Carbon Reduction Analysis and Action Using the CoolClimate Calculator

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Note

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Take Action: **Carbon Reduction Analysis and Action Using the CoolClimate Calculator**

This document presents methods for the *Take Action* page of the CoolClimate Calculator, located at http://coolclimate.berkeley and http://coolclimate.berkeley.edu (forthcoming). The Take Action page allows individuals or households to estimate greenhouse gas and financial savings from a set of low carbon technology investments and behavior change opportunities, collectively called "Actions".

Each individual analysis section and then Action recommendation is itself a mini-calculation tool, allowing users to adjust multiple settings (depending on the action) to reflect their personal options and preferences. The default settings of actions are based on expected settings determined from surveys of representative users. Results are based on local energy and fuel prices (based on data from 28 major US metropolitan regions and all U.S. states), emissions from residential electricity production (at the level of U.S. states or utilities in the case of California), and local heating and cooling needs (for 250 U.S. regions).

The following Actions are available on the www.cookcalifornia.org website and are described in detail in this report:

The carbon footprint savings are presented in metric tons of CO_2 equivalent gases per year for each action and in total (including all pledged actions). Financial metrics include annual financial savings from changes in annual expenditures (e.g., reduced energy bills), 10-year net savings, upfront cost, 10-year net present value (NPV), return on investment (ROI) and simple payback period (in years). Only methods for annual financial savings are included in this report since the other metrics can be readily calculated from annual savings and upfront cost. Users can adjust the discount rate (set to 8% by default) and annual inflation rate (set to 3% by default) which affects NPV and ROI. ROI is defined as ten year NPV over upfront cost.

TRANSPORTATION

1. Buy a more fuel efficient vehicle

> I will trade in [Vehicle 1], which gets **20** miles per gallon and buy a more fuel-efficient model that gets [30] miles per gallon. I will drive this vehicle [10,000] miles per year. I can sell my current vehicle for [$10,000] and purchase a new one for [$12,000].

This action allows users to see the GHG and financial impacts of replacing one of their current vehicles with a more fuel-efficient model. Users select which vehicle they will replace (the calculator remembers the fuel efficiency of each vehicle previously entered), the fuel efficiency of the new vehicle (current vehicle mpg + 10 by default), annual miles this vehicle will be driven, the purchase price of a more fuel efficient vehicle and the expected sales price of their current vehicle (both vehicles assumed to be used by default).

Calculations:

Metric tons CO_2/yr saved:

$$= [miles / miles_c * (gCO2_d + gCO2_i) - miles / miles_n * (gCO2_d + gCO2_i)] / 10^6$$

Where,
miles = miles vehicle driven per year
mpg_c = fuel efficiency (miles per gallon) of current vehicle
mpg_n = fuel efficiency (miles per gallon) of new vehicle
d = direct emissions per fuel type
$gCO2_d$ = direct GHG emissions per fuel type (gasoline or diesel)
$gCO2_i$ = indirect GHG emissions per fuel type (gasoline or diesel)

Annual $ savings:

$$= miles / mpg_c * gas – miles / mpg_n * price$$

Where,
miles = miles vehicle driven per year
mpg_c = fuel efficiency (miles per gallon) of current vehicle
mpg_n = fuel efficiency (miles per gallon) of new vehicle
price = price of gasoline ($/gallon)

2. Telecommute to work

I will stay at home instead of driving to work [4] day(s) per month instead of driving [Vehicle 1], which gets 20 miles per gallon. The one-way distance to work is [20] miles. I will save [2] hours a month by staying home. My travel-free time is worth $[0] per hour to me.

This action calculates GHG and financial benefits from fuel savings in addition to financial savings from time spent at home instead of commuting. The default setting is telecommuting 4 days per month, or roughly once a week. While telecommuting is not an option for many jobs, given that both the carbon footprint and financial benefits of this action are relatively quite high, this tool helps quantify these benefits for those who may be considering this as an option.

A unique feature of this action is giving users the opportunity to explore different financial savings by valuing time spent at home instead of commuting. Reducing commute time generally leads to more time for leisure and/or work, both of which are valued by commuters. In cases where there is a direct tradeoff between commute time and work time, it is reasonable to value travel-free time at a rate equivalent to the wage rate. In these cases, the commuter experiences direct financial benefits by increasing the amount of time dedicated to work. If non-commute time is used for leisure, there may not be direct financial savings; however commuters may "value" this time in the sense that they would be willing to pay an equivalent amount to forgo commuting. The degree to which individual drivers value their travel-free-time also depends on road conditions, comfort and stress levels, the driver's personal feelings about driving and other factors. A recent detailed study[3] of travel time valuation suggests that, on average, the value of travel-free-time for driving personal vehicles should be about 50% of the wage rate. Since financial savings for all other actions in the calculator imply direct (in- or out-of-pocket) savings, the default setting for travel-free-time is currently set to zero. Future versions of the calculator may change this value depending on user feedback.

Metric tons CO_2/yr saved:

$$= miles * 2 * days * 12_{months} * dist / mpgveh_u * \left(EFfuel_d + EFfuel_i\right) / 1000000$$

Where,
days = days user drives to work per month
miles = the one-way distance to work
$mpgveh_u$ = the miles per gallon of vehicle selected by user
$EFfuel_d$ = direct emission factor from fuel (gasoline or diesel)
$EFfuel_i$ = indirect emission factor from fuel (gasoline or diesel)

Annual $ savings:

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3 Todd Litman (2008), "Valuing Transit Service Quality Improvements," Journal of Public Transportation, Vol. 11, No. 2, Spring 2008, pp. 43-64; at www.nctr.usf.edu/jpt/pdf/JPT11-2Litman.pdf; a more complete version is at www.vtpi.org/traveltime.pdf.

$$days * 12_{months} * \left[\left(2 * \left(miles / mpgveh_u * gas\cos t\right) + \left(parking / days\right) + \left(2 * time / 60 * worth\right)\right)\right]$$

Where,

- days = days user drives to work per week
- miles = the one-way distance to work
- $mpgveh_u$ = the miles per gallon of vehicle selected by user
- gascost = current price of fuel ($/gallon)
- time = time (in minutes) trip takes one-way
- salary = how much the user's time is worth

3. Ride Your Bike

I will ride my bike [20] miles per week instead of driving [Vehicle 1], which gets 20 miles per gallon.

This action calculates financial savings greenhouse gas savings from riding a bicycle vs. driving a motor vehicle. Financial savings are calculated for reduced fuel consumption only (other motor vehicle and bicycle expenses are not considered). Carbon footprint savings consider reduced fuel consumption minus an estimate of the carbon footprint from food consumed in order to power (pedal) the given distance on a bicycle. The food carbon footprint is based on the users' diet, as selected under the Food portion of the calculator.

Metric tons CO_2/yr saved:

$$= (miles / mpgveh_u * (EFfuel_d + EFfuel_i) - miles / mph_{bike} * \text{cal}_{bike} * EFdiet) * 2 * 12 / 1000000$$

Where**,**

- miles = number of miles user pledges to ride bicycle instead of driving each week
- $mpgveh_u$ = miles per gallon of vehicle selected by user
- $EFfuel_d$ = direct emission factor from fuel (gasoline or diesel)
- $EFfuel_i$ = indirect emission factor from fuel (gasoline or diesel)
- mph_{bike} = average speed of riding a bicycle, assumed to be 11 mph
- cal_{bike} = additional calories per hour needed to ride a bicycle, assumed to be 300
- *EFdiet* = Emission factor (gCO2e/calorie) for the users diet, as specified in the food portion of the calculator.

Annual $ savings:

$$= \left[\left(miles * 12 months / mpgveh_i * gas\cos t\right)\right]$$

Where,

- miles = number of miles user pledges to ride bicycle instead of driving each week
- $mpgveh_u$ = miles per gallon of vehicle selected by user
- gascost = current price of fuel ($/gallon)

4. Take public transportation

I will take a [diesel bus] [20] miles per week instead of driving [Vehicle 1], which gets **20** miles per gallon. I will save [$10] on parking and spend [$10] per week on public transportation.

This action allows users to compare driving one of their existing vehicles with taking one of the following public transportation modes: diesel bus, natural gas bus, electric subway, Amtrak. Financial savings include reduced fuel consumption and parking fees (insurance and other vehicle expenses are not included) minus public transportation fares.

Annual $ savings:

$$= 52_{\text{weeks}} * (miles / mpgveh_u * gas + parking - ptfare)$$

Where,

- miles = distance that the user pledges to travel via public transit instead of personal vehicle (miles/week)
- $mpgveh_u$ = fuel efficiency (miles per gallon) of vehicle selected by user
- gas = user-entered price of gas ($/gal)
- parking = user-entered cost of parking ($/week)
- ptfare = user-entered cost of public transit fares ($/week)

Metric tons CO_2/yr saved:

$$= 52_{weeks}\left(miles * mpgveh_u * \left(EFfuel_d + EFfuel_i\right) - miles * publictrans_{\text{mod}\,e}\right)$$

Where,

- miles = distance that the user pledges to travel via public transit instead of personal vehicle (miles/week)
- $mpgveh_u$ = fuel efficiency of vehicle selected by user (mpg)
- $EFfuel_d$ = direct emission factor from fuel (gasoline or diesel)
- $EFfuel_i$ = indirect emission factor from fuel (gasoline or diesel)
- $publictrans_{mode}$ = grams of CO_2 per passenger mile per public transport mode (source: WRI and WBCSD, 2009[4], with exceptions noted below)
    - And $\frac{gCO_{2\,bus}}{mile} = 107$
    - And $\frac{gCO_{2\,natgasbus}}{mile} = 78$

      note: Calculated from EIA's Emission Coefficients[5]. Natural gas emissions per mile = ratio of (Pounds CO_2/Million Btu for natural gas) / (Pounds CO_2/Million Btu for Diesel) multiplied by bus emissions/mile.

4 WRI-WBCSD. Greenhouse Gas Protocol. http://www.ghgprotocol.org/

5 EIA, 2009. Greenhouse Gas Emission Factors. http://www.eia.doe.gov/oiaf/1605/coefficients.html

- $$\frac{gCO_{2\,train}}{mile} = 185$$
- $$\frac{gCO_{2\,subway}}{mile} = 163 * \frac{gCO_2 / kWh_{State}}{gCO_2 / kWh_{USAverage}}$$

  note: this factor scales national average emissions from light rail and commuter rail by emission factors for electricity of the given state.

5. Practice Eco-driving

> I currently drive a total of **20346** miles per year, of which [50] % are highway miles. The average fuel economy of my vehicles is **20** miles per gallon. Reducing my top cruising highway speed from [70] mph to [65] mph will improve my fuel economy by 1% per mph reduction over 60 mph. Reducing all rapid acceleration and braking can improve non-highway fuel economy by 3%. Together these actions will improve my fuel economy to **22.8** miles per gallon, saving **76** gallons per year.

This action quantifies the benefits of fuel-saving habits. Reducing top driving speed and rapid acceleration and braking are proven ways to improve fuel efficiency. According to the US Dept. of Energy[6], increasing average highway vehicle speed reduces fuel efficiency by approximately 1% per mph over 55 mph. By default, we assume 50% of miles driven are highway miles[7] and drivers reduce their average highway speed (70 mph by default) 50% of the time. Reducing driving speed from 70 mph to 65 mph is equivalent to reducing driving speed 5 mph, with a corresponding 5% fuel efficiency improvement, 25% of the time.

Users can also choose to reduce rapid braking and acceleration, which is assumed to have 3% improvement on fuel efficiency[8], with 50% assumed compliance rate.

Calculations:

Annual $ savings:

$= miles / mpg_{old} * \$gas – miles / mpg_{new} * \$gas$

Metric tons CO_2/yr saved:

$= miles / mpg_{old} * EF_{d+i} – miles / mpg_{new} * EF_{d+i}$

Where,
Miles = total miles user drives per year

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6 Source: US Department of Energy. Transportation Energy Databook, 2001. Table 7.22.
7 Puget Sound Regional Council. The Puget Sound Regional Council concluded that 43% of regional travel is on highways and expressways, 38% of VMT is on arterials, and 19% is on local roads. http://psrc.org/publications/pubs/view/0908.htm (Accessed May 2009)
8 US EPA. Fueleconomy.gov

$gas = price of gasoline ($/gallon)
EF_{d+i} = GHG emission factor (direct + indirect) for gasoline
mpg_{old} = user's current miles per gallon

$$mpg_{new} = \begin{pmatrix} (mpg_{old} + mpg_{old} * (\%HighwayMiles) * (\%TopSpeed) * (TopSpeed - LowerSpeed * 0.01)) \\ + (mpg_{old} * (1 - \%HighwayMiles) * (TopSpeed - LowerSpeed) * 0.03) \end{pmatrix}$$

Where,
%HighwayMiles = percent of miles user drives at highway speed
%TopSpeed = of all highway miles, the percentage of time user drives at top speed
TopSpeed = average top cruising speed, defined by user
LowerSpeed = the average top speed user pledges to drive

6. Maintain Vehicle 1

I currently drive a total of **20517** miles per year, with an average fuel economy of **20** miles per gallon.

I will keep my tires properly inflated.
I will change my air filter regularly.

According to the U.S. EPA, keeping tires properly inflated improves fuel efficiency by 3.3% on average, in addition to improving safety. Changing a vehicle's air filter regularly (about once a year) improves average fuel efficiency by 3%.

Annual $ savings:

$$\left(\frac{miles}{year} / \frac{miles_{old}}{gallon} * \frac{\$}{gallon}\right) - \left(\frac{miles}{year} / \left(\frac{miles_{new}}{gallon}\right) * \frac{\$}{gallon}\right) + \frac{Hours}{year} * \frac{\$}{hour}$$

Where,

$Miles_{new}$ =

- If user WILL keep tires inflated, mpg + 3.3%,
- If user WILL change air filter, mpg + 3%

Metric tons CO_2/yr saved:
CO2/yr at current mph - CO2/.yr at new mph

$$= \left(\begin{array}{l} \left(\frac{miles}{year} / \frac{miles_{old}}{gallon} * \left(\frac{CO2_d}{gallon} + \frac{CO2_i}{gallon} \right) \right) \\ - \left(\left(\frac{miles_{new}}{year} / \left(\frac{miles_{new}}{gallon} \right) * \left(\frac{CO2_d}{gallon} + \frac{CO2_i}{gallon} \right) \right) + \left(\frac{hours}{year} * \frac{\$}{hour} \right) \right) \end{array} \right) / 1000000$$

Where

- $CO2_d$ = direct emissions per fuel type
- $CO2_i$ = indirect emissions per fuel type

Where,

- $Miles_{new}$ =
  - If user WILL keep tires inflated, mpg + 3.3%
  - If user WILL change air filter, mpg + 3%
- $\frac{hours}{year}$ = (0.5 if "Keep tires inflated") + (0.5 If "Change air filter regularly").
- $\frac{\$}{hour}$ = value of users time, defined by user ($0 is default)

7. Fly less often

Only display this question if user flies more than 1000 miles per year. Display question once. I currently fly [ ] miles per year. I pledge to fly [1000] fewer miles per year by teleconferencing or staying at home.

Annual $ savings:

$$\frac{miles_{fewer}}{year} / \frac{miles}{\$}$$

Where,

- $\frac{miles_{fewer}}{year}$ = miles per year user pledges to reduce
- $\frac{miles}{\$}$ = 10

Metric tons CO_2/yr saved:

$$\frac{miles_{fewer}}{year} * \left(\frac{gCO2_{direct}}{mile} + \frac{gCO2_{indirect}}{mile} \right) / 1000000$$

Where,

$$\frac{gCO2_{direct}}{mile} = 223$$

$$\frac{gCO2_{indirect}}{mile} = 223$$

HOUSING

8. Replace lightbulbs with CFLs

User input
I will replace [5] regular incandescent lightbulbs with high efficiency compact florescent (CFL) lightbulbs. I leave the lights on about [5] hours every day.

Assumptions
Wattage of incandescent bulb: 75
Equivalent wattage of CFLs: 20
Cost per incandescent bulb: 2
Cost per cfl: $0.75
Lifetime (hours) of incandescent: 750
Lifetime (hours) of CFLs: 8000
Price of electricity (cents/kWh): [by US State in cents per kWh]
Grams CO_2 per kWh: [by US State]

Text

Using compact fluorescent lightbulbs (CFLs) in place of incandescent bulbs in your home can save electricity, CO2 emissions, and money. While a typical CFL has a higher upfront cost than its incandescent equivalent, the CFL makes up for this cost many times over through a longer lifetime and significantly lower electricity usage for the same brightness. Typical retail prices for CFLs vary, but have been falling over time. In 1999 the average price of a single CFL was $12.48.[9] By 2000, the average price had fallen to $10.[10] By 2003, prices for small CFL bulbs at large home improvement stores were as low as $3 per bulb. By 2006 the average price for an ENERGY STAR qualified CFL 6-bulb pack had fallen to around $1.70 per bulb. The calculator uses $2 for a CFL bulb and $.75 for an incandescent bulb of equivalent brightness.[11]

Upfront cost:

bulbs * (cost of CFL – cost of incandescent) = $2 - $0.75 = $1.25

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[9] Long Island Power Authority, http://www.lipower.org/newscenter/pr/2006/102506_cal.html
[10] *Northeast Energy Efficiency Partnerships, Inc. (NEEP)* estimates using Massachusetts Electric Company 2002 DSM Performance Measurement Report and U.S.EPA emission factor data. http://www.neep.org/files/ResProducts.pdf
[11] http://www.atlantalightbulbs.com/cfl.html

Annual $ savings:

$$\# \text{ bulbs} * \left(\frac{hours_{lightson}}{day} * \frac{365days}{year} * \left(\frac{W_{incadescent}}{bulb} - \frac{W_{CFL}}{bulb} \right) * \frac{cents_{State}}{kWh} * \frac{\$}{100cents} * \frac{k}{1000} \right)$$

Wattage of incadescents: 75
Wattage of equivalent wattage of CFLs: 20
Lifetime (hours) of incandescent: 750
Lifetime (hours) of CFLs: 8000
$ per incandescent bulb: 2
$ per cfl: $0.75

10 year net savings

= # bulbs * (cost of incandescent * number of incandescents needed in ten yrs) - (cost of CFL * number of CFLs needed in 10 yrs) + (cost of operating an incandescent for 10 yrs) - (cost of operating a CFL for 10 yrs))

Where,
number of bulbs needed for each type = $\frac{hours_{lightson}}{day} * \frac{365days}{year} * 10years / \frac{hrslifetime}{bulb}$

Full CFL formula =

$$\#bulbs * \left(\begin{array}{l} \frac{\$}{incandescent} * \frac{hours_{lightson}}{day} * \frac{365days}{year} * 10years / \frac{hrs_{lifetime}}{incandescent} \\ - \frac{\$}{CFL} * \frac{hours_{lightson}}{day} * \frac{365days}{year} * 10years / \frac{hrs_{lifetime}}{CFL} \\ + \frac{W}{incandescent} * \frac{hours_{lightson}}{day} * \frac{365days}{year} * 10years * \frac{kWh}{1000Wh} * \frac{\$}{kWh} \\ - \frac{W}{CFL} * \frac{hours_{lightson}}{day} * \frac{365days}{year} * 10years * \frac{kWh}{1000Wh} * \frac{\$}{kWh} \end{array} \right)$$

Or, more simply

$$\#bulbs * \left(\begin{array}{l} \frac{\$}{incandescent} * 10years / \frac{hrs_{lifetime}}{incandescent} - \frac{\$}{CFL} * 10years / \frac{hrs_{lifetime}}{CFL} \\ + \frac{W}{incandescent} * \frac{kWh}{1000Wh} * \frac{\$}{kWh} * 10years - \frac{W}{CFL} * \frac{kWh}{1000Wh} * \frac{\$}{kWh} * 10years \end{array} \right)$$

$$* \frac{hours_{lightson}}{day} * \frac{365days}{year}$$

Metric tons CO_2/yr saved:

$$\frac{60w-15w}{bulb}*\frac{Hr}{day}*\frac{kWh}{1000Wh}*\frac{365day}{year}*\frac{gCO2}{kWh}/1000000$$

CO2/kWh is user defined

9. Turn down thermostat in winter

Heating is the single largest contributor to home energy use for typical homes in the United States. According to the EPA,[12] each degree a thermostat is turned down in winter decreases energy consumption by 6%. This appears to be a conservative estimate based on other studies, e.g., Parker et. al (1996).[13] Energy savings can be achieved without sacrificing home comfort when energy is wasted at night, when unoccupied homes are heated during the day, or when the thermostat temperature is simply set too high.

Energy consumption from heating varies dramatically with climate zone. The Calculator chooses typical home heating requirements based on users' proximity to 262 weather stations[14] and home size. Users select natural gas (default), electricity or fuel oil as their heating fuel and choose the number of degrees they will set the thermostat back, on average, at night and during the day. Users can adjust the number of hours the thermostat setting will be changed at night or during the day on weekdays and/or weekends.

Annual household energy consumption in physical units, $E_{PU,}$ is defined as:

E_{PU} = CI/(HDD*(HSF/1000))

Where,

- EPU = annual consumption of energy for heating in physical units
- HDD = heating degree days for the 30 year NOAA average for nearest weather station.
- HSF = heated square feet of home (1854 is the default)
- CI = Average US heating consumption intensity provided by the Residential Energy Consumption Survey15 for each fuel type, as
    - Electricity: 6.283
    - Natural gas: 0.517
    - Fuel oi:0.60

12 US EPA. Programmable Thermostat Calculator. http://www.energystar.gov/index.cfm?c=thermostats.pr_thermostats

13 Parker, D., Mazzara, M., Sherwin, J., 1996. "Monitored Energy Use Patterns In Low-Income Housing In A Hot And Humid Climate," Tenth Symposium on Improving Building Systems in Hot Humid Climates, Ft. Worth, TX, p. 316.

14 Users are asked to choose from one of 262 US locations with similar climate. Choosing location selects average heating degree days from nearest weather station in the NOAA (30 year average: 1971-2000) database: http://www.ncdc.noaa.gov/oa/climate/online/ccd/nrmhdd.html

15 Energy Information Agency. Residential Energy Consumptions Survey (RECS) 2005. http://www.eia.doe.gov/emeu/recs/contents.html

Metric tons CO_2/yr saved:

$= E_{PU} * T_{\Delta} * 0.06 * EF$

Where,

EF = Greenhouse gas emission factors, EF, are:

- Electricity: gCO2e/kWh for user's US State
- Natural gas: 5470 gCO2e/therm (EPA GHG Protocol)
- Fuel oil: 10153 gCO2e /gallon (EPA GHG Protocol)

T_{Δ} = The time-weighted average decrease in thermostat setting (T_{Δ}) is calculated as:
5/7*(wdsetup/24*daydegrees+wdntsetup/24*nightdegrees+wdnoset/24*0) +
2/7*(wesetup/24*daydegrees+wentsetup/24*nightdegrees+weekendnoset/24*0)

Where,

- wdsetup = number of weekday hours thermostat is turned down
- wdntsetup = number of weekday night hours thermostat is turned down
- wdnoset = number of weekday hours thermostat is unchanged
- wesetup = number of weekday hours thermostat is turned down
- wentsetup = number of weekday night hours thermostat is turned down
- wenoset = number of weekday hours thermostat is unchanged
- daydegrees = number of degrees user pledges to turn down thermostat during the day
- nightdegees = number of degrees user pledges to turn down thermostat at night

The following assumptions are provided by EPA[16]:

- Weekday daytime set-up hours: 10
- Weekday nighttime set-up hours: 8
- Weekend daytime set-up hours: 10
- Weekend nighttime set-up hours: 8

Annual $ savings:

$E_{PU} * \$/E_{PU} * T_{\Delta} * 0.06$

Where,

$/PU = price of chosen fuel in dollars per physical unit. Natural gas and electricity prices are US state averages; fuel oil is average US price.[17]

16 US EPA. Programmable Thermostat Calculator.
17 Energy Information Agency. http://www.eia.doe.gov/

10. Turn up thermostat in summer

Energy consumption from cooling varies dramatically with climate zone. The Calculator chooses typical home heating requirements based on users' proximity to 262 weather stations[18] and home size. Air conditioning is assumed to be produced by electricity. Users choose the number of degrees they will set the thermostat back, on average, at night and during the day. Users can adjust the number of hours the thermostat setting will be changed at night or during the day on weekdays and/or weekends.

Annual household energy consumption in physical units, $E_{PU,}$ is defined as:

E_{PU} = CI/(CDD*(HSF/1000))

Where,

- EPU = annual consumption of energy for cooling in physical units
- CDD = cooling degree days for the 30 year NOAA average for nearest weather station.
- CSF = cooling square feet of home (1854 is the default)
- CI = Average US cooling consumption intensity provided by the Residential Energy Consumption Survey19 for electricity as 6.283 (CDD*(HSF/1000))

Metric tons CO_2/yr saved:

= E_{PU} * T_{Δ} * 0.06 * EF

Where,

- EF = gCO2e/kWh for user's US State
- TΔ = The time-weighted average decrease in thermostat setting (TΔ) is calculated as: 5/7*(wdsetup/24*daydegrees+wdntsetup/24*nightdegrees+wdnoset/24*0) + 2/7*(wesetup/24*daydegrees+wentsetup/24*nightdegrees+weekendnoset/24*0)

Where,

- wdsetup = number of weekday hours thermostat is turned down
- wdntsetup = number of weekday night hours thermostat is turned down
- wdnoset = number of weekday hours thermostat is unchanged
- wesetup = number of weekday hours thermostat is turned down
- wentsetup = number of weekday night hours thermostat is turned down
- wenoset = number of weekday hours thermostat is unchanged
- daydegrees = number of degrees user pledges to turn down thermostat during the day
- nightdegees = number of degrees user pledges to turn down thermostat at night

18 Users are asked to choose from one of 262 US locations with similar climate. Choosing location selects average heating degree days from nearest weather station in the NOAA (30 year average: 1971-2000) database: http://www.ncdc.noaa.gov/oa/climate/online/ccd/nrmhdd.html

19 Energy Information Agency. Residential Energy Consumptions Survey (RECS) 2005. http://www.eia.doe.gov/emeu/recs/contents.html

The following assumptions are provided by EPA[20]:

- Weekday daytime set-up hours: 10
- Weekday nighttime set-up hours: 8
- Weekend daytime set-up hours: 10
- Weekend nighttime set-up hours: 8

Annual $ savings:

$E_{PU} * \$/E_{PU} * T_{\Delta} * 0.06$

Where,

$/PU = price of electricity ($/kWh) in users' state.[21]

11. Buy a more efficient refrigerator

This module compares purchasing a conventional refrigerator to purchasing an energy efficient Energy Star qualified model.[22] This module builds on the EPA Energy Star calculator.[23]

Annual electricity consumption is calculated as:

= (fresh volume +1.63 * freezer volume) * kWh/cu.ft + baseload

Where,

	kWh/cu.ft	Baseload kWh/yr
Manual Defrost Refrigerators	8.82	248.4
Partial Automatic Defrost Refrigerators	8.82	248.4
Top Mount Freezer without through-the-door ice	9.8	276
Side Mount Freezer without through-the-door ice	4.91	507.5
Bottom Mount Freezer without through-the-door ice	4.6	459
Top Mount Freezer with through-the-door ice	10.2	356
Side Mount Freezer with through-the-door ice	10.1	406

Notes:

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20 US EPA. Programmable Thermostat Calculator.

21 Energy Information Agency. http://www.eia.doe.gov/

22 A version currently under preparation will compare replacing an old refrigerator with a new one. Some research suggests it is generally cost-effective to replace refrigerators older than 1992, when new appliance standards came into effect.

23 EPA, Energy Star Calculator for Refrigerators.

- Baseload electricity consumption is currently set to a default of 400 kWh/yr until programming improvements can be made.
- Fresh volume and freezer volume are changed by user
- The Energy Star model assumed to consume 80% of non-Energy Star model

Metric tons CO_2/yr saved:

(kWh conventional – kWh Energy Star) * gCO_2/kWh / 1000000

Annual $ savings:

(kWh conventional – kWh Energy Star) * $/kWh

12. Line dry your clothes

This action approximates energy savings from reducing use of electric clothes dryers by drying clothes on a clothes line. According to the Energy Star Savings Calculator, typical families wash 7.5 loads of laundry per week. The default value for clothes dryer is set to 7 loads per week, consuming 1150 kWh per year. Drying clothes on a clothes line eliminates this energy consumption.

Metric tons CO_2/yr saved:

loads/week * kWh/load * 52 weeks * gCO_2e/kWh * %line-dry

Where,

- Loads/week = 7 by default, but adjustable by user
- kWh/load = 3.16. According to EIA (2001)[24], the average household consumes 1150 kWh of electricity to dry clothes, corresponding to 3.16 kWh per load at 7 loads per week. This is consistent with industry data[25] suggesting 3.3 kWh per load.
- gCO_2e/kWh = is electricity emission factor for US state of residence.
- %linedry = percentage of time users pledge to dry clothes on the line

Annual $ savings:

loads/week * kWh/load * 52 weeks * $/kWh * %line-dry

Where,

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24 RECS 2001 Residential Consumption of Electricity by End Use, 2001, http://www.eia.doe.gov/emeu/recs/recs2001/enduse2001/enduse2001.html
25 http://www.mla-online.com/workback.htm

- \$/kWh = price of electricity for US state of residence.

SHOPPING

13. Change your diet

This action compares the carbon footprint of the user's diet, as selected in the carbon footprint calculator, with a new lower-carbon diet, as selected on the Take Action Page. The default carbon footprint has lower than average consumption of meat, dairy and other food products, and higher consumption of fruits, vegetables and cereals. Total caloric intake is reduced from the US average of 2500 to 2200 for the average adult.

Metric tons CO_2/yr saved:

$$\#adults * 365\begin{pmatrix} meatcal_{c-n} * EF_{meat} + dairycal_{c-n} * EFdairy + cerealscal_{c-n} * EFcereals + \\ FVcal_{c-n} * EF_{FV} * othercal_{c-n} * EFother \end{pmatrix} +$$

$$\#children * 365\begin{pmatrix} meatcal_{c-n} * EF_{meat} + dairycal_{c-n} * EFdairy + cerealscal_{c-n} * EFcereals + \\ FVcal_{c-n} * EF_{FV} * othercal_{c-n} * EFother \end{pmatrix}$$

Where,

- $\#adults$ = number of adults in the household
- $\#children$ = number of children in the household
- $meatcal_{c-n}$, $dairycal_{c-n}$, $cearealscal_{c-n}$, $FVcal_{c-n}$, $othercal_{c-n}$ = calories per day fewer household east of meat, dairy, cereals, fruits and vegetables and other food, respectively
- EF_{meat}, EF_{dairy}, $EF_{cereals}$, EF_{FV}, EF_{other} are the GHG emission factors for meat, dairy, cereals, fruits and vegetables and other food, respectively

14. Buy organic

This action compares the carbon footprint and price of conventional food vs. organic food. Currently, there is not conclusive scientific evidence that organic food, in general, has lower greenhouse gas emissions than conventional products. This conclusion is based on a review of eight scientific studies references in Figure 18.[26] Several of these studies demonstrate that organic production has lower yield, contributing to larger carbon footprints on a per unit weight basis.

[26] The authors would be grateful for references to additional scientific studies comparing conventional vs organic food production systems.

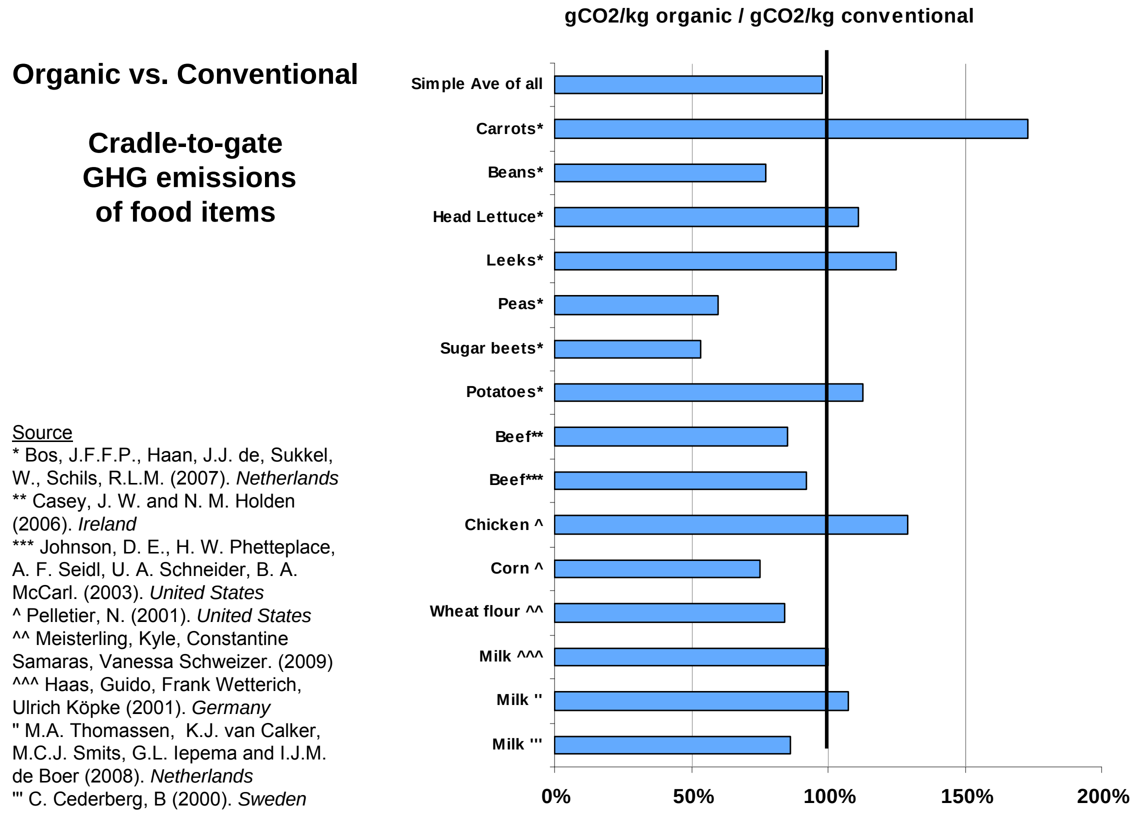

Figure 18. Review of studies comparing the carbon footprint of organic vs. conventionally produced food products.

Carbon footprints can vary dramatically between similar products based on cropping systems, processing and other supply chain processes, the distance and mode of transport to market, and emissions associated with the sale of products. Greenhouse gas emissions from the food individuals buy can be expected to be dramatically different than average values provided by this calculator and emissions from the specific products individuals buy will vary. Food grown in backyards or from a small farm in the users' community may have very low emissions compared to typical farm products, especially if growers commit to using minimal "inputs," such as fertilizer and pesticides, even if these are not technically organic.

While the benefits of organic farming to reduce carbon footprints are still unclear, there are many other important environmental reasons to buy organic food, including reducing chemical toxins in the environment and encouraging sustainable farming practices, which frequently accompany organic farming.

For the purposes of this calculator, organic produce is assumed to have 90% of the carbon footprint of conventionally-grown food products. Users can adjust these assumptions in order to test "what if" scenarios based on their own understanding of the food they purchase.

Metric tons CO_2/yr saved:

HHsize*365*(meatcal*EFmeat*(1-mymeat)*(pledgeorgmeat-eatorgmeat)
+dairycal*EFdairy*(1-mydairy)*(pledgedairy-eatorgdairy)
+fvcal*4.61*(1-myproduce)*(pledgeorgprod-eatorgproduce))/1000000

Where,

- HHsize = number of people in household
- meatcal = average calories of meat household consumes per person per day
- EFmeat = emission factor for meat = 5.85 gCO_2/calorie
- mymeat = carbon footprint of organic meat / carbon footprint of conventional meat
- pledgeorgmeat = percentage of meat user pledges to buy that is organic
- eatorgmeat = percentage of meat user currently buys that is organic
- dairycal = average calories of dairy household consumes per person per day
- EFdairy = emission factor for dairy = 4.86 gCO_2/calorie
- mydairy = carbon footprint of organic dairy / carbon footprint of conventional dairy
- pledgeorgdairy = percentage of dairy user pledges to buy that is organic
- eatorgdairy = percentage of dairy user currently buys that is organic
- fvcal = average calories of produce household consumes per person per day
- EFproduce= emission factor for produce = 4.61 gCO_2/calorie
- myproduce = carbon footprint of organic produce vs conventional produce
- pledgeorgprod = percentage of produce user pledges to buy that is organic
- eatorgprod = percentage of produce user currently buys that is organic

Annual $ savings:

-((HHsize)*365*(meatcal*($meat*mymeatcost-$ meat)*(pledgeorgmeat-eatorgmeat)
+dairycal*(0.0013*mydairycost-0.0013)*(pledgedairy-eatorgdairy)
+fvcal*(0.0015*myprodcost-0.0015)*(pledgeorgprod-eatorgproduce))

Where,

- HHsize = number of people in household
- meatcal = average calories of meat household consumes per person per day
- $meat = price of meat = 0.0017 $/calorie
- mymeatcost = $/calorie organic meat / $/calorie conventional meat
- pledgeorgmeat = percentage of meat user pledges to buy that is organic
- eatorgmeat = percentage of meat user currently buys that is organic
- dairycal = average calories of dairy household consumes per person per day
- $dairy = price of dairy = 0.0013 $/calorie
- mydairycost = $/calorie organic dairy / $/calorie conventional dairy
- pledgeorgdairy = percentage of dairy user pledges to buy that is organic
- eatorgdairy = percentage of dairy user currently buys that is organic
- fvcal = average calories of produce household consumes per person per day
- $produce = price of produce = 0.0015 $/calorie
- myprodcost = $/calorie organic produce vs $/calorie conventional produce
- pledgeorgprod = percentage of produce user pledges to buy that is organic

- eatorgproduce = percentage of produce user currently buys that is organic

Appendix A. Emission Factors

Emissions category	Factor	Units	Estimated error (+/-)	Source
Gasoline (direct)	8,874	gCO2e/gal	1%	(1) EIA(a)
Gasoline (indirect)	1,775	gCO2e/gal	20%	(2) GREET, 2.8a
Diesel (direct)	10,153	gCO2e/gal	1%	(1) EIA(a)
Diesel (indirect)	2,031	gCO2e/gal	20%	(2) GREET, 2.8a
Vehicle manufacturing	56	gCO2e/mile	10%	(3) EIO-LCA, authors' calculations
Average flight	223	gCO2/passenger-mile	10%	(4) WRI/WBCSD
Short flights (<400 mi)	254	gCO2/passenger-mile	10%	(4) WRI/WBCSD
Medium flights (400-1500)	204	gCO2/passenger-mile	10%	(4) WRI/WBCSD
Long flights (1500-3000)	181	gCO2/passenger-mile	10%	(4) WRI/WBCSD
Extended flights (>3000)	172	gCO2/passenger-mile	10%	(4) WRI/WBCSD
Air travel indirect effects	1.00	x direct emissions	30%	(5) Authors' calculation
Public transportation	179	gCO2/passenger-mile	10%	(4) WRI/WBCSD
Miles on bus	107	gCO2/passenger-mile	10%	(4) WRI/WBCSD
Miles on commuter rail (light&heavy)	163	gCO2/passenger-mile	10%	(4) WRI/WBCSD
Miles on transit rail (subway, tram)	163	gCO2/passenger-mile	10%	(4) WRI/WBCSD
Miles on Amtrak	185	gCO2/passenger-mile	10%	(4) WRI/WBCSD
Housing contruction	971	gCO2e/sq. ft.	30%	(6) Authors' calculations
Electricity usage ($)	5,300	gCO2/$	10%	(7) eGRID, (8) EIA(b)
Electricity usage (U.S.average shown)	463	gCO2/kwh	5%	(7) eGRID
Natural gas usage (U.S.average showr	3,352	gCO2/$	5%	(7) eGRID, (8) EIA(b)
Therms natural gas (U.S.average show	5,470	gCO2/therm	1%	(1) EIA(a)
Cubic feet natural gas (U.S.average sl	54.7	gCO2/cu.ft.	1%	(1) EIA(a)
Fuel oil and other fuels	682	CO2e/$(2005)	15%	(3) EIO-LCA, authors' calculations
Water (California average)	444	gCO2e/person	10%	(9) California Air Resources Board
Water, sewage, wastes ($)	4,121	CO2e/$(2005)	15%	EIO-LCA, authors' calculations
Waste (California average)		gCO2e/person	10%	(9) California Air Resources Board
Food	639	gCO2e/calorie	15%	(3) EIO-LCA, authors' calculations
Meat, fish & eggs	1,452	gCO2e/calorie	15%	(3) EIO-LCA, authors' calculations
Beef, pork, lamb, veal	2,531	gCO2e/calorie	15%	(3) EIO-LCA, authors' calculations
Processed meat & other	1,100	gCO2e/calorie	15%	(3) EIO-LCA, authors' calculations
Fish & seafood	1,307	gCO2e/calorie	15%	(3) EIO-LCA, authors' calculations
Eggs and poultry	1,041	gCO2e/calorie	15%	(3) EIO-LCA, authors' calculations
Cereals & bakery products	741	gCO2e/calorie	15%	(3) EIO-LCA, authors' calculations
Dairy	1,911	gCO2e/calorie	15%	(3) EIO-LCA, authors' calculations
Fruits & vegetables	1,176	gCO2e/calorie	15%	(3) EIO-LCA, authors' calculations
Other (snacks,beverages, alcohol,oils,e	467	gCO2e/calorie	15%	(3) EIO-LCA, authors' calculations
Goods (sum of below)	354	CO2e/$(2005)	15%	(3) EIO-LCA, authors' calculations
Clothing	422	CO2e/$(2005)	15%	(3) EIO-LCA, authors' calculations
Furnishings, appliances, other househc	428	CO2e/$(2005)	15%	(3) EIO-LCA, authors' calculations
Other goods	354	CO2e/$(2005)	15%	(3) EIO-LCA, authors' calculations
Medical	201	CO2e/$(2005)	15%	(3) EIO-LCA, authors' calculations
Entertainment	321	CO2e/$(2005)	15%	(3) EIO-LCA, authors' calculations
Reading	274	CO2e/$(2005)	15%	(3) EIO-LCA, authors' calculations
Personal care & cleaning	435	CO2e/$(2005)	15%	(3) EIO-LCA, authors' calculations
Auto parts	527	CO2e/$(2005)	15%	(3) EIO-LCA, authors' calculations
Services (sum of below)	191	CO2e/$(2005)	15%	(3) EIO-LCA, authors' calculations
Vehicle services	334	CO2e/$(2005)	15%	(3) EIO-LCA, authors' calculations
Household maintenance and repair	263	CO2e/$(2005)	15%	(3) EIO-LCA, authors' calculations
Education	181	CO2e/$(2005)	15%	(3) EIO-LCA, authors' calculations
Health care	173	CO2e/$(2005)	15%	(3) EIO-LCA, authors' calculations
Personal business and finances	144	CO2e/$(2005)	15%	(3) EIO-LCA, authors' calculations
Entertainment & recreation	226	CO2e/$(2005)	15%	(3) EIO-LCA, authors' calculations
Information and communication	142	CO2e/$(2005)	15%	(3) EIO-LCA, authors' calculations
Organizations and charity	249	CO2e/$(2005)	15%	(3) EIO-LCA, authors' calculations
Miscellaneous services	251	CO2e/$(2005)	15%	(3) EIO-LCA, authors' calculations

(1) EIA(a), Voluntary Reporting of Greenhouse Gases Program
(2) GREET, 2.8a
(3) EIO-LCA, authors' calculations
(4) WRI/WBCSD, Greenhouse Gas Protocol
(5) Air indirect effects assumed 0.9 plus 0.1 from airports
(6) Housing consctrution: Assume 90 tCO2/50yrs=1.8tCO2/1800sqft
(7) eGRID
(8) EIA(b)
(9) California Air Resources Board