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A comparison of carbon calculators

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Abstract

International attention to carbon dioxide emissions is turning to an individual's contribution, or "carbon footprint." Calculators that estimate an individual's CO_2 emissions have become more prevalent on the internet. Even with similar inputs, however, these calculators can generate varying results, often by as much as several metric tons per annum per individual activity. This paper examines the similarities and differences among ten US-based calculators. Overall, the calculators lack consistency, especially for estimates of CO_2 emissions from household electricity consumption. In addition, most calculators lack information about their methods and estimates, which impedes comparison and validation. Although carbon calculators can promote public awareness of carbon emissions from individual behavior, this paper reveals the need for improved consistency and transparency in the calculators.

Keywords: Carbon dioxide; Emissions; Individual; Calculator; Footprint; Web-based

1. Introduction

With growing awareness of elevated carbon dioxide levels and climate change, attention is turning to individual behavior as a source of global carbon emissions. According to Shui and Dowlatabadi (2005), consumers in aggregate were directly responsible for 28% of US energy consumption and 41% of US CO_2 emissions in the year 1997. In response to this focus on individuals, numerous websites have been created to help calculate an individual's "carbon footprint," or an estimate of the carbon dioxide emissions that an individual is directly responsible for over a given period of time. These calculators typically divide the individual's profile into household activities and transportation, and based on differing formulations of user input they produce a quantified amount of carbon dioxide or carbon dioxide equivalents emitted, generally in units of mass of CO_2 per year. These calculators are provided by government agencies, non-governmental organizations, and private companies. Some of these carbon calculator providers also promote methods for mitigating carbon dioxide emissions through offsets or investments in renewable energy technology. Even when calculators are not coupled with mitigation measures, by providing estimates of individual contributions they play a fundamental role in promoting carbon emission reductions through individual behavior change.

The recent rise in carbon calculators has been accompanied, however, by inconsistencies in output values given similar inputs for individual behavior. In some cases, values can vary by as much as several

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Table 1
Carbon dioxide calculators examined in study

American Forests	http://www.americanforests.org/resources/ccc/
Be Green	http://www.begreennow.com/
Bonneville Environmental Foundation (BEF)	https://www.greentagsusa.org/GreenTags/calculator_intro.cfm
CarbonCounter.org	http://www.carboncounter.org/
Chuck Wright	http://www.chuck-wright.com/calculators/carbon.html
Clear Water	http://www.clearwater.org/carbon.html
The Conservation Fund	http://www.conservationfund.org/gozero
EPA	http://www.epa.gov/climatechange/emissions/ind_calculator.html
SafeClimate	http://www.safeclimate.net/calculator/
TerraPass	http://www.terrapass.com/

metric tons per activity. These variations in output could influence both the types of steps individuals take (e.g., focus on household electricity use versus transportation) and the overall level of effort (e.g., the total amount of emissions reductions achieved or offsets purchased). Variations in calculator outputs also could affect the extent and focus of public pressure on policymakers regarding emissions reduction efforts directed at household and personal transportation emissions. The variations in calculator outputs may be due to different calculating methodologies or conversion factors; the calculators, however, frequently lack the level of transparency needed to understand the reasons for these variations.

This study provides insight into the composition of CO_2 calculators, as well as commonalities in current approaches. The variations found here demonstrate a need for further research and potential standardization in the field of individual CO_2 emission quantification, especially concerning residential electricity consumption. Calculators provide an important tool for individuals to assess their CO_2 emissions. As this field continues to expand, accurate and transparent values will be needed to educate users and motivate effective responses on individual and policy levels.

2. Methodology and calculator comparison

Carbon dioxide calculators generally work by accepting user inputs characteristic of individual behavior and by returning an amount of carbon dioxide emitted as a direct result of such behavior in the form of a user's carbon footprint. This paper examines ten individual greenhouse gas emissions calculators currently available as given in Table 1. These calculators provide a range of calculating methodologies while maintaining enough similarity to facilitate comparison. To provide geographic consistency, only US-based calculators were examined. The calculators and their methods were evaluated based on the information provided on their websites.

To compare emissions outputs for specific input behavior across calculators, an individual profile was created to represent average individual behavior. Values used in this profile were taken from EPA's calculator when possible. In the event that EPA did not account for a behavior, averages provided by other calculators were used. The quantities used to represent individual behavior in the profile are summarized in Table 2.

The analysis focused on three key elements. First, calculators often provide inputs for average behavior if users are unsure of their personal input values. When applicable, therefore, the analysis compared what each calculator considered average behavior and the resulting amount of CO_2 emissions. Second, CO_2 emissions per annum associated with the individual profile shown in Table 2 were compared across calculators. The analysis also compared the inherent conversion factors associated with each behavior in units of pounds of CO_2 per energy use. Third, any mitigation opportunities available to offset an individual's emissions were examined.

2.1. Household[1]

Each calculator typically is broken into two or three main categories, the first of which addresses household energy use. Users are prompted to input their behavior in terms of annual electricity consumption and/or household fuel use: natural gas, fuel oil, propane, kerosene or wood. Beyond the amount of energy consumed, most calculators require few other input characteristics in calculating household emissions.

Electricity consumption is a shared parameter of all calculators examined. It is most frequently requested in terms of kilowatt-hours (kWh) consumed in a given time period (month or year), although EPA and TerraPass use a monthly electric bill and thereby convert to electricity consumed. Average values of household electricity consumed are provided optionally by five calculators: American Forests, BEF, The Conservation Fund, EPA, and TerraPass. To account for housing size,

[1] This analysis of calculators demonstrates the possible variation of outputs given similar inputs. The analysis is not intended to classify a correct or incorrect methodology for emissions estimation or to generalize to the larger population of CO_2 calculators currently in use. In addition, all calculator results were reported, without eliminating outliers, because each result is a value by which users would gauge their level of emissions. Values quoted in this paper from the calculators are reported with all given significant figures.

Table 2
Individual profile of behaviors used in calculator comparison

Household energy	Average annual use
Electricity	12 000 kWh
Natural gas	92 160 ft^3
Fuel oil	651 gal
Propane	488 gal
Kerosene	100 gal
Wood	1 cord
Transportation	
Vehicle miles	11 700 miles
Vehicle efficiency	22 mpg

American Forests and The Conservation Fund provide three averages to choose from: single-family home, town home, and apartment. Values for single-family home were selected to compare averages.

In general, the amount of electricity consumed is converted into CO_2 emissions using conversion factors. Most conversion factors are based on U.S. national averages; however, given the geographic differences in CO_2 levels associated with methods of electricity generation, Be Green, BEF, CarbonCounter.org, SafeClimate, and TerraPass use conversion factors that are state-dependent. Tennessee was chosen in these cases for consistency with the lead author's home institution and because, on average, Tennessee has relatively representative CO_2 emissions per kWh of electricity consumed[2].

Table 3 summarizes CO_2 emissions corresponding to electricity consumption. If optional averages for consumption are provided, they are reported along with their associated CO_2 emissions in columns 1 and 2. Column 3 displays conversion factors employed for lbs CO_2 per kWh of electricity, and column 4 provides CO_2 emissions attributed to the individual profile of 12 000 kWh annually, as stated above in Table 2. From Table 3, the reported amount of carbon dioxide emitted as result of 12 000 kWh of electricity consumption, including outputs from state-dependent calculators, can vary by as much 17 400 lbs (7893 kg) a year.

Eight of the ten calculators examined provide some form of background information on their website about their methodology for estimating electricity-related emissions. Calculators with electricity-related background information typically provide their conversion factor for lbs CO_2 per kWh and a citation. Some nuances are further explained, as in the case of BEF where the user's electricity input is increased by 7% to account for electricity loss in power lines. There is some lack of transparency, however. For example, the Conservation Fund provides two separate conversion factors in its calculator explanation, 1.397 and 1.37 lbs of CO_2 per kWh, and it employs the latter value in calculation. Also, TerraPass's calculation seemingly is dependent on month, though this is not explained. Even in cases where background information is provided, conversion factors vary by non-negligible amounts with little explanation from the calculators concerning the reasons for these differences. This lack of transparency inhibits a clearer understanding of why variations in electricity-related CO_2 emissions occur.

In addition to electricity, each calculator examined includes the use of natural gas as a possible household energy source. Natural gas is input in units of cubic feet or therms consumed per month or year. Averages are again available optionally from four calculators: American Forests, BEF, EPA, and TerraPass. The EPA average value of 92 160 ft^3 (2610 m^3) per year was used to compare all calculators, and results are displayed in Table 4. For

Table 3
Comparison of values for household electricity use and CO_2 emissions

	Average annual electricity use (kWh)	CO_2 emitted for average electricity use (lbs/year)	Electricity conversion (lbs CO_2/kWh)	CO_2 emitted for 12,000 kWh (lbs/year)
American Forests	11 827	17 741	1.50	18 000
Be Green			1.49 [a]	17 908
BEF	11 256	15 657	1.39 [a, b]	16 692
CarbonCounter.org			1.36 [a]	16 280
Chuck Wright			2.00	24 000
Clear Water			0.55	6600
The Conservation Fund	11 827	16 200	1.37	16 440
EPA	12 000	16 440	1.37	16 440
SafeClimate			1.3 [a]	15 600
TerraPass	14 087	19 299	1.37 [a]	16 440
Range			1.45	17 400
Modified Range I [c]			0.19	2308
Modified Range II [d]			0.20	2400
Mean			1.37	16 440
Median			1.37	16 440
Standard deviation			0.351	4208

[a] State-dependent conversion factors.
[b] Recorded value does not reflect 7% line loss.
[c] Modified Range I is the difference in electricity values from state-dependent calculators.
[d] Modified Range II is the difference in electricity values from calculators with background information (excluding Clear Water and Chuck Wright).

[2] On average, Tennessee emits 1.30 lbs CO_2 per kWh; for the U.S., the average is 1.34 lbs CO_2 per kWh. See ENERGY INFO. ADMIN., LONG FORM FOR VOLUNTARY REPORTING OF GREENHOUSE GASES—INSTRUCTIONS 49 (2006), *available at* http://www.eia.doe.gov/oiaf/1605/forms.html.

Table 4
Comparison of values for household fuel oil use and CO_2 emissions

	Average annual natural gas use (ft^3)	CO_2 emitted for average natural gas use (lbs/year)	Natural gas conversion (lbs CO_2/ft^3)	CO_2 emitted for 92,160 ft^3 natural gas (lbs/year)
American Forests	91 643	11 094	0.121	11 157
Be Green			0.120	11 044
BEF	81 200	9792	0.119	11 005
CarbonCounter.org			0.113	10 400
Chuck Wright			0.124	11 390
Clear Water			0.099	9083
The Conservation Fund	91 643	11 089	0.121	11 125
EPA	92 160	11 000	0.120	11 000
SafeClimate			0.132	12 156
TerraPass	82 832	10 026	0.121	11 115
Range			0.033	3073
Mean			0.119	10 948
Median			0.121	11 080
Standard deviation			0.009	785

natural gas, the calculators return a smaller range of values than electricity, but the variation still differs by 3073 lbs (1394 kg)—from 9083 lbs (4120 kg) per year returned by Clear Water to 12 156 lbs (5514 kg) per year returned by SafeClimate.

Six of the ten calculators provide background information concerning CO_2 emissions related to natural gas. Five calculators provide conversion factors with specific citations. TerraPass lists their conversion factor for natural gas but broadly cites the Energy Information Agency (EIA). The conversion factor employed by CarbonCounter.org disagrees with their final result, which may be due to an error concerning metric units conversion. American Forests and Be Green provide no information concerning their calculations of natural gas-related emissions.

All calculators, except Be Green, include fuel oil as an additional source of home energy consumption. Values are input in gallons per year, and an EPA average of 651 gal (2464 L) of fuel oil per year was used for comparison. Results are displayed in Table 5. Values for fuel oil differ by 4512 lbs (2047 kg) of CO_2 emitted per year, with Clear Water reporting 12 432 lbs (5639 kg) of CO_2 per year and SafeClimate reporting 16 944 lbs (7 686 kg) of CO_2 per year.

Propane is included in seven calculators: American Forests, BEF, CarbonCounter.org, Clear Water, The Conservation Fund, SafeClimate, and TerraPass. Averages are provided by American Forests and BEF; and the BEF average of 488 gal (1847 L) per year was used for comparison. Results are shown in Table 6, and the values returned show a variation of 32 869 lbs (14 909 kg) per year.

Background information concerning fuel oil and propane calculations is given by six of the nine relevant calculators and five of the seven relevant calculators, respectively. In both cases, TerraPass maintains its non-

Table 5
Comparison of values for household fuel oil use and CO_2 emissions

	Average annual fuel oil use (gal)	CO_2 emitted for average fuel oil use (lbs/year)	Fuel oil conversion (lbs CO_2/gal)	CO_2 emitted for 651 gal fuel oil (lbs/year)
American Forests	801	17 622	22.0	14 322
Be Green				
BEF	730	16 340	22.4	14 572
CarbonCounter.org			20.3	13 220
Chuck Wright			20.0	13 010
Clear Water			19.1	12 432
The Conservation Fund	801	17 940	22.4	14 580
EPA	651	14 500	22.3	14 511
SafeClimate			26.0	16 944
TerraPass	639	14 295	22.4	14 582
Range			6.9	4512
Mean			21.9	14 241
Median			22.3	14 511
Standard deviation			2.00	1302

Table 6
Comparison of values for household propane use and CO_2 emissions

	Average annual propane use (gal)	CO_2 emitted for average propane use (lbs/year)	Propane conversion (lbs CO_2/gal)	CO_2 emitted for 488 gal propane (lbs/year)
American Forests	515	5665	11.0	5368
Be Green				
BEF	488	6182	12.7	6182
CarbonCounter.org			11.5	5600
Chuck Wright				
Clear Water			78.4	38 237
The Conservation Fund	515	6380	12.4	6060
EPA				
SafeClimate			12.7	6180
TerraPass	722	9148	12.7	6183
Range			67.4	32 869
Modified Range III [a]				815
Mean			21.6	10 544
Median			12.7	6180
Standard deviation			25.0	12 216

[a] Modified Range III is the difference in propane values excluding Clear Water's output.

specific citation of EIA data. Also, CarbonCounter.org's conversion factors continue to disagree with its provided background information for both fuels.

American Forests is the sole calculator to include kerosene as an option in its calculations. It provides an average value of 100 gal (379 L) per year, with a conversion factor of 215 lb of CO_2 per gallon (25.8 kg of CO_2 per L). This results in 2154 lbs (977 kg) of CO_2 emitted for kerosene use per annum. American Forests, however, does not provide clear background information on its calculation of kerosene-related CO_2 emissions. American Forests and Clear Water also incorporate firewood use with conversion factors of 3814 lbs of CO_2 per cord (1730 kg of CO_2 per cord) and 5544 lb of CO_2 per cord (2514 kg of CO_2 per cord) respectively. Averages were not provided, and despite a brief discussion of firewood calculations by American Forests, background information regarding associated emissions was not provided by either calculator.

2.2. Transportation

The second main behavior is personal automotive travel. The typical user input requires the average miles traveled in a given time period and the vehicle's average efficiency (mpg). Be Green and TerraPass deviate from this by asking for the vehicle's make and model, utilizing the EPA's fuel economy database to find average mileage.

Again, default averages for annual miles driven and vehicle efficiency are available as inputs for several calculators in addition to the ability to enter these values manually. American Forests, BEF, CarbonCounter.org, and The Conservation Fund provide averages for a range of vehicle sizes; an average for a midsize sedan was chosen for comparison.

American Forests and The Conservation Fund further refine their CO_2 estimates by differentiating between vehicles with and without an air conditioner. American Forests explains that the yearly loss of vehicle air conditioner coolant is equal to an additional 195 lbs (88.5 kg) of CO_2 emitted into the atmosphere annually. This value is added to the American Forests' final estimation of CO_2 vehicle emissions if an air conditioner is present. The Conservation Fund similarly adds 194.9 lbs (88.4 kg) of CO_2 if an air conditioner is present; this is completed without explanation, however. In this study, vehicles were assumed to have an air conditioner.

Table 7 summarizes the relationship between individual behavior and vehicle-related CO_2 emissions. Columns 1 and 2 display values of average vehicle miles driven and average efficiency if provided as an option by the calculator. Be Green was not included in the comparison, as it was not possible to input the values of this study's individual profile. Column 3 displays the CO_2 emissions associated with these averages. Column 4 displays conversion factors for vehicle use employed by the calculators, and Column 5 displays CO_2 emissions from driving 11 700 miles (18 829 km) annually with a vehicle efficiency of 22 mpg (9.4 km per L). Values returned vary 2360 lbs (1070 kg), from 9340 lbs

Table 7
Comparison of values for personal vehicle use and CO_2 emissions

	Average annual miles driven	Average vehicle efficiency (mpg)	CO_2 emitted from average vehicle use (lbs/year)	Vehicle use conversion (lbs CO_2/gal)	CO_2 emitted for 11,700 miles driven and 22 mpg (lbs/year)
American Forests	11 300	22.2	10 168	19.6	10 615 [a]
Be Green					
BEF	11 904	21.4	10 883	19.6	10 404
CarbonCounter.org				17.6	9340
Chuck Wright	–	25		22.0	11 700
Clear Water				19.0	10 125
The Conservation Fund	11 700	22	10 540	20.0	10 840 [a]
EPA	11 700	22	10 860	20.4	10 860
SafeClimate				19.6	10 404
TerraPass	12 000	–		19.6	10 408
Range				4.4	2360
Modified Range IV [b]				2.9	1520
Mean				19.7	10 478
Median				19.6	10 408
Standard deviation				1.17	623

[a] With an air conditioner.
[b] Modified Range IV is the difference in personal vehicle use values from calculators that explicitly state their conversion factors (excluding Be Green, Chuck Wright, and Clear Water).

Table 8
Comparison of values for personal air travel and CO_2 emissions

	Flight conversion (lbs CO_2/mile)	CO_2 emitted for 830 miles flown (lbs/year)
American Forests	0.44	365
Be Green	0.42	352
BEF	1.36 [a]	1,129
CarbonCounter.org	0.87 [a]	720
Chuck Wright	0.51	426
Clear Water	0.62	517
The Conservation Fund	0.43	360
EPA		
SafeClimate	0.64	528
TerraPass	0.45	373
Range	0.94	777
Modified Range V [b]	0.21	176
Mean	0.64	530
Median	0.51	426
Standard deviation	0.154	255

[a] Includes the effects of additional greenhouse gases and/or contrails.
[b] Modified Range V is the difference in flight values from calculators that do not account for the effects of additional greenhouse gases and/or contrails.

(4237 kg) per year returned by CarbonCounter.org to 11 700 lbs (5 307 kg) per year returned by Chuck Wright.

Seven of the ten calculators provide some form of background information concerning their calculations of vehicle-related emissions. There are some inconsistencies, however. The Conservation Fund reportedly employs a conversion factor of 25.3371 lbs of CO_2 per gallon (3.03605 kg of CO_2 per L) of gasoline—19.2898 lbs of CO_2 per gallon (2.31143 kg of CO_2 per L) emitted directly and 6.0473 lbs of CO_2 per gallon (0.72463 kg of CO_2 per L) emitted in the petroleum refinement process. In actual practice, however, their conversion factor appears to be 20 lbs of CO_2 per gallon (2.4 kg of CO_2 per L) as noted in Table 7. CarbonCounter.org and EPA both report different conversion factors than those actually used in their calculations. American Forests provides no citation for its conversion factors.

Personal air travel is another source of carbon dioxide emissions attributable to individual behavior and as such is included in all calculators except for the EPA calculator. The majority of calculators quantify behavior with either user input of air miles traveled or number of trips taken annually. Two calculators, Be Green and TerraPass, instead request input of departure and arrival city to calculate exact air miles traveled. BEF accounts for other greenhouse gases emitted during flight with the use of CO_2 equivalents (CO_2e), nearly tripling its estimates of CO_2 emissions. CarbonCounter.org also includes the impact of other greenhouse gases and the effect of airplane contrails by doubling their conversion factor for pounds of CO_2 per mile traveled. American Forests optionally allows the user to input number of flights taken per year and then calculates emissions by employing averages of 830.5 miles (1337 km) per flight and 48 mpg (20 km/L) per seat. Be Green provides an average of 2083 miles (3352 km) flown per year, and BEF approximates the length of an average round trip at 1660 miles (2671 km) and allows users to input number of trips taken per year. To compare calculators, a value of 830 miles (1336 km) was input universally, and the resultant emissions are displayed in Table 8. The range of values returned for air travel is large in part based on BEF's use of CO_2e. This results in a range of 777 lbs (352 kg) of CO_2 per year.

Nine calculators include personal air travel, but only four of these provide background information concerning conversion factors or specific citations. BEF and CarbonCounter.org both explain their inclusion of more greenhouse gases in their calculations; neither calculator, however, discloses this fact when displaying users' results. Be Green, SafeClimate, and TerraPass quantify emissions based on conversion factors which vary by trip length. Of these, Be Green provides its conversion factors without citation. SafeClimate provides the conversion factor it employs and broadly cites the GHG Protocol Initiative; TerraPass provides no conversion factors and broadly cites the World Resources Institute.

Beyond personal automotive and air travel, American Forests is the only calculator to include the impact of motorcycles, taxis, rail or subway, city buses, and interstate buses. Mileage in each category is requested, and different conversion factors of pounds of CO_2 per mile are used in each, though given the limited use of these modes of transportation, no average quantification of behavior is provided.

2.3. Offsets

Many of the calculators examined go beyond estimating the carbon footprint associated with individual

Table 9
Comparison of costs of mitigation

	Minimum price (USD)	Minimum amount covered (tons)	Price per ton (USD)
American Forests	15.00	5	3.00
Be Green		1.1	12.73
BEF	40.00		28.00
CarbonCounter.org			10.00
The Conservation Fund	10.00	4	5.00
TerraPass — Housing	29.94	3	9.98

Table 10
Summary of emissions estimation differences

Behavior type	Low (lbs CO_2/year)	Calculator	High (lbs CO_2/year)	Calculator	Difference (lbs CO_2/year)	Difference (tons CO_2/year)
Electricity	6600	Clear Water	24 000	ChuckWright	17 400	8.70
Natural Gas	9083	Clear Water	12 156	SafeClimate	3073	1.54
Fuel Oil	12 432	Clear Water	16 944	SafeClimate	4512	2.26
Propane	5368	American Forests	38237	Clear Water	32 869	16.4
Road Travel	9340	CarbonCounter.org	11700	ChuckWright	2360	1.18
Air Travel	352	Be Green	1129	BEF	777	0.389

behavior and offer a means to mitigate an individual's emissions. Typical methods include reforestation projects or renewable energy development, although specific projects vary. A comparison of price per unit carbon dioxide mitigated is provided in Table 9.

American Forests and The Conservation Fund both use reforestation as their main method of emissions mitigation. After a $15 minimum, American Forests plants trees for a dollar per tree, and each tree accounts for a third of a ton (0.30 metric tons) of CO_2 emissions mitigated. The Conservation Fund plants trees for about $5 per tree after a $5 administration fee. Each tree accounts for four tons (3.6 metric tons) of CO_2 emissions mitigated.

Be Green offers individuals renewable energy credits (REC) that subsidize the production of 1 MWh of electricity from renewable electricity facilities. RECs are priced at $14 per credit, and each REC mitigates the effects of one metric ton of CO_2.

BEF provides similar carbon dioxide offsets through its Green Tags program. Green Tags are quantified units that mitigate CO_2 through the support and development of green energy. BEF offers two types of Green Tags: Cooler Future Green Tags, which cost $20 and through which 99% of contributions supports wind energy and 1% supports solar energy; and Brighter Future Green Tags, which cost $24 and through which 90% supports wind energy and 10% supports solar energy. There is a minimum purchase of two green tags, and employing the price of the Cooler Future Green Tag, BEF mitigates CO_2 for approximately $28 a ton.

CarbonCounter.org offsets CO_2 emissions by funding "projects that reduce CO_2 in the environment." These specifically include energy-efficient renovations, renewable energy projects, and reforestation. CarbonCounter.org charges $10 per ton of CO_2 per year.

TerraPass employs distinct calculators for Home, Road, and Flight and likewise has three separate programs for mitigation that correspond to these categorical distinctions. Payments to TerraPass are used to support projects in wind energy, biomass, and industrial efficiency. For home, there is minimum offset of $29.95 covering 3 tons (2.7 metric tons) of CO_2 and costing $9.98 per ton thereafter. For road, offsets take the form of four different levels of mitigation: "Hybrid," which costs $29.95 and mitigates up to three tons (2.7 metric tons) of CO_2; "Efficient," which costs $39.95 and mitigates up to four tons (3.6 metric tons) of CO_2; "Standard," which costs $49.95 and mitigates up to six tons (5.4 metric tons) of CO_2; and "Utility/Performance," which costs $79.95 and mitigates up to ten tons (9.1 metric tons) of CO_2. For flight, TerraPass offsets are divided into five levels of mitigation, priced from $9.95 covering up to 2500 lb (1134 kg) of CO_2 to $1499.95 covering up to 500 000 lb (2.3×105 kg) of CO_2.

3. Discussion

Although these calculators employ similar approaches to CO_2 estimation, their results often vary, even when using uniform inputs, as shown in Table 10. These variations may be due to differences in calculating methodologies, behavioral estimates, conversion factors, or other sources. However, the lack of transparency makes it difficult to determine the specific reasons for these variations and to assess the accuracy and relevance of the calculations.

For electricity consumption, calculators return CO_2 emission levels that differ by 8.70 tons (7.89 metric tons) per year. This difference is likely because power utilities employ various methods of electricity production that result in different levels of CO_2 emissions for the electricity consumer depending on their geographic location. Five of the calculators attempt to account for these geographic differences by offering state-dependent estimates for electricity-related emissions, but these calculators' resultant values still vary by 2308 lbs (1047 kg) per year. Only one calculator, Chuck Wright, allows user control over the specific fuel utilized in local electric power generation.

Two calculators provide little background information concerning their electricity-related emissions calculation: Clear Water and Chuck Wright. These two calculators display the low and high values for electricity, 6600 lbs

(2994 kg) and 24 000 lbs (10 886 kg) per year respectively. The lack of information makes it difficult to explain the variation. The eight remaining calculators, which are a mixture of state and non-state-dependent calculators, present some form of background information, and their results vary by 2400 lbs (1089 kg) per year.

Natural gas and fuel oil estimates differ by 1.54 tons (1.39 metric tons) per year and 2.26 tons (2.05 metric tons) per year respectively. For both fuel sources, Clear Water returns the low value, and SafeClimate returns the high. Again, Clear Water provides no readily accessible documentation concerning its values. SafeClimate, however, explicitly states the conversion factors employed in these calculations, and it provides references for these numbers. Even with this background information, it remains unclear why the fundamental conversion factors SafeClimate employs are 12% and 17% higher than the median conversion factors found in this study for natural gas and fuel oil respectively.

Propane-related CO_2 estimates demonstrate a large range of 16.4 tons (14.9 metric tons) per year. In this case, Clear Water's estimate for propane is six times larger than the median. When Clear Water's value is removed from this study, the difference between estimates decreases to 815 lbs (370 kg) per year. These ranges demonstrate a marked consistency. Combined with previous estimates, however, the total variation displayed for household energy consumption can be a significant amount, and there is little explanation provided concerning why this variation occurs.

Results for transportation-related emissions also demonstrate variation. Estimates for CO_2 emissions from vehicles differ by 1.18 tons (1.07 metric tons) per year. Seven of the nine calculators examined explicitly provide conversion factors for pounds of CO_2 per gallon of gasoline. Of these seven calculators, their estimates differ by 1520 lbs (689 kg) per year.

For air travel, BEF and CarbonCounter.org attempt to quantify the greater climate impact of commercial flights by using factors that include the effects of other greenhouse gases and airplane contrails. BEF and CarbonCounter.org's estimates are significantly higher than the median emissions for air travel, which may indicate the importance of other greenhouse gases. Excluding BEF and CarbonCounter.org's values for CO_2 emissions, estimates for flight show a difference of about 176 lbs (79.8 kg) per year. Given that there are approximately 28 000 commercial flights a day in the US, values in aggregate could differ by 2500 tons (2200 metric tons) for daily personal travel (NATCA).

Notably, these results reveal a lack of uniformity among calculators. These variations may be a result of different conversion factors employed or distinct methodologies utilized to calculate these estimates of CO_2 emissions. Although these differences may appear small in some cases, when compounded in calculations, they can produce considerable variation in results.

In addition, the reasons for the selection of different conversion factors or calculating methodologies are unclear. The lack of background information emphasizes the need for greater transparency. Transparent calculators would allow users to better understand the calculations and results and to choose a calculator that is more tailored to their needs. Transparency also may influence the extent to which market, social, or regulatory pressures will increase incentives for calculator consistency.

The variability observed here does not necessarily imply invalid results. The discrepancies in output do have potential effects, however. A difference of several tons in an individual's calculation of personal emissions may induce different responses. For example, if a carbon calculator gives a lower value for air travel and a higher value for vehicle use, an individual may be induced to opt for air travel more often. Similarly, if an individual's overall carbon footprint from a specific calculator is higher, the individual may put a greater effort into a range of reductions or offset purchases or both. These variations also may influence the extent to which citizens and policymakers support different types of individual reduction measures.

4. Conclusions

Carbon dioxide calculators are important tools for estimating CO_2 emissions and for providing information that can lead to behavioral and policy changes. As demonstrated, however, these calculators produce estimates of carbon footprints that can vary by as much as several metric tons per annum per individual activity. Using year 2000 values[3], if 1% of the U.S. population had inaccurately estimated their emissions by 2 tons (1.8 metric tons) per person per annum, this would result in a value for CO_2 emissions that was approximately 5.6 million tons (5.1 million metric tons) too high or low[4].

[3] U.S Census Bureau reports the U.S. population to have been 281,421,906 persons in the year 2000. http://factfinder.census.gov/servlet/GCTTable?_bm=y&-geo_id=01000US&- _box_head_nbr=GCT-H6&-ds_name=DEC_2000_SF1_U&-format=US-9 (last visited July 12, 2007).

[4] This mis-estimation would be greater than the CO_2 emissions from the entire country of Costa Rica, which emitted 5.3 million tons (4.8 million metric tons) in the year 2000 (World Resources Institute, 2003).

Although most calculators are relatively new, their numbers are growing, and their methods are proliferating. Calculators can increase public awareness about CO_2 emissions and ways to reduce them, and they can affect the type and magnitude of emissions reduction efforts and offset purchases. But to the extent that carbon calculators lack transparency, individuals and policymakers will be less able to understand and validate the results. Given their prevalence and potential influence, CO_2 calculators can provide even greater public benefit by providing greater consistency and clarity.

Appendix A

Table A1
Comparison of calculators on household energy consumption

	Online sources and references	Offers state-dependent electricity coefficients	Adjusts output for waste and recycling	Allows input of number of occupants	Allows user input over electricity make up	Includes electricity	Includes natural gas	Includes fuel oil	Includes propane	Includes kerosene	Includes wood
American Forests	•		•			•	•	•	•	•	•
Be Green	•	•				•	•				
BEF	•	•				•	•	•	•		
CarbonCounter.org	•	•		•		•	•	•	•		
Chuck Wright					•	•	•	•			
Clear Water			•			•	•	•	•		•
The Conservation Fund	•		•			•	•	•	•		
EPA	•		•	•		•	•	•			
SafeClimate	•	•		•		•	•	•	•		
TerraPass	•	•				•	•		•		

Table A2
Comparison of calculators on transportation

	Allows input of miles per year	Allows input of vehicle efficiency	Allows input of vehicle year, make, and model	Allows input of air conditioner presence	Allows input of miles flown per year	Allows input of number of flights per year	Allows input of city to city	Includes travel by motorcycle, bus, train, and/or taxi
American Forests	•	•		•	•	•		•
Be Green	•		•			•	•	
BEF	•	•			•	•		
CarbonCounter.org	•	•			•			
Chuck Wright	•	•			•			
Clear Water	•	•			•			
The Conservation Fund	•	•		•	•			
EPA	•	•						
SafeClimate	•	•			•			
TerraPass	•		•				•	

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