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Visualization of an Individual Carbon Footprint Mitigation Plan Using Transaction Data

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Abstract

Achieving the objectives of the Paris Agreements requires actions being taken on different fronts. This study looked into how to visualize a carbon footprint mitigation plan for individuals. The research consisted of designing and implementing a prototype containing visualization of a mitigation plan in the Swedish mobile app DO, a newer type of carbon calculator that uses transaction data to estimate the users' carbon footprints. A user study was then conducted with app users to evaluate the visualization.

Findings from the study involved that proper handling of data is important for what a mitigation plan communicates to the user, but that receiving guidance on how to proceed ahead was greatly appreciated regardless. For future research, the visualization of a mitigation plan on small screens could be developed further with the prototype developed for this study as a starting point. It was suggested that such research could revolve around interaction improvements, evaluation with more frequent users, and observing whether a mitigation plan could affect behavior change.

Sammanfattning

För att uppnå Parisavtalets mål krävs att åtgärder vidtas på olika fronter. Denna studie undersökte hur man kan visualisera en nedtrappningsplan för individers livsstilsrelaterade koldioxidavtryck. Studien bestod av utformning och implementering av en prototyp innehållande visualisering av en nedtrappningsplan i den svenska mobilappen DO, en nyare typ av koldioxidkalkylator som använder transaktionsdata för att uppskatta användarnas koldioxidavtryck. En användarstudie genomfördes sedan med appanvändare för att utvärdera visualiseringen.

Resultaten från studien belyste att ordentlig hantering av data är avgörande för vad en nedtrappningsplan kommunicerar till användaren, men att få vägledning om vägen framåt var uppskattat oavsett. För framtida forskning kan visualisering av en nedtrappningsplan på små skärmar utvecklas vidare med prototypen utvecklad för denna studie som utgångspunkt. Det föreslogs att sådan forskning skulle kunna kretsa kring förbättringar av interaktionen, utvärdering med mer frekventa användare och att observera huruvida en nedtrappningsplan kan påverka beteendeförändringar.

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ABSTRACT
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Author Keywords
Information visualization; carbon footprint; carbon calculators; small screens; transaction data.

CSS Concepts
• Human-centered computing ~ Visualization • Human-centered computing ~ Interaction design

1. INTRODUCTION

Technology and economic incentives are often addressed in policy approaches when discussing measures that need to be taken to achieve the Paris Agreement targets [1,9,20]. But the fact is that several researchers argue that lifestyle changes also play an important role in the climate issue [1]. After all, households demand goods and services that drive economic development and thus drive emission patterns [10]. For example, in 2009, 72% of the global greenhouse gas (GHG) emissions were related to household consumption [11]. Furthermore, it has been stated that the climate crisis is closely linked to excessive consumption, where the most wealthy countries are mainly responsible for the historical GHG emissions and generally have the largest carbon footprints per capita [16].

Authoritative reports, such as the Intergovernmental Panel on Climate Change (IPCC) Special Report on Global Warming of 1.5° C [14], have specifically highlighted the major impact of lifestyle changes. Despite this, limited efforts have been made in the scientific literature and policy approaches to show the potential contribution that lifestyle changes could make in keeping global warming within the limit of 1.5 °C [1]. In this context, “carbon calculators” could be seen as a powerful tool as they combine technological innovation with lifestyle changes. These calculators allow individuals to map their lifestyle linked to carbon emissions by providing data about lifestyle and living conditions that the calculators use to estimate the users’ carbon footprints [3,4]. The overall purpose is similar - to help people understand their impact on the environment and provide feedback to promote more environmentally friendly behavior [3,4].

Consumption patterns are essential when determining an individual’s carbon footprint, especially in wealthy countries, since those footprints tend to be significant [8]. Most carbon calculators base their estimations on the users’ answers to questions about, e.g., traveling habits, eating patterns, living situations, and similar. To estimate consumption-related emissions as accurately as possible, it is beneficial to access to more detailed data than answers to questions about consumption habits. Recently, there has been a rise in the development of calculators that allow more detailed insight into emissions caused by consumption by using transaction data from bank statements [4]. In these calculators, an estimation of the carbon footprint caused by each transaction is made. The transactions are then categorized and presented as a visualization to communicate how the user’s carbon footprint is distributed. With this sort of calculator, the users are allowed to take part in more accurate estimates, more straightforward input options and are given an incentive to continue using it. Furthermore, this approach reduces the risk of biased input from the users as they do not enter the data themselves [4].

Figure 1. The DO app's visualization of a user's monthly carbon footprint.

A Swedish such service is provided by Doconomy, a fintech startup founded in 2018. Their solution includes a credit card that is linked to a mobile app called "DO" that estimates and visualizes the credit card holder's carbon footprint based on transactions made with the card. As can be seen in Figure 1, the visualization consists of a donut chart showing how the user's carbon footprint is distributed monthly between different lifestyle categories such as "Food and Beverages", "Health and Beauty", and "Shopping".

This study aimed at investigating how the data that was being collected and presented in the "DO" app could be visualized in another way to inform users on how to reduce their carbon footprint in line with the targets of the Paris Agreement. Hence, the study aimed at answering the following research question:

How to use individual transaction data to visualize a carbon footprint mitigation plan compatible with the Paris Agreement targets on small screens?

2. BACKGROUND

2.1 Information Visualization

Data is constantly being collected to an increasing extent, and information visualization is essential to process this data and make it understandable to humans. Information visualization is about understanding, presenting, and analyzing data better by using visual tools such as charts, maps, and diagrams. Some basic visualizations have become familiar to most people and are encountered more or less daily, such as line graphs, pie charts, and scatter plots [17]. The visualizations can be both static and interactive, but to understand more complex data and explore more in-depth, the latter is preferable.

When designing an interactive visualization, the usability aspect is of significance. In addition to identifying an ideal way to map the data to graphical elements, one should consider device and user context. Those considerations are crucial as information visualization is applied to many different areas (e.g., stock quotes, health and fitness tracking, and weather forecasts, to name a few) and is used on devices with various properties, functionalities, and modalities. Technical limitations such as differences in screen size, mobility context, and interaction techniques usually create obstacles when trying to transfer something designed for desktops to a mobile device [6]. An example of a concept used for information visualization on desktops is Overview + Detail, which provides two views simultaneously, one for context and one for details. However, when this approach is applied to mobile devices, it tends to fail due to the limited screen space. It becomes difficult to fit the two views properly while at the same time making sure that they are readable.

As part of the research on information visualization, a mantra describing the interaction process has become very well known. The mantra is called the Visual Information-Seeking Mantra and was coined by Ben Shneiderman in 1996 [19]. It divides the interaction process into four different tasks; overview first, zoom and filter, then details-on-demand. It says that the user should be given an overview of the entire data collection first, be able to zoom in on interesting items and filter out uninteresting data, and finally get the opportunity to explore additional details of the data when needed. Although interaction technology has evolved a lot since 1996, the mantra is still useful for today's interactive information visualizations. It addresses fundamental user tasks that one should support regardless of device and context. How the user is allowed to perform these tasks depends on the platform and purpose.

2.1.1 *Design for Mobile Devices*

When it comes to information visualizations on mobile devices, research has been made focusing on different parts of the development and experience. Some examples of what the research includes are an evaluation of the role and meaning of the mobile phone for collecting and visualizing data [15], evaluation of various visualizations to give recommendations on which ones are appropriate depending on data structure and purpose [18], attempts to find methods for evaluating mobile visualizations [5], and exploration co-using several mobile devices to distribute and interact with multivariate data [13].

A student work report [12] addressed how interaction methods and choice of visualization affect information visualizations on mobile devices. The report proposed that the design process should focus on interaction rather than the visualization itself. Other suggestions were to ensure that the zoom functionality is sufficient, that the interactive objects are not too small, and that over-cluttering is avoided. These technical challenges and limitations that come with the development and design for mobile devices were also stressed by Chittaro in 2006 [6]. Chittaro presented a checklist of six steps to provide designers with guidelines specifically targeting the creation of mobile visualization applications. The six steps were posed as questions that the designer could ask oneself:

1. Mapping. *How is information visually encoded?*
2. Selection. *Among available data, what is relevant to the considered task?*
3. Presentation. *How is the visualization laid out on the available screen space?*
4. Interactivity. *What tools does the device provide to explore and rearrange the visualization?*
5. Human factors. *Does the interface take into account human perceptual and cognitive capabilities?*
6. Evaluation. *Has the visualization's effectiveness been tested on users?*

2.3 Individual Data on Carbon Footprint and Carbon Calculators

2.3.1 Clarification of Terms

Carbon calculators refer to tools that estimate environmental impact caused by GHGs, with a primary focus on carbon dioxide. Despite the name, some carbon calculators take other GHGs into account, such as nitrous oxide and methane. In this study, "carbon calculator" is used to indicate a tool that estimates carbon dioxide equivalents (CO_2e), i.e., GHGs. Furthermore, "carbon footprint" is used to refer to generated CO_2e.

2.3.2 Carbon Calculator Apps

Carbon calculators have been around for several years, and over time, solutions have been developed that provide more features than just the estimation of carbon footprint. Several mobile apps have taken the step further and applied strategies to promote behavioral changes that lead to smaller carbon footprints. Some examples that are available now on the market are Deedster [21], Habits [22], and Eevie [23]. These include an estimate based on questions about lifestyle habits followed by recommendations on measures that the users can take to reduce their carbon footprints. In addition, all services visualize the user's footprint with the help of various graphic elements (see Figure 2), i.e., they apply information visualization to communicate the data with the users. However, Deedster is the only one that allows interaction that "zooms in" on an element and provides the user with more details.

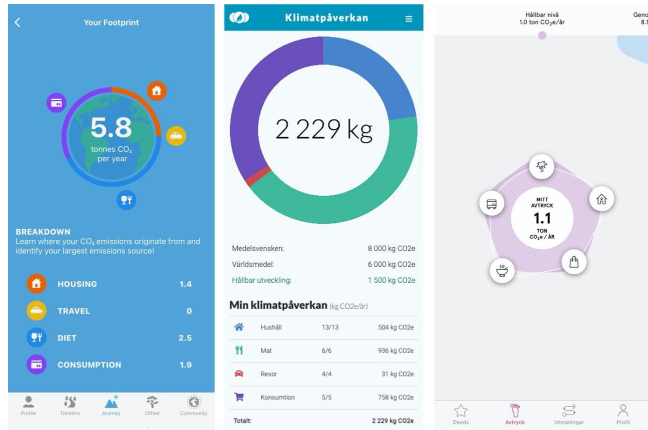

Figure 2. Screenshots of visual representation of the user's carbon footprint in Eevie, Habits, and Deedster.

In a literature review by Dreijerink et al from 2020 [9], it was concluded that studies, looking into the effects of carbon calculators on pro-environmental behavior, present mixed results. However, it was found that carbon calculators effectively raise awareness and increase knowledge, but that it is not enough only to provide personalized feedback based on the users' input. Approaches that also included guidance and thorough feedback on how users could reduce their carbon footprint were considered more effective.

2.3.3 Carbon Calculator Apps Using Transaction Data

The trend of offering more insight into emissions caused by consumption using transaction data is newer [4]. Some released mobile apps that use this approach are Finnish My Carbon Action [24], American Joro [25], and Swedish Svalna [26]. Research covering this more new type of carbon calculator that uses transaction data is limited [4]. Barendregt et al. (2020) [4] and Andersson (2020) [3] have done research on Svalna, where they have addressed the user experience perspective and discussed advantages and disadvantages with Svalna's approach. Svalna provides its users with estimates of their carbon footprint by using transaction data from the users' bank statements, registry data, and user input, such as questions about lifestyle habits. The papers [3,4] provide several suggestions for further developing this type of calculator and essential aspects that one can consider to improve the user experience. However, the possibility to use the app's data to inform users of a way forward that is compatible with the Paris Agreement targets was not included in any of the papers. Nor was the use of information visualization addressed. Svalna's interface contains information visualization in several views. For example, the user's carbon footprint over time is visualized in several places in the app (see Figure 3).

Figure 3. To the left: a screenshot of Svalna's home view that shows a line graph and donut chart representing the user's carbon footprint over the past few months and whether the footprint currently is increasing or decreasing. To the right: a screenshot of Svalna's "emissions view" visualizing the user's historical carbon footprint in a steam chart color-coded according to lifestyle categories. This graph is interactive since one can filter on categories and scroll horizontally to see data from earlier.

2.4 Lifestyle Carbon Footprint Targets

To meet the Paris Agreement targets, several scenarios for mitigation pathways have been developed. The scenarios apply mitigation strategies containing different combinations of technological innovations, changes in society and consumption, and utilization of negative emission technologies. Various scenarios have been developed because the Paris Agreement does not state how the end goal of keeping the global average temperature rise below 1.5 ° C is to be attained. Thus, there are different ways to reach the goal depending on how the different strategies mentioned above are used.

The technical report published in 2019 by the Institute for Global Environmental Strategies in Hayama, Japan [1] analyzed different mitigation scenarios to calculate globally uniform per capita targets for carbon footprint from household consumption for the years 2030, 2040, and 2050. The report's authors suggested that it is necessary to pursue lifestyle targets for carbon footprints of 2.5 tCO_2e by 2030, 1.4 by 2040, and 0.7 by 2050 to be in line with the ambitious target of 1.5 ° C without relying on negative emission technology. If negative technologies are considered, the upper limits of the targets will be raised to 3.2, 2.2, and 1.5 tCO_2e per capita in 2030, 2040, and 2050. Targets for the three lifestyle domains that tend to cause the largest carbon footprints were also developed and presented in the report. These domains were nutrition, mobility, and housing.

Since these targets are supposed to be applicable globally, the reduction will be unequally distributed since the current carbon footprint per capita is different between nations. It is also reasonable given the difference in living standards in undeveloped versus developed countries and that an increase in living standards in undeveloped countries will require more of the total carbon budget [2]. For example, in Sweden, the carbon footprint per capita is around 8 tons per year which is significantly higher than the global average [27]. Going from 8 tons to 2.5 tons in nine years would require a percentage decrease of approximately 12% per year ($8 \times 0.88^9 \approx 2.5$).

3. METHOD

The methods used to answer the research question can be described as a process divided into three phases (see Figure 4).

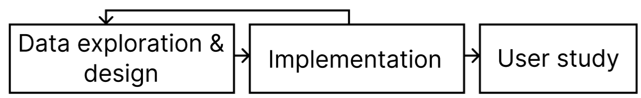

Figure 4. Flowchart containing the different phases of the process to answer the research question.

3.1 Data Exploration and Design Process

3.1.1 Calculating a Mitigation Plan

Before the design process could start, the data structure for the current data that was being collected in the DO app was examined to identify visualization possibilities. From this, a concept prototype was designed using the software Figma.

The concept's core focus was on providing the user with a visualization of a mitigation plan consistent with the Paris Agreement targets. To do this, the numbers in the technical report [1] were used to calculate annual targets until 2030 for total carbon footprint and the three domains presented in the report. The numbers from the report were considered suitable for this study since they were a result of research that focused on lifestyle-related carbon footprints from households. It was also in line with Doconomy's use of the Åland Index[1], which aims to be a global standard. The targets for 2030 were chosen as they were closest in time of the study. Furthermore, the numbers that do not rely on negative emission technologies were used.

The Åland index, which was used for categorizing the data in the app, was not divided into the exact three domains as the technical report presented targets for. The app contained 11 categories by which the transactions were categorized. To present the user with targets that were rooted in numbers from research, the app's categories were translated to fit the domains. Thus, nutrition consisted of the categories "Food

[1] Åland Index is the index used for the CO_2e calculations for payments and financial transactions in the DO app [28].

and Beverages" and "Restaurants and Bars". Mobility consisted of "Transportation" and "Holiday and Travel", and the housing domain contained "Household and Accommodation" and "Home and Garden".

The formula used to calculate each annual target for total footprint was:

$$total\ annual\ footprint\ for\ start\ year\ \times (1 - annual\ reduction)^{2030\,-\,start\ year} \approx 2.5$$

For instance, if a user had transactions that made up a total carbon footprint of 8 tons year 2020, the annual target for 2021 would be calculated as ($8 \times (1\text{-}annual\ reduction)^{2021\text{-}2020}$). The annual reduction and goal would be calculated as:

$$annual\ reduction = \left(\left(\frac{2.5}{8}\right)^{\left(\frac{1}{10}\right)} - 1\right) \times (-1) = 0.109 \ldots \approx 11\%$$

$$annual\ goal\ for\ 2021 = 8 \times (1 - 0.11)^{2021-2020} = 8 \times 0.89 = 7.12\ tons$$

Details of how the mitigation plan was designed and implemented will be described in chapter 4.

3.1.2 Design Process

As the study aimed to explore how the data could be presented in a new way to users, the current codebase for the app was considered appropriate to start from. In this way, an addition could be designed to the existing app instead of creating an entirely new environment. This choice meant that implementation of the design could be made and be tested with real users. However, it also meant that some technical conditions needed to be considered in the design process. Therefore, some iterations were made of the design to solve technical challenges encountered during the implementation. Further details of the implementation phase will be described in chapter 4.

Furthermore, the Visual Information-Seeking Mantra [19] and Chittaro's six steps [6] were present during the design process. In addition, findings from studies covering carbon calculators were also considered, such as the effectiveness of approaches that include guidance and thorough feedback [9]. Finally, the other carbon calculator apps mentioned above currently on the market [21–23,26] were looked into. Their information visualizations were evaluated partly for inspiration and to identify how certain features could be designed in a more user-friendly way.

3.2 User Study

As the prototype was implemented in the existing codebase and thus could be tested with real users, a user study was conducted to evaluate the prototype.

3.2.1 User Tests

The purpose of the user study was to collect data that could be used to analyze the interaction with the designed prototype and the prototype's ability to convey information. Therefore, user tests were conducted using the task analysis method, meaning that each participant was given a few tasks to perform during the test session. The method allows observations of the users' interaction without telling them how to do it [7]. In addition, quantitative data can be collected and compared to identify interaction patterns. It thus becomes an effective method for evaluating the prototype's ability to convey what is desired.

Each task consisted of answering a question in natural language. From these tasks, quantitative data were collected by measuring the time to complete each task, the number of clicks and scrolls, if the visualizations were interacted with through clicks, and if the task was successfully completed. In total, each participant was given seven tasks to complete, where each task was given only after the participant had finished the previous one.

Subsequently, semi-structured questions were asked to gather further thoughts and opinions. In this way, parallels could be drawn between how the participant interacted with the prototype and what they thought of it. Typically, questions were asked about things observed during the interaction, but also the prototype as a whole. Thus, both qualitative and quantitative data were collected. The interviews were then analyzed through a thematic analysis that consisted of systematically reviewing gathered data to find patterns and themes.

All tests were conducted virtually where the test participant used their mobile to interact with the prototype while sharing the screen. Each test session lasted for around 40 minutes.

3.2.2 Online Form

Before and after each test session, the participant answered an online form consisting of two different segments. The first one contained questions about the participant's usage of the card and app. The second one consisted of statements about their carbon footprint which they took a stand on a Likert scale where the value 1 corresponded to "strongly disagree" and 6 to "strongly agree". The responses to the forms were analyzed to identify whether the prototype affected the perception of their carbon footprint and see if there was a link between the perception of their carbon footprint and their use of the card and the app. The analysis of the second part of the form was made through paired sample t-tests to observe statistically significant differences in responses before and after each test session.

3.2.3 Participants

To enable the prototype to be tested, the implementation was set up for a test environment. The people with access to this environment were employees at Doconomy; thereby, every employee with a credit card connected to the DO app was asked to participate in the study. This group of people was, although employed, considered representative for the target group, meaning the end-users, who one could assume are environmentally aware as they have applied for this service. In addition, the choice of test group allowed the participants to test the prototype with their own data. Since the study focused on how transaction data could be used, it was considered advantageous to evaluate the solution in as realistic a scenario as possible. The test subjects could then relate to the visualizations on a more personal level than if they interacted with sample data.

In total, ten people participated, four females and six males in ages between 29-59. The participants worked in different areas, such as sales, economics, marketing and development.

4. IMPLEMENTATION

The app was previously based monthly rather than annually. Because the goals in the technical report were based on annual goals, the prototype was chosen to be designed as a standalone experience rather than being integrated into the home view with the donut chart (see Figure 1). The prototype was navigated via the home view and consisted of four main views consisting of visualizations with different target focus. From these views, other views serving zooming and details-on-demand purposes were available through interaction with the visualizations (see Figure 5). The next sections of this chapter will be arranged according to Chittaro's six steps [6] to describe the implementation process for the different views of the prototype.

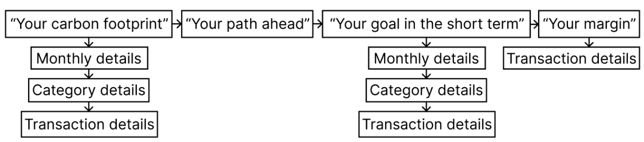

Figure 5. Flowchart of the prototype's different views and their hierarchy.

Figure 6. To the left: the prototype's first view visualizing carbon footprints from all months the user had used the credit card in a horizontally scrollable stacked bar chart. To the right: view displayed when clicking a bar from the previous view showing monthly details as a bar chart.

4.1 Mapping: How Was Information Visually Encoded?

The prototype was designed to give the user the opportunity to first explore their historical carbon footprint in a view called "Your carbon footprint". This was to give the user an understanding of what their carbon footprint had looked like before they were presented a way forward. This first view of the prototype was navigated via the home screen.

Previously, the user had only been able to see their carbon footprint one month at a time as a donut chart. To give a more straightforward overview, all months that the user had used the app were presented in a visualization which allowed comparison between all months. This visualization consisted of a horizontally scrollable stacked bar chart where each bar represented the total carbon footprint of a month (see the left view in Figure 6). The colors in each bar corresponded to the lifestyle categories according to which the carbon footprint was divided. The month with the largest carbon footprint decided the max value of the y-axis.

To follow the Visual Information-Seeking Mantra [19], the user could click on each bar and navigate to a view visualizing monthly details representing what was behind the height of the clicked bar. This visualization consisted of a bar chart where each bar corresponded to carbon footprint from one of the lifestyle categories for the selected month (see the right view in Figure 6). The user could then navigate to category details by clicking on a bar that displayed a list of the transactions that made up the clicked bar (see the left view in Figure 7).

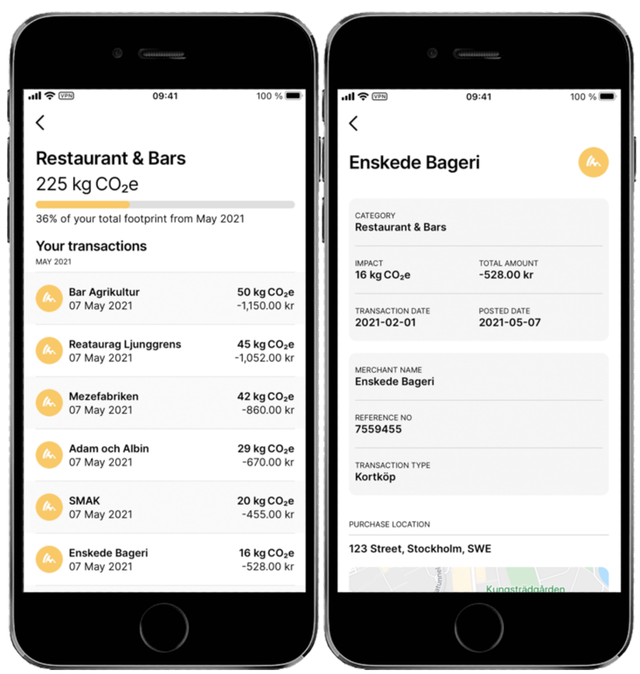

Figure 7. To the left: view displayed when clicking a category bar from the monthly details view showing details about transactions that made up the clicked bar. To the right: view which was displayed when clicking on a transaction from the list in the category details view, showing details about the transaction.

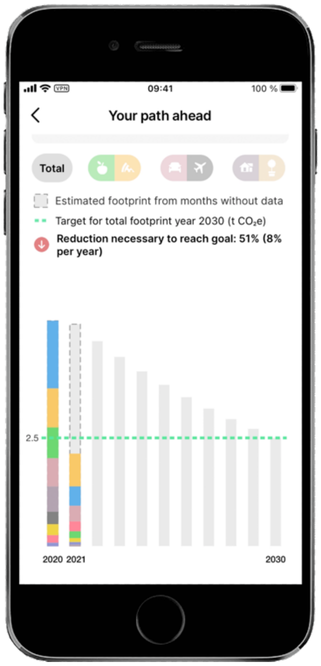

Figure 8. View visualizing a personalized mitigation plan consistent with the Paris Agreement targets based on the user's data as a bar chart.

For additional details about each transaction, such as the location where the transaction was performed, the user could click on each row in the list to navigate to a view containing details about the clicked transaction (see the right view in Figure 7).

After the user got to explore their historical carbon footprints, the user could move on by scrolling to the bottom of the screen and clicking a button which said "Explore your path ahead". Then they reached the view which consisted of the mitigation plan (described in more detail in section 3.1.1).

The mitigation plan was visualized as a bar chart where each bar represented one year (see Figure 8). The first bars from the left were actual data and were therefore stacked according to carbon footprints from the different lifestyle categories. From 2022 onwards, the height of each bar was an annual target that followed the individual mitigation plan towards the target for the year 2030.

As can be seen in figure 8, a dashed border was used around the bars where actual historical data constituted the bar but where no data for a whole year existed. This was to visually tell the user that the height of the bar was an estimate. For example, the 2021 bar was an estimate of the total annual footprint made based on the months that had passed at the time of the interaction. A horizontal green dashed line was used to show the user the 2030 target and how the user's carbon footprint compared to it.

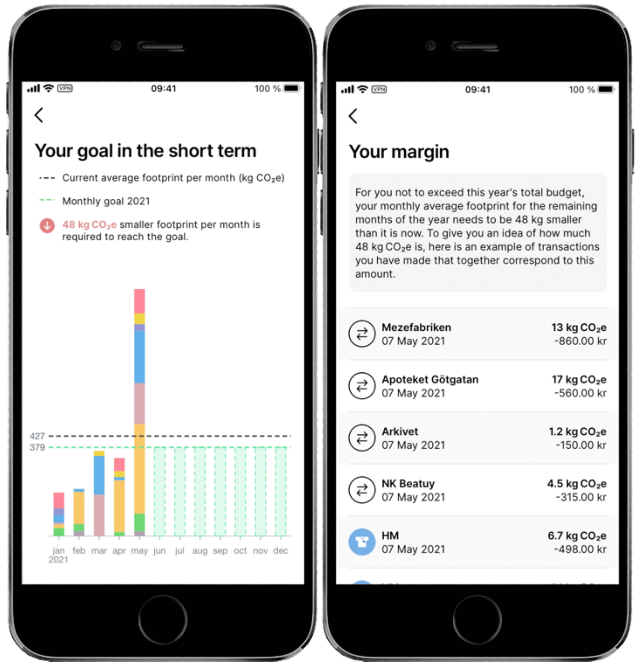

Figure 9. To the left: view visualizing how to follow the mitigation plan monthly in the short term. To the right: view displaying an example of transactions made by the user that together correspond to the amount that the user needed to reduce their monthly carbon footprint with the remaining months of the year to follow the mitigation plan.

The next view was navigated to by scrolling to the bottom and clicking a button saying "Explore your goal in the short term". This view was determined by how the user's carbon footprint compared to the target for total emissions year 2030. If the user's estimated carbon footprint for 2021 was larger than the target for 2030, the user could explore their mitigation plan in the short term monthly. If, on the other hand, the user already had an estimated annual footprint for 2021 that was smaller than the target for 2030, the user received a comparison between the current average monthly footprint and what the monthly footprint needed to be during 2030, i.e., how much below the target the user currently was. This was to create an idea of the margin to the goal.

Regardless of the outcome, the view consisted of another bar chart where each bar corresponded to one month. As can be seen in the left view in Figure 9, the months passed consisted of actual data stacked with colored blocks corresponding to carbon footprint from the lifestyle categories. The remaining bars were a representation of what the average for the remaining monthly footprint needed to be to follow the mitigation plan. The black dotted line showed the user's current average monthly footprint in 2021, and the green dashed line showed what the user should strive for in the remaining months of the year to follow the mitigation plan.

The next and last view was reached by, again, scrolling down to the bottom and clicking a button saying "Explore your margin". In this view, the user's margin to the monthly average target was set in relation to their own executed transactions (see the right view in Figure 9). This was to make it easier for the user to understand how large the margin was when it came to actual purchases. Therefore, a list was displayed of transactions that the user had performed whose carbon footprint corresponded to the margin's size. At the bottom of this view, a button could be clicked, which navigated the user back to the home view.

4.2 Selection: Among Available Data, What Was Relevant to the Considered Task?

The available data consisted of transactions with several different parameters linked to them. To present relevant information to the user, these transactions were processed according to the goals of each visualization. For example, the goal of the first view that visualized the user's historical carbon footprint was to obtain an overview. Therefore, only the parameters carbon footprint, lifestyle category, and date were picked out in the processing of the transactions to sum, group, and sort them into a stacked bar chart. However, the user was offered details-on-demand in the connecting views that could be navigated to by clicking on the bars. Thus, for each view, the transactions were reviewed and filtered out irrelevant parameters depending on what details were to be displayed.

The motivation behind encoding historical carbon footprint data before presenting the mitigation plan was that it was considered relevant to show the user the background to why the plan looked the way it did since the plan was calculated based on the user's data.

4.3 Presentation: How Was the Visualization Laid Out on the Available Screen Space?

The app was locked in portrait mode, and the prototype was therefore designed in the same aspect ratio. This meant that having bar graphs vertical instead of horizontal gave more space for the height of the bars than the width, which made it easier to compare the heights of the bars with each other. In all bar chart visualizations, the number of bars was between 10-12 except for the "Your carbon footprint" view, which could consist of significantly more than 12 bars. Since the bars should be clickable for more details, they needed to have a minimum width and space between them so that only one bar could be clicked at once. In all views except the "Your carbon footprint" view, this was not a problem as all bars were accommodated on the screen's width. However, this issue was resolved by making the chart with historical data horizontally scrollable. A white overlay area with low opacity was placed on the area to the left of the y-axis to visually tell the user that the chart could be scrolled, i.e., that there was more to see if the user scrolled to the right (see the left view in Figure 6).

To make the best use of the screen size, the mantra [19] was applied to avoid over-cluttering, i.e., details were divided into different views that the user had to navigate between instead of displaying everything at once in one view. The intention with this was also to create a clear hierarchy in the information presented. As previously mentioned, the bars were clickable, and the purpose of this was to make navigation a natural part of the exploration process. When a bar was clicked, a type of "zoom in" occurred where the user was navigated to a more detailed view containing the data representing the clicked bar. This method is called semantic zooming, a form of details-on-demand that allows the user to see different amounts of details in a view by zooming in and out without enlarging or reducing the content of the view itself [20]. Although this particular interaction was not a traditional pinch to zoom, one could consider the visualization being displayed as a zoomed-in version of the clicked bar. It could also be considered as a way of applying the concept previously mentioned used for desktop visualizations, Overview + Detail, but that the views are in this case divided into several screens.

Another design choice made to give the visualizations as much space as possible was to make all views vertically scrollable, so the user could center the visualization and make it fill up the entire screen space.

4.4 Interactivity: What Tools Did the Device Provide to Explore and Rearrange the Visualization?

The "Your carbon footprint" view could be filtered into different categories. In this way, the user was allowed to explore one or more categories and their change over time. Zooming in this chart consisted of the bars being clickable, which navigated to a view that showed one month at a time. In this view, the user could also scroll through different months by clicking arrows (see the right view in Figure 5). This interaction allowed the user to compare months with each other and how the categories' carbon footprint changed over time by seeing how the bars' heights changed through an animation. To find out exactly which transactions made up the height of the bar, the user could "zoom in" by clicking on the bar and navigating to a view that showed a list of the underlying transactions. This view also showed another detail-on-demand by telling the user what percentage this category accounted for the selected month's total carbon footprint.

The interactivity of the view containing the mitigation plan consisted of filters and clickable bars (see Figure 10). The bars, in this case, did not navigate the user further to another view but showed details-on-demand in the form of labels that showed the bar's y-value, i.e., an annual target according to the mitigation plan. The filter functionality consisted of the ability to choose to see a mitigation plan for the total carbon footprint or one of the three domains nutrition, mobility, and housing. This could be done by clicking on the buttons above the chart.

Figure 10. To the left: view displaying details-on-demand after clicking the bars. To the right: the mitigation plan filtered on nutrition.

The "Your goal in the short term" view was also interactive with clickable bars. Then the user came to the monthly details view displaying a "zoomed in" version of the chosen month. Unlike when the user navigated to this view via the "Your carbon footprint" view, the y-axis was scaled after the month with the largest footprint the current year instead of overall. The user could also click on the bars here to see category details followed by transaction details.

The last view, "Your margin", was interactive in the same way as the view, which displayed category details. Each transaction in the list was clickable. By clicking on a transaction, the user was navigated to a view that showed more details about the transaction.

4.5 Human Factors: Did the Interface Take Into Account Human Perceptual and Cognitive Capabilities?

Since navigation was a central part of the exploration process due to the limited screen space, the focus was on reminding the user wherein the hierarchy they were located. This was done mainly by using colors. For example, in the view where the user saw a list of transactions that caused the height of a bar in the previous view, the user was reminded of which category they had clicked on using a horizontal bar that showed in color what percentage the category made up of the selected month's total carbon footprint (see the left view in Figure 7). Furthermore, cognitive overload was avoided by applying the mantra [19] and striving not to display more information at once than necessary.

4.6 Evaluation: Has the Visualizations' Effectiveness Been Tested on Users?

The visualizations' effectiveness was tested on users. See section 3.2 for further details on the tests' structure and section 5 for the results.

5. USER STUDY RESULTS AND ANALYSIS

5.1 Form

The results from the form which each test participant completed before and after each test session showed a significant increase in mean value in responses to two out of nine statements. As these two were of particular interest to this study's focus, they will be presented in more detail further.

The first statement was "You know how large your carbon footprint is" which had a mean value increase of 1,2 with a 95% confidence interval. Before the test, the mean value was 4,2, and after it was 5,1.

The second statement was "You know the amount your carbon footprint needs to be reduced by in the future" which had a significant increase but with a 90% confidence interval. This mean value changed from 4,1 to 5,3. Further details of the results from these t-tests are to be found in Table 1.

Statement	T-test result	Mean value increase	Confidence interval
You know the amount your carbon footprint needs to be reduced by in the future.	0,089	1,2	90%
You know how large your carbon footprint is.	0,041	0,9	95%

Table 1. Results from paired t-test for the two statements of which the responses' mean value received a statistically significant difference.

The increase in mean values may indicate that the participants learned more about how large their carbon footprint was and how much it needed to be reduced by in the future by interacting with the prototype.

Since the participants also responded to questions about their usage of the card and app, the participants could be divided into user groups according to those answers. 50% of the participants answered that they used their card for a few single transactions, 30% for about half or less than half than all of their transactions, and 20% for all their transactions except a few where they use another card. In other words, the majority of the participants did not use their card enough so that the app could cover their entire carbon footprint.

Given the above, it was therefore not entirely unexpected that there were differences between how these user groups responded to the form. The participants who only used their card for a few single transactions had a mean value increase of 2,2 compared to 1,1 for the whole group in response to the statement regarding reduction in the future. This indicates that these participants learned something about how they needed to reduce their carbon footprint in the future, even though the visualizations represented an incorrect image due to a lack of data. It is conceivable that they could understand and relate to the goal for 2030 thanks to their knowledge of their carbon footprint from before.

The participants who used their cards the most had a larger mean value increase which was 1, compared to 0 for the whole group in response to the statement "You know how to reduce your carbon footprint". This could be a consequence of the fact that more data was to be used as a starting point in the mitigation plan and in the creation of the list of transactions that constituted a margin to the target.

5.2 Tasks

The following tasks were given to the participants:

1. Find out which month has generated the largest carbon footprint.
2. Find out how large the carbon footprint was that month.
3. Find out which category caused the largest footprint that month.
4. Find out which transaction caused the largest footprint in that category.
5. Find out your carbon footprint target for 2030 and how much you need to reduce your total carbon footprint to reach that target.
6. Find out how large your carbon footprint can be next year according to your mitigation plan.
7. Find out which of the three lifestyle areas nutrition, mobility, and housing that requires the largest change for you to reach the 2030 target.

Tasks 1-4 were given when the participant explored their carbon footprint in the "Your carbon footprint" view. When those tasks were completed, the user was asked to continue to the "Your path ahead" view where tasks 5-7 were given. The results from the quantitative data collected concerning the interaction with visualizations and the success rate for each task are presented in Table 2. The other metrics, time and number of clicks to complete each task, are presented in Figures 11-12.

As shown in Table 2 and Figures 11-12, the metrics differed between the tasks. Long time and many clicks to complete a task may indicate that the task was hard to grasp, that the user had a hard time finding the information they were looking for, or difficulties in understanding the visualizations. Since qualitative data also was being collected, more indicators could help identify the underlying reason for the results.

Task	Interaction	Success
1	40%	100%
2	60%	90%
3	80%	100%
4	80%	100%
5	33%	80%
6	86%	70%
7	83%	70%

Table 2. Results of the metrics interaction and success rate for each task given during the user tests. Interaction refers to the number of participants who clicked or scrolled the charts to perform the task, and success to the number of participants who succeeded in completing the task.

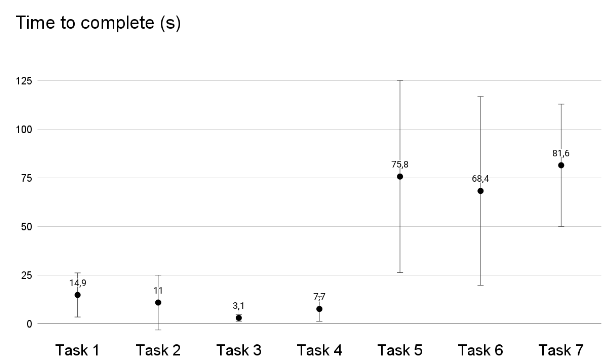

Figure 11. Mean values and standard deviation of time for completion of tasks.

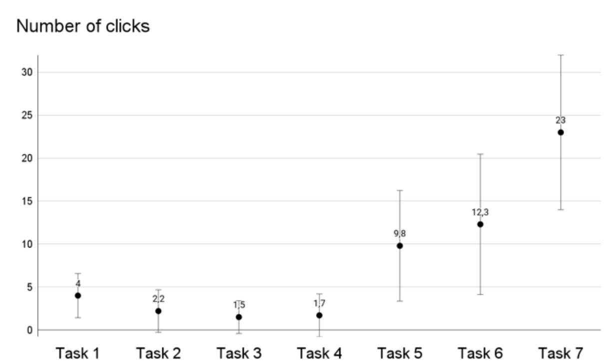

Figure 12. Mean values and standard deviation of the number of clicks for completion of tasks.

5.3 Thematic Analysis

The thematic analysis made on the qualitative data collected during the user tests resulted in different themes. Therefore, the next-following sections in this chapter are arranged according to the themes that were considered as most interesting for the study. The participants of the user study are referred to as P1-P10 in this section. All quotes are translated from Swedish.

5.3.1 Overall Impression of the Prototype

All participants expressed positive feedback regarding their overall impression of the prototype. The input included, for example, that it was clear, fun, pleasant to the eye, and easy to understand.

“This is gold! Nudging rooted in numbers.“ - P8

“This is the best attempt so far in trying to educate people and making them analyze their carbon footprint. I think this would encourage users to use their cards more. “ - P2

Four people, P2, P4, P5, and P10 thought that integrating this prototype into the app would be a boost as it filled a feature that was missing before. The addition added guidance and feedback to the app. P2 said that representing the data in this context could be a way to get people to analyze more as they would have something to relate their carbon footprint to. P2 also thought that the addition could encourage users to use the card more as the visualizations would be more accurate with more data. P5 explicitly said that this was the first time their data was set in relation to a plan ahead.

P3, P8, and P9 pointed out that they could, for the first time, see all their months' data at the same time, unlike before when they could only see one month at a time in the donut chart. Thus, the thought that the “Your carbon footprint” view showed an overview nicely and clearly. P9 said that their carbon footprint became easier to grasp.

5.3.2 Visualization of Mitigation Plan

As can be seen from the quantitative results from the tasks 5-7 that were given in connection to the “Your path ahead” view (see Table 2 and Figures 11-12), one can observe that some participants did not succeed in completing the tasks and that it required longer time and more clicks for those who did. This was also reflected in the qualitative data collected during the participants' interaction with the mitigation plan. A general first impression among the participants was that the view was a bit overwhelming as it contained more information than the view before. But once they grasped the concept and purpose, all expressed positive opinions about it. The comparison line, meaning the green horizontal line which benchmarked the 2030 target, was especially positively received. P3 and P4 wished that the line also would have been present in the first view by benchmarking the monthly target for 2030.

P4, P5, and, P7 said that the mitigation plan made the path ahead feel like something that they could handle. P4 said that by breaking down the target on an annual basis, it did not feel as overwhelming and hard as the thought of what the carbon footprint needs to be by 2050 — seeing the 2030 target felt more feasible. P7 described the visualization of the mitigation plan as a way of turning something hard to grasp into something very clear.

“4% annually should not be a problem!” - P5

“The mitigation plan is individual yet mutual. Regardless of the starting point, we must all reach the same target. “ - P7

Four participants found the three lifestyle area filters confusing as they did not reflect the app's categories. Some thought that the filter buttons corresponded to their three categories with the largest carbon footprint. When the names of the three lifestyle areas were read out in task seven, several of the participants did not understand what they corresponded to. This was also the task that took the longest time to complete and required the most clicks. Several participants began navigating to other views instead of filtering using the buttons. Three participants did not interact with the filters at all and could therefore not complete the task.

Other feedback concerned clarity of the mitigation plan where the participants expressed different needs. For example, P5 and P6 wanted to know more about the calculations of the plan, and P8 would have preferred the information placed in the legend above the chart to be integrated directly into it.

5.3.3 Increase the Visualizations’ Accuracy

A recurring topic during the user tests was how the lack of data affected the visualizations. Those who had not used their cards much said they probably would have learned a lot more from the experience if the app had reflected their actual total carbon footprint. Both P3 and P5 addressed this issue with a suggestion of how to solve it. The suggestion involved integrating communication with the user when they were suspected of having an unrealistic small carbon footprint compared with the average Swede. The app could then ask questions, similar to the ones in the form, about the user’s use of the card. The numbers used for the visualizations would then be adjusted accordingly. P3 otherwise raised the importance of communicating to the user that only carbon footprint tracked via the app formed the mitigation plan.

5.3.4 Usability Concerns

A few suggestions regarding usability were raised by the participants, where some recurred more than once. The most common was vertical scrolling, where four participants, P1, P2, P6, and P7, expressed that they would have preferred that all content in a view was resized to the available screen space, even if it would have meant that the height of the bars would have been decreased.

Two participants, P2 and P4, also expressed that they probably would have missed the buttons in the bottom that took the user to the following main view as they were not visible without scrolling down to the bottom of the screen.

5.3.5 The Visualizations in General

In general, the visualizations received positive feedback. P1 and P9 recognized themselves in the visual appearance and thought that the added views felt like a natural part of the app. They liked that the views contained many visual elements instead of numbers as it made it easy to understand. P6, P8, and P10 addressed that they liked the clarity of bar charts and that the bars could be clicked to see more details.

However, P6 and P10 pointed out that they did not understand that they could click on the bars at first, so P6 suggested a symbol that would encourage the user to click on them.

6. DISCUSSION

This study aimed to answer the research question "*How to use individual transaction data to visualize a carbon footprint mitigation plan compatible with the Paris Agreement targets on small screens? "*. This was explored by designing and implementing a prototype that was an extension of the Swedish mobile app DO, a newer type of carbon calculator that uses transaction data made with a linked credit card to estimate the users' carbon footprints. The prototype was evaluated by conducting a user study where each participant interacted with their own visualized customized mitigation plan.

The study results pointed out that the concept of receiving guidance in reducing one's carbon footprint as a visualized plan was appreciated by users. However, it emerged that the use of the service greatly affected the visualizations as the foundational data was generated with a bottom-up approach. The accuracy of the visualizations thus became affected when lacking sufficient data. Nevertheless, by adapting to the amount of data available, the concept could still work and achieve its purpose of guiding the user in reducing their carbon footprint to be aligned with the Paris Agreement targets.

When designing the mitigation plan, it was assumed that the users used their cards as much as possible and that the app thereby would reflect their actual carbon footprint. Unfortunately, this was not the case for most of the participants in this study, so the user tests' results did not turn out quite as expected. The mitigation plan did not reflect a correct picture for those participants since the app did not cover their entire carbon footprint. However, finding that several participants did not use the service as assumed was an important and interesting result. It pointed out the importance of having sufficient data or at least proper handling of different amounts of data when designing information visualizations. However, as some of the participants expressed, allowing the users to explore and analyze their data in relation to a benchmark may be a means to increase commitment and use of the service.

Furthermore, the user study resulted in findings concerning usability aspects which are to be discussed in the next-following chapter.

6.1 Usability

6.1.1 Vertical Scrolling

The idea of allowing vertical scrolling was to let the visualizations accommodate as much of the screen area as possible. The intention was thus that the user could center the visualization to interact with it and that over-cluttering would be avoided by hiding surrounding content. However, negative feedback concerning the vertical scrolling was received. Therefore, it would probably be advantageous from a usability point of view to make the bar charts smaller to see all the content in one view without scrolling. This finding also goes in line with the student work report's [12] proposal about making the interaction the focus of the design rather than the visualization itself.

6.1.2 Adjustments According to Different Users

The implementation included handling different user scenarios, although it was clear from the results that further handling would increase usability. For example, several participants expected to filter on their three categories with the largest carbon footprint instead of those that generally tend to cause the largest in the "Your path ahead" view. Through research, it might have been possible to develop targets for each category in the app instead of being limited by those used from the technical report [1]. One could then have allowed the user to interact with an even more customized mitigation plan.

6.1.3 Different Needs in an Overview

From the user study results, it seemed as if the users had different needs in the overviews. Some participants expressed that they would have liked more details displayed right away and not on-demand, while some instead felt overwhelmed. By observing the quantitative data, one can see a large range between the participants in how long it took to complete the tasks and the number of clicks necessary (see Figures 11-12). This could be due to different reasons, such as people simply wanting different information displayed to them. It may also be due to all participants interacting with the prototype for the first time, so perhaps they had particular wishes based on the tasks they were asked to complete. In conclusion, it could have been interesting to see whether the result would turn out differently by having users interacting with the prototype by themselves before evaluation or if it is simply a matter of different user needs.

6.1.4 Semantic Zooming

This study found that participants thought it was easier to interact with semantic zooming by clicking on the bars than buttons. When they navigated from "Your path ahead" to the following view built on the mitigation plan but presented on a monthly short-term basis, some participants did not understand how the views were connected. This could have been redesigned so that the whole interaction followed a common thread where the semantic zooming would be done more invariably throughout the entire experience.

6.2 Method Criticism

One could assume that the end-users of the DO service may be environmentally conscious since they have chosen to apply for the connected credit card. As a result of this assumption, the participants in this study were considered reasonable representatives of the end-users because of their workplace, i.e., a sustainability-focused company. However, despite their awareness, it turned out that the majority of the participants did not use their cards that much. Therefore, it could have been beneficial to research how the app was being used before starting the design process so that the design and implementation could have been adjusted accordingly. One could, for instance, ask for the user to input an estimation of how much of their total purchases they use the card for. However, in the absence of this information, it could be considered favorable that the participants in this study were employed by the company providing the service. Due to them being well acquainted with it, they could grasp the concept without larger obstacles and provide valuable insights regardless of how much they had used the service themselves.

Knowledge about the use of the app at an earlier stage of the research process could also have been beneficial in designing the tasks for the user study, though, as it was clear that some tasks were easier to complete than others. For example, task number six, where the participant was asked to find out their carbon footprint target next year according to their mitigation plan, was confusing for those participants whose carbon footprint in the app was smaller than the target for 2030. For them, the visualization was not displayed as a mitigation plan; instead, it showed they had already reached the goal. Had the participants' use of the card been known before, it would have been possible to adapt the task to such a scenario.

Moreover, the difference in the use of the app between the participants may have been why not more than two out of nine statements in the online form received a statistically significant mean increase. It could also result from having a small number of respondents or because some responded with the highest value possible before the test and that a higher value thus was not available after.

6.3 Future Work

The mitigation plan developed for this study could be applied to other carbon calculators or similar services. The only requirement for the calculations is an estimate of an individual's carbon footprint on an annual basis. Using bar charts and a comparison line was one way to represent the way forward visually, but one could also explore other visualization methods.

Furthermore, the prototype developed for this study may serve as a basis for future work examining the effectiveness of the visualized plan on more frequent card users. Since the participants in this study so well received the concept, it would be interesting to see if it would be perceived differently by more frequent users and if the perception of the user's carbon footprint would be affected to a greater extent. Such evaluation could then be done with users outside the company. Future work could also revolve around conducting studies looking into whether a mitigation plan integrated into a carbon calculator contributes to promoting behavior change.

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APPENDIX 1

Interview Questions

The user study consisted of ten participants interacting with the created prototype for the first time. During each test session, the participant interacted with the prototype while completing a set of tasks. Afterward, each participant answered some pre-defined semi-structured questions about their experience and the prototype overall, but also questions regarding things observed during the interaction. However, all participants did not receive the same questions because they answered some questions from discussions that arose in connection with previously asked questions. The pre-defined questions were as follows:

1. What did you think about this?
2. What did you find difficult?
3. What did you find easy?
4. What did you find confusing?
5. What do you feel you have learned from this experience?
    1. Would you consider sharing your lessons with people around you?
6. What do you think about the goals for 2030?
7. How did you experience the graphic visualizations?
8. What insights has the interaction helped you come to regarding your carbon footprint?

Example of questions the participants received that regarding things observed during the interaction:

1. When you entered the view containing the mitigation plan, you mentioned you did not understand at first that you could filter. Would you like to elaborate on that? What did you find hard to grasp?
2. You mentioned that you did not understand that the bars could be clicked at first and that it could have been made clearer. What do you think could have made that clearer for you?
3. You said that you prefer bar charts over the donut chart. Why is that?
4. When you were interacting with the “Your goal in the short term” view, you raised some concerns. Would you like to elaborate on what you found difficult regarding that view?

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