The Potential of Conservation Behavior: Modeling CO_2 Emissions Reduction for California

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ABSTRACT

Human activities have driven climate change by increasing greenhouse gases in the Earth's atmosphere, potentially risking social and economic stability throughout the globe. In order to understand the possibilities for abating continued climate change, models have been developed to demonstrate the efficacy of different emissions reduction methods. Increased adoption of long-term energy-conserving behaviors offer the ability to address the primary driver of increased emissions, which is demand. Studies involving behavior have avoided or minimized attention to conservation and lifestyle, instead focusing on the short-term and on efficiency. This study models California household emissions from the current decade to 2050, seeking the largest emissions reductions from lifestyle shifts such as dietary and transportation changes. It adapts a carbon footprint calculator to a hypothetical behavior adoption rate, determining the long-term scenario with existing examples of reduced consumption. Results indicate that even slowly modified consumption behavior in the California household can help ensure the success of AB32 and the 2050 goals of California, as well as ensuring demand is addressed and becomes a less forceful driver of environmental damages.

KEYWORDS

Lifestyle; Climate Change; Carbon; GHG; Energy

INTRODUCTION

Human activities have driven climate change by increasing greenhouse gases (GHG) in the Earth's atmosphere, with the largest contribution coming from fossil fuel use (IPCC 2007). Climate change threatens to increase the frequency and magnitude of heat waves and tropical cyclones, raise sea levels, reduce biodiversity and damage ecosystems. Adaptation to such variability is expected to be challenging in many world regions (Schneider et al. 2007). While the scientific community has been providing evidence for alarm, fossil fuel use is expected to increase by 44 percent from 2006 to 2030 (EIA 2009). Given these conditions, it is critical to understand different societies' potential to reduce GHG emissions through changed energy consumption patterns.

Today an active area of behavior and energy (B&E) research seeks to understand and change people's behaviors with the end goal of reducing anthropogenic carbon emissions. In the early 1970s, a diverse mixture of business, political and academic actors began the first generation of studies to develop demand side management (DSM) of the US energy system (Lutzenhiser 1993). These DSM projects examined the efficacy of different approaches to curb household energy consumption, such as educating consumers about their energy habits or incentivizing the purchase of efficient appliances (Wilson and Dowlatabadi 2007). Going into the 1980s, B&E research findings were encouraging; in this period social and behavioral factors curbed consumption growth by 20% (Lutzenhiser 1993). But energy prices decreased in the mid-1980s, undercutting financial incentives along with social and political interest. The output of behavior and energy research community dwindled into the next decade (Lutzenhiser 1993). B&E research reemerged with the surge in climate and energy concerns in the 2000s; in 2006 the first annual Behavior, Energy and Climate Change Conference took place, and the event's attendance has been increasing every year (BECC 2010).

Researchers within the B&E field have been modeling and estimating potential emissions reductions from behavior changes. These B&E models can be roughly categorized into either consumer-oriented 'carbon footprint calculators', or policy-oriented models and estimations seeking to quantify the future energy savings from measures like DSM programs. The carbon calculators give consumers an estimate of their current emissions profile, and often recommend actions to curb energy consumption. One such calculator[1] is the Berkeley Institute for the

[1] The Precourt Energy Efficiency Center lists several other calculators: http://peec.stanford.edu/behavior/tools.php

Environment's (BIE) Cool California model and website, and this BIE model underpins the research discussed in this paper (BIE 2010). Amongst the policy-oriented projects there are three major recent works. Gardner (2008) provides the first work, which starts with an examination as to where households use the most energy, and then focuses on what new behaviors or modifications save the most energy. Second, Laitner et al. (2009), of the ACEEE, uses a range of previous results and applies a Monte Carlo simulation to predict possible adoption and emissions reduction rates. This work includes a very long list of actions, but largely focuses on home efficiency measures. Third, Dietz et al. (2009) model 10-year savings with bottom-up engineering calculations multiplied by consumer adoption rates. These rates are either estimated by experts or are rates of adoption in a possibly analogous project. All three estimate potential in increasing frequency of behaviors, such as decreasing water heater temperature or regular car maintenance. All recommended actions are short term and explicitly avoid impacting lifestyle.

The B&E field has focused on two areas of energy consumption reduction: more efficient energy use and reduction of use (Abrahamse et al 2005). This paper distinguishes these areas as efficiency and conservation. The three future abatement models mentioned above are predominantly efficiency oriented and explicitly avoid direct lifestyle-based impacts, such as changes in diet or shifting personal transportation away from automobiles and toward lower carbon options (Dietz 2009, Laitner 2009)

Lifestyle-based conservation actions are a currently under-analyzed segment of behavior solutions yet they are essential to reduce demand, the primary driver of increased emissions. A more comprehensive set of models can help scale up behavior-oriented energy solutions to match the business as usual demand. To begin this area of investigation, I have modeled the emission reduction potential of several long-term conservation-behavior changes. The model is restricted to California to ensure that this work was an achievable first attempt, and has the predictions scaled out to 2050. California provides more extensive data than many other states and regions. The 2050 date was chosen to reflect the same time scale of the longer-term policy objectives, such as the 80% below 1990 emissions levels goal recommended by the IPCC and desired by the state of California (Schwarzenegger 2005). This model demonstrates a first approach to long term energy-conservation modeling, and indicates high emissions-reduction potential for well-considered conservation measures.

METHODS

Overview of model basis and design

I used spreadsheet-based modeling in Microsoft Excel 2007. The underlying emissions impact model has been designed by the BIE Cool California project, and is used to estimate the current total footprint of Californians, as well as for computation of the emissions reduction from changed behavior. BIE's model has been adapted to estimate future emissions based on population growth expectations. The behavior change options are reduced, to focus on the most promising behaviors, and improve the quality of future estimations.

The BIE project provides a variety of emissions reducing actions. This original list was reduced to conservation-oriented behaviors which would result in long-term continuous reductions, and then further reduced for the behaviors which would provide the most emissions savings. A final evaluation was based on the ability to envision the behavior being widely supported by different political and market actors. For example: there are many industries and groups which would be interested in the adoption of a healthier diet. There is profit for businesses, and there are non-profit and public institutions which seek to improve the health of individuals and groups. On the other hand, it is questionable if there would be a large number of people or powerful groups immediately interested in a wide scale switch to line-drying.

This project's model takes the savings associated with key actions, and multiplies against an estimated rate of adopters across California, along with California Census Bureau population trends[2]. The penetration rate was determined by cross-examining successful conservation programs and case studies in cities or neighborhoods with low carbon footprints against estimates of energy demand in California. The purpose of this is to see if the chosen behaviors could significantly counteract a possible increase in energy demand by consumers. In the cross-examination determinations were made that were subjective, but followed the following example of logic: An unrealistic change was determined to be disproportionate changes such as simulating the average Californian telecommuting many days a week, or converting most or all of their driving miles to bicycling miles.

BIE calculator design

The foot print calculation and the reductions calculation are all a part of the life-cycle consumer-based accounting of the BIE calculator. Please see Jones (2005), Jones et al (2008),

[2] www.census.gov/population/www/projections/ppl47.html

and BIE (2010) for an exploration of these topics and the BIE project's implementation of it. For easy reference, formulas for the reductions listed below are listed in the appendix.

This is a generalization of how the energy-conservation actions or behaviors model together:

$$\sum_{x=2010}^{2050}[(OldBehaviorEmissions - NewBehaviorEmissions) \times PenetrationOfNew_x \times HHGrowth_x]$$

Where,

i-j: Year being modeled

OldBehaviorEmissions: Emissions to potentially change

NewBehaviorEmissions: Changed or changing emissions

$PenetrationOfNew_x$: Extent to which new behavior has been adopted

$HHGrowth_x$: Predicted Growth in number of households for California

Given the replication of the BIE model for emissions estimates, the following subheadings labeled **X Emissions** are brief, and I would once again request the reader reference the Jones and BIE citations for more depth.

Carbon calculator current emissions

Vehicle Emissions CO2 emissions from cars come from both direct emissions from burning gasoline, and indirect emissions. Indirect CO2 production includes emissions from the manufacturing and transport of gasoline, manufacturing the car, and miscellaneous maintenance such as repairs and part replacement. For purposes of illustration, the average U.S. household (HH) statistics will be explained. In 2001, the average U.S. HH drove 21,200 (ORNL 2005), which is the latest year average household vehicles miles traveled are available at a national level. The fuel economy of the U.S. motor vehicle fleet is roughly 20 mpg (ORNL 2009). The burning of one gallon of gasoline produces 8,874 gCO_2 (EIA 2009). All vehicles are assumed to be gasoline since diesel is only a small fraction of the U.S. fleet. The average U.S. HH then has direct emissions calculated as:

21,200 miles / 20 mpg * 8,874 gCO_2/gallon = 11.9 mtCO2e/yr.

Public Transportation Emissions The Transportation Energy Data Book (ORNL 2007) provides total US passenger miles per transport mode. Emission factors for public transit modes are provided by the World Resources Institute database (WRI). These estimates assume average occupancy of public transit modes. Indirect well-to-pump emissions from transportation fuels are assumed to be 20% of direct emissions (Center for Trans. Research, Argonne National Laboratory, GREET).

Air Travel Emissions Emission factors for air travel are provided by World Resources Institute database (WRI). Using ACES data, the spreadsheet calculates given total miles per year, or number of short, medium, long or extended flights, depending on the availability of data for a given region.

Diet Emissions The model uses the Economic Input-Output Life Cycle Assessment (EIO-LCA), designed by the Green Design Institute at Carnegie Mellon University. It is used to calculate emissions from food, goods and services.

Carbon calculator reduced emissions

Telecommuting Reductions This action calculates GHG benefits from fuel savings from time spent at home instead of commuting. It should be noted that there is uncertainty to the net savings, as telecommuting represent a complex series of new actions which have not been extensively observed. Extra trips from home, and heat and cooling for a home which may have been otherwise empty could result in less emissions reductions.

Bike Replacing Car Reductions Households will ride a bike a certain number of miles per week instead of driving. This action calculates greenhouse gas savings from riding a bicycle vs. driving a motor vehicle. Carbon footprint savings consider reduced fuel consumption minus an estimate of the carbon footprint from food consumed in order to go the given distance on a bicycle.

Public Transport Replacing Car Reductions This action compares driving an existing vehicle with taking one of the following public transportation modes: diesel bus, natural gas bus, electric subway, Amtrak.

Air Travel Reductions Business travel is reduced by teleconferencing or other means.

Diet Change Reductions This action compares the carbon footprint of an older diet with a new lower-carbon diet, consisting of reductions in unnecessary calories, and replacement of excessive red meat and dairy calories with fruits, grains, and other foods. Total caloric intake is reduced from the US average of 2500 to 2200 for the average adult, and USDA eating guidelines help suggest the shifts in calories across food types (Table 1).

	New Californian Diet	Average US Diet
Meat	244	543
Dairy	186	286
Fruit & Veg	488	271
Cereals	970	669
Other	331	736
Total	2219	2505

Table 1. Diet transition modeled.

Casting a sample scenario

Scenarios dictate the degree of penetration the behaviors have, and are designed to inform policy makers of the different futures possible. For this first incarnation of the model, one scenario has been generated. After the mix of quantitative and qualitative judgments described in the methods overview was complete, the reductions simulation was set with these achievements in 2050 for the average Californian household:

30 miles per week are accomplished by the use of a bicycle instead of a car

30 miles per week are from public transportation instead of a car

The diet is switched from that of an average US citizen to one similar to the recommendations by the USDA

1,000 of annual flying miles are reduced

4 days of work are done via telecommuting every month

These numbers represent the average accomplishment. A simplifying assumption is that the households who cannot or will not reach these numbers will be counter-balanced by those who overachieve. The result averages to the points above. The model evenly distributes the final adoption achievements across the 2010 to 2050 time period. The adoption rate that is exhibited was then compared to successes of documented conservation programs and case studies of low carbon footprint living.

Assumptions I am assuming different conditions for each scenario,, which must be explicit in order to even describe the scenario. My model is not meant to give predictions of what future adoption rates would be given a policy. Instead it says that if you accomplished a given adoption rate, the benefits would be X metric tons of CO2e reduced at year 2050. A major assumption I make is that all other conditions are holding steady. My numbers will not take into account major infrastructure changes in California that may happen, nor will they be able to take into account some possible major shifts such as a shift to plug-in vehicles complete by 2030. See

BIE website for additional assumptions. The BIE calculator is an extensively developed model, and to accomplish the breadth it does, many assumptions are required.

RESULTS

Results for California emissions today

The current average California household has most emissions in transportation with 18.2 metric tons, with emissions equally distributed in the other areas, at 6 or 7 metric tons each (Fig. 2).

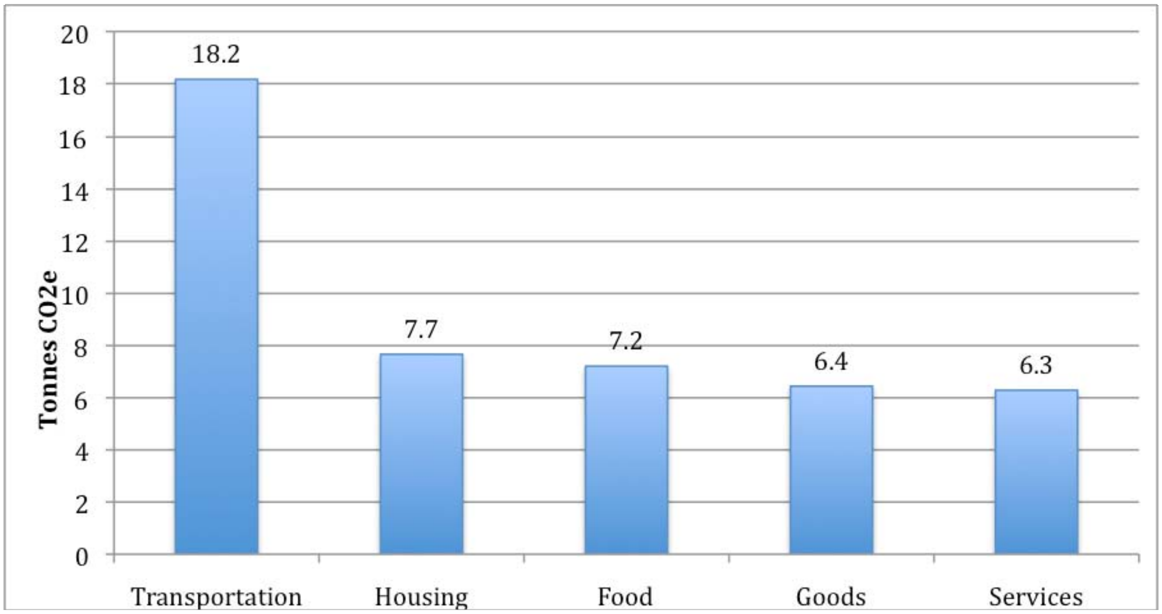

Figure 2. Current average California household emissions by area of activity.

Transportation

The majority of transportation emissions come from direct motor vehicle fuel (Table 2). But at 9.6 metric tons per household, it is a small majority. The total emissions are almost twice the motor vehicle direct-emissions.

Table 2. Transportation Emissions Sources.

Emission Source	CO2e Emitted
Motor vehicles (direct)	9.6
Air travel (direct)	1.7
Public trans (direct)	0.2
Motor vehicles (indirect)	2.5
Vehicle mfg	1.2
Air travel (indirect)	1.7
Public trans (indirect)	0.0
Auto parts	0.4
Vehicle services	0.8
Total	18.2

Diet

Processed foods contribute large emissions to the Californian diet, as the processing required produces significant emissions, resulting in 2.4 metric tons of CO2e. Next is meat, primarily as red meat, at 2.1 metric tons. Dairy is the final CO2e-intensive source, with 1.2 metric tons (Table 3). The other sources are much lower in CO2e per calorie, and also fruits and vegetables are not consumed in high amounts in the average household.

Table 3. Dietary emissions sources.

Emission Source	CO2e Emitted
Meat	2.1
Dairy	1.2
Other Food	2.4
Fruits and Vegetables	0.7
Cereals and Bakery	0.8
Total	7.2

Housing, Goods, and Services

These areas of activity do not contain any of the chosen behavior solutions for this study, as described in the methods section. While solutions in these areas are important, they do not meet the criteria set in this project to achieve high savings with actions that coalitions of interested individuals and organizations can build momentum upon.

Business as usual (BAU) forecast

The business as usual scenario multiplies the current CO2e per household and scales it according to projected population growth of California.If households maintain the same average footprint as seen today, by 2050 we can expect annual emissions to reach one gigatonne of carbon dioxide equivalent (Figure 3, Table 4).

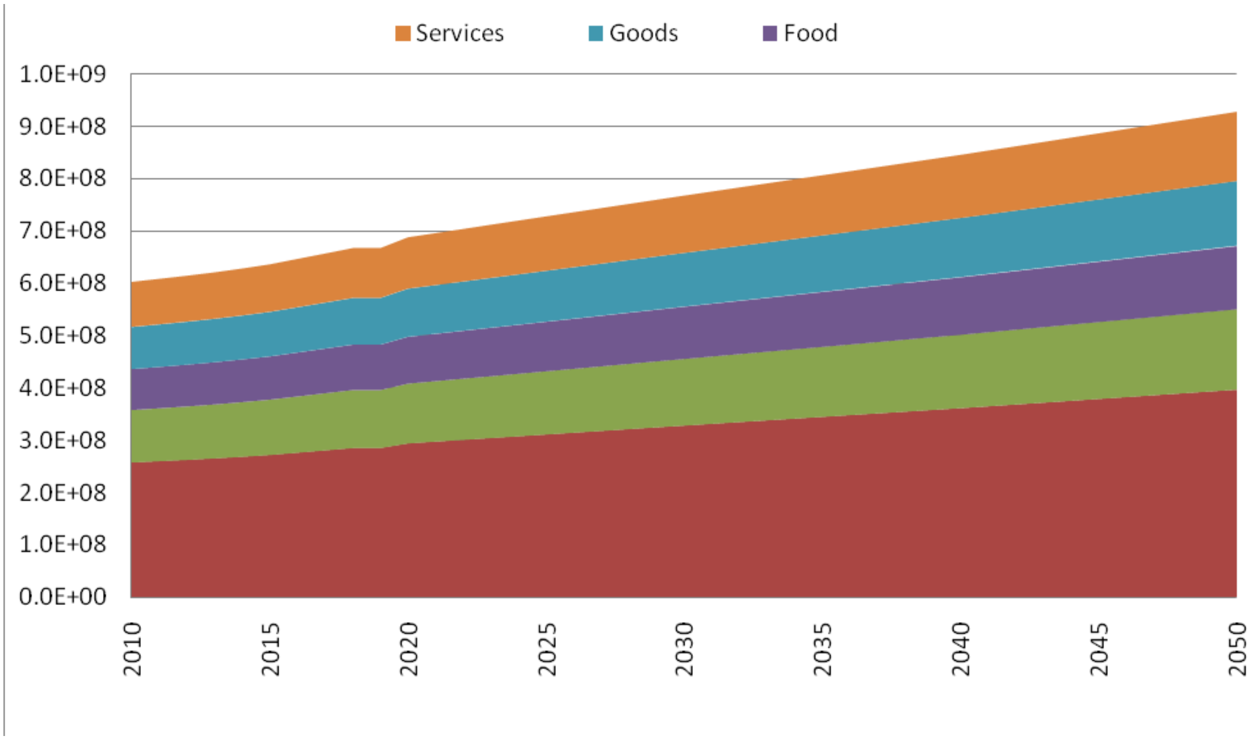

Figure 3. Total forecasted california emissions from households. The y-axis is metric tones of CO2e.

Table 4. Total forecasted California emissions from households.

	2000	2010	2020	2030	2040	2050
California Population (millions)	34	39	44	49	54	60
MT CO2e emitted by CA HH	570	602	687	767	844	926

Scenario results

This run represents emissions reductions if the average Californian household adopted the emissions-reductions advice delineated in the methods section, with diet change represent the single largest change per household, though transportation as a category of reductions is greater than diet (Table 5).

Table 5. Metric tons of carbon dioxide equivalent reduced per household.

Ride my bike	Use public transportation	Reduce air travel	Change my diet	Telecommute to work
0.87	0.71	0.94	1.38	1.07

Diet and transportation reductions are similar in the percent reduction they represent for the category of behavior, and together they can reduce the household emissions by over 10 percent (Table 6).

Table 6. Reductions per household aggregated by category, total and percent reduction.

Transportation	2.6	6%
Diet/Shopping	1.4	4%
Total footprint reduction	5	11%

Long-run reductions show that by 2050 over one hundred megatons of CO2e can be saved in a year from this change to a healthy diet and a more balanced transportation lifestyle (Table 7). The rate of adoption is an 11% footprint reduction distributed over 40 years, finally resulting in an annual reduction of over 100 million tons (Figure 4).

Table 7. Reduced levels of household-based California emissions

	2000	2010	2020	2030	2040	2050
Reduced CO2e emitted by CA HH	508	582	657	733	807	886
Difference	62	71	81	90	99	109

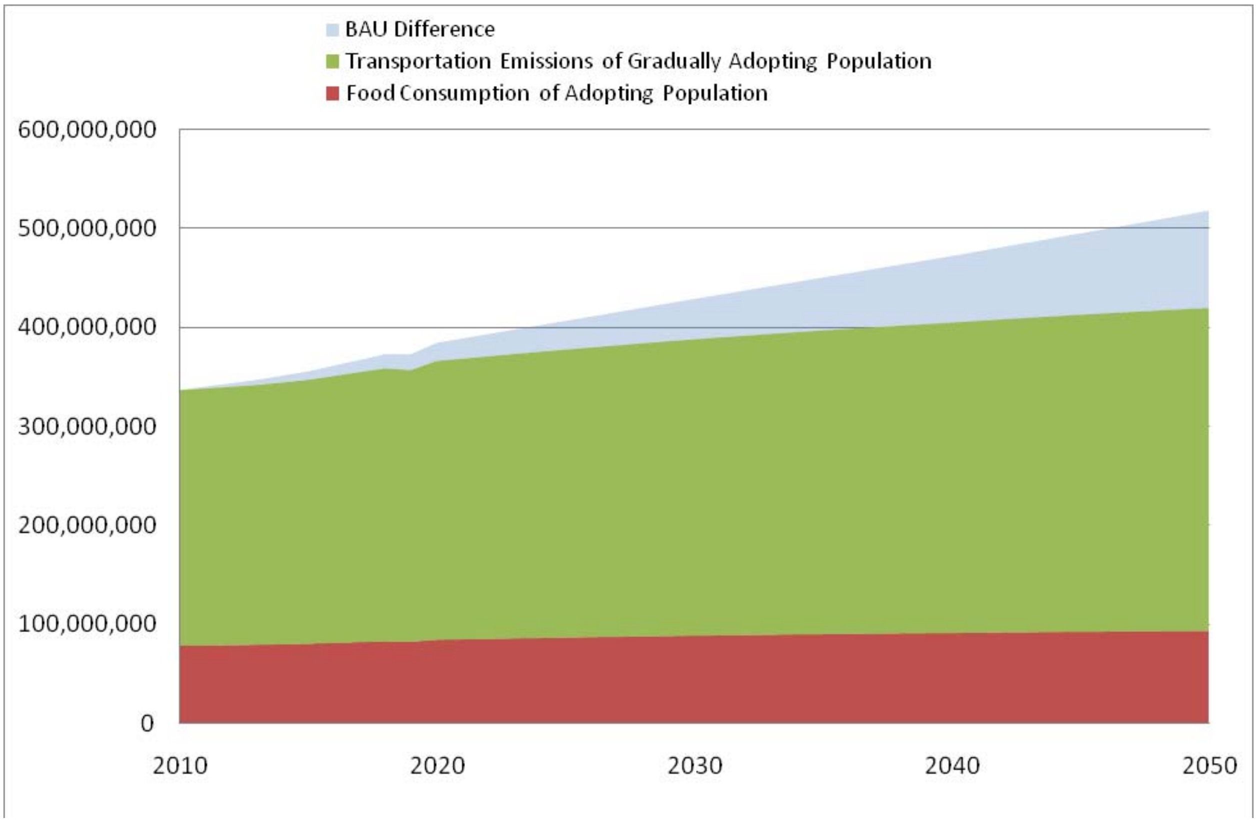

Figure 4. The scenario forecasted out to 2050. The y-axis shows metric tons of CO2e, and the graph shows just the emissions from food and transport.

DISCUSSION

A key finding of this work is that a very gradual adoption of a small set of behavior changes can result in 100 million tons of carbon reduced. The following figure helps illustrate why this number can be very valuable for California.

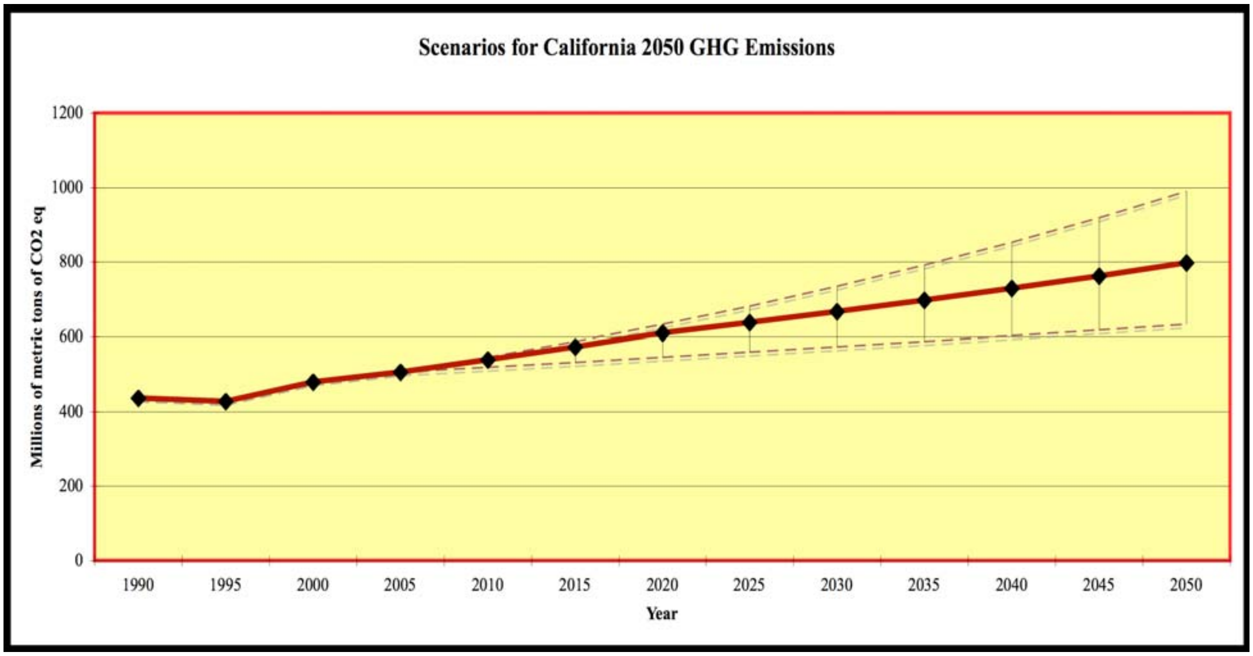

Figure 5. Low, medium and high growth rate predictions of California's GHG footprint (Schiller 2007).

Steven Schiller of the California Institute of Energy and Environment has identified that the lofty 2020 AB32 emissions reductions goals may not put California on a reductions trajectory to which achieves the 80% below 1990 emissions goal (Schiller 2007). If California is even on the moderate energy consumption growth curve, the state will need to accomplish yet more unprecedented emissions reductions efforts reach the 2050 goal (Figure 5). The key finding that this paper offers is the ability to use conservation to put California on the low growth rate curve. Lifestyle shifts provide the extra measures that are needed to provide a whole set of energy solutions that can combat the climate problem.

There were several unanticipated experiences with this project, which have changed the original project scope to some degree. Original plans included a high resolution model of California, one in which the model estimated the conditions and potential on a county-by-county basis. Unfortunately, limitations in a wide variety of datasets proved to be a challenge. This was not as much of a loss as I imagined, because the margin of error in many well established datasets was enough to make the more-detailed plans irrelevant.

In comparison to this project's results, Gardner (2008) found that by changing their way technologies are chosen and used households can reduce consumption by about 30 percent. And Dietz (2009) claims that in 10 years 20% of household direct emissions can be reduced. Laitner (2009) measures the opportunity as being reductions of 20 to 25 percent of current household energy consumption. Given these time frames, the behaviors discussed in this paper certainly seem achievable by 2050. While the three discussed here discuss very high numbers, its not as shocking when one takes into consideration that 80% of US energy used results from consumer demand (Shui 2005).

Stangeland (2008) offers a less technical approximation of emissions reductions from lifestyle. The report calls the reductions potential a 'lifestyle wedge.' This work is from more of a think-tank setting, and Stangeland reports although it is exceptionally challenging to predict the emission reduction potential that could be achieved through lifestyle changes, it is estimated that demand for energy could be reduced 1 percent by 2015 and 10 percent by 2050. This estimate by Stangeland further frames the results in my work as plausible.

To explore the possibilities and implications for acting upon this work, it is crucial to examine the current support for lifestyle and behavior emissions reductions. The largest and most esteemed scientific body regarding climate change, the Intergovernmental Panel on Climate Change, has shown support for conservation oriented behavior change (IPCC 2007). The IPCC points out consumption patterns have been influenced by historical social contexts and are subject to change. Other research has touted consumption pattern change as 'holy grail' (Jackson 2005) of environmental policy. In addition to ascribing value, this symbolism also indicates the challenge envisioned of actually accomplishing effective consumption policies. Consumption pattern change has also been labeled as the 'next wave' (Simons 2001). Again, themes of sustainable consumption are placed in language that indicates an enthusiasm while seemingly putting it outside of the grasp of today's policies.

To bridge this gap between hope and accomplishment, it is important to refer to the growing body of knowledge learned from previous work. It has been recognized in the behavior and energy research realm that there is a need to identify barriers-to-change (McKenzie 1999). Behavioral psychologists say to change behavior we must first understand the barriers that exist

(McKenzie 1999). One example is that safety-concerned parents often resist purchasing more efficient, but smaller, vehicles. So instead, a focus on reducing aggressive driving can help safety and fuel efficiency. Overlapping incentives such as overcoming the US' obesity epidemic (CDC 2009) and the emissions footprint can present a win-win opportunity. Reducing the households' food carbon footprint may be only a side benefit compared to the health benefits of reducing obesity. The value of social networks has also become a key tool in behavior research (Jackson 2005, Spaargaren 2000). Systems of social response can be added as another incentive upon the environmental and financial merits of "green actions". Finally, utilizing networks and localizing a message has proven in studies to be crucial aid to help target messages to diverse audiences (Mankoff 2007).

Quantitative future implications

This work is very implementation, and there is a lot of room for development. More modeling can be done using similar techniques, or explore other approaches. Either way, if this behavior work is to integrate into the larger policy and modeling projects, it will need to address the challenge of understanding the relationships to other life-cycles (Jackson 2007). Without a reasonable estimation of how transforming one field may impact another, such as changes in the dietary markets impacting transport and shipment systems, it is difficult to rigorously measure the effects lifestyle changes have on the entire energy demand and production system.

Concerns

There exists room for concern regarding efficiency-only behavior approaches arise when looking at the behavior and energy literature. Wolfgang Sachs (1993) outlines limitations of efficiency for sustainability, pointing out that efficiency without sufficiency, the extent we contain our consumption, is necessary. He claims that unrestrained consumption, even with its impacts modified by efficient technology, will inevitably result in environmental and climate problems. By addressing conservation and lifestyle choices, we can overcome concerns of myopic solutions. It is easy to limit oneself to advising policy-makers of solutions that fit easily into market problematization and solution making. This is the risk of being the expert for a government, as economist Robert Nelson has pointed out for policy experts (Nelson 1987). Without proper evaluation of all options, it is possible to overlook potentially revolutionary change. Further work in this area is needed, as this paper's efforts are small in scale to the question at hand.

Conclusion

For a state with a history of tapping new opportunities for climate and energy goals, lifestyle and conservation opportunities offer a meaningful next step. With increased research and verification of the opportunities available, as well as the honing of methods to incite conservation, California can pioneer the policy arena yet again. Conservation behaviors offer the opportunity to receive energy reductions immediately, and an extra measure to getting AB32 on track. While it was a feature not used in my model, the BIE project includes financial calculations, and all of these behaviors are have significant financial incentives are there (BIE 2010). Modeling is not crystal ball, but a way to provide insight into possibilities, and if lifestyle and energy models develop and progresses in complexity we will be able to further establish what is so far promising to be the next twenty dollar bill on the ground.

ACKNOWLEDGEMENTS

I would like to thank Michael McNeil, Daniel Kammen, Chris M. Jones, Gabriel Wong-Parodi, Jim McMahon, Kurt Spreyer, Patina Mendez, and Rick Diamond for all of their help in the creation and development of this project.

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APPENDIX

Table 8. Various Calculations for 9 Behavior-Changes

CA Individual Behavior-Change Savings Potential1	Minimum Change	Maximum	Change Unit	Minimum Change Impact (CO2)
Change Diet	1	1	N/A - see assumptions	0.6
Practice Eco-driving	65	55	mph highway	0.93
Telecommute to work	1	10	days	0.26
Public Transport	10	100	miles	0.23
Reduce Air Travel	500	3000	miles flown	0.23
Maintain my vehicles	1	1	N/A - see assumptions	0
Ride my bike	5	40	miles	0.14
Turn up thermostat in summer	82, 79	86, 83	I will set my thermostat to x degrees F on summer days and y degrees F on summer nights.	0.1
Turn down thermostat in winter	5	10	Turn down thermostat x degrees on winter nights	0.25
CA Individual Behavior-Change Savings Potential1	Maximum Change	% Change Estimated min	% Change Estimated max	Maximum Technically Possible (MT)
Change Diet	1.77	0.066666667	0.196666667	2.39497756
Practice Eco-driving	2.35	0.054705882	0.138235294	1.683408953
Telecommute to work	2.61	0.015294118	0.153529412	1.869658454
Public Transport	2.27	0.013529412	0.133529412	1.626101414
Reduce Air Travel	1.41	0.013529412	0.082941176	1.010045372
Maintain my vehicles	0.71	0	0.041764706	0.508604407
Ride my bike	1.13	0.008235294	0.066470588	0.809468986
Turn up thermostat in summer	0.24	0.009090909	0.021818182	0.265698589
Turn down thermostat in winter	0.5	0.022727273	0.045454545	0.553538727
CA Individual Behavior-Change Savings Potential1	min w family size growth	max given family size growth	given ca hh growth 2050 min	given ca hh growth 2050 max
Change Diet	0.66780822	1.970034247	13356164.38	39400684.93
Practice Eco-driving	1.03510274	2.615582192	20702054.79	52311643.84
Telecommute to work	0.28938356	2.904965753	5787671.233	58099315.07
Public Transport	0.25599315	2.526541096	5119863.014	50530821.92
Reduce Air Travel	0.25599315	1.569349315	5119863.014	31386986.3
Maintain my vehicles	0	0.790239726	0	15804794.52
Ride my bike	0.15582192	1.257705479	3116438.356	25154109.59
Turn up thermostat in summer	0.11130137	0.267123288	2226027.397	5342465.753
Turn down thermostat in winter	0.27825342	0.556506849	5565068.493	11130136.99
		15.79366438	67671232.88	315873287.7

FORMULAS

Air Travel Emissions

Total emissions from air travel are given by:

I = M x D x W x C

Where,

I = Impact, in terms of CO2e per year

M = passenger miles per year

D = direct emission factor

W = 1.2, to account for indirect well-to-pump emissions from jet fuel

C =1.9, to account for additional radiative forcing of contrails

Telecommuting Reductions

Metric tons CO_2/yr saved =

$$Days * 12_{months} * CommuteDist / mpgveh_u * \left(EFfuel_d + EFfuel_i\right)$$

Where,

Days = days user telecommutes for work per month

CommuteDistance = the round-trip distance to work

$mpgveh_u$ = the miles per gallon of vehicle

$EFfuel_d$ = direct emission factor from gasoline

$EFfuel_i$ = indirect emission factor from gasoline

Bike Replacing Car Reductions

Metric tons CO_2/yr saved =

$$(BikeMiles / mpgveh_u \quad (EFfuel_d \quad EFfuel_i) \quad BikeMiles / mph_{bike} \quad cal_{bike} \quad EFdiet) \quad 2 \quad 12$$

Where,

BikeMiles = number of miles HH rides bicycle instead of driving each week

$mpgveh_u$ = miles per gallon of vehicle used by household

$EFfuel_d$ = direct emission factor from gasoline

$EFfuel_i$ = indirect emission factor from gasoline

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 model

Public Transport Replacing Car Reductions

Metric tons CO_2/yr saved =

$$52_{weeks}\left(miles * mpgveh_u * \left(EFfuel_d + EFfuel_i\right) - miles * publictrans_{mode}\right)$$

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 gasoline

$EFfuel_i$ = indirect emission factor from gasoline

$publictrans_{mode}$ = grams of CO_2 per passenger mile per public transport mode[3]

Air Travel Reductions

Metric tons CO_2/yr saved = $\frac{miles_{fewer}}{year} * \left(\frac{gCO2_{direct}}{mile} + \frac{gCO2_{indirect}}{mile}\right)$

Where,

$Miles_{fewer}$= reduced flying miles

$gCO2_{direct}$ = direct air travel emissions

$gCO2_{indirect}$ = indirect air travel emissions

3 WRI-WBCSD 2009. Greenhouse Gas Protocol. http://www.ghgprotocol.org/

Diet Change Reductions

Metric tons CO2/yr saved=

$$\left[\begin{array}{l} Adults_{HH} * 365\begin{pmatrix} meatcal_{diff} * EF_{meat} + dairycal_{diff} * EFdairy + \\ cerealscal_{diff} * EFcereals + FVcal_{diff} * EF_{FV} * othercal_{diff} * EFother \end{pmatrix} \\ + \\ Children_{HH} * 365\begin{pmatrix} redmeatcal_{diff} * EF_{redmeat} + dairycal_{diff} * EFdairy + \\ cerealscal_{diff} * EFcereals + FVcal_{diff} * EF_{FV} * othercal_{diff} * EFother \end{pmatrix} \end{array}\right]$$

Where,

$Adults_{HH}$ = Adults per household of given county

$Children_{HH}$ = Children per household of given county

$meatcal_{diff}$, $dairycal_{diff}$, $cearealscal_{diff}$, $FVcal_{diff}$, $othercal_{diff}$ = change in calories-per-day of meat, dairy, cereals, fruits and vegetables and other food

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