Submission to *Sustainable Production and Consumption*
Publication Type: *Article*

The State of Carbon Footprint Calculators: An Evaluation of Calculator Design and User Interaction Features

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December 2017
Revised October 2018

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Abstract

The individual carbon footprint has become a widely used concept for communicating both the causes of climate change and the many opportunities to reduce greenhouse gas emissions. Thanks to standardized greenhouse gas equivalencies and carbon-intensity metrics for everyday activities, many organizations have created online carbon footprint calculators, often with a great deal of input categories and user customization. This particular study critically examines the state of online carbon footprint calculators that target the individual. A calculator Feature Index was developed using guidance from carbon calculator literature and an extensive review of common calculator features and architecture. This index was then applied to 31 online carbon footprint calculators, summarized in heat index tables and scores generated using radar plot methodology. Overall trends are identified and specific lessons are taken from the cluster of six calculators with highest Feature Index scores. Finally, this review of performance features is paired with a survey of individuals concerning their interactions with online carbon footprint calculators. Using this feedback and the performance evaluation indices, recommendations are made for improving carbon footprint calculator design.

Keywords: Carbon emissions; Carbon calculator; Calculator comparison; Footprint; Online

1 INTRODUCTION

The relationship between everyday behavior, carbon emissions, and global climate change lies at the core of understanding and addressing climate change. Chatterton et al. (2009) posited that people are aware of the dangers of climate change but are not able to relate to it or understand it. However, they found that new users of carbon footprint calculators were able to gain an appreciation for carbon emissions information. Thus, carbon footprint calculators can play an important role in educating and motivating lifestyle changes (Baker, 2006).

Carbon footprint calculators take a variety of forms and approaches, but all seek to measure the carbon emissions that result from a given activity or set of activities (Wiedmann and Minx 2007). The term "ecological footprint" is generally attributed to Rees (1992), who developed a methodology to quantify an activity's impact on a range of ecological systems including water, biodiversity, and climate, measured as an atmospheric carbon flux. The derivation of carbon emissions (from energy production activities and natural processes) is relatively straightforward, and the underlying data is more easily tracked, compared to other portions of the ecological footprint (Čuček 2012). Thus, "carbon footprint" has become mainstream as interest grows in calculating non-financial impacts of government, business, and individual activities (Mulrow et al. 2016). Carbon footprint calculators have been developed for both public and private use, and they have focused on measuring the carbon footprint of nations, organizations, and individuals alike.

This study focuses on carbon footprint calculators (hereby referred to simply as "calculators") that are publicly available and that focus on the individual. These calculators vary greatly in depth and scope. The simplest calculators derive a carbon emission value based on energy-related activities alone. More detailed calculators consider lifestyle or consumption choices such as food and travel. Still others attempt to provide advice on reducing carbon emissions, based on the user's input. Several studies have compared and analyzed differences

between carbon footprint calculators. Padgett et al. (2008) compared 10 calculators focused on individual users in the United States. They found significant differences in the carbon footprint estimates of these calculators, given the same input parameters. The authors, while recognizing the potential for carbon calculators to increase public awareness and motivate behavior and political change, called for a higher degree of standardization across calculators. In another study, Kenny et al. (2008) observed the increasing trend of personal and household use of carbon calculators in Ireland. They also traced the inconsistencies and contradictions between calculators to differences in assumptions and input parameters. For example, carbon emissions from water use was considered to varying extents, and some calculators did not consider it at all. Kim (2009) discussed the potential of carbon footprint calculators to contribute to both public awareness and behavior change. In particular, Kim (2009) emphasized the need to communicate carbon footprint information in a way that promotes education and action. Based on previous data and articles, Birnik (2013) created a set of 13 principles for evaluating carbon footprint calculators. Birnik (2013) used these principles to compare levels of detail and calculation methodology, as well as each calculators' ability to compare results among users. Here again, the study highlighted the lack of consistency between carbon footprint calculators and called for standardization. The Birnik principles helped guide the basis of comparison used in this study.

In preparing a comparison of carbon footprint calculators, a general survey was conducted of individuals who had and had not used a carbon footprint calculator previously. The aims in conducting this survey were to: i) gather general perceptions of carbon footprint calculators, their popularity and their utility, and ii) discover whether users changed their behavior as a result of using a calculator.

This study of personal carbon footprint calculators is motivated by a need to assess the *depth* (defined as the range of activities assessed) and *engagement* (defined as user interaction features) of currently available calculators, with an eye to designing better calculators. In this study, a methodology was developed to assess carbon footprint calculators and apply it to 31 online carbon footprint calculators, selected from an intensive web search (Table 1). The 31 calculators were chosen based on popularity within three categories: Government, Non-profit, and private.

The analysis and comparison of calculators are focused on their input categories and user engagement rather than on the calculation methodology or assumptions behind each calculator (which has been done effectively by numerous researchers in the past). Thus, whether two calculators provide the same carbon emissions measure, given the same inputs, is not a basis for comparison in this study. Rather, factors such as the variety of activities (e.g., water use, transportation, electricity) considered and whether the calculator includes behavior change suggestions is used as a basis in this study.

The article continues by formulating the methodology of assessing and comparing carbon footprint calculators. In the next section, the results of the analysis are noted and illustrated through a Feature Index and radar plots. These sections are then followed by an interpretation of the results collected in this study.

Table 1. *Inventory of Online Carbon Footprint Calculators*

Type	**Name**	**Link** (accessed September 27, 2017)
Govern	Climate Neutral (United Nations)	climateneutralnow.org/Pages/footprintcalculator.aspx

	Environmental Protection Agency (EPA)	www3.epa.gov/carbon-footprint-calculator/
Non-Profit/Charitable	Carbon Fund	carbonfund.org/individuals/
	Carbon Offsets to Alleviate Poverty (COTAP)	cotap.org/carbon-footprint-calculator/
	Center for Climate and Energy Solutions (C2ES)	carbonfootprint.c2es.org/
	Cleaner and Greener	www.cleanerandgreener.org/resources/pollutioncalculator.html
	Conservation Fund	gozero.conservationfund.org/calc/household
	Conservation International	www.conservation.org/act/get_involved/carbon_calculator/Pages/default.aspx
	Cool Climate Network	coolclimate.berkeley.edu/calculator
	Forest Credits	www.forestcredits.org.uk/
	Institute of Electrical and Electronics Engineers (IEEE Spectrum)	spectrum.ieee.org/static/carbon-calculator-2009
	International Student Carbon Footprint Challenge (ISCFC)	web.stanford.edu/group/inquiry2insight/cgi-bin/i2sea-r2a/i2s.php?page=fpcalc
	Lehigh University	www.ei.lehigh.edu/learners/cc/carboncalc.html
	My Climate	www.myclimate.org/
	Shrink Your Foot	store.shrinkyourfoot.org/carbon-footprint-calculator
	The Nature Conservancy	www.nature.org/greenliving/carboncalculator/
	World Wide Fund for Nature (WWF)	footprint.wwf.org.uk/
Private	CarboTax	www.carbotax.org/
	Carbon Footprint Ltd.	www.carbonfootprint.com/calculator.aspx
	Carbon Independent	www.carbonindependent.org/
	Carbon Solutions Group	www.carbonsolutionsgroup.com/carbonfootprintcalc.html
	Carbonify	www.carbonify.com/carbon-calculator.htm
	Chuck Wright	www.chuck-wright.com/calculators/carbon.html
	Climate Care	climatecare.org/calculator/
	Empowerment Institute	www.empowermentinstitute.net/lcd/LCDcalcNet_2012.html
	General Electric's iVillage	www.ge.com/ivillage/calculator/
	Green Progress	www.greenprogress.com/carbon_footprint_calculator.php
	Henkel	footprintcalculator.henkel.com/en
	Michael Bluejay	michaelbluejay.com/electricity/carboncalculator.html
	Native Energy	www.nativeenergy.com/household-carbon-calculator.html

	TerraPass	www.terrapass.com/carbon-footprint-calculator

2 METHODOLOGY

2.1 Calculator Comparison Method

A standard set of indices and evaluation categories was used to qualitatively score each calculator's depth of inputs and engagement of users. These criteria were devised using carbon calculator literature review and various test runs of the criteria. The indices and evaluation categories are listed in Table 2.

For the index *Input Categories*, the categories of comparison were determined by the activity categories most commonly used in a sub-set of test run calculators. The index *Depth of Measurement* is concerned with the level of explanation provided to the calculator user as well as the amount of input detail the calculator required of the user. The evaluation categories for this index were determined by common observations of input detail, found via literature review and user survey. The categories of comparison for the index *Display Quality* were determined by the authors based on observations of the most useful methods for communicating calculator results. Finally, the categories for *Takeaway of Information* were based on the need to communicate the meaning of the calculator results and motivate users to modify aspects of their carbon footprint.

Table 2. *Carbon Footprint Calculator Performance Evaluation Indices and Categories*

	Index	**Evaluation Categories**
Depth of Inputs	Input Categories	Home Energy Transportation Air Transportation Food Water/Wastewater Extra Categories

	Depth of Measurement	Multiple Ways of Calculating Home Energy Green Energy Option Included Flight Categories Explained Specifics Asked About Food Emissions US State Differences Accounted
User Engagement	Display Quality	Emission Values Shown for Each Category Country and World Averages Report Display Final Value Display Quick Version
	Takeaway of Information	Carbon Footprint Comparisons Advice for Lowering Emissions Quantified Carbon Reduction from Following Advice Educates on Carbon Emissions

2.2 Assessment of Data

For each of the 31 calculators, this study completed a full footprint assessment and recorded the details of calculator features in each of the evaluation categories. Heat index tables were created to display qualitative and comparative information about each calculator. Each calculator is given a High, Medium, or Low/None rating for each category, communicating the extent to which a calculator collected input data, communicated information, or engaged the user.

The color coding is as follows: High = green, Medium = yellow, Low/None = red. For the Home Energy category, a calculator that collects data for at least 6 major types of home energy or included Renewable Energy as an option received a High rating, 4-5 types received a Medium rating, and 0-3 types received a Low rating. For the transportation category, a calculator that collects data for at least 5 major modes of transportation received a High rating, 3-4 modes received a Medium rating, and 0-2 modes received a Low rating. For air transportation, a calculator that collects detailed data on flight origin/destination or specific airports received a High Rating, a calculator that includes the type of flight (short, middle, long) or miles flown received a Medium Rating, and no information on air transportation received a Low rating. In cases where a binary evaluation is conducted, only Medium and Low are used as evaluation markers. For example, in the Food and Water/Wastewater categories a "Yes" equates to Medium or yellow or "No" equates to Low or red. For the Extra Categories section, 3-4 categories received a High Rating, 1-2 categories received a Medium Rating, and 0 categories received a Low Rating.

The calculator comparison process was completed by creating radar plots. These plots can be seen in Figure 1 and serve as both a quantitative and visual comparison. In the radar plots, the 15 most data-rich evaluation categories are assigned to an axis that represents values from 0 (at the axes intersection) to 3 (at the edge of the plot). Generally, these values correspond to the category's rating (0 = None/Not Applicable, 1 = Low, 2 = Medium, 3 = High). For binary evaluations, 3 is assigned to "Yes" and 0 is assigned to "No." Plotting these values on a radar

graph and connecting each point to its neighbor radially yields an area, which is used to score the overall performance of each calculator.

2.3 User Survey

In addition to analyzing current carbon calculators, the survey "Your Carbon Footprint Identity" was conducted in order to compare calculator user experiences and preferences with the state of practice found among the reviewed calculators. The survey also revealed the level of common knowledge of carbon calculators, greenhouse gas emissions, and home energy use. The survey was conducted under an Internal Review Board (IRB) process through the University of Illinois at Chicago. The survey was distributed to a general audience through email, academic newsletters, and social media, and it garnered 216 participants. Survey responses were gathered anonymously using Google Forms.

Data was collected on participants' gaps in greenhouse gas emissions knowledge and whether carbon calculators were effective in changing the participants' behavior. Participants were also asked how they rank carbon footprint categories based on knowledge, curiosity, and impact. In addition, data was collected on home energy use and demographics. In total, the participants were asked 32 questions and spent between 5-10 minutes taking the survey.

3 RESULTS

3.1 Comparing Online Carbon Footprint Calculators

The *Index of Carbon Footprint Calculators by Input Category* (Table 2) describes each calculator's inclusion of carbon emission sources and the extent to which each calculator gathered user information for the source category. For each category, the calculator is given a rating based on the level of detail gathered from the user. All calculators collected at least some information on Home Energy use, and all but one calculator (97%) gathered information on Transportation. Air Transportation was also commonly recorded, factoring into 27 of 31 (87%) calculators. Food and Water/Wastewater were the least common categories, included in 42% and 16% of calculators respectively. The review also identified additional categories that appeared in each calculator. Common extra categories included waste and recycling, purchases or consumption activities, health, education, and leisure/recreational activities. More than half (61%) of calculators included input categories beyond the five baseline categories on which the analysis focused.

The full results of the study are provided in Tables A.1-A.3 in the Supplementary Materials.

Table 2. *Index of Carbon Footprint Calculator by Input Category*

	Home Energy	Transportation	Air Transportation	Food	Water / Wastewater	Extra Categories
Carbon Independent	Electric, Gas, Oil, Wood, Bottled Gas, Coal	Car, Bus, Train	Based on distance of travel to destinations outside UK	Yes	No	Health, Education, Miscellaneous

COTAP	Electric, Gas, Propane, Oil	Car	Short, Medium, Long, Extended	No	No	No
The Nature Conservancy	Based on home type and State (US) of residency	Car	Long, Short	Yes	No	Recycling, Waste
US EPA	Electric, Gas, Propane, Oil	Car	No	No	No	Waste
WWF	Electric, Gas, Propane, Oil	Car, Motorcycle, Bus, Train	Categories defined by distance from the UK	Yes	No	Miscellaneous
Carbon Footprint Ltd	Electric, Gas, Oil, Coal, LPG, Wood, Propane	Car, Motorcycle, Bus, Train, Tram, Subway, Taxi	Flight Information: origin/destination	Yes	No	Pharmaceuticals, Electronics, Education, Leisure Activities
Terrapass	Electric, Gas, Oil, Propane, Gasoline, Diesel	Car, Electric Car, Boat, Train, Bus, Ferry, Taxi	Flight Information: fuel used, total miles, or trip length	No	No	No
Cool Climate Network	Electric, Gas, Oil, Other Fuels	Car, Bus, Train, Inter-City Rail	Short, Medium, Long, Extended	Yes	Water only (based on average)	Purchases (split by goods and services)
ISCFC	Gas, Electric, Wood, Coal, Solar, Wind, Geothermal	Car, Bus, Train	Yes	Yes	Water and Wastewater	Personal Purchases, Recycling
C2ES	Gas, Electric, Propane, Oil	Car (Electric & Hybrid), Motorcycle, Bus, Train	Short, Medium, Long	No	No	No
Conservation International	Electric, Gas, Oil, Propane, Wood	Car	Short, Long	Yes	No	No
Carbon Fund	Electric, Gas, Oil	Car, Bus, Train	Flight Information: origin/destination	No	No	No
Native Energy	Not Specified	Car	No	No	No	No
Climate Neutral Now	Electric, Gas, Heating Oil, Vegetable Oil, Wood, Charcoal	Car, Bus, Train, Motorbike, Subway	No	No	No	Waste
My Climate	Electric, Oil, Gas, Wood, District Heating	Car	Flight Information: origin/destination	No	No	Company, Cruise, Event
Forest Credits	Electricity, Gas, Oil, LPG	Car, Van, Motorbike, Train, Bus, Taxi, Ferry	Flight Information: Distance or origin/destination	No	No	Business
Lehigh Carbon Calculator	Based on home type	Car, Bus	Based on number of flights	Yes	No	Energy Star Appliances
Michael Bluejay	Electric, Gas, Oil	Car	Based on number of flights and hours	Yes	No	No
Carbon Solutions Group	Oil, Gas	Car	Based on miles flown	No	No	No
IEEE Spectrum	Electric, Gas, Oil	Car	Short, Medium, Continental, Intercontinental	No	No	No
Chuck Wright	Electric, Gas, Oil	Car	Based on miles flown	No	No	No

Conservation Fund	Electric, Gas, Oil, Propane	Car	Based on miles flown	No	No	Waste, Recycling
iVillage	Electric, Gas, Propane, Oil	Car, Bus, Train, Subway, Taxi	Based on number of flights	No	Water usage based on baths and showers per week	Waste, Recycling
Carbonify	Electric, Gas, Propane, Oil	Car, Train	Based on miles flown	Yes	No	Waste
Empowerment Institute	Electric, Gas, Propane, Oil	Car	Based on miles flown	No	No	Waste
Climate Care	Electric, Gas, Propane, Oil, Wood, Renewables	Car	Based on airports	No	No	Event
Henkel	Electric, Gas, Oil, Wood, Renewables	Car, Bus, Train, Motorbike, Bike, Walk	Based on km flown	Yes	Based on showers, baths, laundry, dishwasher	Sports, Holiday Travel and Accommodations
Green Progress	Electric, Gas, Oil	Car	Based on miles flown	Yes	No	Waste, Recycling
Shrink Your Foot	Electric, Gas, Propane, Oil	Car	Based on miles flown	No	No	No
Cleaner and Greener	Electric, Gas	No	No	No	No	No
Carbotax	Based on type of home, size, insulation, and heating and cooling habits	Car, Train, Bus	Commuter, Short, Medium, Long, Extra-Long	Yes	Water for lawns, gardens, and plants	Waste, Recycling, Appliances, Lighting, Shopping
Legend	Red = low detail	Yellow = moderate detail	Green = high detail			

3.2 Radar Plots

Radar plots offer a visual synthesis of the data collected for the four indices to assess carbon footprint calculators. Fifteen evaluation categories (of a total of 20 measured) were selected as dimensions for the radar plots. The five categories with the least number of responses (Water/Wastewater, Green Energy Option Included, Final Value Display, Carbon Footprint Comparisons, and Quantified Carbon Reduction from Following Advice) were removed from the radar plot analysis in order to avoid overweighting the least used categories. The categories that had the most positive responses were selected as dimensions for the radar plots. These fifteen categories are: Home Energy, Transportation, Air Transportation, Food, Extra Categories, Multiple Ways of Calculating Home Energy, Flight Categories Explained, Specifics Asked About Food Emissions, State Differences Accounted, Emission Values Shown for Each Category, Country and World Averages, Report Display, Simple/Quick Version, Advice for Lowering Emissions, and Educates on Carbon Emissions. The categories appear on the radar plots in the order listed, arranged counterclockwise. It is noted that the category “State Differences Accounted” defaulted to a score of zero (0) for three of the calculators that were UK-focused. However, the results show that two of these – Carbon Independent and WWF – were high-scoring despite the handicap. The category served as an attribute representing the inclusion of regional detail in the calculator design.

The radar plot scoring method yields an area measure, which we used to evaluate the calculator's overall performance. Results show that the Carbon Independent calculator has the highest area with 19.32 [no unit], with Carbon Footprint Ltd and Cool Climate Network being close second and third calculators with areas of 18.51 and 17.69 respectively. Other calculators with notable high performance measures are WWF (15.25), ISCFC (14.44), and Carbotax (14.64). Generally, high-scoring calculators shared the following features:

- Allowed users to enter the greatest range of home energy use, transportation, and food consumption data, from highly detailed to general averages.
- Provided carbon footprint results in both aggregated and detailed/segregated forms.
- Paired carbon footprint results with actionable advice for lowing emissions.

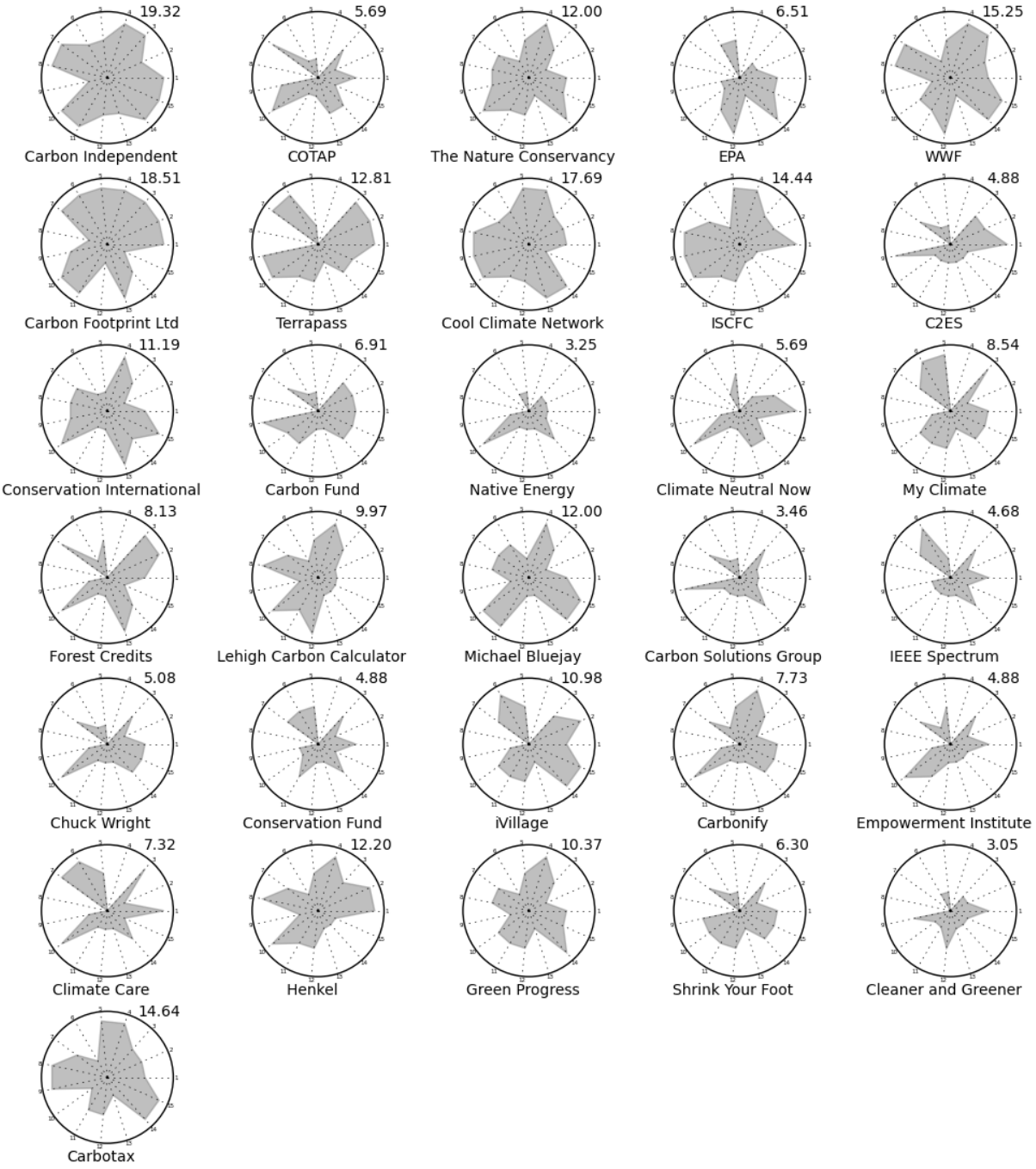

Figure 1. *Radar Plots for all Online Calculators***.** The names of the calculators are shown below the plot and the area for each calculator is shown in the top right corner of each plot.

3.3 Survey Results

As seen in Figure 2, out of all survey participants, a majority (53%) had used a carbon footprint calculator previously; however, only 8.9% could recall their calculated footprint measure. Additionally, 15.9% of the participants indicated that a carbon footprint calculator was effective in changing their daily energy consumption habits (Figure 2).

Participants generally conveyed low familiarity with energy use at home and how this translates to emissions factors or daily activities. Approximately 75% of participants reported knowing Little, Very little, or Nothing at all about their home energy use. When asked how 1 kg of CO_2 or 1 kWh of energy translates to daily activity, 8.8% and 16.2% of participants (respectively) indicated that they could equate these measures to a corresponding level of activity.

Despite general unfamiliarity with consumption data, participants demonstrated that they could easily access this data from their bills. A majority of participants indicated that they could access gas (75.5% Yes), electricity (91.7% Yes) and water use (53.8% Yes) information from utility bills they receive at home. Finally, when survey participants were asked about how much they know about their home's energy use, 53.7% stated they know "a little," while 21.8% stated they know "a lot" (Figure 3).

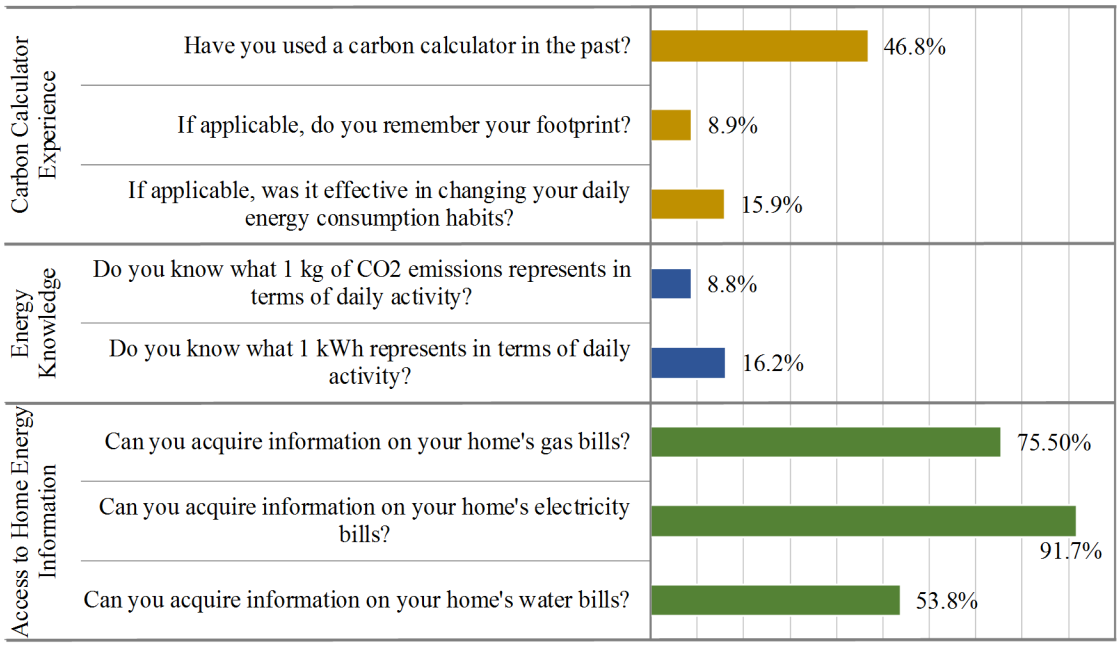

Figure 2. *Carbon Calculator User Survey Results Summary*

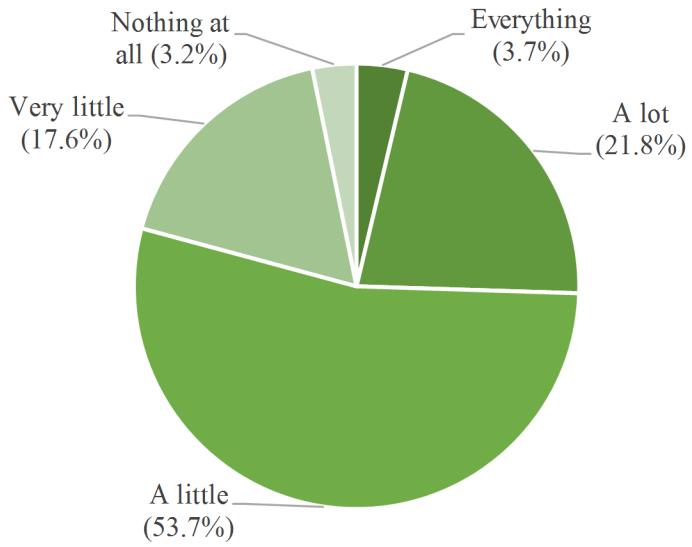

Figure 3. *Responses to "How much do you know about your home's energy use?"*

4 ANALYSIS AND DISCUSSION

This study highlighted calculator users' understanding of and engagement with carbon calculators. Survey participants generally ranked *transportation* above other calculator input categories when asked which categories they were both knowledgeable and curious about. Survey participants also generally estimated that transportation was highly significant in determining one's total carbon footprint. These results suggest that participants know about and are curious about transportation, and they also recognize the significant influence of transportation activities on their carbon footprint calculation. Thus, current carbon calculators should continue to include the transportation category and take into account multiple modes, including air transportation.

In contrast, survey participants ranked energy from electricity and natural gas low when asked to estimate the most impactful carbon footprint categories. This observation reflects a misunderstanding of the impact of home electricity and gas usage on the carbon footprint. Although we do not know the reason for this misunderstanding, we can speculate that the general lack of options in electricity and gas providers (often under monopoly) and the fact that power plants are often "out of sight" is a disincentive to learning about their impacts—unlike transportation since many people have the option to walk/bike, ride transit, or use a private vehicle, and their impact are felt directly.

We note, however, that most carbon calculators score high for the level of information detail gathered under the Home Energy category. Future calculators may concentrate on better describing the role of electricity and gas on one's carbon footprint specifically, and factoring in variations in regional grid energy mixes. Additionally, calculator evaluations show that many calculators gather information on home energy use but fail to explain the links between daily activity, energy use, and emissions. Based on survey respondent's answers regarding prior knowledge of energy use levels, an improved calculator would simultaneously ask detailed questions about home energy use and explain how impactful home energy use is on the carbon footprint.

The calculator evaluation tables and radar plot scores provide a guide to important features of carbon footprint calculators. Within each index we identified those evaluation categories that had the most "High" ratings. These categories represent calculator features that have the most depth and detail across all calculators surveyed. Within Depth of Measurement (Table A.1) the three top categories were: Flight Categories Explained, Specifics Asked About Food Emissions, and US State Differences Accounted. These categories had a High rating for 7 of the 31 calculators. For the Display Quality index (Table A.2), Emissions Value Shown for Each Category was the top evaluation category, with 18 calculators receiving a High rating. Finally, within the Takeaway of Information index (Table A.3), Advice for Lowering Emissions had the most High-rating calculators (9). Based on the 31 carbon calculators analyzed and compared, these categories should be considered a high priority for an effective calculator.

The user survey also garnered similar responses. For example, the carbon footprint category of air transportation ranked high for how impactful participants believe the category is in terms of carbon emissions. Food was ranked high when participants were asked how curious they were about a particular category. This is further evidence that these categories are important aspects of an effective carbon calculator. The calculator should provide a great amount of detail and information when explaining and providing options for these categories.

Findings about effective carbon footprint calculators were derived from those calculators with the highest radar plot areas. Among the top six calculators (those with an area greater than one standard deviation from the mean) all of them gathered detailed information about food, receiving a High rating in the Food category. Some of these top calculators were focused on detailed calculations over motivating the user to change behavior. Carbon Footprint Ltd and ISCFC scored low on all or most of the categories within the Takeaway of Information index, however, they scored high in nearly every other evaluation category, especially Input Categories and Depth of Measurement. Carbon Independent had the top overall rating for Takeaway of Information.

Finally, in order to frame the findings of the study alongside other carbon footprint calculator evaluations, the results are compared with the calculation algorithm-focused study by Birnik (2013) compared their respective calculators by subjecting them to 13 principles. They determined 13 "literature-derived carbon footprint calculation principles" and then tested if the calculators included these principles. Table 3 presents a cross-examination of the five calculators that were included in this study as well as Birnik's. In order to create a comparison, this study's radar plot areas were translated into a "Weak, Average, or Strong" rating. Radar plot areas over 15.00 received a Strong rating, 8.00 to 15.00 received an Average rating, and below 8.00 received a weak rating. Both this study and the Birnik study found similar results for the EPA calculator, the Nature Conservancy calculator, and the Conservation International calculator. Both studies produced an average rating for the Nature Conservancy and Conservation International calculators and a Weak rating for the EPA calculator.

Table 3. *Birnik (2013) Results Comparison*

Calculator	Birnik Rating	Radar Plot Equivalent
Carbon Fund	Average	6.91 (Weak)
Terra Pass	Weak	12.81 (Average)
EPA	Weak	6.51 (Weak)
Nature Conservancy	Average	12.00 (Average)
Conservation International	Average	11.19 (Average)

5 CONCLUSION

This study analyzed and compared 31 online carbon calculators in order to identify the most essential inputs and user engagement features. A user survey was also conducted to inform the analysis. The most essential carbon calculator features are home energy and transportation input, explanations for flight categories, advice for lowering emissions, and to have emission values shown for each category calculated. The areas that need the most detail and information are home energy, transportation, explanations for flight categories, food emissions, how they account for state differences, and how they educate and advise on lowering emissions. Through these findings and the development of the radar plots, the best examples of carbon calculators studied are Carbon Footprint Ltd., Carbon Independent, and Cool Climate Network.

This reinforces the importance of merging detail-oriented calculator features with user-friendly calculator features, yielding carbon footprint calculators that are both more accurate and engaging, leading to higher use and better retention of knowledge among users. There is also an opportunity to improve the gathering and interpretation of carbon footprint information using data science and machine-learning techniques (Derrible and Ahmad 2015, Ahmad et al. 2016, Derrible 2016a). Given that many calculators gathered address or zip-code information, there is a significant opportunity in aggregating regional carbon footprint data to derive locally-tailored emissions reduction and infrastructure decisions (Derrible 2016b). Finally, there is much work to be done in improving carbon footprint calculators' approach to user interaction and behavior change, perhaps by better integrating with mobile phone/sensor technologies. In this context, calculators could easily move beyond simply calculating carbon emissions, combining measurement of economic, social and environmental metrics.

ACKNOWLEDGEMENTS

This work was supported by the National Science Foundation Graduate Research Fellowship Program under Grant No. 1444315. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation. Moreover, this research was supported in part by the NSF CAREER award 1551731

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