour intention gap by equipping its users with the skills and information required to make an informed decision when choosing between products, which would result in more environmentally-friendly food choices. However, several problems were identified with its implementation, which prompts for a second, better, version.

1.2 Aims

The aim of this project is to develop a second version of Envirofy (Envirofy 2.0) that is built with a fundamentally different system architecture and is equipped with additional features (e.g. runs on another website). This version will utilise behaviour change intervention techniques to help consumers make environmentally friendly decisions when shopping on Tesco's and Waitrose's websites. The new system architecture will allow for higher flexibility of the browser extension, which will allow it to easily adapt to other supermarket websites. Additionally, this new version will offer higher efficiency, lower display latency, and a lower carbon footprint when compared to the first Envirofy version.

1.3 Summary

This chapter introduced the motivations and aims behind the project. The remainder of this paper is structured as follows:

- **Chapter 2** builds upon chapter 1 and further explains the necessary background about the intervention techniques used, related environmental HCI research, the choices of the supermarket websites on which Envirofy 2.0 will work, and the existing problems with the first version of Envirofy.
- **Chapter 3** outlines the requirement analysis process which involved developing the set of functional and non-functional requirements for the product.
- **Chapter 4** discusses the design process which involves the system architecture, the tools and technologies used and the user interface while justifying each design decision through linking it to the project requirements.
- **Chapter 5** outlines the implementation of the second version of Envirofy based on the project requirements and design decisions.
- **Chapter 6** outlines the evaluation process followed to ensure the project requirements were met, which involved performance evaluation, unit testing, acceptance testing, and a usability study.
- **Chapter 7** summarises this paper while identifying opportunities for future work for Envirofy.

2 Background

This chapter will examine the background of the project. First, problems with the first version of Envirofy are investigated. Second, related HCI research will be explored and linked to how it was utilised in Envirofy. Third, the intervention techniques implemented in Envirofy will be discussed and justified by behaviour change theory. Finally, the choice of the supermarket websites with which Envirofy is compatible is explained.

2.1 Envirofy V1.0

The first version of Envirofy[1] was developed by Shakeri and Mccallum (2021). It is considered to be "the first e-commerce grocery tool for real shoppers" that aims to nudge its users into making more environmentally friendly food purchases (Shakeri and Mccallum 2021). The browser extension only works on Tesco's online-shopping website with the aim of creating a more generalised version that would cater for the rest of the supermarket chains in the UK. Furthermore, after investigating Envirofy's source code, several problems were identified, which prompted the need for a more robust, modular and flexible version of Envirofy. The identified problems are as follows:

2.1.1 Modularity

The first version of Envirofy does not follow the software design principle of separation of concerns. Every functionality of the system is packed inside one big Javascript file. This rendered the source code to be tightly coupled and to have very low modularity. This is problematic as maintaining a tightly coupled source code is hard because a minor change can have a ripple effect on the rest of the system, making it more difficult to reuse or test a particular module. Additionally, the source code included a large amount of hardcoded CSS attributes as well as food GHG emission values, which rendered the browser extension increasingly inflexible and thus, harder to make more generalised to work on other supermarket websites. This project aims to make Envirofy's source code loosely coupled and modular, which will allow for greater flexibility and robustness.

2.1.2 Carbon Footprint

Envirofy's first version has a moderately high carbon footprint, which is ironic considering the browser extension's main objective is decreasing GHG emissions. It works by crawling each product's specific webpage from the products listed on the supermarket webpage. In Tesco's case, there are 24 (could be increased to 48) products per product list page, which means that each time a user checks a product list webpage, 24 HTTP requests are initiated to scrape individual product-related CO2 data. This amounts to 163.2 (6.3g * 24) grams[2] of CO2 emitted per user query. Based on a pilot study run by Shakeri and Mccallum (2021), a user performs, on average,

[1] Source code can be found at: https://osf.io/hm9gv/

[2] Carbon footprint per HTTP request found at: https://medium.com/wedonthavetime/guest-blog-post-the-alarming-environmental-impact-of-the-internet-and-howyou-can-help-6ff892b8730d

30 queries per shopping session, which means that a shopping session, while using the first version of Envirofy, has a carbon footprint of 4.53 Kg. The aim of this project is to reduce Envirofy's carbon footprint to a negligible amount which will make it a valid tool to lower GHG emissions.

2.1.3 Latency

Envirofy starts crawling each product's webpage, calculating its carbon footprint, and displaying the carbon footprint data after the webpage content has loaded from Tesco's server. This results in a high latency of > 2000 ms. This lag is way above the recommended threshold of 1000 ms, after which the quality of the user experience starts declining (Bartuskova and Krejcar 2015). This project aims to lower the latency to below the recommended threshold of 1000 ms, which will ensure better effectiveness and a better user experience for the browser extension.

2.2 Related Work

Envirofy builds on extensive research from various categories. These categories include:

- The effect of **dietary changes** on the environmental impact of food consumption.
- HCI research related to **Eco-feedback** and its effect on consumer behaviour.
- Research related to **food labelling** and its effect on consumer behaviour.

Each of these categories will be further explored in-depth and linked back to the Envirofy project.

2.2.1 Dietary Change

Dietary change holds significant potential for an action that consumers can take to reduce the environmental impact of their food consumption. Past research found that a shift from meat dependent diets towards plant-based diets can deliver substantial environmental benefits that scale up to a 49% reduction in the food supply chain's GHG emissions (Poore and Nemecek 2018). Additionally, dietary change, with the aim of reducing food consumption's carbon footprint, is not only constrained to trading meat and dairy products for plant-based alternatives but also to choosing locally produced food as well as those with minimal packaging.

Envirofy does not directly affect consumers' diet but rather aims to educate users about the environmental impact of meat-based diets by associating that type of diet with a high environmental impact when compared to its plant-based counterpart. In other words, Envirofy utilizes behaviour change interventions to promote sustainable food choices when grocery shopping.

2.2.2 Eco-feedback

With rising concerns about the earth's environmental wellbeing around the globe, environmental issues, such as climate change and air pollution, have become active targets for research within HCI. A specifically popular form of environmental HCI research, Eco-feedback technology, investigates the use of technology in relaying feedback to users with the aim of reducing their environmental impact (Froehlich et al. 2010). The influence of Eco-feedback has been demonstrated in numerous studies where it was applied in different contexts such as water usage, energy consumption, and food consumption (Froehlich et al. 2012; Petkov et al. 2012). However, the existing research relating to the application of Eco-feedback on food consumption has not touched on the total environmental impact of a consumer's food choices but rather focused on a sub-category of the total impact, such as the impact of the consumption of organic food (Zapico et al. 2016) or the impact of food waste (Lim et al. 2014). Furthermore, the application of Eco-feedback in a food consumption context and its influence on consumer behaviour have only been studied "post-purchase". For instance, Zapico et al. (2016) developed a web visualization platform where

users were able to see their purchase history and food purchases' trends with a specific focus on whether the food was organic or not. The display of data relied on already purchased food, which meant that a direct intervention at the point of purchase was not possible. Luo et al. (2017) found, in their study, that interventions introduced at the *point of purchase* offer a better chance of influencing the consumer into performing the desired behaviour (environmentally friendly food choices in our case).

Froehlich et al. (2010) argued that most people lack awareness of the environmental impact of their day-to-day behaviour. Envirofy utilizes Eco-feedback as a means to bridging this *environmental-literacy gap* by raising its users' awareness about the environmental impact of their food consumption. Additionally, Envirofy contributes to environmental HCI research by becoming the first tool to implement behavioural intervention techniques at the point of purchase, which aims at better addressing the behavioural intention gap (Hedin et al. 2019).

2.2.3 Food Labelling

Food labelling has been used in many different contexts with the sole aim of providing the consumer with a better understanding of certain details of a product. This technique aims to equip the consumer with sufficient knowledge which would allow for an informed shopping decision. However, food labelling has not always been successful in shifting the consumer's behaviour. A large body of literature, discussing the effectiveness of food labelling on guiding and affecting consumer behaviour towards eco-friendly shopping, deemed food labelling to be uninformative and ineffective (Bleda and Valente 2008; Schumacher 2010; Thibert and Badami 2011; Tobler et al. 2011). This was largely attributed to the fact that the current food labelling system does not directly indicate a product's environmental impact but rather focuses on barely informative labels such as labels indicating a product being organic or locally produced. Food labels are often found to be misleading as not all products that are organic or locally produced necessarily have a low environmental impact. For example, in a study performed by (Lea and Worsley 2008), consumers, who were identified as "environmentally-conscious", were completely unaware of the very high environmental impact of meat consumption. In such a case, any meat products with a locally produced or organic label would mislead the consumer into thinking that an environmentally friendly shopping decision was achieved where in reality, that was not the case. Additionally, these misconceptions only seem to widen the behaviour intention gap. Most consumers, who were found to be willing to make environmentally-friendly decisions when shopping (Kimura et al. 2010; Sharp and Wheeler 2013), may be misguided without the necessary environmental information that would allow them to make an informed shopping decision. This, in return, leaves the consumers no choice but to rely on the "organic" and "locally produced" labels when shopping.

Envirofy builds on these research findings and aims to address the behaviour intention gap by improving the availability and accessibility of product-related environmental information at the point of purchase. To achieve this, Envirofy implements a carbon labelling system, which was proven to be an effective technique that reduces consumers' carbon footprint while grocery shopping (Brunner et al. 2018; Vlaeminck et al. 2014). The carbon-labelling system focuses on three main processes that take place during a product's lifecycle. Past research identified two main processes that contribute the most towards greenhouse gases emissions during a product's lifecycle (Tobler et al. 2011):

- The transportation process (Lorry, Train or Airplane)
- The production process of the product (e.g. Meat production Vs Plant foods production)

The environmental impact of both processes was found to be the most important factor that a consumer must take into account to reduce the environmental impact of their food purchases (Lea and Worsley 2008). Additionally, a third process's carbon footprint, the product's packaging, was included in the carbon-labelling system. The main reason behind this inclusion lies in

the misconception that was identified in previous studies (Lentz et al. 2018) where consumers overestimated the environmental impact of the product packaging. Displaying the packaging carbon footprint would allow to resolve this misconception and help equip consumers with the appropriate knowledge to make environmentally-friendly shopping decisions.

2.3 Behaviour Change Techniques

A systematic review of digital behaviour intervention techniques found that most studies lacked a connection to theoretical behaviour frameworks or concepts (Hedin et al. 2019). Thus, Envirofy's development was guided by behaviour change theory, specifically the behaviour change wheel (BCW), which will help boost the likelihood of influencing a user's behaviour (Michie et al. 2011). The BCW is mainly comprised of analysing current user behaviour, understanding the mechanisms that need to be altered to achieve targeted behaviour (in our case, the purchase of food from a supermarket's website), and finally the intervention techniques used to influence user behaviour (Michie et al. 2011). Envirofy implements the following interventions:

2.3.1 Traffic Light System

Plain carbon labelling, which is the display of a product's carbon footprint without any guidance on what it means, results in consumers struggling to relate the emissions, in grams of carbon, to something they understand (Thøgersen and Nielsen 2016). For instance, 89% of respondents in a study found interpreting plain carbon labels confusing (Gadema and Oglethorpe 2011). Envirofy addresses this issue by utilising the traffic light colour scheme (Figure A.1), which has shown an increase in carbon labelling's effectiveness in communicating a product's environmental impact (Thøgersen and Nielsen 2016).

2.3.2 Carbon Footprint Display

Providing real-time feedback to users about their consumption is an effective way of influencing their behaviour (Vine et al. 2013). Envirofy takes advantage of this by implementing a running total that is always displayed to the user while reflecting the total carbon footprint of the items in the basket. Additionally, to help minimize the effect of plain carbon labelling (see Section 2.2.1), Envirofy displays, in addition to the raw carbon data, the number of trees required to offset the total carbon emissions of a user's shop in a year (Figure 2.1), which can provide some context and understanding to the raw carbon emissions value (Waygood and Avineri 2011).

2.3.3 Re-ordering Of Products

Previous research identified the user environment to be an important factor affecting consumer behaviour, which can be manipulated to result in the desired consumer behaviour (Kurz 2018). The benefit of this approach is that consumers could be nudged towards better choices without necessarily forcing these choices on them (Hollands et al. 2013).

To help decrease the environmental impact of Envirofy's users, items with lower carbon footprint were made more salient through changing the order in which products are displayed on the supermarket website. The order of the items is based on their carbon footprint, with the products with the lowest carbon footprint showing up first and items with the highest carbon footprint showing up last (Figure 2.1).

2.3.4 Motivational Messages

Motivational messages have been shown to increase consumers' perceived effectiveness, which will positively affect their choice of sustainable food purchases (Honkanen and Young 2015).

Additionally, delivering these motivational prompts while the targeted behaviour is in action (in Envirofy's case: while shopping) can boost the perceived effectiveness and competence of shopping sustainably (Gifford and Comeau 2011).

Envirofy prompts the user with a randomly chosen motivational message (from a set of reputable sources) each time the user decides to shop. This aims to increase the user's perceived effectiveness and competence by explaining the impact of their shop on the environment and backing it up by a reputable source.

2.4 Supermarket Choices Decision

The grocery retail industry, with a market value estimated at 205 Billion pounds in the UK (Statista 2021), is considered the only major channel through which consumers' food consumption behaviour can be studied and hence influenced. With such increasing demand and the rapid rate at which e-commerce has become a competitive edge for retail shops, all major supermarket chains raced to support online shopping. Envirofy relies on supermarket websites to provide real-time interventions, which is easier to implement than in physical grocery stores. The browser extension aims to function on all major supermarkets, but certain technical and time limitations, which will be further explained in later chapters, prevents a wider deployment. Envirofy 2.0 currently runs on Tesco's and Waitrose's websites. The reasons behind the supermarket selection are further explored in the following subsections.

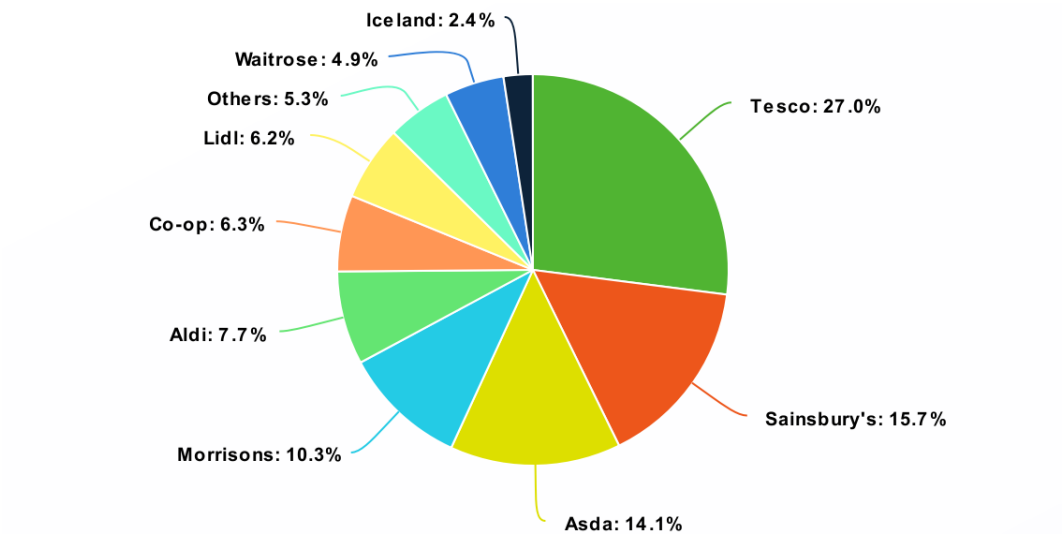


Figure 2.1: *A pie chart showcasing the major UK supermarket chains' market shares based on a 3-year survey (2017-2020) (Statista 2021)*

2.4.1 Tesco

Tesco is one of the biggest grocery chains in the United Kingdom. It leads the grocery retail industry with nearly a third of UK shoppers getting their groceries from Tesco (Figure 2.1). Additionally, Tesco leads "industry-wide action to tackle some of the biggest environmental challenges facing the world today" (Tescoplc.com 2021). Some of their most recent sustainable initiatives involve cutting on plastic in their food packaging as well as introducing the first recycled food-grade plastic packaging (Tescoplc.com 2021).

The Tesco e-commerce website is considered the first supermarket to be made compatible with Envirofy. This decision was taken based on Tesco's very large user base, which will not only result in a large user base for Envirofy but will also allow for large scale HCI research on consumer behaviour about food consumption in the UK. Additionally, Tesco's pledge to help tackling environmental issues opens up opportunities for future collaborations between Envirofy and Tesco, which will be beneficial to environmental HCI research.

2.4.2 Waitrose

Waitrose is considered one of the most contributing supermarkets when it comes to tackling environmental issues (Clayton 2020). The supermarket chain is the 8th biggest supermarket chain in the UK (Figure 2.1) and it has a much smaller customer base when compared to Tesco. In this case, however, the quantitative aspect of Waitrose's user base was not the actual motive behind the decision to make Envirofy compatible with the supermarket's e-commerce website.

The main reason Waitrose was chosen as the next grocery shop to get *envirofied* was the qualitative aspect of the supermarket's user base. Waitrose is known to cater for users belonging to a higher-than-average social class. For instance, a survey run on supermarket shoppers found that nearly half (47%) the shoppers at Waitrose belong to social class A or B (i.e higher income than the UK average) when compared to only 21% of shoppers at Tesco (Jeffries 2004). This is an interesting characteristic that could be studied and contrasted with Tesco users' food consumption behaviour, which would help, in the future, establish whether a relationship between a user's social class and their environmentally friendliness, when it comes to food choices, exists or not.

2.5 Summary

This chapter examined the first version of Envirofy and the main theoretical concepts that dictated Envirofy's development while also exploring related HCI research. Additionally, behavioural intervention techniques implemented in Envirofy were described and linked to behavioural theory. Finally, the choice of supermarkets on which to make Envirofy compatible was justified.

3 Requirements Analysis

This chapter discusses the functional and non-functional requirements of the project and how they were elicited.

3.1 Requirements Elicitation

This project was proposed by a post-doctoral researcher at the University of Glasgow, Gözel Shakeri (the client), who wanted to create a new version of Envirofy that is more efficient, more environmentally friendly, more effective, more generalised (compatible with numerous supermarkets), and has a lower display latency than the first version. The requirements were identified at the beginning of the project but were iteratively revisited and updated as the project progressed. This was an agile process that allowed for requirement analysis and negotiation during the weekly client-meetings. This permitted the author to refine the requirements, prioritise the key features and ensure that the project was on the right track.

The high-level requirements collected from these meetings were:

- Storing food's carbon footprint data to be accessed instead of crawled every time a user shops.
- Developing and integrating the behavioural intervention techniques to utilise the stored carbon data.
- The newer version should have a lower intervention-techniques-display latency when compared to the first version (Section 2.1.3).
- The newer version should have a negligible carbon footprint when compared to the first version (Section 2.1.2).

3.2 Functional Requirements

Once the requirements elicitation process was completed, the functional requirements could be established. This type of requirements aims to outline the expected behaviour of the software system. The functional requirements were documented using the MoSCoW approach (Agile-Business 2014). MoSCoW is a prioritisation technique that ranks the requirements, based on their significance in the system, using 'Must Have', 'Should Have', 'Could Have' and 'Won't Have' categories.

3.2.1 Must Have

These requirements are essential for the successful implementation of the software product. Failure to meet these requirements would result in a product that is not viable.

M.1 Storage of food's carbon data - The software product must be able to fetch all of the supermarket product's carbon footprint and store it to be accessed upon request.

M.2 Sorting of products - The software product must be able to sort the food items on the supermarket webpage in ascending order based on the food item's carbon footprint.

M.3 Display of motivational messages - The software product must prompt the user with a motivational message at the beginning of every new shopping session (Section 2.3.4).

M.4 Display of product's carbon data - The software product must display each food item's total carbon footprint as well as the breakdown of that carbon footprint through the use of the Traffic Light System (Section 2.2.3 and 2.3.1)

M.5 Display of the running total (Section 2.3.2) - The software product must display the total carbon footprint of the items in a user's basket as well as the number of trees required to absorb the total resulting GHG emissions in a year.

M.6 Real-time updating of the running total - The software product must continuously update the running total, which means that the addition or removal of items from the user basket must be handled.

3.2.2 Should Have

These requirements are considered of high importance, but they are not vital for the browser extension's ability to perform its main functionalities.

S.1 Logging - The software product should log the user's actions on the supermarket website (i.e Removal of item from basket, checking out, etc.) and store these logs to be studied later.

S.2 Information upon hovering - The software product should provide the functionality of displaying the breakdown of a food item's carbon footprint when the user hovers on that item.

3.2.3 Could Have

These requirements are desirable and are not essential for the functioning of the system. They will be implemented only if time permits doing so.

C.1 Integration of Envirofy's sorting into the supermarket website's sorting - This essentially means that when a user changes the sorting of the items based on a certain criterion (i.e Alphabetically) the items would reflect this in addition to Envirofy's sorting function.

C.2 Development of a new behavioural change technique (BCT) - The product could incorporate a new BCT, which in this case would be changing the picture quality of food items that have a high carbon footprint.

3.2.4 Won't have

These are requirements that are not going to be delivered and were agreed on with the client that they are out of scope. In addition, they present opportunities for implementation in the future.

W.1 Alternative item recommendation - The software product would have the functionality to recommend an environmentally friendly alternative to items with a high carbon footprint.

W.2 Carbon taxation - The product would include the functionality of allowing the user to offset the carbon footprint of the shopping session through paying for the planting of trees to a third party service provider(e.g. www.plantyourchange.com).

3.3 Non-Functional Requirements

In addition to the functional requirements, non-functional requirements were established as well. Non-functional requirements do not seek to describe a system's behaviour, but rather aim to denote the attributes expected of that system. Later chapters build on these requirements to arrive at the architectural design and implementation decisions.

NF.1 Latency - The browser extension must have a latency of 1000 ms or lower for the display of the behavioural change techniques.

NF.2 Carbon footprint - The browser extension must have a negligible carbon footprint.

NF.3 Modularity - The browser extension must be maintainable and easily extendable with new or updated features.

NF.4 Flexibility - The browser extension must provide flexibility to be implemented on other supermarkets' websites.

NF.5 Integration - The software product must allow for future integrations with the supermarkets that might require direct access to the food items' carbon data.

3.4 Summary

This chapter detailed the identification of the set of functional and non-functional requirements and how they were arrived at. In addition, it explained how the MoSCoW prioritisation technique was used to set out the project scope. The next chapters discuss how these requirements were incorporated into the development of the browser extension.

4 Design

The product's system architecture decision was arrived at using two software development principles. The first principle involved following the Minimalist Architecture. In this approach highest priority is given to the architectural requirements and then the least possible is done to achieve them (Malan and Bredemeyer (2002)). The second approach involved utilising the component-based software development principle. Under this approach, the system was designed to use small, loosely coupled, reusable and modular components, which allow for better maintainability as any change done to the system is localised to the individual component, hence it does not affect the rest of the system (Hopkins (2000)).

This combination of approaches ensured that requirements **NF.3** and **NF.4** are adhered to, while maintaining the development process on the right and most efficient path.

The resulting architecture of Envirofy 2.0 comprises 4 major components:

- **UI Component** - The user interface where the behaviour intervention techniques are displayed to the user by the browser extension.
- **Database Component** - The placeholder of the crawled products along with their carbon footprint metadata.
- **Crawler Component** - Component that allows for the scraping of the supermarkets' products and their metadata.
- **Web API Component** - Component that handles the business logic for the browser extension.

This was the foundational architectural plan from the beginning of the project. The main focus was on having all the supermarket's food-related carbon metadata stored to be served upon request. Section 4.1 discusses the initial system architecture as well as the identified problem with it. Section 4.2 discusses the solution to the problem as well as the revised system architecture.

4.1 System Architecture

4.1.1 Initial System Architecture

Initially, Envirofy 2.0 relied mainly on the already stored food-related carbon metadata to display the behavioural change interventions. Figure 4.1 displays the initial system architecture diagram where the components are identified. As we can see, the crawler firstly begins by crawling the supermarket website to gather all the food-item metadata, independently of the browser extension, which then helps calculate each item's carbon footprint. Then, after the carbon footprint of each item is calculated, they get stored in the database. The crawling was to be run on a Bi-monthly basis, through the use of cron jobs, to cater for newly added food items on the supermarket website. At this stage, a user can start using Envirofy on their web browser. The user starts by interacting with a supermarket's online shopping website (Tesco or Waitrose). This prompts the browser extension to collect the food items' names that are currently displayed on the user's webpage and send them to the web API. The API, then, fetches the corresponding food items' carbon metadata and relays them back to the browser extension. Finally, the browser extension

utilises the received carbon data to display the behaviour intervention techniques to the user, on the supermarket's webpage.

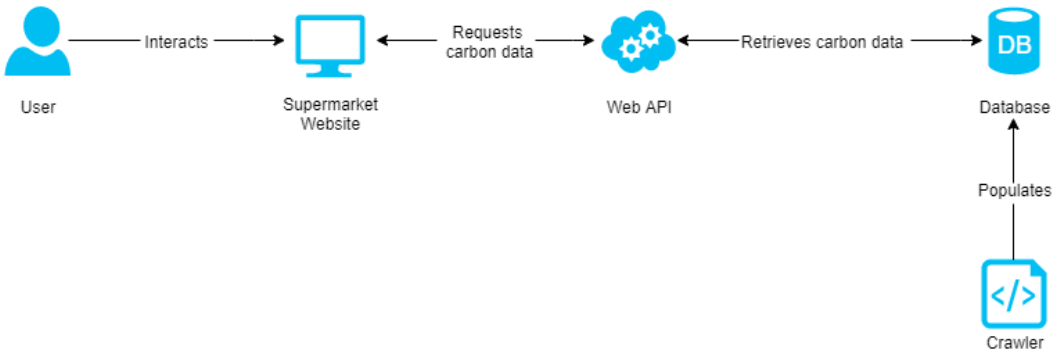


Figure 4.1: *Initial system architecture.*

There were two major issues with this approach, however. Firstly, if the supermarket decided to add a large batch of new products in between the times that the crawler runs, it might be long before these new items' carbon footprint gets stored in the database, severely disrupting the browser extension's functionality. Secondly, running the crawler on a Bi-monthly basis have a huge carbon footprint amounting to 410 Kg of CO2 per month (number of products on average per retailer * carbon footprint per HTTP request * Bi-monthly = 3000 * 6.83 * 2). This essentially offsets the effect of Envirofy and severely violates requirement **NF.2**. The initial architecture, then, had to be revised to address both issues.

4.1.2 Revised System Architecture

Figure 4.2 displays the revised system architecture diagram. We can see that an additional minor component was added – the crawler script. This component's main functionality is to allow for the instantaneous crawling of a product, the calculation of its carbon footprint and its storing in the database (Section 5 for more details). This approach eliminated the need to run Bi-monthly cron jobs, saving a huge amount of CO2 emissions and ensuring the compliance with requirement **NF.2**. In the revised system architecture, the crawler begins by crawling the supermarkets' food items (Tesco and Waitrose) and then populating the database with the calculated carbon footprint metadata. The user can then interact with one of the supermarket websites, which upon loading prompts the browser extension to initiate an API call with the food items displayed on the user's browser. The web API, then, tries fetching the corresponding carbon footprint metadata from the database. If all the requested products' data were found in the database, the carbon metadata are sent back to the browser extension through the web API to be utilised in displaying the behavioural change techniques. If, however, one or more products' data could not be fetched from the database, the crawler script gets triggered and instantaneously crawls the specified product, calculates its carbon footprint and stores it in the database. The were-missing product(s)'s data are then appended to the response data and sent back, through the web API, to the browser extension to be displayed.

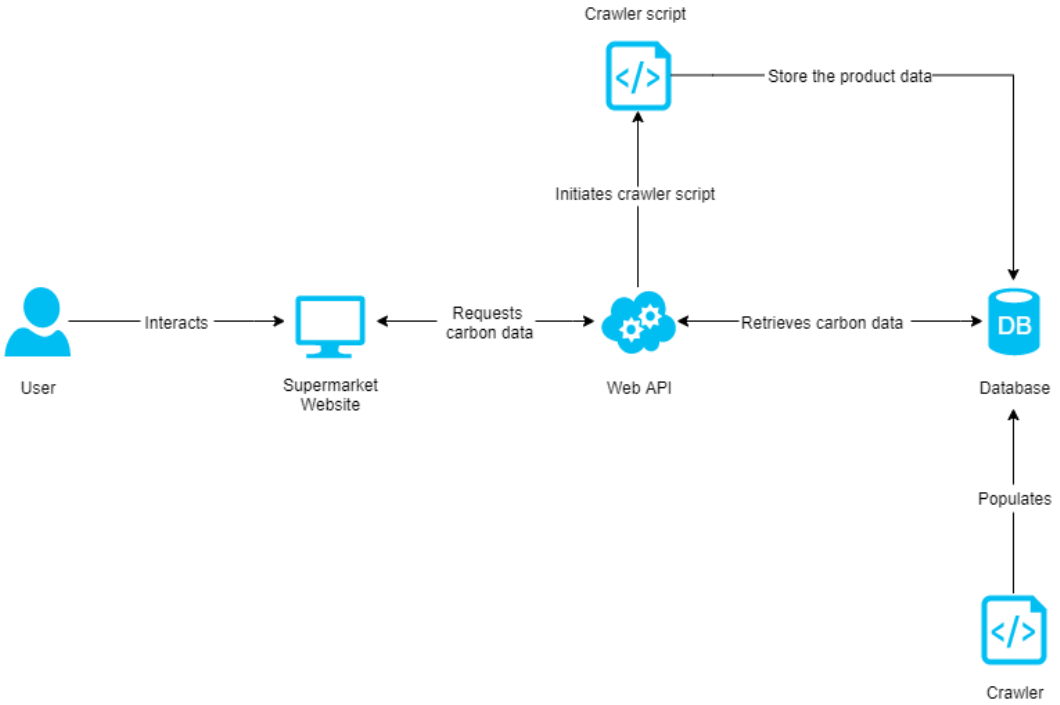


Figure 4.2: *Revised system architecture.*

4.2 User Interface

A major part of the Envirofy browser extension is the display of the Behaviour Change Techniques (BCTs) identified in Section 2.3. There was no need to undergo the user interface design process (i.e creating wireframes, prototyping, etc.) as the client had already provided an example (Envirofy 1.0) of where the BCTs should be located on the supermarket's webpage. The main design points that were focused on were:

- The running-total should always be displayed to the user (i.e on any of the supermarket's webpages: checkout page, welcome page, etc.)
- Each food item should have the four icons (Total carbon footprint and its breakdown: production carbon footprint, transport carbon footprint and the packaging carbon footprint) displayed.
- Each food item in the user's basket should have a traffic light system label indicating its environmental impact (carbon footprint and corresponding colour).

Figure 4.3 showcases an example of Envirofy 2.0 in action for the Tesco online shopping website. We can see the different BCTs displayed which involve:

1. The running total which is attached to the basket column, as shown in the top right corner of Figure 4.3, as the trolley is always displayed across Tesco's different webpages.
2. The icons representing the breakdown of the carbon footprint of each food item
3. The labelling of the items in the basket with a colour from the traffic light system and their corresponding carbon footprint.

Figure A.1 showcases an example of Envirofy 2.0 in action for the Waitrose online shopping website. The display of BCTs on Waitrose's website shares high similarity with that on the Tesco website as requested by the client. The reason behind this is to establish a consistent layout to prevent the existence of confounding variables in any future studies utilising Envirofy 2.0.

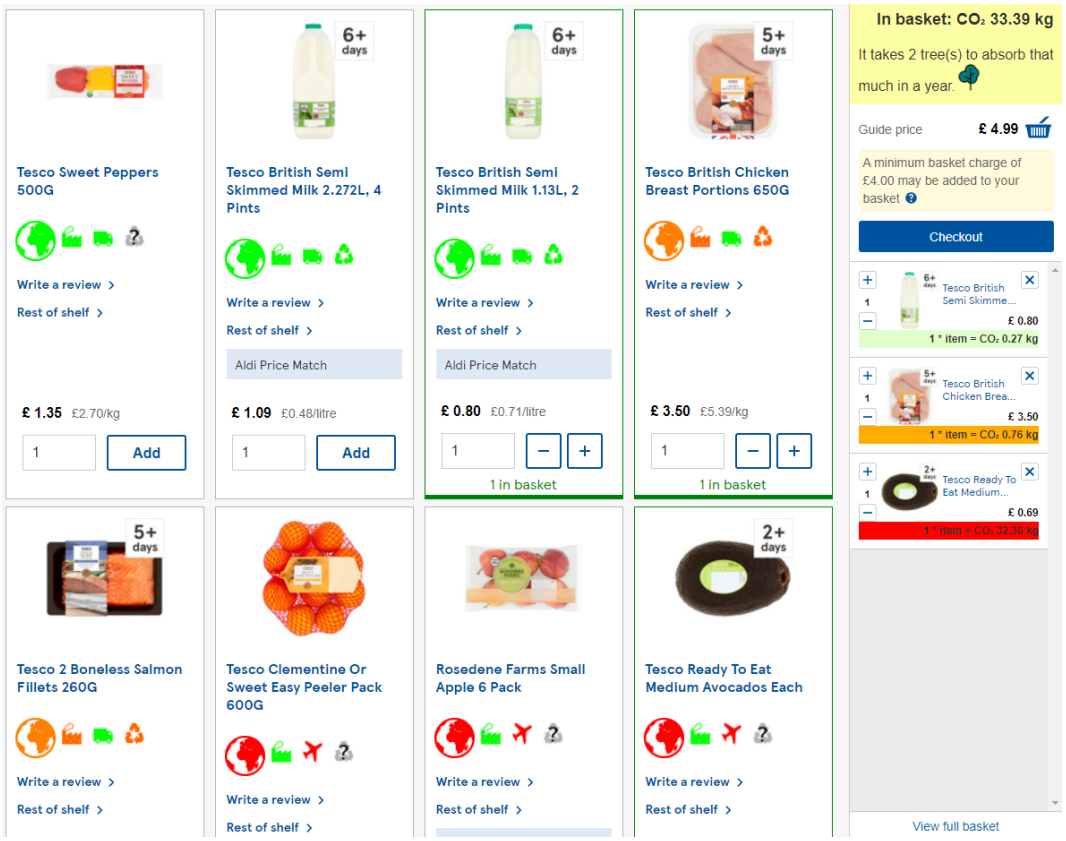


Figure 4.3: *Envirofy 2.0 in action on the Tesco online-shopping website (All fresh food category, accessed on 17-02-2021).*

4.3 Tools And Technologies Used

In order to develop the software product, appropriate technologies and tools must be selected. Numerous options were available to utilise in the development of the different components; The selection process of the software technologies used for each component is examined and the reasoning behind each selection is explained.

4.3.1 User Interface

The user interface is essentially the Envirofy browser extension. The browser extension's main function is displaying the behaviour change techniques on the supermarket webpage, which is mainly achieved through the manipulation of the HTML DOM. The consensus on developing a browser extension is to utilise Javascript with additional third-party libraries (i.e Jquery). Additionally, the first version of Envirofy was also developed using Javascript. It was then decided that Envirofy 2.0 will be developed using Vanilla Javascript, which essentially means development using Javascript without using any external libraries. The reason behind this is that Vanilla Javascript has all the necessary functionalities needed to achieve all the functional requirements as well as a much faster execution time when compared to third-party libraries (VanillaJS 2021). This would then contribute to the development of a fast and efficient Envirofy 2.0. This ensured requirement **NF.1** is met.

4.3.2 Web API

The web API represents the pivotal component of the software system. It is responsible for handling the sending and receiving of the carbon footprint data between the browser extension and the database. There exist many types of web API protocols such as SOAP, RPC, and REST. Each of these has its own pros and cons and use cases.

For Envirofy 2.0, the web API needs to facilitate client-server communication, needs to be reliable and scalable and needs to provide a uniform interface to allow for communication between different applications (see **NF.5**). For these reasons, the web API component was implemented to be RESTful. Even though there exist a plethora of frameworks (Ruby on Rails, Laravel, etc) to implement a RESTful API, the author opted to utilise the Django-rest framework. This decision was mainly based on the time limitations that exist for this project, as other frameworks have a steep learning curve and would require the author to learn a new programming language; However, the Django-rest framework utilises a programming language that the author is proficient in, Python.

4.3.3 Crawler

The crawler is a crucial component of the Envirofy 2.0 system architecture. As the crawler is considered a back-end component that may sometimes get triggered using the RESTful API, as discussed in Section 4.1.2, and the possibility to easily integrate with Django's models, it was decided that the crawler should be developed using Python. Additionally, Python offers a good variety of choices when it comes to web scraping frameworks. Even though there are three major scraping tools (Scrapy, Selenium, and BeautifulSoup), it was decided that the crawler would be developed using the Scrapy framework. The reason behind such a decision lies in Scrapy's self-sufficiency, which means that it does not need any other external libraries to be able to crawl and save data. In other words, Scrapy can sustain a robust web-scraping project on its own, unlike the other two tools which require additional libraries in order to function and have a features-scope similar to that of Scrapy. Finally, Scrapy offers seamless integration with Django's models rendering the storage of scraped data easy and straightforward.

4.3.4 Database

In order for the crawler and the RESTful API to function, a database engine was needed. There exist two types of database engines: a NoSQL-based database engine and a SQL-based database engine. The storage of the food-related carbon footprint did not really require a relational database engine as the database is used simply for storing and fetching the carbon data. However, Envirofy 2.0 was developed with future development in mind (development after the project period), which meant that the "Won't have" functional requirements (see Section 3.2.4) were taken into account during development. As some of these requirements would require a SQL-based database, it was decided to use a PostgreSQL database engine. A PostgreSQL database offers storage of both SQL (structured) and NoSQL (unstructured) data, high scalability potential (essential for the huge food carbon data to be stored), and seamless integration with the Django framework.

5 Implementation

This chapter will discuss the implementation stage of Envirofy 2.0. First, software engineering practices used are examined. Implementation details and the challenges encountered as well as how they were overcome for each of the system components will then be discussed. Finally, the deployment process for Envirofy 2.0 and the challenges faced will be investigated.

5.1 Software Engineering Process

Throughout the project, the following software engineering practices were adhered to.

5.1.1 Agile Development

The software development process followed the Agile Manifesto (Beck et al. 2001). The development was iterative in nature, with very close communication with the client. Weekly meetings were set up from the very beginning of the project during which, project progress was demonstrated. The time-span in-between meetings served as the sprint. These sprints were utilised to research HCI literature, identify new requirements or refine existing ones, or develop new features. Other Agile methodologies such as refactoring and Continuous Integration were also utilised during the development process.

No specific Agile framework, such as Scrum or Kanban, were followed when developing Envirofy 2.0. A few documentation artefacts were used to help with the development process:

- A document captured the minutes of each client meeting.
- A second document was used to log the time spent on each task.
- A third document contained general observations about the project, key points from HCI literature, challenges encountered, and the project requirements.
- A Trello board was used for issue management.

These artefacts were utilised because the project was developed by only one person, the author, which meant that communication with other team members did not need to be accounted for.

5.1.2 Version Control

From the very beginning of the project, Git, which is a distributed version control system, was used during the development of this project. Git is a well-known source control system and was mainly used because of its reliability and simplicity of use.

The project repository was hosted on Github mainly because of the features provided, specifically the Continuous Integration and Continuous Delivery pipeline feature. The main benefit of the remote repository is to always have a functional backup for the source code in case the local copy malfunctions. Further, branches were created for each new feature that was to be developed. This helped ensure features were developed separately, leaving the functional source code on the master branch untouched.

5.1.3 Issue Management

Issue management was used throughout all the development stages of Envirofy 2.0. This helped the author keep track of the different project requirements while also letting the author know exactly what was done and what is left to be produced. Figure 5.1 displays a Trello board which was set up with a different list of issues grouped into categories such as 'To do', 'Blocked', 'In progress', 'Ready', and 'Done', which help indicate the stage at which the issue is currently at. This provided an efficient and helpful overview of the project progress. Additionally, the setting up of deadlines helped ensure the project progress remained on time as well as helped estimate the needed time for other issues that were to be implemented.

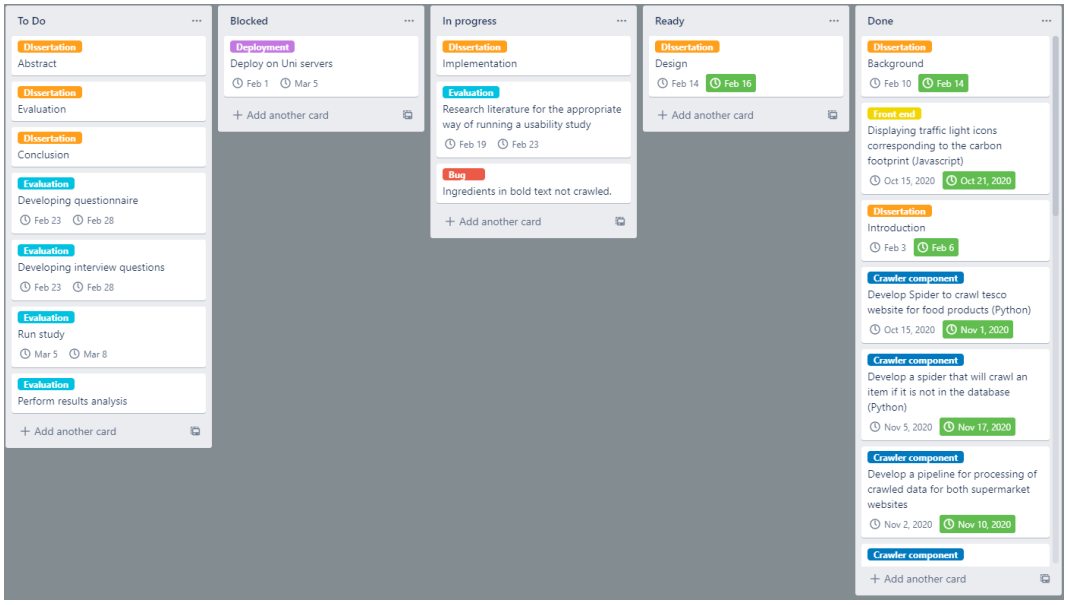


Figure 5.1: *Trello board for Envirofy 2.0 issue management. Issues are split into multiple lists to indicate their current stage, are labelled relevant to what the task involves and are equipped with a start and due date.*

5.1.4 Continuous Integration and Delivery

Continuous Integration (CI) is mainly concerned with the process of frequently integrating new features into the project by having an automated script that tests and builds the software to ensure that the build was successful. Continuous integration was used slightly later after development started as there was not much to test against at the beginning. Github Actions were used to build the CI pipeline, which comprised unit tests. CI was only implemented on the Backend components (Crawler, RESTful API and Database) as the frontend's (browser extension) correctness was not verified through unit tests but rather through acceptance tests (see Chapter 6).

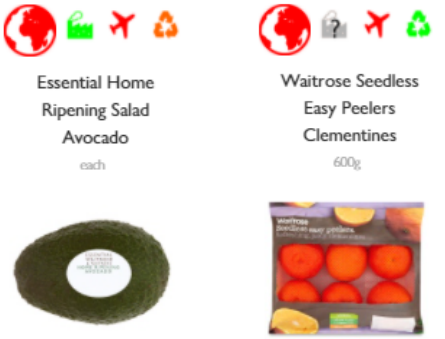
Continuous Delivery (CD) works in conjunction with the CI pipeline by deploying the software if it passes the build without errors. CD was set up for the backend components, which represent the main part of the system with which the browser extension communicates. An update on the master branch would pass through the CI pipeline on Github and, if successful, would get deployed on Heroku, a platform as a service company, where the API was hosted. Unfortunately, technical difficulties were faced with Heroku (Section 5.5) and the API was moved to one of the University's servers, which meant that CD was halted.

5.2 User Interface Component

Upon the loading of the supermarket webpage, the browser extension scrapes the names and the URLs of the products, turns them into JSON data representation and sends it to the RESTful API. Corresponding carbon data is received from the API and four icons are displayed using the traffic light colour scheme (Section 2.3) for each of the products on the webpage (Figure 5.2a):

1. A globe icon representing the total carbon footprint of the product.
2. A vehicle icon representing the transportation's carbon footprint.
3. A factory icon representing the production' s carbon footprint.
4. A recycling icon representing the packaging's carbon footprint.

The traffic light colour threshold values were based on a study run by (Brunner et al. 2018). If any of the carbon breakdown categories are missing for a product (insufficient information to calculate the carbon footprint for that category), a grey icon with a question mark is displayed instead (Figure 5.2b)



(a) *Example of all traffic light icons in action.*

(b) *Example of traffic light icons with one unknown value.*

Figure 5.2: *Example of the display of the traffic light icons implemented by Envirofy 2.0 on the Waitrose website (a) shows all traffic light icons when all the carbon breakdown values are available. (b) shows all traffic light icons when one of the categories from the carbon breakdown values is unknown (production value in this case).*

Furthermore, carbon data received from the API was injected into each product's HTML node to be retrieved when a user decides to add a product to the basket. This was done to minimise the browser extension's carbon footprint, as items added to the basket, and hence updating the running total, would have required making a redundant API call to fetch the product's carbon data for a second time. Additionally, the user's local storage was leveraged to store the products added to the basket, along with their carbon footprint, to appropriately update the running total when a product is added or removed from the basket. This data is erased from the local storage when the user decides to checkout. Moreover, each product listed on the webpage was assigned event-listeners for clicks on the addition-to-the-basket buttons and the increase- or decrease-amount buttons, which would allow for the running total to be updated accordingly.

This approach relies heavily on hardcoded CSS selectors, as this is the only way to perform DOM manipulation and data scraping. This meant that making Envirofy more generalised, to cater for all the UK supermarket chains, was only possible through making Envirofy compatible with each supermarket chain's own website. Due to the time limitations of this project, it was agreed

with the client to deliver a version of Envirofy that is compatible with Tesco and Waitrose, which represented the highest priority for the client.

Envirofy 2.0 followed the same approach for both supermarkets, with some modifications implemented in Waitrose's case due to the dynamic nature of Waitrose's website when compared to the more static oriented Tesco website. For example, MutationObserver, "which is a built-in Javascript object that observes a DOM element and fires a callback when it detects a change" (Javascript 2021), was used to wait for the dynamic content of Waitrose's website to load so that the Envirofy 2.0 can collect products' data and send them to the API.

5.3 RESTful API Component

The Restful API was implemented using the Django Rest framework. Django's views were utilised to map URLs to certain functionalities. There are two main scenarios through which the API is used. In both scenarios, the Serializer library was utilised due to its simplicity of turning JSON data into a python-readable format and vice versa.

The first scenario is concerned with the handling of the requested products' carbon metadata from the browser extension, which are fetched from the database and returned to the browser extension, through a HTTP response, if found. If one or more of the requested products' metadata couldn't be found in the database, a crawler script is triggered to crawl the missing product's webpage and calculate the corresponding carbon footprint, which is then stored in the database and appended to the data being sent back to the browser extension. This was implemented using a Django view function that is linked to a specific URL on which the browser extension sends the data.

The second scenario involved receiving the logs of the user actions from the browser extension and storing them in the database. This followed a similar approach to the handling of products' carbon metadata, where a view linked to a URL was used to send the logs on, which then get stored in the database using Django's models.

5.4 Crawler Component

The crawler component was developed using the Scrapy web scraping library in Python. Almost all web scraping methodologies rely on the HTML of the webpage to perform web scraping. This is the case with the Scrapy library, which, for Envirofy 2.0, relied on CSS selectors to target the desired data to be scraped.

Figure 5.3 displays how the Scrapy library works and how it is integrated with the Django framework. First, a *spider* initiates a request to the desired webpage and receives an HTML response, which gets parsed for extraction of data. The spider, which has all the necessary rules and CSS selectors, extracts the data and builds *items*, which are temporary placeholders, that are then passed to Scrapy's pipelines. These pipelines are one of the most beneficial features of Scrapy as they offer built-in post-collection data processing. After the data is processed, Django model objects are created to allow the data to be stored in the database.

For Envirofy 2.0, various pipelines are used to process the crawled data. However, there exists three main ones that are considered critical for the functioning of Envirofy 2.0. These pipelines calculate a food item's total environmental impact (TEI) by calculating and summing the carbon footprint of the item's food production (FP), packaging(P) and transport mode (TM).

The carbon footprint of a food item's production is calculated using the ingredients scraped from the item's webpage. For example, the item "Breaded Chicken Goujons 270G" [1] has "Chicken

[1] https://www.tesco.com/groceries/en-GB/products/279935929

(58%), Wheat Flour, Rapeseed Oil, Water, Pea Fibre, Yeast, Salt, Dextrose" as ingredients. Each ingredient's mean carbon footprint is extracted from a JSON file that contains carbon footprint data gathered from Berners-Lee (2011) and Poore and Nemecek (2018). As the make-up percentage is not specified for the rest of the ingredients, a decay function is used to calculate the remaining 42%:

$$y = a(1 - b) * x \tag{5.1}$$

where **x** is the number of remaining items in the list, **(1-b)** is the decay factor, and **a** is the remaining percentage (e.g. 42%), and **y** is the amount of carbon footprint.

The position of the ingredient in the ingredients list affects the extent to which it contributes to the total FP carbon footprint (i.e an item at the beginning will have a greater contribution than an item at the end). If no ingredients list was provided on the product page, the ingredient will be extracted from the title and the FP carbon will only be based on that (e.g. bananas from "Tesco Bananas Loose").

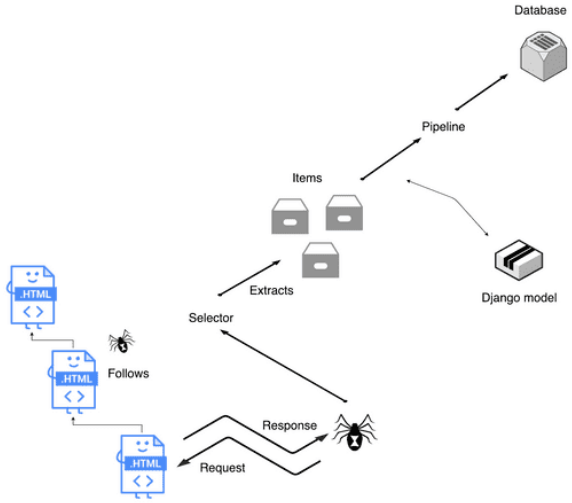


Figure 5.3: *High-level workflow diagram of the crawling process as achieved by the Scrapy library spider.*

The packaging's carbon footprint is calculated using the average CO2 emissions of the plastic's lifecycle, which includes the production, recycling, and waste handling of the packaging (Juerg 2009). The carbon footprint is computed by counting the occurrences of words related to plastic (i.e. "recyclable", "not recyclable", "polypropylene,") and multiplying that count by the average carbon value of plastic during its lifecycle. It is worth noting, however, that this calculation assumes all recyclable plastic is recycled.

The carbon footprint of an item's transportation is calculated using:

$$y = d * m * w \tag{5.2}$$

where **d** is the approximate distance transported, **m** is the average carbon footprint of the mode of transportation used (i.e plane, lorry, train), and **w** is the net weight of the item.

If a product originates from just one country, the distance from the UK to that country is calculated in kilometres using the country's capital coordinates(found at CSG (2021)). If the product has multiple countries from which it can originate and the UK is one of them, it is

checked if that product is in season in the UK, if it is, then the product is assumed to have originated from the UK. However, if the product is not in season in the UK or the UK is not one of the countries in the list, the average distance from the UK to all the countries in the country list is calculated. The transport mode is decided based on the distance calculated and whether that product is perishable. Perishable foods are known to be transported by plane or train whereas non-perishable food is transported by sea or lorry (Timeforchange.com 2021). Additionally, if a food item originated in Europe and is perishable, it is assumed to be transported using a train and non-perishable food is assumed to be transported by lorry (Warehousespace.com 2021).

The implementation of the crawler on Tesco's website was achieved through a URL parameter (i.e "page=2" in "https://www.tesco.com/groceries/en-GB/shop/fresh-food/all?page=2") to move on to the next product list page (also known as pagination). However, this was not as simple when it came to the implementation on the Waitrose website. This had to do with how the Waitrose website serves its content. Unlike Tesco's static-serving website, Waitrose's website serves its content dynamically without any pagination, which was challenging as Scrapy is not equipped to deal with dynamic websites. This was addressed by utilising the Selenium library, which is a web-based automation tool. Selenium was integrated into the crawler so that all the items could be crawled successfully by clicking on the *load* button whenever the crawler was finished crawling the current items on the page.

5.5 Deployment

Envirofy 2.0 was planned to be deployed on Heroku from the beginning of the project. Heroku was an attractive choice as it offers free hosting services and simple integration with Django-based projects.

A deployment was scheduled midway through the development process to ensure that Envirofy 2.0 is ready for the evaluation stage. The deployment's success was of critical importance for the evaluation stage, especially in the current circumstances (i.e. Covid-19) that rendered face-to-face interactions almost impossible. The deployment on Heroku was almost successful. Testing Envirofy 2.0's functionality after deployment showed that the crawler component, which is Envirofy 2.0's most important component, was for some reason unable to run. To address this, the author tried deploying the project using Docker containers. This solution was unsuccessful as the crawler remained non-functional. A temporary solution that allowed to test Envirofy's deployment was crawling the data locally, storing it in a local database then dumping the data onto the remotely hosted database on Heroku. This was also deemed unpractical as the crawler script (Chapter 4) would then be unable to run.

Finally, it was decided to try and deploy Envirofy 2.0 on the University of Glasgow's servers. A virtual machine (Ubuntu 20.04) was used to host the backend components (Crawler, REST API and Database). A web server was setup up using Nginx (nginx.com 2021) and the components were linked to that webserver using Gunicorn, which is a web server gateway interface used to run Python applications (gunicorn.org 2021). This deployment was successful as the crawler was able to run and no further issues were faced.

5.6 Summary

This chapter reviewed the implementation stage of the development process of Envirofy 2.0. Software engineering practices used in this project were explored, highlighting how they helped during the development. Then, system components were further investigated from a technical perspective while highlighting the challenges faced in their implementation and how these were overcome. Finally, the deployment process was reviewed while justifying the deployment decisions taken.

6 Evaluation

This chapter discusses the evaluation and testing techniques used to evaluate Envirofy 2.0. The following research questions, derived from the project aims and the non-functional requirements, are answered in this chapter: *Does Envirofy 2.0 have a reduced carbon footprint when compared to Envirofy 1.0?*, *Does Envirofy 2.0 offer a lower loading latency than Envirofy 1.0?*, *Does Envirofy 2.0 offer a better usability experience than Envirofy 1.0?*

6.1 Unit Testing

Unit tests were developed to prove the correctness of the code behind Envirofy 2.0 as well as to ensure that the system is behaving as expected without any issues. The tests developed mainly focused on the backend components of Envirofy 2.0 (REST API, crawler, database). It was decided that developing unit tests for the browser extension would not be an effective way to test it as it is mainly responsible for displaying the data received from the backend components. Django's testing library was used for the development of the unit tests as it provided all the necessary features needed for creating the unit tests.

The Coverage.py library (Coverage.py 2021) was used to measure the code coverage of the unit tests on the backend components to ensure that the unit tests were effectively covering all the system functionalities. Figure I.1 displays the code coverage report on the backend components of Envirofy 2.0. The report indicates a code coverage of 85% while taking into account statement and branch coverage, which increases the confidence in the software quality.

6.2 Acceptance Testing

Acceptance testing aims to assess the system behaviour from a user's perspective. The test cases are based upon the project's requirements, which ensures that the software product is behaving as the client specified. Acceptance tests for Envirofy 2.0 were developed using the Selenium Integrated Development Environment (Selenium.dev 2021), which is a web testing automation framework that aims to simulate a user's behaviour.

The tests cases examined the ways a user could interact with a supermarket website and the behaviour expected from Envirofy 2.0, including the display of the appropriate carbon values and carbon labels, the updating of the running total when items are added or removed from the basket, the appropriate running total updates when increasing or decreasing the amount of an item in the basket and the addition of an item from its webpage instead of the main webpage of the supermarket (Figure A.3).

6.3 Performance evaluation

Non-functional requirement **NF.1** states that the browser extension must have a low latency for the display of the behaviour intervention techniques, specifically, a latency lower than 1000 ms. To determine whether this requirement was met, a performance evaluation was carried out

using the Google Chrome Runtime Performance Monitoring tool (Devtools 2021). This tool provides in-depth analysis of code execution on a given page as well as the specific execution times down to specific code snippets. The latency for this evaluation was determined to be the time taken since the browser extension started executing, up until the behaviour intervention techniques were successfully displayed on the webpage. This offered a fair and consistent way to allow for comparison between both versions. Table 6.1 displays the results of measuring the latency 10 times for each version of Envirofy as well as the corresponding average latency and standard deviation.

Version	Latency (ms)										Average	Standard Deviation
Envirofy 1.0	2823	2665	2854	2677	2597	2815	2789	2712	2532	2640	2710	107
Envirofy 2.0	573	558	652	528	517	502	529	483	440	538	532	54

Table 6.1: *Latency evaluation results in milliseconds for both versions of Envirofy (1.0 and 2.0)*

The results indicate that Envirofy 2.0 has much lower latency, with an average of 532 ms, compared to that of Envirofy 1.0, which has an average latency of 2710 ms. The higher latency values and the corresponding variability for Envirofy 1.0 could be attributed to how this version gathers the carbon data, which is through initiating Http requests for each of the products listed on the webpage. Nonetheless, the results of this evaluation demonstrate that requirement **NF.1** was successfully satisfied.

Furthermore, non-functional requirement **NF.2** states that Envirofy 2.0 must have a negligible carbon footprint when compared to the first version of Envirofy. Envirofy 1.0 was found to have, on average, a carbon footprint of **4.53 Kg** per shopping session (Section 2.1). The carbon footprint of Envirofy is calculated by multiplying the average carbon emissions per Http request[1] with the number of Http requests made by Envirofy in a shopping session. The carbon footprint of the hosting server was excluded from this calculation as it is intrinsically difficult to calculate Envirofy's footprint fraction from the total server footprint, as a server hosts various other services. Additionally, the carbon footprint of the server is irrelevant for the comparison as both versions of Envirofy depend on a server for their functioning. Envirofy 2.0 makes **two** Http requests per a products-displaying webpage (request and response from server). Shakeri and Mccallum (2021) found in their study that the average number of products-displaying webpages visited by a user in a shopping session to be **30**. Using this info, we are able to calculate Envirofy 2.0's carbon footprint to be **0.38 Kg** (6.3g * 2 * 30) per shopping session[2]. Consequently, Envirofy 2.0's much lower carbon footprint (12 times less) when compared to the first Envirofy version, indicates that requirement **NF.2** was successfully met.

6.4 User Evaluation

As Envirofy 2.0 is designed for research purposes with the potential of becoming a commercially available product, a user evaluation was needed to ensure that the system is usable and is behaving as expected. Two main experiments were developed to evaluate Envirofy 2.0. The first experiment was mainly concerned with evaluating the usability of Envirofy 2.0 on the Waitrose website as it has not been evaluated on there before. The second experiment was concerned with evaluating

[1] Carbon footprint per HTTP request is equal to 6.3 g, found at: https://medium.com/wedonthavetime/guest-blog-post-the-alarming-environmental-impact-of-the-internet-and-howyou-can-help-6ff892b8730d

[2] Carbon footprint per Http request * Http requests per product-displaying webpage * number of product-displaying webpages visited on average per user in a shopping session

the usability and performance of Envirofy 2.0 on the Tesco website as well as comparing it to those of Envirofy 1.0. A total of 9 participants (4 females and 5 males) took part in the user evaluation, undergoing both experiments (Within-subject study). Participants were asked to fill a pre-interview questionnaire (Appendix B) and were supplied with a guide that explained how Envirofy works before conducting the study via a video meeting. The evaluation conformed with the ethics requirements of the School of Computing, which can be found in Appendix H.

6.4.1 Experiment 1

For the first experiment, participants were asked to perform three tasks (Appendix D) on the Waitrose website while expressing their thoughts aloud (think-aloud approach) (Nisbett and Wilson 1977). The tasks aimed to simulate a real-world online shopping session by giving the participant the freedom of choice when performing the shopping tasks as well as through asking the participant to pick items from different food categories (i.e. vegetables, meat, and fruits) as a normal user would. The purpose of the think-aloud approach is to qualitatively evaluate Envirofy 2.0, identify any usability issues that were faced by several participants as well as identify features that were specifically liked by participants. After the participants finished the tasks, they were asked three questions (Appendix E) that aimed to detect any usability issues and identify any self-perceived improvement in the participant's knowledge of the environmental impact of food choices. Finally, participants were asked to fill in a questionnaire (Appendix C) designed using the standardised system usability scale (SUS) (Brooke 1996). The purpose of the SUS questionnaire is to quantitatively measure the usability of Envirofy 2.0 on the Waitrose website.

6.4.2 Experiment 1 Results

The goal of the first experiment was to evaluate the usability of Envirofy 2.0 on the Waitrose website.

Think-aloud Study

Qualitative data relating to Envirofy 2.0's usability was collected using the Think-aloud approach in addition to three interview questions. The most common feedback received included:

- "*I really like the colour coding used. I think it is really useful and easy to understand.*"
  All participants expressed how they liked the traffic light colour scheme. They found it to be straightforward and easy to comprehend. Some participants felt more engaged and attentive when picking their items now that there was a potentially damaging impact on the environment.
- "*I had no previous knowledge relating to the environmental impact of food, but using Envirofy allowed me to make better decisions when shopping based on the environmental impact information provided.*"
  All participants, except for two, stated that Envirofy 2.0 helped focus their attention on the impact of food on the environment, and that without it not much thought would be put into the environmental impact of food.
- "*I cannot find the total carbon footprint, am I doing something wrong?*"
  A total of eight participants seemed to struggle with a step of a task asking them to identify the total carbon footprint of the items in the basket (yellow banner at the top of the webpage in Figure A.1). One participant said that they could not see the total carbon footprint because the video chat window was covering it. Another participant thought that it was a part of the Waitrose website and hence did not give much attention to it. All the participants that did not notice the total carbon footprint suggested that it would be better to have the total shown above the items in the basket to make it more noticeable.
- "*Red icons make me feel guilty, so I try to avoid items that have any red icons.*"

More than half the participants stated that the icons were the main factor driving their choice of food items. They explained that they tried to stay away from items that have red icons displayed on them and rather pick items that are more environmentally friendly (i.e. with green icons).

The findings of this think-aloud study indicate that Envirofy 2.0 was effective in delivering the required features on the Waitrose website, but there is room for improvement. This was evident with how certain participants struggled to identify the total carbon footprint, indicating a need to change its position on the webpage in a future iteration.

System Usability Questionnaire

Quantitative data relating to Envirofy 2.0's usability on the Waitrose website was collected using a system usability scale questionnaire. There are 10 questions in the SUS questionnaire, with answers ranging from 1 to 5, where 1 means "Strongly disagree" and 5 means "Strongly agree". A SUS questionnaire provides a quantitative measure for the usability of a system by transforming the results into a score that ranges from 0 to 100, with a higher score indicating better usability and ease of use. Table 6.2 displays the usability scores of the 9 participants, with a mean of 90.

User 1	User 2	User 3	User 4	User 5	User 6	User 7	User 8	User 9	**Mean**
78	95	85	80	88	100	90	95	93	90

Table 6.2: *Individual SUS scores for Envirofy 2.0 on the Waitrose website*

In an empirical evaluation of the SUS, it was found that systems with a score of 70 or above are considered to have adequate usability, while systems with even better usability scoring in the high 70s to upper 80s (Bangor et al. 2008). Consequently, we can confidently conclude from Table 6.2 that Envirofy 2.0 provides ease of use and offers a good experience in terms of usability, further strengthening the positive feedback gathered from the think-aloud study.

6.4.3 Experiment 2

Following the completion of the first experiment, participants were asked to partake in a second experiment. Like the first experiment, participants were asked to perform shopping tasks, following a think-aloud approach, on the Tesco website while Envirofy 2.0 is active. To take into consideration the effect of the first experiment on the participants, only the first two tasks were asked to be performed, which can be found in Appendix D. After the tasks were completed, the participants were asked five questions (Appendix E) that investigate the browser extension's performance as well as seek to identify any usability issues or standout features liked by the participants. Finally, participants were asked to fill in the SUS questionnaire to provide a quantitative measure of the usability of Envirofy 2.0 on the Tesco website. The same exact procedure was then repeated using Envirofy 1.0, which allowed for comparing both versions' quantitative and qualitative usability and performance data. After the experiment was run using Envirofy 1.0, participants were then asked which version they would prefer to use and why, which would provide further insight into whether a version is better than the other.

6.4.4 Experiment 2 Results

The aim of the second experiment was to evaluate the usability and performance of Envirofy 2.0 on the Tesco website while comparing it to those of Envirofy 1.0. Qualitative and quantitative data were collected for each version.

Envirofy 2.0: Think-aloud Study and Interview Questions

Common feedback collected from the think-aloud study and the interview questions for Envirofy 2.0 on the Tesco website is as follows:

- "*Overall, this version is quite informative*"
  Half the participants stated that they were satisfied with the amount of carbon information displayed for the products when asked how they felt about the carbon information displayed. The other half felt that the coverage was adequate.
- "*I prefer the location of the total carbon footprint on the Tesco website*"
  Five participants indicated that they preferred the position of the total carbon footprint on the Tesco webpage than its location on the Waitrose webpage, further indicating that its position on Waitrose.com would be better positioned in the basket.
- "*I felt that the Waitrose version was slightly faster*"
  When asked about how the participants felt about the loading speed of the carbon information icons, 4 participants stated that they felt that icons loaded faster on the Waitrose website. Even though in both cases it was Envirofy 2.0, this could be attributed to how users on Waitrose must scroll down before seeing any actual items whereas on Tesco products are seen instantly upon the loading of the webpage.

Envirofy 2.0: System Usability Questionnaire

Table 6.3 displays the results of the SUS questionnaire for Envirofy 2.0 on the Tesco website. We can see that Envirofy 2.0 has an average score of 91, which is a good score based on Bangor et al. (2008)'s findings. We can then conclude that Envirofy 2.0, on Tesco.com, provides ease of use and offers a good experience in terms of usability.

User 1	User 2	User 3	User 4	User 5	User 6	User 7	User 8	User 9	**Mean**
78	95	88	73	93	100	93	100	98	91

Table 6.3: *Individual SUS scores for Envirofy 2.0 on the Tesco website*

Envirofy 1.0: Think-aloud Study and Interview Questions

Common feedback collected from the think-aloud study and the interview questions for Envirofy 1.0 on the Tesco website is as follows:

- "*This version is definitely slower than the other version*"
  4 out of the 8 participants stated that they can feel lagginess with this version of Envirofy without being asked about it. All participants stated that there was noticeable difference in the loading speed between this version and Envirofy 2.0 when directly asked about how they felt about the loading speed.
- "*I feel like this version has less information than the other version*"
  All participants stated that this version lacked information about the environmental impact of food when compared to Envirofy 2.0
- "*The lack of information and the abundance of grey icons made me hesitant when choosing the products*"
  Half the participants mentioned that the lack of information was rendering shopping more difficult as it was making them more hesitant when selecting items.
- "*I would like to see more information and more products covered*"
  When asked whether there is something they would like changed in this version all participants answered that they would like more carbon information displayed.

Envirofy 1.0: System Usability Questionnaire

Table 6.4 displays the results of the SUS questionnaire for Envirofy 1.0 on the Tesco website. We can see that Envirofy 1.0 has an average score of 79, which is an above average score based on Bangor et al. (2008)'s findings. We can then conclude that Envirofy 1.0, on Tesco.com, offers a good experience in terms of usability.

User 1	User 2	User 3	User 4	User 5	User 6	User 7	User 8	User 9	**Mean**
68	90	78	70	95	78	73	92	63	79

Table 6.4: *Individual SUS scores for Envirofy 1.0 on the Tesco website*

Quantitative Analysis

We can see from both Table 6.3 and Table 6.4 that Envirofy 2.0 was found to have a higher SUS average score than Envirofy 1.0, indicating a better usability experience under Envirofy 2.0. To further strengthen this claim, statistical analysis is performed where the independent variable is the Envirofy version (1.0 and 2.0) and the dependent variable is the usability (SUS score). The hypothesis for the experiment is therefore:

H_1 Envirofy 2.0 offers an improved usability when compared to Envirofy 1.0.

To prove this hypothesis the following null hypothesis must be rejected:

H_0 Envirofy 2.0 does not offer a better usability when compared to Envirofy 1.0.

As the data sets for both versions have a number of participants less than thirty and hence normal-distribution cannot be assumed, it was decided to use a non-parametric test such as the Mann-Whitney test (Mann and Whitney 1947). The Mann-Whitney test calculates a statistic called U whose distribution is known under the null hypothesis. The confidence level was set at 0.05 and a two-tailed test was used to make sure that the case of a decreased usability under Envirofy 2.0 is not dismissed. From the data above, we were able to calculate the U statistic to be 15 and the critical value of U at $p < .05$ to be 17. Therefore, we can conclude that the result is significant at $p < .05$. This signifies that we can reject the null hypothesis and we can confidently conclude that Envirofy 2.0 does, indeed, offer a better usability when compared to Envirofy 1.0.

Qualitative Analysis

The feedback provided by participants for Envirofy 2.0 on Tesco.com was very similar to the one they provided during the first experiment on Waitrose.com. Most participants found this version *quite* informative and beneficial in educating them about the environmental impact of food. On the other hand, Envirofy 1.0 received negative feedback relating to its performance. Some participants were quick to comment on the difference in speed between both versions. Additionally, most participants commented on the noticeable lack of information that this version had compared to Envirofy 2.0. The same participants claimed that this lack of information deteriorated their experience using the browser extension as they felt it made their shopping decisions more difficult. Finally, after participants got to use both versions of Envirofy, they were asked which version they would prefer using. All 9 participants agreed that they would prefer using Envirofy 2.0 while justifying this decision by stating that Envirofy 2.0 offered faster loading times and more carbon information for the products displayed.

Discussion

We can see that qualitative and quantitative results complement each other in terms of indicating that Envirofy 2.0 offers a better usability experience than Envirofy 1.0. Additionally, it was apparent in the qualitative analysis that participants were able to notice a better performance in Envirofy 2.0, which supports our earlier findings under the performance evaluation where Envirofy 2.0 was found to be faster and more efficient than Envirofy 1.0. Finally, all participants opted for choosing Envirofy 2.0 over Envirofy 1.0 when asked which version they would prefer using, further indicating Envirofy 2.0's superior usability and performance.

7 Conclusion

This paper so far has discussed the aims and motivations behind Envirofy 2.0, the related research, followed by the requirements set to achieve the project aims. Then, the design and implementation of the system were analysed before performing an extensive evaluation of Envirofy 2.0. This chapter provides a summary for the whole project then proceeds to explore future work that could be carried out to render Envirofy 2.0 more effective in achieving its goals. Finally, a reflection is given concerning the project and the decisions undertaken throughout.

7.1 Summary

Envirofy 2.0 is a modular and extensible browser extension designed to educate its users about the environmental impact of their food choices when shopping on Tesco.com and Waitrose.com. This new, improved, version offers replacement to its predecessor, Envirofy 1.0, which was known to possess some undesirable issues such as a high display latency, a high carbon footprint as well as low flexibility and modularity. Envirofy 2.0 leverages a flexible architecture, which is designed for low latency and high extensibility that allows for an increased compatibility with online supermarkets while reducing its carbon footprint. The system was evaluated in a variety of ways, including unit testing, performance evaluation and user evaluation. It was found that Envirofy 2.0 was effective in providing its users with adequate information relating to the environmental impact of their food choices. Additionally, Envirofy 2.0 proved to offer a much faster displaying time than that of Envirofy 1.0 with Envirofy 2.0 displaying the carbon information up to five times faster than Envirofy 1.0. Finally, Envirofy 2.0 proved to offer a better usability experience than that of Envirofy 1.0 with users, who have tried both versions, always preferring to utilise Envirofy 2.0 in the future. Envirofy 2.0 can be found at: https://chrome.google.com/webstore/detail/envirofy/fmbajfbkfhhalbjkdjcoofoecepccofi

7.2 Future work

Should this project be extended in the future, the following suggestions would prove to add value to Envirofy 2.0 as well as help users make more environmentally friendly food-shopping decisions.

7.2.1 New Behaviour Change Technique

Envirofy 2.0 possesses huge potential for enriching the HCI research field that focuses on sustainability and the environment. Envirofy 2.0's flexible architecture allows it to easily incorporate new features that might help investigate a new way to influence a user's shopping behaviour. For instance, a new behaviour change technique involving degrading an item with a high carbon footprint's picture quality could be added in a future iteration. This might prove to be a useful feature that will help boost Envirofy's effectiveness in swaying its users to more environmentally friendly food choices.

7.2.2 Carbon Offsetting

There is an ongoing global trend that involves offsetting one's carbon footprint primarily by paying for the plantation of new trees. Envirofy 2.0 can, in the future, capitalise on such a trend by offering its users the option to offset the carbon footprint of their shopping session through paying for the planting of trees to a third-party service provider such as at www.plantyourchange.com. With Envirofy 2.0 's flexible architecture, integrating this carbon offsetting feature in the future should be easy and straightforward.

7.2.3 Item Recommendation

Another feature that could prove very useful is the recommendation of an item. This feature would allow Envirofy 2.0 to have the functionality of recommending an environmentally friendly alternative to items with a high carbon footprint. This would also help boost Envirofy 2.0's effectiveness in influencing consumer behaviour towards more sustainable shopping. Again, due to Envirofy 2.0 flexibility, incorporating new features into the browser extension is seamless and thus this feature should be easy to integrate.

7.3 Reflection

This project represents the most comprehensive piece of work that I have ever, single-handedly, delivered. I was able to further strengthen my project management skills while highlighting the importance of working within a requirements scope and time constraints. Further, this project equipped me with the knowledge of how to develop a browser extension, which I had never known before. This project also had a considerable research aspect to understand how the behaviour change techniques aim to influence consumer behaviour. Doing that research provided me with knowledge and insights that I do not think I would have ever come across if it was not for this project, which I believe will prove quite useful for my future career.

Overall, I am very happy to have worked on this project, and I believe it has the real potential to be of use in future research, which might one day become the foundation of saving our world from the environmental threats it is currently facing.

A | Envirofy - Waitrose

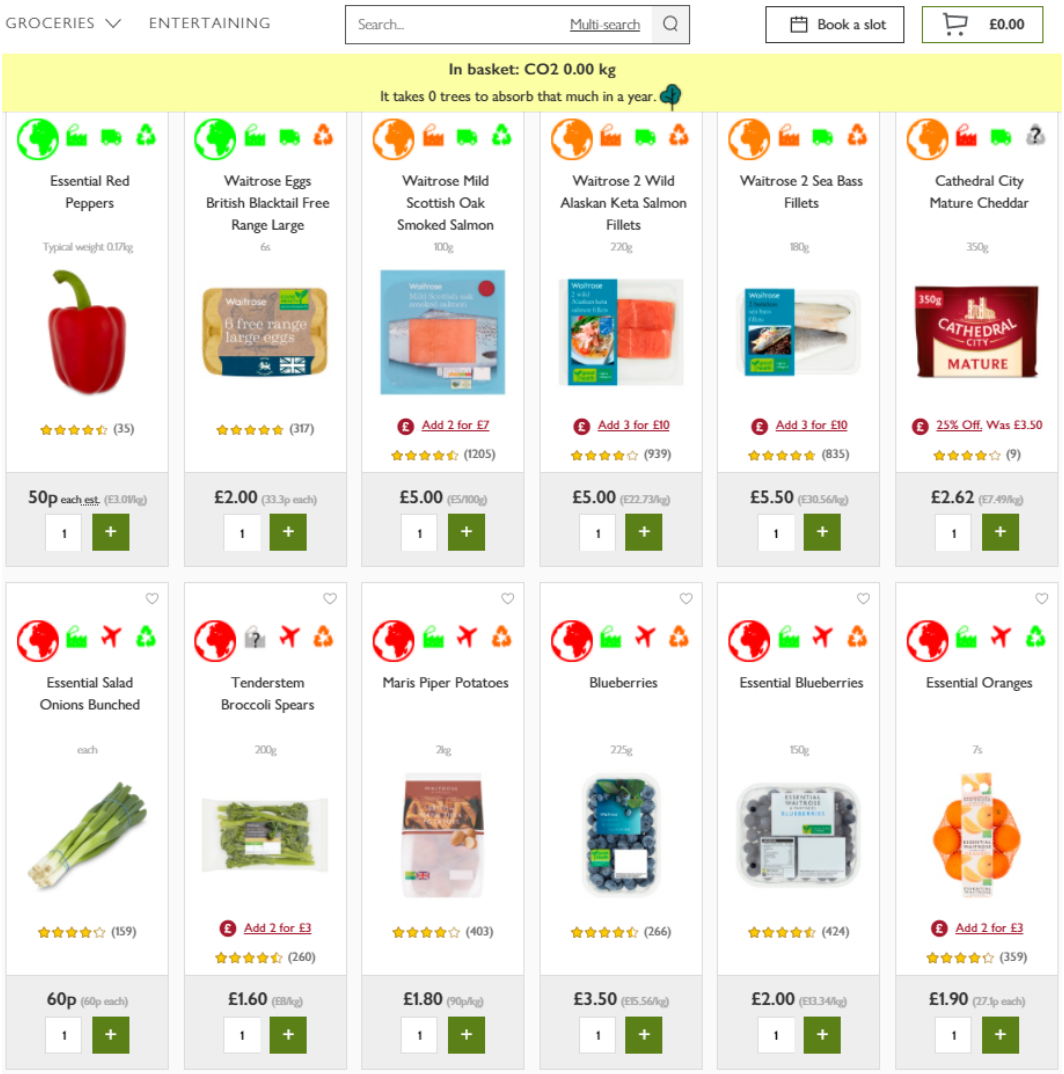


Figure A.1: *Envirofy 2.0 in action on the Waitrose online-shopping website.*

Figure A.2: *The labeling of items in the user's basket on the Waitrose online-shopping website.*

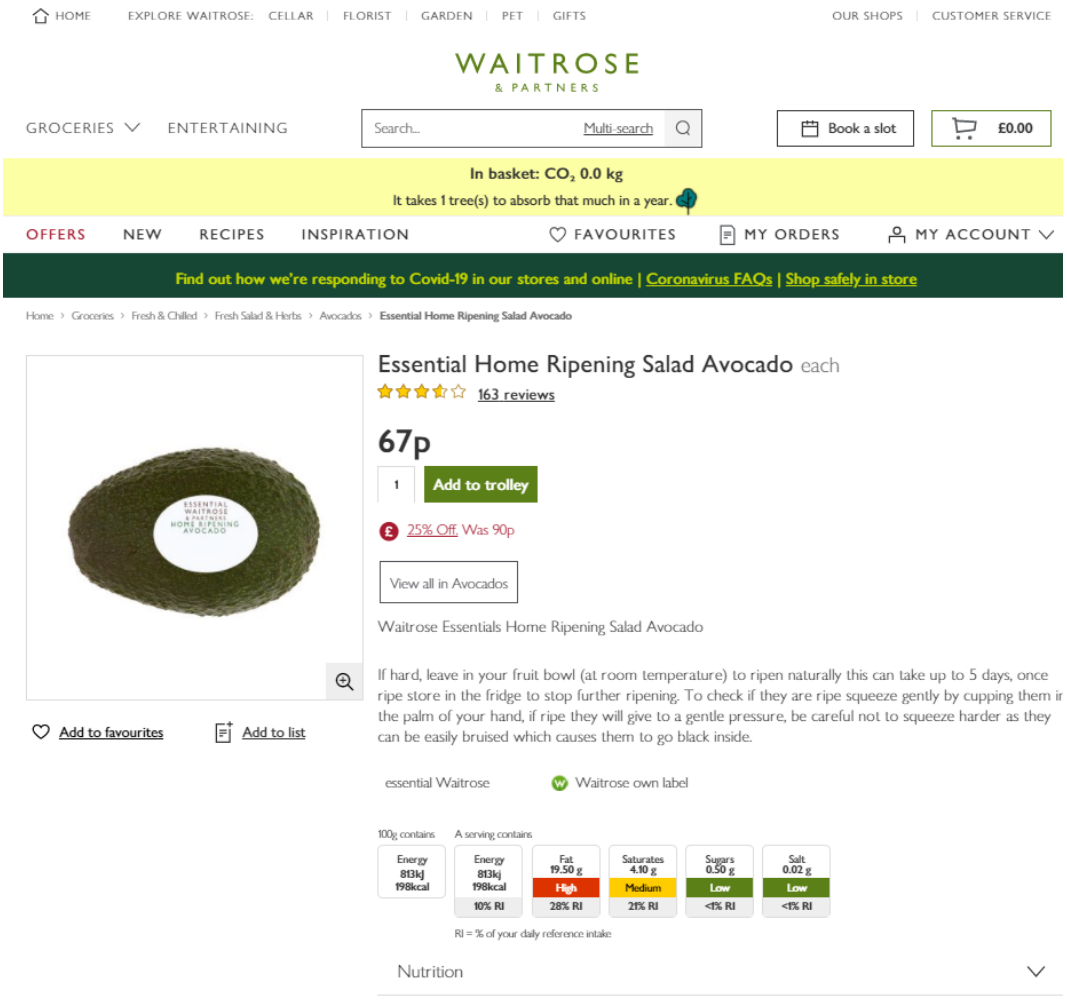


Figure A.3: *Example of a single product's webpage on the Waitrose website.*

B Pre-interview Questionnaire

This Appendix contains the pre-interview questionnaire completed by participants before the user evaluation experiments.

Envirofy - Pre-interview

Thank you for agreeing to take part in this study.

This study aims to quantitatively and qualitatively measure the usability of a browser extension, called Envirofy, that supports grocery e-commerce customers through allowing them to make environmentally conscious and friendly decisions when shopping.

Please be advised that the purpose of this research is not to analyse or judge you and your food purchases, but to help us understand the system, and allow us to improve it.

This questionnaire will help collect demographic data to help out with the analysis of the study outcome. No-one outside of the research team will be able to find your name, or any other information which could identify you.

It is worth stressing that you are always free to withdraw from the study at any time and without giving a reason.

* Required

1. Please provide the user ID that was given in the email. *

2. Please tick the boxes below to confirm that you have read and understood the privacy notice. *

- [ ] I consent to the University processing my personal data for the purposes detailed above.
- [ ] I have read and understood how my personal data will be used.

3. Consent Form: Please tick the boxes to confirm your consent. *

- [ ] I confirm that I have read and understood the Participant Information Sheet.
- [ ] I have had the opportunity to think about the information, ask questions and understand the answers I have been given.
- [ ] I am over 18 years of age.
- [ ] I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason, without my legal rights being affected.
- [ ] I confirm that I agree to the way my data will be collected and processed.
- [ ] I understand that all data and information I provide will be kept confidential and will be seen only by the research team.
- [ ] I agree that my name, contact details and data described in the information sheet will be kept for the purposes of this research project.
- [ ] I understand that if I withdraw from the study, my data collected up to that point will be retained and used for the remainder of the study.
- [ ] I agree to take part in the study.
- [ ] I do not have any color vision deficiencies (i.e color blindness)

4. Which age bracket do you belong to? *

- ○ 18-24
- ○ 25-34
- ○ 45-54
- ○ 55-64
- ○ 65 and over

5. What gender do you identify with? *

- ○ Woman
- ○ Man
- ○ Non-binary
- ○ Prefer to self-describe
- ○ Prefer not to say

6. What is the highest level of education you have completed? *

- ○ Primary School
- ○ GSCEs or equivalent
- ○ A-levels or equivalent
- ○ Undergraduate Degree
- ○ Post-graduate Degree
- ○ Doctoral Degree
- ○ Other

7. How many adults live in your household? *

8. Who is the main cook in your household? *

- ○ I am
- ○ My partner / parents/ care giver/ flat mate(s)
- ○ We cook together
- ○ Other

9. Who is responsible for grocery shopping *

- ○ I am
- ○ My partner / parents/ care giver/ flat mate(s)
- ○ We shop together
- ○ Other

10. What diet do you follow? *

- ○ No specific dietary restrictions
- ○ Vegetarian (I do not eat meat or fish)
- ○ Pescatarian (I do not eat meat)
- ○ Flexitarian (I rarely eat meat and fish)
- ○ Vegan (I do not eat any animal products)
- ○ Other

11. What is the main reason you follow your diet? *

12. Please answer these questions to the best of your ability. *

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
In general, I feel I know a great deal about environmental issues and problems.	◯	◯	◯	◯	◯
I have a great deal of knowledge about green products (e.g. energy-saving products, environmentally friendly foods, eco-friendly house products).	◯	◯	◯	◯	◯
I have a great deal of knowledge about environmentally friendly foods.	◯	◯	◯	◯	◯
I consider myself an expert on environmentally friendly foods.	◯	◯	◯	◯	◯
I generally know less than my friends about environmentally friendly foods.	◯	◯	◯	◯	◯

13. Please answer these questions to the best of your ability. *

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
When grocery shopping, I know how to judge the environmental impact of food items.	◯	◯	◯	◯	◯
When grocery shopping, I think I know enough about carbon footprints to feel pretty confident when I make a purchase.	◯	◯	◯	◯	◯
When grocery shopping I find it easy to choose environmentally friendly foods.	◯	◯	◯	◯	◯
When grocery shopping I can identify environmentally friendly foods.	◯	◯	◯	◯	◯
When grocery shopping I cannot distinguish between environmentally friendly and harmful food products.	◯	◯	◯	◯	◯
When grocery shopping I can find environmentally friendly foods among other foods.	◯	◯	◯	◯	◯

14. Please answer these questions to the best of your ability. *

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
I believe my actions have an influence on global warming and climate change	◯	◯	◯	◯	◯
My green consumption behavior can have a positive impact on the environment	◯	◯	◯	◯	◯
It is worthwhile for the individual consumer to do something about pollution.	◯	◯	◯	◯	◯
When I buy products, I try to consider how my use of them will affect the environment.	◯	◯	◯	◯	◯
Since one person can have an effect on pollution, it makes a difference what I do.	◯	◯	◯	◯	◯

15. Have you used any digital tool (mobile application, google search, browser add-on, etc.) to help you shop more sustainably? *

- ◯ Yes I consistently use one
- ◯ Yes, I occasionally use one
- ◯ Yes, I used to use one but not anymore
- ◯ No, I have never used one

C System Usability Questionnaire

This questionnaire aims to measure the usability of the system. It consists of a 10 item questionnaire with five response options; from Strongly agree to Strongly disagree.

1 I think that I would like to use this system frequently.

1 = strongly disagree, 5 strongly agree

1 2 3 4 5

2 I found the system unnecessarily complex.

1 = strongly disagree, 5 strongly agree

1 2 3 4 5

3 I thought the system was easy to use.

1 = strongly disagree, 5 strongly agree

1 2 3 4 5

4 I think that I would need the support of a technical person to be able to use this system.

1 = strongly disagree, 5 strongly agree

1 2 3 4 5

5 I found the various functions in this system were well integrated.

1 = strongly disagree, 5 strongly agree

1 2 3 4 5

6 I thought there was too much inconsistency in this system.

1 = strongly disagree, 5 strongly agree

1 2 3 4 5

7 I would imagine that most people would learn to use this system very quickly.

1 = strongly disagree, 5 strongly agree

1 2 3 4 5

8 I found the system very cumbersome to use.

1 = strongly disagree, 5 strongly agree

1 2 3 4 5

9 I felt very confident using the system.

1 = strongly disagree, 5 strongly agree

1 2 3 4 5

10 I needed to learn a lot of things before I could get going with this system.

1 = strongly disagree, 5 strongly agree

1 2 3 4 5

FINISH

0%

Powered by SurveyLab

D User Evaluation Tasks

This appendix contains the tasks the participants were asked to perform. In both experiments, participants were asked to perform the following tasks:

D.1 Task 1

1. Search for meat and add any two items to basket.
2. Search for vegetables section add any two items to basket.
3. Search for fruits and add any two items to basket.
4. Search for snacks and add any two items to basket.
5. Identify the item with the highest carbon footprint.

D.2 Task 2

1. Remove 2 items from basket.
2. State the total carbon footprint of the items in basket.
3. State the number of trees required to offset the carbon footprint of the items in basket in a year.
4. Identify the item with the lowest and highest carbon footprint in basket.
5. Remove all items from basket.

D.3 Task 3

1. Go to the Vegetables section.
2. Select one item on the page and click on it to visit its page.
3. Add it to basket
4. State the total carbon footprint of its lifecycle.
5. Identify the most carbon contributing factor during the item's lifecycle.

E Experiment Interview Questions

E.1 Experiment 1

- Is there something that you would keep/lose/change about this browser add on?
- How do you feel about your knowledge relating to the impact of food on the environment after using the browser extension?
- Any other things you want the researcher to know?

E.2 Experiment 2

- How did you feel about the loading speed of the icons and labels on the food items?
- How did you feel about the carbon information? In terms of the amount of items that have complete carbon footprint information displayed?
- Would you use this version in your everyday shopping if it became commercially available? If no then Why?
- Is there something that you would keep/lose/change about this version?
- Any other things you want the researcher to know?

F Introduction and Debrief Scripts For The User Evaluation On Waitrose

F.1 Introduction Script

This experiment aims to quantitatively and qualitatively measure the usability of a browser extension, called Envirofy, that supports grocery e-commerce customers through allowing them to make environmentally conscious and friendly decisions when shopping. In order to do this, we need to ask people to perform some tasks while Envirofy is running, so we can collect usability and performance data to make sure that the browser extension is working as expected and is offering a software product of good quality. In order to do this I will ask you to perform some shopping tasks. I will be observing you while you perform the tasks and will ask you to express your thoughts loudly.

After you are done, I will ask you some questions and will ask you to fill out a short questionnaire Please ask questions if you need to and please let me know when you are finished. I might also take notes of your think-aloud thoughts for later analysis.

Please remember that it is the system, not you, that is being evaluated. You are welcome to withdraw from the experiment at any time. Do you agree to taking part in this evaluation? Do you have any questions before we start?

F.2 Debrief Script

The main aim of this experiment was to investigate the usability of Envirofy on the waitrose website. Do you have any comments or questions about the experiment? Please take a note of my email address which was supplied to you in the information sheet in the email that contained all study related info. Please let me know if you have any further questions about this experiment. Thank you very much for taking the time to help with my project.

G Introduction and Debrief Scripts For The User Evaluation On Tesco

G.1 Introduction Script

This experiment aims to quantitatively and qualitatively compare two versions of a browser extension, called Envirofy, that supports grocery e-commerce customers through allowing them to make environmentally conscious and friendly decisions when shopping. In order to do this, we need to ask people to perform some shopping tasks on Tesco.com while Envirofy is running, so we can collect usability and performance data. This will help determine which version is offering a better and more efficient performance. In order to do this I will ask you to perform some tasks. I will be observing you while you perform the tasks and will ask you to express your thoughts loudly.

After you are done, I will ask you some questions and will ask you to fill in a short questionnaire Please ask questions if you need to and please let me know when you are finished. I will also take notes of your think-aloud thoughts for later analysis.

Please remember that it is the system, not you, that is being evaluated. You are welcome to withdraw from the experiment at any time without giving any reason. Do you agree to taking part in this evaluation? Do you have any questions before we start?

G.2 Debrief Script

The main aim of this experiment was to compare two versions of Envirofy to determine which one is better. Do you have any comments or questions about the experiment? Please take a note of my email address which was supplied to you in the information sheet in the email that contained all study related info. Please let me know if you have any further questions about this experiment. Thank you very much for taking the time to help with my project.

H Ethics Approval and Signed Checklist

School of Computing Science
University of Glasgow

Ethics checklist form for assessed exercises (at all levels)

This form is only applicable for assessed exercises that use other people ('participants') for the collection of information, typically in getting comments about a system or a system design, or getting information about how a system could be used, or evaluating a working system.

If no other people have been involved in the collection of information, then you do not need to complete this form.

If your evaluation does not comply with any one or more of the points below, please contact the Chair of the School of Computing Science Ethics Committee (matthew.chalmers@glasgow.ac.uk) for advice.

If your evaluation does comply with all the points below, please sign this form and submit it with your assessed work.

---

1. Participants were not exposed to any risks greater than those encountered in their normal working life.

   Investigators have a responsibility to protect participants from physical and mental harm during the investigation. The risk of harm must be no greater than in ordinary life. Areas of potential risk that require ethical approval include, but are not limited to, investigations that occur outside usual laboratory areas, or that require participant mobility (e.g. walking, running, use of public transport), unusual or repetitive activity or movement, that use sensory deprivation (e.g. ear plugs or blindfolds), bright or flashing lights, loud or disorienting noises, smell, taste, vibration, or force feedback

2. The experimental materials were paper-based, or comprised software running on standard hardware.

   Participants should not be exposed to any risks associated with the use of non-standard equipment: anything other than pen-and-paper, standard PCs, laptops, iPads, mobile phones and common hand-held devices is considered non-standard.

3. All participants explicitly stated that they agreed to take part, and that their data could be used in the project.

   If the results of the evaluation are likely to be used beyond the term of the project (for example, the software is to be deployed, or the data is to be published), then signed consent is necessary. A separate consent form should be signed by each participant.

   Otherwise, verbal consent is sufficient, and should be explicitly requested in the introductory script.

4. No incentives were offered to the participants.

   The payment of participants must not be used to induce them to risk harm beyond that which they risk without payment in their normal lifestyle.

5. No information about the evaluation or materials was intentionally withheld from the participants.
   Withholding information or misleading participants is unacceptable if participants are likely to object or show unease when debriefed.

6. No participant was under the age of 16.
   Parental consent is required for participants under the age of 16.

7. No participant has an impairment that may limit their understanding or communication.
   Additional consent is required for participants with impairments.

8. Neither I nor my supervisor is in a position of authority or influence over any of the participants.
   A position of authority or influence over any participant must not be allowed to pressurise participants to take part in, or remain in, any experiment.

9. All participants were informed that they could withdraw at any time.
   All participants have the right to withdraw at any time during the investigation. They should be told this in the introductory script.

10. All participants have been informed of my contact details.
    All participants must be able to contact the investigator after the investigation. They should be given the details of both student and module co-ordinator or supervisor as part of the debriefing.

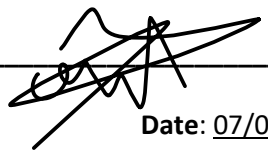
11. The evaluation was discussed with all the participants at the end of the session, and all participants had the opportunity to ask questions.
    The student must provide the participants with sufficient information in the debriefing to enable them to understand the nature of the investigation. In cases where remote participants may withdraw from the experiment early and it is not possible to debrief them, the fact that doing so will result in their not being debriefed should be mentioned in the introductory text.

12. All the data collected from the participants is stored in an anonymous form.
    All participant data (hard-copy and soft-copy) should be stored securely, and in anonymous form.

Course and Assessment Name: Level 4 Individual Project

Student's Name: Youssef Ramadan

Student Number: 2299608

Student's Signature: 

Date: 07/03/2021

Dr. Christoph Scheepers
Senior Lecturer

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University of Glasgow
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Christoph.Scheepers@glasgow.ac.uk

Ethical approval for:

Glasgow, March 7, 2021

Application Number: 300200141

Project Title: Envirofy: An Online Shopping Tool which Supports Green Shopping Behaviour

Lead Researcher: Dr Gozel Shakeri

This is to confirm that the College of Science and Engineering Ethics Committee has reviewed the above application and **approved** it. Please keep this letter for your records.

Please note that if your proposal involves **face-to-face research**, approval to carry out this research is only granted when one of the following two conditions has been met:

(a) You have performed a risk assessment of your research protocol in your research facility, had it approved by your Head of School / Director of Institute, and received permission to proceed with this specific research project, or

(b) The University has generally lifted its social distancing restrictions on face-to-face interaction, including research.

If any of the above is true, or if your research collects data in a format that does <u>not</u> require social contact (e.g., online research), you may begin data collection now. Approval for this project lasts for 6 months from the date you are allowed to proceed with data collection.

Also please download and read the Collated Comments associated with your proposal. This document contains all the reviews of your application and can be found below the approval letter on the Research Ethics System. These reviews may contain useful suggestions and observations about your research protocol for improving it. Good luck with your research.

Sincerely,

Dr Christoph Scheepers
Ethics Officer
College of Science and Engineering
University of Glasgow

I Unit Testing Coverage

Coverage report: 85%

Module	statements	missing	excluded	branches	partial	coverage ↑
crawler\pipelines.py	216	38	0	138	17	78%
crawler\spiders\single_product_spider.py	72	4	0	24	5	89%
backend\views.py	61	4	0	6	2	91%
backend\admin.py	4	0	0	0	0	100%
backend\apps.py	3	0	0	0	0	100%
backend\models.py	20	0	0	0	0	100%
backend\serializers.py	6	0	0	0	0	100%
backend\tests.py	41	0	0	0	0	100%
backend\urls.py	6	0	0	0	0	100%
crawler\items.py	4	0	0	0	0	100%
crawler\settings.py	7	0	0	0	0	100%
envirofy\settings.py	24	0	0	0	0	100%
envirofy\urls.py	3	0	0	0	0	100%
Total	**467**	**46**	**0**	**168**	**24**	**85%**

Figure I.1: *Code coverage report using Coverage.py indicating an 85% code coverage*

7 Bibliography

AgileBusiness, 2014. URL https://www.agilebusiness.org/page/ProjectFramework_10_MoSCoWPrioritisation.

A. Bangor, P. T. Kortum, and J. T. Miller. An empirical evaluation of the system usability scale. *International Journal of Human-Computer Interaction*, 24(6):574–594, 2008.

A. Bartuskova and O. Krejcar. Loading speed of modern websites and reliability of online speed test services. *Computational Collective Intelligence*, pages 65–74, 2015.

K. Beck, M. Beedle, A. van Bennekum, A. Cockburn, W. Cunningham, M. Fowler, J. Grenning, J. Highsmith, A. Hunt, R. Jeffries, J. Kern, B. Marick, R. C. Martin, S. Mellor, K. Schwaber, J. Sutherland, and D. Thomas. Manifesto for agile software development, 2001. URL http://www.agilemanifesto.org/.

M. Berners-Lee. *How bad are bananas? The Carbon Footprint Of Everything*. Greystone Books, 2011.

M. Bleda and M. Valente. Graded eco-labels: A demand-oriented approach to reduce pollution. *Technological Forecasting & Social Change*, 76(2009):512–524, 2008.

J. Brooke. Sus: A quick and dirty usability scale, 1996.

F. Brunner, V. Kurz, D. Bryngelsson, and F. Hedenus. Carbon label at a university restaurant – label implementation and evaluation. *Ecological Economics*, 146:658–667, 2018.

A. Clayton, 2020. URL https://www.ethicalconsumer.org/retailers/shopping-guide/supermarkets.

Coverage.py, 2021. URL https://coverage.readthedocs.io/en/coverage-5.0/index.html.

I. CSG. Countries, capitals, latitude and longitude table, 2021. URL http://www.csgnetwork.com/llinfotable.htm.

M. A. Delmas, N. Nairn-Birch, and J. Lim. Dynamics of environmental and financial performance: The case of greenhouse gas emissions. *Organization & Environment*, 28(4):374–393, 2015.

C. Devtools. Get started with analyzing runtime performance, 2021. URL https://developers.google.com/web/tools/chrome-devtools/evaluate-performance.

C. Dey, C. Berger, B. Foran, M. Foran, R. Joske, M. Lenzen, and R. Wood. Household environmental pressure from consumption: an australian environmental atlas. pages 280–316. Sydney University Press, 2007.

T. Dietz, G. T. Gardner, J. Gilligan, P. C. Stern, and M. P. Vandenbergh. Household actions can provide a behavioral wedge to rapidly reduce us carbon emissions. *Proceedings of the National Academy of Sciences*, 106(44), 2009.

J. Froehlich, L. Findlater, and J. Landay. The design of eco-feedback technology. *Proceedings of the 28th international conference on Human factors in computing systems - CHI '10*, 2010.

J. Froehlich, S. Patel, J. A. Landay, L. Findlater, M. Ostergren, S. Ramanathan, J. Peterson, I. Wragg, E. Larson, and F. e. a. Fu. The design and evaluation of prototype eco-feedback displays for fixture-level water usage data. *Proceedings of the 2012 ACM annual conference on Human Factors in Computing Systems - CHI '12*, 2012.

Z. Gadema and D. Oglethorpe. The use and usefulness of carbon labelling food: A policy perspective from a survey of uk supermarket shoppers. *Food Policy*, 36(6):815–822, 2011.

P. Gerbens-Leenes and S. Nonhebel. Consumption patterns and their effects on land required for food. *Ecological Economics*, (42):185–199, 2002.

R. Gifford and L. A. Comeau. Message framing influences perceived climate change competence, engagement, and behavioral intentions. *Global Environmental Change*, 21(4):1301–1307, 2011.

gunicorn.org, 2021. URL https://gunicorn.org/.

B. Hedin, C. Katzeff, E. Eriksson, and D. Pargman. A systematic review of digital behaviour change interventions for more sustainable food consumption. *Sustainability*, 11(9), 2019.

G. J. Hollands, I. Shemilt, T. M. Marteau, S. A. Jebb, M. P. Kelly, R. Nakamura, M. Suhrcke, and D. Ogilvie. Altering micro-environments to change population health behaviour: towards an evidence base for choice architecture interventions. *BMC Public Health*, 13(1), 2013.

P. Honkanen and J. A. Young. What determines british consumers' motivation to buy sustainable seafood? *British Food Journal*, 117(4):1289–1302, 2015.

J. Hopkins. Component primer. In *Communications of the ACM*, pages 43(10):27–30, 2000.

Javascript. Mutationobserver, 2021. URL https://javascript.info/mutation-observer.

S. Jeffries. 'i'm rich and i'm living well. shopping here is part of that', 2004. URL https://www.theguardian.com/lifeandstyle/2004/mar/12/foodanddrink.shopping.

Juerg. Plastic bags and plastic bottles – co2 emissions during their lifetime, 2009. URL https://timeforchange.org/plastic-bags-and-plastic-bottles-co2-emissions-during-their-lifetime/.

A. Kimura, Y. Wada, A. Kamada, T. Masuda, M. Okamoto, S.-i. Goto, D. Tsuzuki, D. Cai, T. Oka, and I. Dan. Interactive effects of carbon footprint information and its accessibility on value and subjective qualities of food products. *Appetite*, 55(2):271–278, 2010.

V. Kurz. Nudging to reduce meat consumption: Immediate and persistent effects of an intervention at a university restaurant. *Journal of Environmental Economics and Management*, 90:317–341, 2018.

E. Lea and A. Worsley. Australian consumers' food-related environmental beliefs and behaviours. *Appetite*, 50(2008):207–214, 2008.

G. Lentz, S. Connelly, M. Mirosa, and T. Jowett. Gauging attitudes and behaviours: Meat consumption and potential reduction. *Appetite*, 127:230–241, 2018.

V. Lim, A. Jense, J. Janmaat, and M. Funk. Eco-feedback for non-consumption. *Proceedings of the 2014 ACM International Joint Conference on Pervasive and Ubiquitous Computing: Adjunct Publication*, 2014.

L. Luo, B. Li, S. Berkovsky, I. Koprinska, and F. Chen. Online engagement for a healthier you. *Proceedings of the 26th International Conference on World Wide Web Companion - WWW '17 Companion*, 2017.

J. I. Macdiarmid, F. Douglas, and J. Campbell. Eating like there's no tomorrow: Public awareness of the environmental impact of food and reluctance to eat less meat as part of a sustainable diet. *Appetite*, 96(2016):487–493, 2015.

R. Malan and D. Bredemeyer. Less is more with minimalist architecture. In *IT professional*, pages 4(5):48–47, 2002.

H. B. Mann and D. R. Whitney. On a test of whether one of two random variables is stochastically larger than the other. *The Annals of Mathematical Statistics*, 18(1):50–60, 1947.

S. Michie, M. M. van Stralen, and R. West. The behaviour change wheel: A new method for characterising and designing behaviour change interventions. *Implementation Science*, 6(1), 2011.

nginx.com, 2021. URL https://nginx.com/.

H. V. Nguyen, C. H. Nguyen, and T. T. B. Hoang. Green consumption: Closing the intention-behavior gap. *Sustainable Development*, 27(1):118–129, 2019.

R. E. Nisbett and T. D. Wilson. Telling more than we can know: Verbal reports on mental processes. *Psychological Review*, 84(3):231–259, 1977.

P. Petkov, S. Goswami, F. Köbler, and H. Krcmar. Personalised eco-feedback as a design technique for motivating energy saving behaviour at home. *Proceedings of the 7th Nordic Conference on Human-Computer Interaction Making Sense Through Design - NordiCHI '12*, 2012.

J. Poore and T. Nemecek. Reducing food's environmental impacts through producers and consumers. *Science*, 360(6392):987–992, 2018.

I. Schumacher. Ecolabeling, consumers' preferences and taxation. *Ecological Economics*, 69(2010): 2202–2212, 2010.

Selenium.dev, 2021. URL https://www.selenium.dev/.

G. Shakeri and C. Mccallum. Envirofy your shop: development of a real time tool to support eco-friendly food purchases online. *CHI 2021 (forthcoming)*, 2021.

A. Sharp and M. Wheeler. Reducing householders' grocery carbon emissions: Carbon literacy and carbon label preferences. *Australasian Marketing Journal*, 21(4):240–249, 2013.

Statista, 2021. URL https://www.statista.com/statistics/295656/grocery-retail-market-value-by-channel-in-the-united-kingdom-uk.

Tescoplc.com, 2021. URL https://www.tescoplc.com/sustainability/.

J. Thøgersen and K. S. Nielsen. A better carbon footprint label. *Journal of Cleaner Production*, 125 (2016):86–94, 2016.

J. Thibert and M. G. Badami. Estimating and communicating food system impacts: A case study in Montreal, Quebec. *Ecological Economics*, 70(2011):1814–1821, 2011.

Timeforchange.com. Co2 emissions for shipping of goods, 2021. URL https://timeforchange.org/co2-emissions-for-shipping-of-goods/.

C. Tobler, V. H. Visschers, and M. Siergrist. Eating green. Consumers' willingness to adopt ecological food consumption behaviors. *Appetite*, 57(2011):674–682, 2011.

VanillaJS, 2021. URL http://vanilla-js.com/.

I. Vermeir and W. Verbeke. Sustainable food consumption among young adults in belgium: Theory of planned behaviour and the role of confidence and values. *Ecological Economics*, 64(3): 542–553, 2008. doi: 10.1016/j.ecolecon.2007.03.007.

S. J. Vermeulen, B. M. Campbell, and J. S. Ingram. Climate change and food systems. *Annual Review of Environment and Resources*, 1(37):195–222, 2012.

D. Vine, L. Buys, and P. Morris. The effectiveness of energy feedback for conservation and peak demand: A literature review. *Open Journal of Energy Efficiency*, 02(01):7–15, 2013.

P. Vlaeminck, T. Jiang, and L. Vranken. Food labeling and eco-friendly consumption: Experimental evidence from a belgian supermarket. *Ecological Economics*, 108:180–190, 2014.

Warehousespace.com. How is food transported?, 2021. URL https://www.warehouse-space.co.uk/food-transport.html.

E. O. D. Waygood and E. Avineri. Does "500g of co2 for a five mile trip" mean anything? towards more effective presentation of co2 information. *In Proceedings of the Transportation Research Board 90th Annual Meeting*, page 23–27, 2011.

WWF, 2021. URL https://www.wwf.org.uk/learn/effects-of/climate-change.

J. L. Zapico, C. Katzeff, U. Bohné, and R. Milestad. Eco-feedback visualization for closing the gap of organic food consumption. *Proceedings of the 9th Nordic Conference on Human-Computer Interaction*, 2016.