Visualization of Quantified Self with movement and transport data

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Visualisering av Quantified Self med rörelse- och transportdata

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ABSTRACT
Transport systems account for a large part of the world's CO\textsubscript{2} emissions. In order to reach goals, set to lower emissions, we need to travel less by car and increase the use of sustainable means of transportation. Through the use of self-tracking devices and by visualizing the data collected, individuals can learn about, and discover, habits, patterns and practices amongst themselves. In this thesis, the question of how much individuals know about their own CO\textsubscript{2} emissions created from the modes of transportation they use on an everyday basis, is explored.

The paper examines how a visualization of personal movement and transport data affects individuals’ understanding of their own CO\textsubscript{2} emission as well as their motivation towards using more sustainable modes of transportation. A two-week user-study was conducted with 15 participants. The participants tracked their movements and transports using a mobile application on a smart phone, and their data was presented in a web-application. Prior and post to the user-study, a self-evaluation questionnaire based on the COM-B model was handed out.

Results showed that participants’ understanding increased regarding putting their emission amounts in relation to what is low and what is high between transportation modes. An increased awareness of personal transportation patterns and what the environmental impact the choice of transport mode has, was indicated. Further, participants’ motivation towards using more sustainable modes of transportation seems to be dependent on realizing if they have low or high emissions but also if there exist available alternative transport options to switch to.

SAMMANFATTNING
Transportssystem står för en stor del av världens koldioxidutsläpp. För att nå utgångspunktmål måste färre resor göras med bil och användandet av hållbara transportmedel öka hos individer. Genom att börja spåra sig själv inom olika områden, och genom att bli presenterad sin insamlade data, kan individer upptäcka och lära sig om vanor, mönster och praxis bland dem själva. I denna avhandling undersöks hur mycket individer vet om sina egna koldioxidutsläpp som skapas av de transportmedel som de använder dagligen.


Resultaten visade att deltagarnas förståelse ökade när det gäller att sätta sina utsläppsmängder i förhållande till vad som är lägt respektive högt mellan olika transportmedel. En ökad medvetenhet om personliga transportmönster och hur stor miljöpåverkan valet av transportläge har, indikerades. Vidare verkar deltagarnas motivation att använda mer hållbara transportmedel vara beroende utav om de inser att de har låga eller höga utsläpp, men också om det finns tillgängliga, alternativa, transportmedel att byta till.
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Keywords
Quantified self, Sustainable HCI, Persuasive technology, Human Computer Interaction, Visualization

1. INTRODUCTION
Over the last couple of years, research on sustainable HCI has become a fast growing field within the science community [6]. During the last decade, several HCI research projects have been carried out in order to recognize issues on attitudes and behaviors of individuals with the focus on motivating people towards more sustainable lifestyles [ibid.].

In 2013 the Swedish Energy Agency (Energimyndigheten) announced a project with the goal of exploring energy efficiency in the field of energy, IT, and design. The vision of the project is to have a society where citizens have sufficient knowledge of environmental issues to be able to engage in shaping energy systems of the future [7]. The project supports, for instance, research that aim to affect individuals’ behavior with respect to energy use, climate impact, and electricity and heat production. This thesis adds to the project by investigating transportation and movement patterns for Swedish citizens. Specifically, it examines how Quantified Self (QS) data can affect users’ awareness, motivation, and knowledge in relation to sustainable transportation.

It has been found that transport systems accounts for a large portion of the worlds energy consumption and CO₂ emissions, and within urban environments, emissions from transports are increasing faster than any other energy sector [1]. In Sweden, car is the main mode of transportation used (~60%) for all domestic travels made by citizens [23]. The most frequent reason to travel by car is because of leisure activities while travels to and from work and school is on second place.

The Stockholm municipality has set a goal to reduce greenhouse gas emissions to 2.3 ton per resident per year by 2020 [17]. In 2015, emissions per resident in Stockholm was 2.5 ton, where transport constituted the largest part of emissions at 1.2 ton. In 1990, when the data collecting began, emissions per resident was at 5.4 ton. Over the next 25 years, the emissions were reduced by 53%. Most of this decrease occurred in the (house) heating sector, leaving transport emissions at an almost constant level [ibid.]. Furthermore, the government in Sweden [24] and the Swedish Transport Administration [24] has set a goal to reduce the levels of CO₂ from domestic transports by 60-80% by 2030 compared to the level of 2010.

To lower transport emissions, residents of Sweden need to switch to more sustainable modes of transportation. In order to explore how this switch can be achieved on an individual level, this thesis has (1) observed individual’s transportation habits, (2) implemented a system that presents and visualizes one’s own CO₂ emissions footprint, and (3) evaluated how users are affected by seeing this. The thesis aims to encourage reflection and knowledge of residents’ emissions from transports, and to increase motivation to use more sustainable modes of transportation, i.e. bicycling and public transport, among the residents.

The following sections of the report are structured in such a way that relevant terminology and related work is introduced first, followed by the thesis’ research question. Secondly, the method used in the thesis is presented together with a summary of the target group, and recruitment of participants. Thirdly, results, discussion, and conclusion are presented in the final chapters of the report.

2. BACKGROUND
The background starts with a description of, and critique against, persuasive technology, then follows an explanation of the
Quantified Self and the challenges that users have when collecting data of themselves. Further, different persuasion strategies are brought up followed by a presentation of similar research projects that have been carried out. Lastly, a framework for constructing behavior interventions is introduced.

2.1 Persuasive technology
In 2010, DiSalvo et al. [6] attempted to map the landscape of sustainable HCI research with the aim to explore what type of methods that are commonly used within this research field. Persuasive technology was found to be the most common method among the collected papers. Forty-five percent of the examined papers were using persuasive technology in order to affect individual’s behavior. Persuasive technology can, according to the authors, broadly be divided into two categories, strong or passive. Both categories have the intention of convincing users to adapt to sustainable manners using HCI designs and applications, but through different approaches. Through strong persuasion, a user is explicitly presented with information about how sustainable his/her behavior is. Through passive persuasion, information about broad effects are presented, and often “implicitly contextualized within the topic of sustainability” [ibid.].

Persuasive technology can play a key part of HCI research when attempting to achieve behavior change. However, how to use persuasive technology in an effective way to shape behavior is still an unanswered question within the HCI field of research. One problem with persuasive technology approaches, according to [3], is that most current researchers, in the area of sustainable HCI, make their own definition of sustainable behavior and then tries to persuade users to act and change behavior accordingly. This methodology, though, may not appeal to all users and can instead cause a reverse effect. Rather, according to the authors, an application could be designed to provide users with resources that increases knowledge to encourage discussion and reflection and that is not framed as a “means of prescribing behavior”. The dangers of not facilitating user reflection is also emphasized by [13] who argues that it is important for persuasive technologies to encourage users to contemplate the significance of protecting the environment, both from a personal and a global perspective. The authors also define the reverse effect, brought up by [3] as a boomerang effect, meaning that people who consume less energy than average, are likely to increase their consumption levels if the method of persuasion intervention is not constructed properly.

Another genre in sustainable HCI research is pervasive and participatory sensing [6]. This field focuses on involving participants in data collection using sensors. Often, participants in these kinds of studies may not have expert knowledge of gathering and analyzing data, but could, in some cases, be experienced in the area that is being investigated. This type of collected data is usually called Quantified Self data.

2.2 The Quantified Self
Quantified Self (QS) data is often used with the aim to build insights and increase understanding of one’s habits in different areas, e.g. training, food ingestion, or sleep pattern. Usually, data is presented through visualizations to enable a user to analyze personal habits and performance [15]. QS is defined by three major actions: acquiring data, visualizing data, and cross-linking of data to find possible correlations between factors [ibid.]. Progress has been made when analyzing how, when and where QS practitioners collect data, in what ways QS data is affecting individuals, as well as if this data can increase knowledge about oneself and alter attitudes towards certain behaviors [5,10,15,19,22]. Two issues have been identified at individual level. First, users have difficulties of handling and drawing relevant conclusions of the vast amount of data that is being collected [4,5,15]. Second, there is a lack of well-designed applications that can present the data in a useful and easy-to-understand way, which lets users discover correlations between factors that would otherwise be difficult to see [15].

Today, many self-monitoring applications exist that allow users to track a wide range of different data from their lives. The different types of data vary from input from the outside (e.g. calories or CO₂ consumed), certain states (e.g. mood, oxygen level in blood), or metric values of activities, e.g. kilometers run, amount of tabs used in internet browser during a workday [15].

2.3 Persuasion strategies through Quantified Self
Anagnostopoulou et al. [1] presents an analysis and summary on current research of persuasive technologies for personal sustainable transport behaviors in urban environments. The discussed articles utilize quantified self-data in different ways aiming for attitudinal or behavioral change through persuasive technologies. Twelve papers were selected and reviewed, and five different strategies, used either combined or isolated, were identified. The five strategies were categorized as follows: challenges & goal setting, self-monitoring, personalized messages, gamification & rewards, social comparison. A combination of these strategies are thought to help trigger a behavior change in different areas toward a more sustainable direction.

2.3.1 Goal setting and goal comparison
Letting participants set up their own goals and challenges, incentivizes self-competitiveness and enables a comparison between past, present, and future performance [1]. Goal setting has been shown to work well when the goals are realistic, defined by the participant, and when the participant can see his/her progress as well as receiving feedback upon it [19]. In some cases, both primary and secondary goals can be used to further encourage performance. If the primary goal is failed, the secondary goal can still be achieved, making a participant not lose faith in his/her performance. Sometimes estimations of one’s own abilities might not conform with reality and therefore, by enabling secondary goals or subgoals, participants can be helped to achieve, and maintain, positive progress over time [ibid.].

2.3.2 Self-monitoring
Self-monitoring, in this context, refers to automation of data tracking and applying computer technology to ease data handling of participants [1]. By applying automated data tracking, participants can spend more time on analyzing performance and focus on achieving eventual predetermined goals instead of having to attend to tasks as inputting data to an application, data exporting, and data transformation. Automated self-monitoring has been an issue for individual transportation tracking systems in past research. Most papers have developed their own tracking algorithms to determine what types of transportation modes that have been used by participants [9,12,14]. Though tracking is not always accurate in these papers, transportation mode is recognized automatically in some cases. In other cases, users have to specify mode of transportation themselves. In this thesis, the mobile application “Moves” [18] has been used to track location and movement data of participants. Moves identifies walking, running, bicycling, and flying by airplane automatically, and then classifies other types of transportation modes as “transport”. The user can then edit and specify type for each transport trip inside the application, e.g. car, bus, or underground. The application has been
used in previous research, e.g. a similar study by Baird & Zhao [2] who examined sustainable transportation habits in Canada. A more thorough description of Moves is presented in section 3.3.1.

2.3.3 Gamification
Gamification and reward elements are common functionalities when using persuasive technologies for behavior change. These elements could take the form of badges, trophies, or score boards to encourage competitiveness between peers and to drive participants to perform better than the rest of the group. It should be noted, however, that competitive elements sometimes do not motivate users to continue with a certain behavior [1,19]. According to [1] persuasion through competition do not motivate “a broad range of people” and can have the effect of people losing interest of keeping up with using a system or tracking themselves after a while.

2.3.4 Personalization
To personalize an application, making it “aware” of context, user preferences, and user capabilities, is seen as an important possibility to facilitate user behavior change. Instead of presuming that users will look up information themselves, proactive actions, e.g. delivering information at the right moment, is considered an effective intervention method for behavior change [1]. In this way, an alternative behavior can be suggested to a user at the right time, and help users to make the most suitable choice at the moment. Such proactive functionalities could, for instance, suggest more sustainable modes of transportation or travel routes when driving. It could also send personalized messages and notifications that encourage users to increase their use of sustainable means of transport.

2.3.5 Persuasion through social comparison
Sherpherd et al. [21] describes social comparison as “a phenomenon wherein people match their rate of performance to the rate of the people working around them”. In this thesis, social comparison is implemented as a visualization where each user can compare their data and performance against others. By displaying peers’ performances and letting subjects make social comparisons, the subjects’ actions can be affected. Previous studies in this area have shown that social comparisons can help motivate subjects to alter their behavior, e.g. performance against peers [1,11,12]. However, comparing oneself against better or worse performers can have different outcomes. [10] argues that extreme upward comparisons could make subjects either very discouraged or disinterested and extreme downward comparison can cause an effect similar to the boomerang effect described previously. Being a top performer can lead people to become passive and the authors describes this as “being the overall highest performer could be a source of apathy” [ibid.]. Still, comparing oneself against similar people who are slightly better can have a positive motivating effect among individuals, but if the comparative people are very dissimilar to each other, then often, the comparison has no effect [ibid.].

Social comparison visualizations have also been shown to encourage discussion and reflection upon one’s own behavior if implemented in an appropriate context and environment [25].

2.4 The Behavior Change Wheel
The Behavior Change Wheel is a framework developed by Michie et al. [16]. Its purpose is to help researchers, focused on behavior change, to understand when and/or how to intervene in order to cause a change in the user behavior. The central part of the framework is to understand the three components Capability, Opportunity, and Motivation and how these components drive or hinder individuals’ behavior. The authors define this as the COM-B model. Using the three components, key issues can be recognized on a given behavior, thus making it possible to design specific interventions that can help individuals adopt a new habit or conform to a new behavior completely. Each component is divided into two parts, see Figure 1. Since the thesis is focused on how technology and design can affect users understanding of their current transportation habits it will specifically target reflective motivation and psychological capability. The former is defined by Michie et al. as “Reflective processes involving plans (self-conscious intentions) and evaluations (beliefs about what is good and bad)” (e.g. intending to stop smoking) and the latter as “Knowledge or psychological skills, strength or stamina to engage in the necessary mental processes” (e.g. understanding the impact of CO₂ on the environment).

![Figure 1. The Behavior Change Wheel](image)

The third component, opportunity, and especially physical opportunity, is important with regard to transportation behavior as this component considers if individuals have access to the right equipment and/or services in order be able to change a behavior. For example, if one does not own a bicycle or a public transportation traveler card it might be harder to drive less. Physical opportunity aspects are included in some parts of this study, but since the goal is to explore users’ understanding and motivation the main focus has been set to examine psychological capability and reflective motivation.

Nine intervention functions are presented and should be applied depending on what the intended goal of the intervention is and what component that is being targeted. This study aims to raise understanding of one’s own travel habits and to aid participants to reflect about sustainable modes of transportation. Therefore, educational and persuasive intervention functions should be applied to help participants in those areas. The authors [16] defines these interventions as “increasing knowledge or understanding” (education) and “using communication to induce positive or negative feelings or stimulate action” (persuasion).
Furthermore, [16] also brings up several Behavior Change Techniques (BCTs) that should be used in combination with the chosen intervention function(s). Some of the BCTs are in line with previously mentioned persuasion strategies that have been used with persuasive technologies. A selection of the BCTs that are mentioned and used in this thesis, are Habit formation, Goal setting, Self-monitoring of behavior, and Social comparison. The authors also comment that self-evaluation through surveys can be a useful source of information. A questionnaire model is presented that is designed specifically for addressing the three main components in the Behavior Change Wheel [16].

2.5 Related work

An early effort to use persuasive strategies in HCI was made by Froehlich et al. [9] who developed a mobile application, called UbiGreen, to study how to affect Americans’ transport behaviors. During a three-week field study Froehlich et al. tested the application on 14 participants that sensed and exposed personal transport behavior through an ambient visualization. Results showed that participants valued individual feedback and suggestions were made that it should be possible to compare one’s data from one week to another. Though no behavior change could be confirmed, a few indications of participants using more environmental friendly modes of transportation were retrieved through the final survey of the study.

Jariyasunant [12] carried out a similar experiment on citizens of the San Francisco Bay Area. Over three weeks 135 persons tracked their usage of different modes of transportation using a mobile application. Participants could, during this time, visit a web application to view their transportation patterns and retrieve feedback based on four categories, as well as compare their data against peers. The four different factors that were measured were the time spent on transportation mode, cost, CO₂ emissions, and calories burned. Participants could also compare their own data over time to understand their patterns more accurately. A pre and post survey were handed out before and after the three-week study period. The participants could estimate on Likert scales personal opinions based on six categories: awareness, perceived norms, goal setting, attitude towards sustainable behavior and health benefits, and intentions. A statistically significant change in awareness was identified in relation to participants’ travel patterns. Furthermore, an intention to drive less and walk more was recognized.

Lowry et al. [14] also conducted a study based on QS transportation data and built a web application to visualize personal travel feedback to the participants. In the web application, participants could correct routes and specify the transportation mode that was used. Cost, calories burned, CO₂ emissions, and travel time was also presented to the user, categorized into walking, bicycling, driving a car, and riding a bus. Fifty participants tried the application over two weeks, and no behavior change could be recognized during this time, though an increase of reflective thinking of one’s travel patterns was identified.

2.6 Research question

The thesis aims to investigate the following question:

*How does a visualization of the Quantified self, affect individuals’ understanding of their transportation habits, with respect to CO₂ emissions?*

In this study, individuals were people residing in Sweden. A further description of the participant recruitment process is presented in section 3.1.

3. METHOD

The study was divided into three parts, a pre-study survey, a two week (15 days) application study, and ending with a post-study survey. During the two-week application study, participants used a website that visualized and presented their individual CO₂ emissions from transportation. The surveys and the application are further explained in sections 3.2 and 3.3.

3.1 Participant recruitment

In order to recruit participants to the study, two inquiries were sent out. One inquiry was handed out to a Facebook group called “Miljövänligare Vardagsliv” (“Environmentally friendly everyday life”)¹ that contains approximately 15,700 members and one inquiry was sent out to friends on my own Facebook page. In the first inquiry, 0 of 8 people that answered from the group “Miljövänligare Vardagsliv” could be included in the study due to either only possessing an Android phone, or not responding when being contacted. Users possessing Android phones were discarded because the Android version of the mobile application Moves lacked functionalities that were necessary for the study, e.g. specifying type of transportation mode that had been used during the day. Only iPhone users could be included in the study. In the second inquiry, 7 of 26 people that answered could participate, the rest could not be included due to the reasons mentioned above. Furthermore, 15 students from the Royal Institute of Technology were asked to participate. Eight students completed all tasks of the study, making it a total of 15 participants (9 males, 6 females). The students received university credits as a reward for participation.

3.2 Pre and post survey

Two surveys were created using the questionnaire model, presented by [16], as a basis in order to target transportation behavior and attitudes towards environmental issues in particular. The surveys contained questions that considered the three components of the COM-B model: capability, opportunity, and reflection. One survey was handed out prior to the two-week study, and one after it had finished.

The questions were designed as statements with Likert scales where participants could fully disagree or fully agree on a scale from 1 to 5. In the pre survey, statements were categorized into three sections. The first section contained statements of regarding physical opportunity, e.g. focusing on what type of transportation that was used the most on a daily basis, if the participant possessed a driver’s license, and if they regarded it economically expensive to travel by different modes of transportation. In the second section, statements were focused on getting an understanding of the participants’ psychological capabilities as well as their understanding of their own CO₂ emissions. The third section contained statements of motivational nature, focused towards using sustainable modes of transportation.

The post survey was designed in the same way as the pre survey, but did not contain the first section regarding physical opportunity. In addition to the Likert statements, twelve qualitative questions were added to further understand participants’ thoughts towards tracking themselves, and to see if a higher degree of motivation

¹ Miljövänligare vardagsliv, available at: https://www.facebook.com/groups/279469128757971/, [2017-04-11]
towards using sustainable methods of transportation could be recognized. Five of these questions were formulated as yes/no/do not know with an option to motivate the answer. The remaining seven were open ended questions asking how they perceived using the application as well as how they perceived each visualization section in the web application.

The Likert statements were, upon completion of the study, statistically analyzed by doing a two-tailed Wilcoxon signed-rank test [8]. Since the data is paired, meaning that the two scores are tied to each participant, the Wilcoxon signed-rank test was used to calculate if a statistically significant change could be identified for each statement. The test was performed using an online tool².

3.3 Applications

3.3.1 Moves app

In order to track what kind of transportation mode participants were using, the mobile phone application Moves [18] was used. Moves is a commercial application developed by ProtoGeo which tracks movements using data from the accelerometer and the GPS sensors inside the mobile phone. It automatically recognizes walking, running, bicycling, and flying by airplane, and remaining transportation modes (such as car, bus, underground, or train) can be specified by the user inside the phone application. If not specified, it is presented as transport only. A user can see his/her transportation pattern as either a timeline or visualized on a map to better understand habits and the use of certain transportation modes. Moves also calculates steps taken and calories burned per day.

3.3.2 Web application

In this study, a custom web application was built in order to extract participants’ travel data from Moves and to visualize participants own CO₂ emissions.

The web application was designed to present participants’ CO₂ emissions based on their own transportation behavior. The different modes of transportation that were used were car, bus, underground/commuter train, train, and airplane. These were visualized with respect to CO₂ emissions, distance and time. Users were also presented with the distance and time spent on walking, running, and bicycling. Lastly, users could also compare against benchmark emission values such as the average Swede’s daily CO₂ emissions from transportation and an estimated daily emission goal for 2030.

The Swedish government [20] and the Swedish Transport Administration [24] has set up an emission goal for Sweden to lower its CO₂ emissions from transport with 60-80% by 2030 from Sweden’s transport emission values of 2010. The emission goal used in the web application was estimated using CO₂ emissions data from domestic transports in 2010 from SCB³, and an 80% decrease was calculated. Further, a benchmark value of a Swede’s average CO₂ emissions per day was also estimated using domestic transport data from SCB (latest year with data was 2015 at the point of designing the web application).

Benchmark data for CO₂ emissions per transport mode was collected from the Swedish Environmental Protection Agency (Naturvårdsverket) [26], which has compiled average CO₂ emission factors for different modes of transport in Sweden. In Table 1, the emission factor for each transportation mode used in the study, is presented. The factors do not include CO₂ equivalents and all data presented for participants in the study have not taken CO₂ equivalents into account. The reason behind not including CO₂ equivalents is because of difficulties finding data for all transport modes looked at.

Table 1. Emission factors used to calculate CO₂ emissions for each transportation mode used in the study.

<table>
<thead>
<tr>
<th>Transport mode</th>
<th>Emission factor (kg CO₂/km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Car</td>
<td>0.16</td>
</tr>
<tr>
<td>Bus</td>
<td>0.041</td>
</tr>
<tr>
<td>Underground/commuter train</td>
<td>0.007</td>
</tr>
<tr>
<td>Train</td>
<td>0.000002</td>
</tr>
<tr>
<td>Airplane</td>
<td>0.129</td>
</tr>
</tbody>
</table>

Emissions could be viewed in three sections of the web application. First, an overview of daily emissions divided by transportation mode was presented, as seen in Figure 2. Every column represents one day, and the height of the column represents the total amount of emissions (kg CO₂) that day. Here, the user can also compare one’s emissions against the estimated emission goal set for 2030.

Figure 2. Daily emissions. Each column represents a day, where the height corresponds to the total emission. The columns are divided by transportation mode. The horizontal line represents the 2030 emission goal.

Secondly, the participants could compare their average emissions per day with both other participants and the average Swedish citizen, as well as to the estimated emission goal for 2030, see Figure 3. Thirdly, a section visualizing the participant’s total CO₂ emissions since starting the study was presented (Figure 4). In this section, the sum of all emissions were displayed first. Second, participants were presented what their amount of emissions correspond to, compared to other activities such as hours of watching TV, hours of using a laptop, and amount of charges it takes to charge a mobile phone⁴. In addition, a median value of the other participants’ total emissions was displayed. Below, the participants could view total emissions (kg), total distance (km), and total time spent (hours) divided on each transportation mode.

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² AI-Therapy Statistics, available at: https://www.ai-therapy.com/psychology-statistics/hypothesis-testing/two-samples?groups=1&parametric=1, [2017-05-03]


Participants could also view time and distance spent per transportation mode presented in pie charts in a forth section, as well as total steps taken and total calories burned (fifth section) during the study, further down on the web application.

From MoveS, participants’ travel data were extracted and compiled, and is presented in Table 2. Transportation modes that had been used by the participants was identified as well as how many uncategorized transportation modes participants had. During the study, participants made on average 30.4 trips each using vehicles (car, bus, underground/commuter train, train, airplane, bicycle). This value also includes uncategorized transportation modes. Six participants (F1, M3, F4, F5, M7, M8) had a higher average than the emission goal of 2030 (1.1 kg CO2/day) at the end of the study, and three of those had a higher CO2 emission than the average Swede (4.9 kg Co2/day). The two participants with highest estimated emission values per day (M3, F4) both flew by airplane once during the study. Further, M2 and M6 had not categorized any transportation trips during study. Still, these participants are included in the result as their responses from the pre and post survey have shown indications of reflection around their travel habits.

4.2 Travel data

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4.3 Surveys

4.3.1 Statements

Of the seventeen statements from the surveys, two were found to have a statistically significant change using the Wilcoxon signed-rank test after completion of the study. The test statistic is denoted by the letter T, and effect size by r. The first statement was “I have a good understanding of how much carbon dioxide I emit from the means of transport I use” which had a significantly higher score after the study (M = 3.13) compared to before (M = 2.13), T = 2.5, p < .05, r = -0.475. The second was “Based on what I know today, it’s likely that I will change my behavior so that I travel more by sustainable transportation” which had a significantly higher score after the study (M = 2.60) compared to before (M = 1.53), T = 10, p < .05, r = -0.464.

Another statement that increased in score after the study, although not significant at p<0.05, was “I have a good understanding of how much carbon dioxide people in my vicinity emit from the means of transportation they use”. It had after the study increased from M = 1.93 to M = 2.67 (T = 12, p = .056, r = -0.349). All statements can be viewed in Table 3.

Overall, participants indicated that they think that environmental issues are important and that they believe themselves to have low CO2 emissions. Further, they believe that their CO2 emissions by transport does not have a large impact on the environment.

4.3.2 Yes/No/Do not know

Eight participants agreed that by using an application that presents one’s CO2 emissions footprint by transportation, they get more motivated to use sustainable modes of transportation. Six participants disagreed with various reasons. Participant M4
Most mentioned an increased degree of insight in emission presents one’s CO₂ presents one’s CO₂ emission when asked how they experienced it to use an application that
4.3.3
every day or who travels by plane often (M8).
but other groups in society who, for example, travels by car to work
study (F2), or that it was not the participant that needed to change their
were already happy with their performance (M6), that their most
motivations of those who disagreed was that they
lacked. Some motivations of those who disagreed was that they
put their CO₂ footprint in relation to what is a

Table 2. Compiled participant travel data from the Moves application. Walking and running trips are not included. Walking data includes movement such as walking from bus stop to underground station, and has therefore been discarded.

<table>
<thead>
<tr>
<th>Participant</th>
<th>Age</th>
<th>City size</th>
<th>Average CO₂ emissions per day (kg)</th>
<th>Total amount of trips made with vehicles</th>
<th>Uncategorized transports (%)</th>
<th>Most common mode of transportation used (n=trips)</th>
</tr>
</thead>
<tbody>
<tr>
<td>M1</td>
<td>22</td>
<td>Big city</td>
<td>0.55</td>
<td>9</td>
<td>12.5</td>
<td>Car &amp; boat (2)</td>
</tr>
<tr>
<td>F1</td>
<td>60</td>
<td>Medium city</td>
<td>11.1</td>
<td>58</td>
<td>0</td>
<td>Car (48)</td>
</tr>
<tr>
<td>M2</td>
<td>23</td>
<td>Big city</td>
<td>0</td>
<td>13</td>
<td>100</td>
<td>-</td>
</tr>
<tr>
<td>F2</td>
<td>25</td>
<td>Big city</td>
<td>0.8</td>
<td>41</td>
<td>0</td>
<td>Underground (18)</td>
</tr>
<tr>
<td>F3</td>
<td>22</td>
<td>Big city</td>
<td>0.08</td>
<td>17</td>
<td>0</td>
<td>Underground (9)</td>
</tr>
<tr>
<td>M3</td>
<td>27</td>
<td>Big city</td>
<td>15.47</td>
<td>38</td>
<td>58</td>
<td>Underground (9)</td>
</tr>
<tr>
<td>M4</td>
<td>21</td>
<td>Big city</td>
<td>0.96</td>
<td>42</td>
<td>8</td>
<td>Bus (13)</td>
</tr>
<tr>
<td>M5</td>
<td>24</td>
<td>Big city</td>
<td>1.0</td>
<td>20</td>
<td>5</td>
<td>Underground (11)</td>
</tr>
<tr>
<td>F4</td>
<td>22</td>
<td>Big city</td>
<td>13.67</td>
<td>19</td>
<td>20</td>
<td>Bus, bicycle &amp; train (4)</td>
</tr>
<tr>
<td>M6</td>
<td>24</td>
<td>Big city</td>
<td>0</td>
<td>49</td>
<td>100</td>
<td>-</td>
</tr>
<tr>
<td>F5</td>
<td>39</td>
<td>Big city</td>
<td>2.94</td>
<td>29</td>
<td>0</td>
<td>Car (15)</td>
</tr>
<tr>
<td>M7</td>
<td>19</td>
<td>Big city</td>
<td>1.48</td>
<td>23</td>
<td>35</td>
<td>Bus (8)</td>
</tr>
<tr>
<td>F6</td>
<td>29</td>
<td>Big city</td>
<td>0.81</td>
<td>8</td>
<td>0</td>
<td>Car &amp; underground (3)</td>
</tr>
<tr>
<td>M8</td>
<td>21</td>
<td>Big city</td>
<td>1.52</td>
<td>46</td>
<td>2</td>
<td>Car (25)</td>
</tr>
<tr>
<td>M9</td>
<td>31</td>
<td>Big city</td>
<td>0.55</td>
<td>44</td>
<td>2</td>
<td>Underground (21)</td>
</tr>
</tbody>
</table>

highlighted that the length of the study was too short to have a significant impact on his motivation, F1 and F3 mentioned that it was hard to choose other, more sustainable options, than they already used. Participant M7 answered “do not know” with the motivation that there is not much he can change in his travel habits; bus is the best option available.

Eleven participants agreed to have reflected more often about how much CO₂ they emit from the means of transportation they use when using an application that presents one’s CO₂ footprint. Participant F1 answered do not know with the motivation that it would have been good to be able to compare different fuels, such as diesel, petrol, or electricity, an option which the web application lacked.

Ten participants agreed and three disagreed that they had learned to put their CO₂ footprint in relation to what is a high and what is a low amount when using the application.

When asked if, by using an application that presents your personal CO₂ emissions, they thought that they needed to use sustainable transportation more often, six agreed, eight disagreed, and one did not know. Some motivations of those who disagreed was that they were already happy with their performance (M6), that their most frequently used mode of transportation was not included in the study (F2), or that it was not the participant that needed to change, but other groups in society who, for example, travels by car to work every day or who travels by plane often (M8).

4.3.3 Open ended questions
When asked how they experienced it to use an application that presents one’s CO₂ emissions participants had varied responses. Most mentioned an increased degree of insight in emission relations between different modes of transportation. Participant M4 highlighted the importance of awareness and feeling of togetherness for environmental issues:

“The application made you to think about your travels and made you more aware of how your daily transport habits look like. That awareness fostered a mindset that raised questions about environmental impact. I believe that more people need to participate in using similar applications [...], to be able to feel a sense of togetherness. When that sense of community starts to exist, things can start happening.”

Participant M5, F4 and M9 all mentioned that it gave them more insight in putting the emission values in relation to each other. M9 thought that this probably would affect his travel decisions in the future:

“In particular, it gave more insight of how big difference it is between bus and train. I always struggle when choosing train/underground over bus, but this will probably affect my decisions in the future.”

Another (M7) pointed out that even though it is good to have your footprint noted, there is not much you can do if you already travel a lot with sustainable modes of transportation:

“Interesting and frightening. Good to have it noticed. Unfortunately, there isn’t much more that I can do. I travel by public transport more or less all the time”

Of the visualizations in the web application, most participants described the first section with daily emission values as “interesting” and that it was “good to see directly how your choices affect one’s carbon footprint”. However, two participants, M1 and M2, highlighted that they were not that affected since one of them
only owned a bicycle (M2) and the other had zero emissions on most days during the user study (M1).

Further, the remaining visualization sections on the website (comparison, total overview of emissions, as well as distance and time spent on each transportation mode) were also evaluated with open ended questions.

Half of the participants had positive responses towards comparing against peers, while half did not find it either interesting or clear. Participant F1 commented: “Don’t know what it says. Where do the other participants live? I think that it is important with an equivalent comparison group in order for me to be able to compare.” while M8 described it: “Fun because of the competitiveness. I had probably not checked the website as often if that element was missing in the study.”

When comparing with the daily emission goal of 2030, most of the participants indicated a positive attitude towards the comparison, and a few participants commented that it was depressing or that it made you feel hopeless and that it felt difficult and unattainable to reach the goal. Several participants indicated signs of learning or understanding in their answers: “It was an eye opener.” (M5), “An aha experience! I thought that I easily would be under the goal, especially when traveling with bus. But how wrong I was that day in the beginning when I exceeded it. That day is also very representative for my daily travels [...]” (M9), “I thought it was interesting and fun to find that most of my daily trips are in line with the goal with a good margin” (F3).

The overview of total emissions per transportation mode was appreciated by most participants. Comments were made that it made oneself more motivated to use sustainable modes of transportation, that it was informative and exciting, and that it made you understand what type of transportation that is recommended. Participant M9 highlighted thoughts of worry against future trips: “Mostly scary because I start to think of how the values will change when I will travel by airplane later this year”. Two participants thought that it was either pointless because of already having low emission values (M1), or not interesting when traveling mostly by bicycle (M2).

The last section, visualizing time and distance spent per transportation mode, was also evaluated. Five participants commented that it was “interesting”, while other comments varied between “it was hard to understand” (F2), “depressing” (M6, M7), and “Nothing new really [...] It is fun to see how much time it takes to walk to different places” (F3).
5. DISCUSSION

5.1 Understanding
It is clear that being presented your own CO₂ emissions on a daily basis increased the participants’ understanding of emissions related to different modes of transportation, and an increased understanding of one’s own emissions can be identified within the group. Firstly, through the statistically significant increase of the statement regarding understanding how much emissions they have through the means of transportation they use. Secondly, several comments show a raised awareness and an increased insight of how much different modes of transportation emit with regard to CO₂. Worth noting is that even though an increase could be identified from the survey statement, the score went up from a quite low value to only a slightly higher value. Participants instead expressed that they had gained a higher understanding through the open ended questions in the post-survey. In addition, it seems like the presented emission goal of 2030 helped participants to understand their own emissions in relation to what can be considered high or low. This affects the psychological capability positively as it helps the participants to make an informed choice of what transport mode that is more sustainable, but only to the extent of what their physical opportunities allow. As one participant (M7) mentioned, bus is the only feasible transport alternative for him. This means that his physical opportunities are limited and that he is unable to make a choice at all.

Many participants commented upon realizing how much CO₂ a certain mode of transportation emits. Although the group thought that environmental issues are important, many were surprised on how high the CO₂ emissions was from especially car and airplane compared to bus and underground. The participants realized this when they traveled with these modes during the study, which implies that not many had that knowledge prior to the study.

5.2 Motivation
By intervening with education, intentions to change transportation habits has overall increased in the group, and affected participants’ reflective motivation. For those participants that realized that their emission values were low, no increase in motivation towards using more sustainable means of transport could be identified. As [13] describes, it is important to not only present information in order to affect users, but to facilitate reflection. A failure in this regard could instead lead to decreased motivation, and in some cases create a boomerang effect, e.g. individuals who consume less energy than the average person tends to increase in energy consumption instead. In this study, however, the lack of motivational impact for some participants can be argued as to be a consequence of raised awareness as well as an increased understanding of one’s travels and emission values among the participants. In some cases, it can also be about not having any viable transport alternatives, e.g. if bus is the only option available as mentioned previously.

The result from the qualitative questions shows that a majority of participants started to reflect upon their daily transportation and CO₂ footprint. Some participants showed signs of reflective processes, as Michie et al. [16] defines reflective motivation, see section 2.5. For example, participant M9 expressed both a will to continue use the web application after completion of the study, and plans to travel by train more often than bus when faced with the option to choose transportation mode. Participant M4 also expressed thoughts of reflection, especially about his daily travels in relation to society. He highlighted the importance of raising awareness of environmental issues and to create a community feeling which could lead to decreased CO₂ emissions from individuals. In general, according to the qualitative answers, participants have often reflected on their CO₂ emissions during the course of the study.

Both a declining and an increased score from the statement “Based on what I know today, it’s likely that I will change my behavior so that I travel more by sustainable transportation” can indicate that a participant has increased one’s understanding of his/her transportation behavior while at the same time indicating if participants intend to change transport habits. For example, one participant (M1) realized that he already had very sustainable habits with regard to transportation and therefore declined in score from 3 to 1 after the study was complete. Based on the newly acquired insights of personal CO₂ emissions from the web application, his intention to change transport habits did not increase. The statement has overall, similar to the previously mentioned statement, increased marginally in score from a very low value to a slightly higher, which means that participants disagree to a lower extent.

5.3 Persuasion elements

5.3.1 Peer comparison
Comparing one’s data with peers did not seem to be a motivating factor in the scope of this study. Only one participant (M8) explicitly mentioned that he got more motivated and competitive because of being able to compare against the peers. As mentioned in section 2.3.5, comparison strategies within sustainable HCI has been discussed previously in several articles of persuasion and can have divided impacts on users [10,13]. In some cases, social comparison can be a motivating factor, often for those who consume more energy than the average individual. It can also create a boomerang effect, mentioned previously, that results in increased energy consumption for those who are below the average. In this case, no sign of increased motivation in the group because of peer comparison was indicated. Participants either realized during the study, or knew prior to it, that they already had sustainable transportation habits. In order to identify if a boomerang effect will take place, the study needs to continue over a longer period of time.

The majority of participants are residents in big cities, and tended to already have low CO₂ emissions. Bicycling, and public transport were perceived in the beginning of the study as the main means of transportation by the participants. This seemed to conform with the results, although some commented that they had used car more often than usually during this time period. Participant F1 is the only one living in a middle sized city and who had reflections of where the other peers lived and what travel habits they had. The same participant was also the most frequent driver during the study and had the largest average emission value aside from those who traveled by airplane. Participants’ area of residency should be a factor to take into consideration when comparing CO₂ emissions within a population. Urban citizens in large cities have more opportunities to use other means of transportation than the car, and in this study, most big-city residents tended to already have quite sustainable transportation habits.

5.3.2 Goal comparison
Comparison against the calculated emission goal for 2030 was something that most participants thought was interesting and relevant. It seems that, by being presented with a benchmark value, participants can easier put their emissions in relation to what is recommended. When comparing to the goal, competitiveness between peers is disregarded and participants can instead focus on improving their emission values. However, a few participants remarked that it was depressing or made them feel hopeless. Those remarks are in line with the critique against comparison elements in persuasive HCI designs [10,13]. Goal comparison seems to be
an important strategy to consider as a majority of participants expressed positive attitudes towards the goal comparison value. Further, post-survey responses indicate that participants have increased their understanding of putting their own emissions in relation to what can be seen as a high or low amount because of this comparison element.

Participants were also given a comparison towards the average Swede’s daily CO₂ emissions, but this comparison element was not mentioned much in the qualitative responses. Compared to the estimated 2030 emission goal, the average Swede’s daily emissions were approximately four times higher (1.1 kg vs. 4.9 kg). Even though most participants had significantly lower emissions than 4.9 kg, the score did not increase for the statement of participants agreeing that others should travel more with sustainable modes of transport. Only three people, of which two flew by airplane during the study, had a higher emission than the average. Because of the low emissions and the low number of participants in the group, it can be questioned whether the participants are a representative sample of Sweden’s population or the estimated value is realistically defined.

5.3.3 Personalization
Personalization of data, and making an application more aware of a user’s preferences is seen as a powerful tool to both ease the workload of a user and to nudge users into certain ways of thinking [1]. In this case certain personalization features could not be implemented. Some users expressed a wish to specify certain travel options, such as fuel type, amount of people in a vehicle, and values for electric cars - options that are very relevant when calculating CO₂ emissions from travels. Further, it would have been preferred if the mobile application Moves could recognize additional modes of transportation automatically instead of having the user categorize, for example, car and underground trips every day. A few participants mentioned that this process was a bit time consuming and tiresome in the long run. Although automated transportation recognition is improving in this regard [9,12,14], development has not yet reached a point where travel mode recognition is reliable and works seamlessly for the user. Though some personalization elements is included in the web application, e.g. a greeting message presenting current emissions for today, it could not be determined if it had any effect on motivating participants.

5.4 Limitations and method criticism
As mentioned above, the web application lacks elements of personalization that can help promote certain behaviors, or further increase knowledge of one’s travel habits. For example, a car driven by electricity has a lower degree of CO₂ emissions. One participant mentioned this explicitly when evaluating the overall experience for the web application - a critique that implies that emission values presented for that particular participant might not have reflected the actual emissions for said participant.

The emission factors used to calculate CO₂ emissions are, in this study, not taking CO₂ equivalents into consideration. Thus, traveling by airplane is actually seen as a more sustainable mode of transportation when comparing to travels by car. The reason for not calculating with CO₂ equivalents is simply because of difficulties finding reliable data for all modes of transportation examined. The Swedish Environmental Protection Agency [26] has compiled a template of emission factors of CO₂ for the most common transportation modes used in Sweden, and these were the numbers used in the study. These numbers represent emissions of fossil CO₂ from exhaust pipes, and in the case of rail traffic, the emission has been calculated based on emissions from electricity production.

Further, this study on behavior change has some limitations with regards to the short time span of two weeks. Two weeks is not enough in order to be able to identify real behavior change among individuals.

6. CONCLUSION
By presenting and visualizing one’s CO₂ emission footprint based on individual transport habits, this study’s participants’ understanding and reflection about their own travel behavior was increased. Because of being able to compare against both a low and a high benchmark, participants were helped to understand the amount of their own emissions. More specifically, participants have learned to set CO₂ emissions from different modes of transportation in relation to each other and understood how much more, e.g. a car emits compared to bus or underground.

By logging your travels every day, a habit of reflecting about how and where you traveled is slowly being created. During the study, participants showed an increase in awareness of their transportation patterns as well as the environmental impact that the choice of transport mode has with regard to CO₂ emissions.

According to comments made by participants, comparing oneself against a long-term low emission goal seems to have affected them more than comparing against a high emission value based on the average citizen in Sweden. Peer comparison showed no greater effect with regard to motivation. Further, participants who had very low CO₂ emissions, as well as those who did not have any possibilities to choose other, more sustainable modes of transportation, displayed no signs of increased intention to use more sustainable modes of transports in the future.

7. FUTURE WORK
For future research, it would be interesting to broaden the target group to involve more individuals living in rural environments, in order to compare emissions and habits against urban residents. To also expand the amount of people and time span for the study would be beneficial for analyzing behavior change.

This thesis focuses mainly on the two components motivation and capability from the COM-B model, presented by [16]. Future work should incorporate opportunity more to further understand the intrinsic relationship between the three components.

Lastly, some users expressed a need for more options to specify travel data. Functionalities such as changing fuel type, define number of people in vehicle, and options for electric modes of transportation should be included in future research.

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9. REFERENCES
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