Creen: A Carbon Footprint Calculator Designed for Calculation in Context

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Abstract. Concerns regarding the environment and the impact humans constantly have on the environment has been a growing concern for decades, but there is still a substantial lack of environmental literacy and action among most of the population in what they can do to reduce the damage they may be indirectly causing. Given that many people express an interest in helping the environment, this paper presents a prototype of a carbon footprint calculator which interprets a carbon footprint estimate into a form that can be more accessible to people so that they may be empowered to make more informed decisions with greater awareness of their own impact.

Keywords: Human-computer interaction · Sustainability · Internet of Things

1 Introduction

Many people express their environmental impact as being important, yet there is a significant gap in the understanding of carbon output, carbon footprints, and their calculation [4,10,20]. The measurement of carbon output in pounds, kilograms, or tons is difficult for people to conceptualize as a gas by volume is not something readily accessible for many [1,21]. It is often hard for users to evaluate their energy consumption and to further take actions on saving energy. This study aims at resolving these issues through effective design with feedback which incorporates a metric to display carbon output in relation to the number of trees required to offset the CO_2 footprint and integrating Internet of Things (IoT) devices to improve measurements while limiting the need for user input.

To identify core challenges experienced by users in attempting to understand their environmental impact regarding carbon footprints, we conducted personal interviews and an online survey. Based on collected feedback, we developed a prototype Carbon Footprint Calculator app that asked a minimized number of questions in order to reduce the burden of usage and create a system with understandable feedback to enhance user awareness of their carbon footprint.

N. G. Taylor et al. (Eds.): iConference 2019, LNCS 11420, pp. 769–776, 2019.
https://doi.org/10.1007/978-3-030-15742-5_72

2 Related Work

Interest in greenhouse gas emissions and carbon footprints has been on the rise and continues to be a topic of discussion across many fields of science, yet standards for measuring and reporting carbon footprints are still developing. Pandey et al. reviewed numerous carbon footprint calculators that exist online or through consultants and found very few reported the same results even when given identical inputs [14]. Goodier discussed the calculation of carbon footprints on larger scales for companies, cities, and even countries and reported measurements in tons of carbon dioxide [8] while Weidema et al. suggested alternatives for presenting carbon footprint measurements [23].

As concerns grow regarding methods to reduce carbon footprints and environmental impact, insights from previous eco-design literature influence new attempts at communicating the knowledge of carbon footprint impact. In an attempt to understand the motivation of people's environmental behaviors, psychologists proposed several different models revealing human behavior. In the pro-environmental context, we focus mostly on norm-activation and rational-choice models. Norm-activation models prescribe that people's social behaviors are mainly subject to moral or personal norms [2,7,16,18], while the premise of rational-choice models is that environmentally conscious behaviours are aggregated from individual preferences which seek to minimize cost and maximize benefits [2,7,16]. As environmental behaviours usually impact a community base, in which personal behaviors can affect others as well as future generations, Schwartz's model [18] suggests that people's environmental behaviors will be improved when they are aware of the negative consequences they have on others. The "self-centered" rational choice models suggest that people would improve their environmental behaviours to improve personal benefits.

These models serve as the fundamental frameworks helping people understand human behaviors towards the environment. Yet to incorporate these models into products and interventions through integration of motivational techniques is an essential task for a designer. Previous work [7,16,19] has found comparative feedback an efficient way to motivate people's behaviors. Comparative feedback, with certain kinds of comparisons, used in persuasive applications promote behaviour change in areas such as energy conservation [6,13,16]. This comparative feedback includes self-comparison and social comparison. Self-comparison, refers to comparing one's current performance to past performance, whereas social comparison refers to comparing one's performance to that of others. However, these comparisons usually prove too complex for users to perceive the impact of their energy consumption on the environment [17].

Researchers [9,15–17] utilized eco-visualization to reveal energy consumption. Pierce et al. defines eco-visualization as "*any kind of interactive device targeted at revealing energy use in order to promote sustainable behaviours or foster positive attitudes towards sustainable practice*" [17]. Consumption data is often visualized as descriptive graphs [15,24] or metaphors [3,11,16], while some designers apply critical design to eco-visualization by utilizing different levels of artifacts and animations to increase people's environmental awareness [17].

The review of previous research has shown the potential of utilizing comparative feedback and eco-visualization to encourage pro-environmental behaviours. However, these have not been well applied to carbon footprint calculation. Furthermore, as IoT devices become popular among users, it is meaningful to work on designs that connect IoT devices with sustainable behaviors, which serves as the main motivation of this study. This paper addresses how eco-visualized comparative feedback could be designed to calculate carbon footprints. In particular, our work aims at providing design implications on eco-visualized comparative feedback through mobile and IoT devices.

3 Methodology

Informal semi-structured interviews were conducted with different groups to gauge their behaviors, insights, and ideas regarding the use of technology, environmental conservation concepts, and their intersection. Our participants included a PhD Student in environmental science, an owner of a construction company, attendees of a meeting by a student sustainability committee, and a group of four undergraduates. Through the interviews we gained insights regarding recycling practices, resource conservation habits, technology use, transportation methods, and levels of environmental literacy and understanding.

We additionally conducted an online survey generated from previous findings [1,4,10,20,21] and our interview results. The survey link was posted to social media and sent in email for participants to submit responses. Of the 31 total respondents (20 males, 10 females, 1 other), approximately 84% were between 18 and 34 years of age. Although the distribution is not representative of the United States at large, it is still a fairly diverse population for an initial investigation. Participants were asked questions regarding environmentally conscious shopping habits, recycling, transportation, attitude towards environmental concerns, and use and perception of Internet of Things (IoT) devices.

4 Preliminary Findings

Based off the information gleamed from previous work [5,7,12,16,17,22] and our user study, we concluded the main findings below to help create our initial design. From our interviews and questionnaires, most participants expressed their demands on measuring resource consumption and the effect it had on the environment. They also stated that measurements should be given in understandable formats. For example, the standard reported measurement of carbon output is in tons of CO_2, which is not clear for users. Therefore, the calculation should utilize understandable metaphors such as the number of trees needed to process the amount of carbon output. Participants expressed their concerns about manually inputting data. Since the footprint calculation requires many variables, users normally need to input all data manually, and have to re-enter data each time. Moreover, certain variables such as energy consumption are not easy to collect, which increases the difficulty of calculating their carbon footprint.

Based on user needs, our carbon footprint calculator is designed as a mobile app for users to calculate their carbon footprint based on their general energy consumption. In order to automatically acquire energy usage through smart devices, the app needed access to APIs of smart home devices (e.g., Nest, Wemo). Participants showed their willingness to connect indoor smart devices for energy consumption calculation to automate portions of measuring consumption.

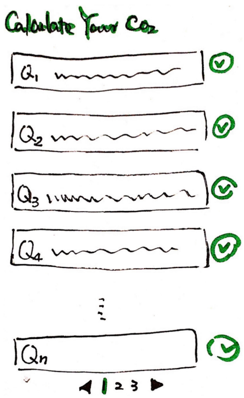

Fig. 1. Initial prototype design of calculator questionnaire.

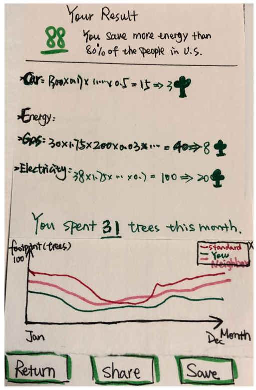

Fig. 2. Initial prototype design of calculation results.

Nationwide energy usage estimates are stored in the back-end to enable usage comparison between personal and national averages. Finally, personal information (e.g., number of cars, bikes, etc.) will be collected and logged with account information for carbon footprint calculations to protect privacy. Energy usage data will be stored in the app to calculate the carbon footprint automatically.

To get users familiar with our app immediately, the application would provide users a guide to learn about the app (e.g. how to adjust the settings, how to setup the connection between smart devices and the app). Considering a potentially broad user group, the guidance should be simple and easy to understand. Moreover, the app is designed with incremental information requests since requesting large amounts of data during initial use may overwhelm users. Therefore, the app initially requests a minimal amount of information from users to give an estimate of the user's carbon footprint, then incrementally asks for further information to refine and give more accurate estimates over time.

5 Design Process

5.1 Initial Prototype Design and User Study

Based on the findings above, we made our initial design using paper prototyping (see Figs. 1 and 2 for examples). The paper prototypes include several potential main interfaces such as calculation questionnaire, the calculation results and analysis, and the smart home devices connection and input.

To evaluate our prototype idea and gather further user insights and feedback, we conducted think-aloud walkthroughs with 8 participants. We presented our paper prototypes to each participant, and asked them to verbalize their thoughts and feelings while interacting with the prototypes. Insightful user feedback was collected, specifically, many users showed interest in how their energy consumption and carbon footprint compared to the national average, which supports the idea of comparative feedback we discussed previously. To incorporate these features, we reworked our design and developed a demo app for further study.

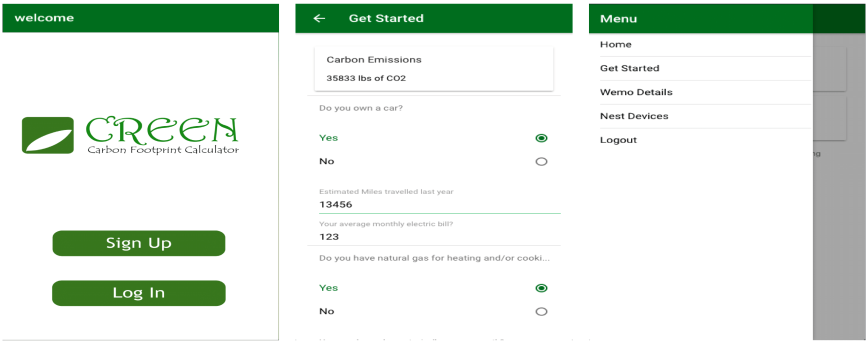

Fig. 3. Main interfaces of Creen (left to right): login, information collection, and menu.

5.2 Advanced Design Demo and Field Pilot

Based on the results of our study, we revised our prototypes and implemented a low-fi functional demo. In our design (see Fig. 3), users need to provide the basic information about their energy consumption. All the information we gathered was based on carbon footprint calculation equations [1]. The app automatically stores information and recalls it for users to edit or update on subsequent uses.

Figure 5 shows the final calculation page. By applying the comparative eco-visualization, the personal carbon footprint result is presented along with the average carbon footprint in the United States. In order to improve user's awareness of their environmental impact, each result comes with a value in pounds and the number of trees needed to process that value. Less than average results are shown in green and results higher than average are shown in red. The salient colors aim to strengthen the feedback comparison. The results show a distribution of energy consumption for categories based on U.S. averages. We compare electricity usage with average consumption in the U.S. and an energy efficient home generated by a local electrical provider, and illustrate it according to monthly usage. We provided users the detailed energy consumption breakdowns using their smart home devices as seen in Fig. 4. Once users chose the tab for smart devices, they saw a detailed consumption page detailing how much energy was consumed in real time and a distribution for different appliances.

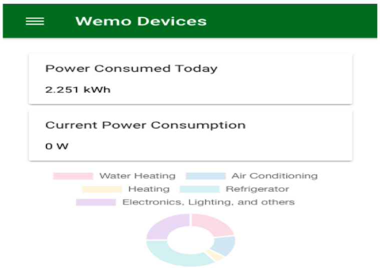

Fig. 4. Data from Wemo smart plug.

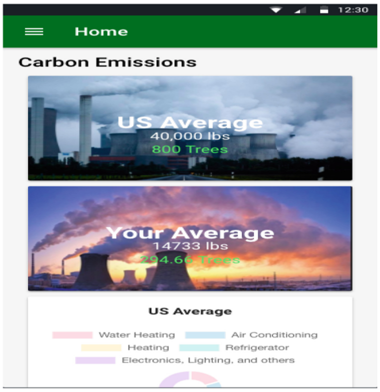

Fig. 5. Calculation results page. (Color figure online)

To evaluate the redesigned demo, 8 new participants were recruited to test the design on their own phones for a week before being interviewed about their experience. Of the participants, 75% reported an increase in their awareness of carbon footprints, with one participant expressing joy that their results were much lower than the national average. Half of the participants reported surprise that the U.S. average was so high. Participants reported some critiques of the application, such as some measurements being difficult to estimate (e.g. number of therms of gas used). Suggestions of a specific breakdown for the total carbon footprint and not just energy usage were received by half of the participants.

6 Conclusion and Future Work

As global warming contributes to environmental impacts, people continue to take interest by seeking actions to take on their own. Carbon footprints as a measure of carbon output, is growing as a personal impact factor for people. Current carbon footprint calculation requires complex user inputs and present results in a complicated and non-user-friendly manner. Therefore, the goal of this research was to create an application that assists in not only measuring carbon footprints, but to also convey that measurement in an accessible and easy to understand manner while reducing the potential for incorrect estimates of resource usage. Through interviews, literature reviews, think-alouds, and iterative design, we created a mobile carbon footprint calculator that utilizes user input and real time data from IoT devices to measure energy consumption and report a personalized carbon footprint. In future work, we will conduct larger field deployment studies with our functional prototype to explore how user input and calculation results affect user behavior, increase automated calculation of measurements through IoT devices and mobile phones, and gain more insights to refine our design.

Acknowledgements. We thank all our participants and Dr. Jean Camp for her invaluable insights.

References

1. Energy awareness quiz (2012). https://energy.gov/eere/education/downloads/energy-awareness-quiz
2. Bamberg, S., Möser, G.: Twenty years after hines, hungerford, and tomera: a new meta-analysis of psycho-social determinants of pro-environmental behaviour. J. Environ. Psychol. **27**(1), 14–25 (2007)
3. Carroll, J.M., Mack, R.L., Kellogg, W.A.: Interface metaphors and user interface design. In: Handbook of Human-Computer Interaction, pp. 67–85. Elsevier (1988)
4. Coyle, K.: Environmental literacy in America: what ten years of NEETF/ROPER research and related studies say about environmental literacy in the US. National Environmental Education & Training Foundation (2005)
5. Diekmann, A., Preisendörfer, P.: Environmental behavior: discrepancies between aspirations and reality. Rationality Soc. **10**(1), 79–102 (1998)
6. Foster, D., Lawson, S., Blythe, M., Cairns, P.: Wattsup? Motivating reductions in domestic energy consumption using social networks. In: Proceedings of the 6th Nordic Conference on Human-Computer Interaction: Extending Boundaries, pp. 178–187. ACM (2010)
7. Froehlich, J., Findlater, L., Landay, J.: The design of eco-feedback technology. In: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, pp. 1999–2008. ACM (2010)
8. Goodier, C.I.: Carbon Footprint Calculator. SAGE Publications, London (2011)
9. Holmes, T.G.: Eco-visualization: combining art and technology to reduce energy consumption. In: Proceedings of the 6th ACM SIGCHI Conference on Creativity & Cognition, pp. 153–162. ACM (2007)
10. Krause, D.: Environmental consciousness: an empirical study. Environ. Behav. **25**(1), 126–142 (1993)
11. Krippendorff, K.: The Semantic Turn: A New Foundation for Design. CRC Press, Boca Raton (2005)
12. Levine, D.S., Strube, M.J.: Environmental attitudes, knowledge, intentions and behaviors among college students. J. Soc. Psychol. **152**(3), 308–326 (2012)
13. Mankoff, J., et al.: Stepgreen.org: increasing energy saving behaviors via social networks. In: ICWSM (2010)
14. Pandey, D., Agrawal, M., Pandey, J.S.: Carbon footprint: current methods of estimation. Environ. Monit. Assess. **178**(1–4), 135–160 (2011)
15. Petersen, D., Steele, J., Wilkerson, J.: WattBot: a residential electricity monitoring and feedback system. In: CHI'09 Extended Abstracts on Human Factors in Computing Systems, pp. 2847–2852. ACM (2009)
16. Petkov, P., Köbler, F., Foth, M., Krcmar, H.: Motivating domestic energy conservation through comparative, community-based feedback in mobile and social media. In: Proceedings of the 5th International Conference on Communities and Technologies, pp. 21–30. ACM (2011)
17. Pierce, J., Odom, W., Blevis, E.: Energy aware dwelling: a critical survey of interaction design for eco-visualizations. In: Proceedings of the 20th Australasian Conference on Computer-Human Interaction: Designing for Habitus and Habitat, pp. 1–8. ACM (2008)

18. Schwartz, S.H.: Normative influences on altruism. In: Advances in Experimental Social Psychology, vol. 10, pp. 221–279. Elsevier (1977)
19. Siero, F.W., Bakker, A.B., Dekker, G.B., Van Den Burg, M.T.: Changing organizational energy consumption behaviour through comparative feedback. J. Environ. Psychol. **16**(3), 235–246 (1996)
20. Synodinos, N.E.: Environmental attitudes and knowledge: a comparison of marketing and business students with other groups. J. Bus. Res. **20**(2), 161–170 (1990)
21. Vandyke, C.: An environmental footprint quiz for WPI students. Ph.D. thesis, Worcester Polytechnic Institute (2009)
22. Vicente-Molina, M.A., Fernández-Sáinz, A., Izagirre-Olaizola, J.: Environmental knowledge and other variables affecting pro-environmental behaviour: comparison of university students from emerging and advanced countries. J. Cleaner Prod. **61**, 130–138 (2013)
23. Weidema, B.P., Thrane, M., Christensen, P., Schmidt, J., Løkke, S.: Carbon footprint: a catalyst for life cycle assessment? J. Ind. Ecol. **12**(1), 3–6 (2008)
24. Wood, G., Newborough, M.: Dynamic energy-consumption indicators for domestic appliances: environment, behaviour and design. Energy Build. **35**(8), 821–841 (2003)