Residential Solar Panels and Their Impact on the Reduction of Carbon Emissions

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ABSTRACT

Anthropogenic greenhouse gas emissions, especially carbon, have had a momentous impact on the onset of climate change. To address this issue, California has adopted Assembly Bill (AB) 32, which sets a goal for California to reduce its greenhouse gas emissions back to 1990 levels by the year 2020. One way to reduce carbon emissions is to mitigate fossil fuel electricity production by using renewable energy instead. A residential solar panel system, for example, has the capability of providing for the electricity needs of an entire home with about 80% lower carbon emissions than fossil fuels. I studied residential solar systems in California and their potential for helping California meet its AB 32 target. My objectives were to determine: the percentage of homes that have currently installed solar and the amount of carbon emissions this has reduced; the percentage of homes that should install solar for California to significantly mitigate carbon emissions when compared to baseline current emissions; and the groups of households that should be the main focus of government emissions mitigation policies. While currently 0.9% of California households have installed solar systems, I found that at least 60% of homes would need to install solar to significantly reduce carbon emissions by 2020. The largest barrier to solar implementation is cost; thus, in order to get 60% of homes to install solar, the government must implement and enhance subsidy and feed-in tariff policies. However, focusing on electricity generation is not the only solution for reaching the AB 32 target; other sources of emissions must also be considered.

KEYWORDS

renewable energy; solar energy; AB 32; California; residential households

INTRODUCTION

Anthropogenic greenhouse gas emissions have had a significant impact on climate change (Hughes 2000). Increased warming from greenhouse gas emissions has had many effects, including rising ocean temperatures and sea levels, a change in global precipitation patterns, and melting glaciers (Ibrahim 2000, Hughes 2000). Carbon accounts for 80% of all the greenhouse gas emission contributions to global warming (Lashof and Ahuja 1990); in fact, carbon dioxide will cause more than half of the climate change that will occur over the next century (Vitousek 1994). Over the past two hundred years, carbon dioxide emissions have been increasing, mostly due to industrialization and rising demands for electricity and the associated fossil fuel burning (Lenton 2003). Energy demands are expected to increase by a factor of 1.5 to 3 by 2050, which will lead to a continually increasing trend in carbon dioxide emissions (Ibrahim 2000). Because rising carbon emissions have become an increasing problem, the mitigation of carbon emissions is necessary and many governments are adopting policies that promote this.

California passed Assembly Bill 32 (the Global Warming Solutions Act) in 2006, a policy designed to reduce the state's greenhouse gas emissions. Assembly Bill 32 sets a goal for the state to reduce its greenhouse gas emissions to 1990 levels by the year 2020 (Nunez 2006). The electricity sector (commercial and residential) is the second largest contributor to greenhouse gas emissions (CARB 2008); thus, adopting cleaner methods of generating electricity will help omit a large source of these emissions. The California Air and Resources Board has recommended the adoption of renewable energy technology to provide for about a third of the state's energy needs in order to reduce the greenhouse gas emissions associated with fossil fuel use (CARB 2008).

Renewable energy technology derives power from sources such as wind, sun, and biomass and it is a viable option for generating clean electricity to meet energy requirements (De Vries et al. 2007). One of the main benefits of renewable energy is that it generates significantly lower carbon dioxide emissions than fossil fuels (Table 1). With lower carbon emissions, the adoption of renewable energy technology can help reduce global warming. One way that renewable technology is currently being adopted is through the installation of solar panels on residential homes and apartments; a typical solar system can meet the energy needs of an entire household (Pearce 2002). Homes in California consume about 34 % of all state-generated electricity (U.S. Department of Energy 2008); therefore, the utilization of solar panels on residential homes has the potential to greatly reduce carbon emissions in California. However, the impact of California residential solar panels on carbon emissions reductions and the extent to which their utilization can help meet AB 32 goals is still unclear.

Table 1. Carbon emissions from different sources of energy (Martin 2006, IEA 2011). Solar, wind, hydro, and biogas are renewable.

Energy Source	**Fossil Fuels**	**Solar**	**Wind**	**Hydro**	**Biogas**
Carbon emissions (g/kWh generated)	504	99	10.2	10	11

My objectives are to determine the amount of carbon emissions that are being mitigated through the use of residential solar panels in California and whether or not solar panels can have a significant impact in helping California reduce carbon emissions in order to meet AB 32 standards. The questions I will address are: 1) What percentage of households have currently installed solar panels and how much carbon emissions has this reduced? 2) What percentage of households should install solar panels in order to have a significant difference in carbon emissions between baseline emissions and reduced emissions in 2020? 3) Which categories of households can contribute the most to carbon emissions reductions?

METHODS

Study Population

My study population includes all residential homes in California. The overall population of California is 37,691,912. There are 12,577,498 occupied residential households in California and the land area of California is 155,779.22 square miles (U.S. Census Bureau 2012). It should be noted that due to the large state size and population, there are many variations in demographics, solar panel types, and solar panel usage; therefore, I made certain assumptions and simplifications, such as assuming that all homes use or will use a 3kW solar system and that this solar system will provide for the energy needs of the entire home. A typical solar system consists of multiple solar panels. Hereafter, the terms "solar system" and "solar panels" will be used interchangeably. For the purposes of answering my research questions I grouped my study population into the following categories: households with and without solar systems; low-income and high-income households; rented and owned households; and apartment buildings and all other households.

The U.S. Department of Housing and Urban Development defines low-income households as those with income levels at or below 80 percent of the median income (HUD 2012). California's median household income is $60,883 (U.S. Census Bureau 2012). Therefore, I have defined low-income households to be at or below the $50,000 income level, regardless of household size and occupancy. The U.S. Census Bureau has defined apartments as five or more housing units and that is the definition that I have used for my study (U.S. Census Bureau 2011).

Reduction in carbon emissions due to solar panel installation

I gathered information on the number of currently installed solar systems from 2006 through 2012 from the California Solar Initiative (CSI) website (http://www.californiasolarstatistics.ca.gov) and calculated the percentage of residential households in California that have installed solar systems and the amount of carbon emissions that have been mitigated due to the installation of these systems. The CSI is a program overseen by the California Public Utilities Commission that offers rebates to consumers that install solar panels based on the performance of their solar panels. The data is derived from applications that have been submitted by solar panel contractors on the behalf of consumers in order for consumers to receive rebates for installing solar. The dataset includes size, cost, location, incentive, and consumer and producer information for all solar panels installed in California, and has undergone a series of data integrity filters before being released to the public. I used the number of residential consumers that had applied for rebates (since 2006) as an estimate of the amount of residential homes in California that have solar systems. Possible biases from using this dataset could emerge from the fact that it excludes consumers that did not undergo the application process for rebates or were not qualified for an incentive for some reason (e.g. the contractor they hired was not a qualified contractor, the consumer does not buy electricity from PG&E, SCE, or SDG&E).

An average 3kW solar system has the potential to meet the energy needs of an entire household (Pearce 2002). Due to the lack of data about the size of each individual solar system in California, I assumed that all households have installed a 3kW system and that this system is meeting all the energy needs of the households. Therefore, the carbon emissions that would result from producing fossil fuel electricity for an entire household is the amount of carbon emissions that are being avoided by installing one solar system.

Approximately 6.9×10^{-4} metric tons of CO_2 are emitted for the generation of one kWh of electricity (EPA 2005). In order to include variance in my study and account for the differences in energy usage across California, I looked at the average household electricity use for each county, which was found on the California Energy Commission Website (http://ecdms.energy.ca.gov/elecbycounty.aspx). I used Equation 1 for this calculation (Table 2).

Table 2. Equations used to calculate the carbon emissions avoided for each household that installs solar and the total carbon emissions avoided by installing solar systems.

	Equation
Eq. 1	*(6.9×10^{-4} *)(EPH) = CO_2 avoided per household that installs solar*
Eq. 2	*(CO_2 avoided **)(# of homes in California that have installed solar) = Total carbon emissions avoided ****

* Metric tons of CO_2 emitted per kWh of electricity generated
EPH: Electricity Use Per Household (in kWh)
** Answer from Eq. 1
*** Currently; Due to solar panel installation
Note: units of CO_2 emissions is in metric tons

The answer for the above equation was calculated for each county in California. To determine the total amount of carbon emissions that have been avoided due to the current installation of solar systems, I used Eq. 2 (Table 2). Eq. 2 gave me a different answer for each county, so I calculated a meta-average and standard deviation from that. It should be noted that I am not including lifecycle emission costs for solar panels in these calculations because those are generally offset by the solar panels themselves within a few years (Pearce 2002).

Percentage of households that should install solar panels to make a significant difference in carbon emissions reduction

I gathered information on baseline carbon emissions from a report by the California Air Resources Board (CARB) and then calculated the total carbon emissions that would result in 2020 if different percentages of households installed solar panels by that time. The information for the baseline carbon emissions projected for 2020 if current use habits continue is available in the 2008 Scoping Plan developed by the California Air Resources Board (http://www.arb.ca.gov/cc/scopingplan/document/adopted_scoping_plan.pdf). CARB, the lead agency responsible for implementing AB 32, is required to develop a scoping plan to outline strategies that the state should adopt in order to achieve the 2020 greenhouse gas emissions limit (427 million metric tons CO_2). In order to develop these strategies, CARB first determined what the baseline (business-as-usual) emissions in 2020 would be if no mitigation strategies are implemented; this baseline is 507 million metric tons (CARB 2008).

Using the county averages for the amount of emissions avoided due to solar panel usage (from Eq. 1), I first assessed the amount of carbon emissions that would result in 2020 if 25 percent, 50 percent, 75 percent, and 100 percent of all residential homes in California installed solar panels. Similar to my calculations above, I combined the results for each county and performed an ANOVA using R Commander (Fox 2005) to determine if there was a significant difference between the total carbon emissions for each percentage group and the baseline projected emissions. I did face some limitations in my statistical analyses due to the fact that the 2020 baseline emissions estimated by CARB does not include a measure of variance. Once I found this first significant cutoff, I repeated the above methods for smaller percentage intervals (55%, 60%, 65%, and 70%) to get a more precise percentage of significance.

Groups of households that can lead to a significant reduction in carbon emissions by installing solar

I gathered information on the percentage of the different types of households in California from the 2010 U.S. Census (www.census.gov). Of all the data collected on households, there were approximately 1.6% of household counts that had errors (0.5% due to duplication of another housing unit and 1.1 % due to other reasons including nonresidential or nonexistent housing units). Of all residential homes, 45% are rented, 25% are apartment buildings, and 44% are low-income (U.S. Census Bureau 2012); the U.S. Census Bureau did not report on which homes were overlapped (e.g. both rented and low-income). A possible source of bias from using this data is that low-income households are less likely to respond to the census (Groves and Couper 1998).

I determined the amount of carbon emissions that can be reduced if different types of households install solar. Emissions reductions were calculated for situations in which: 1) only apartments install solar; 2) only low-income households install solar; and 3) only rented homes install solar panels. I chose these specific types of households because they have been shown to have a lower interest in installing solar systems due to feasibility and cost issues (Mills and Schleich 2009). My calculations are similar to my previous calculations using Eq. 2.

I performed an ANOVA comparing the emissions reductions for each group of household types. By doing so, I can determine which group of households could contribute the most to the carbon emissions reductions, and consequently, which group should be the main focus of government policies.

RESULTS

Current Scenario: Reduction in carbon emissions due to solar panel installation

Of the 12,577,498 residential homes in California, 113,533 (0.9%) have installed solar (CSI 2012). A mean of 696,544 metric tons CO_2 emissions (SD: 236,049) have been avoided due to the installation of these solar systems.

Alternative Scenarios: Resulting carbon emissions if different percentages of homes install solar

The baseline 2020 carbon emissions are projected to be 507 million metric tons (CARB 2008). I found that if at least 60% of all California homes installed solar systems, there would be a significant difference ($p<0.05$) between the resulting carbon emissions after these solar installations and the baseline emissions for 2020 (Table 3). The mean decrease in emissions in the 60% scenario would be 46,299,025 metric tons. If 100% of all California homes installed solar, then the difference between the resulting carbon emissions and the baseline emissions would be highly significant ($p<0.001$) (Fig. 1).

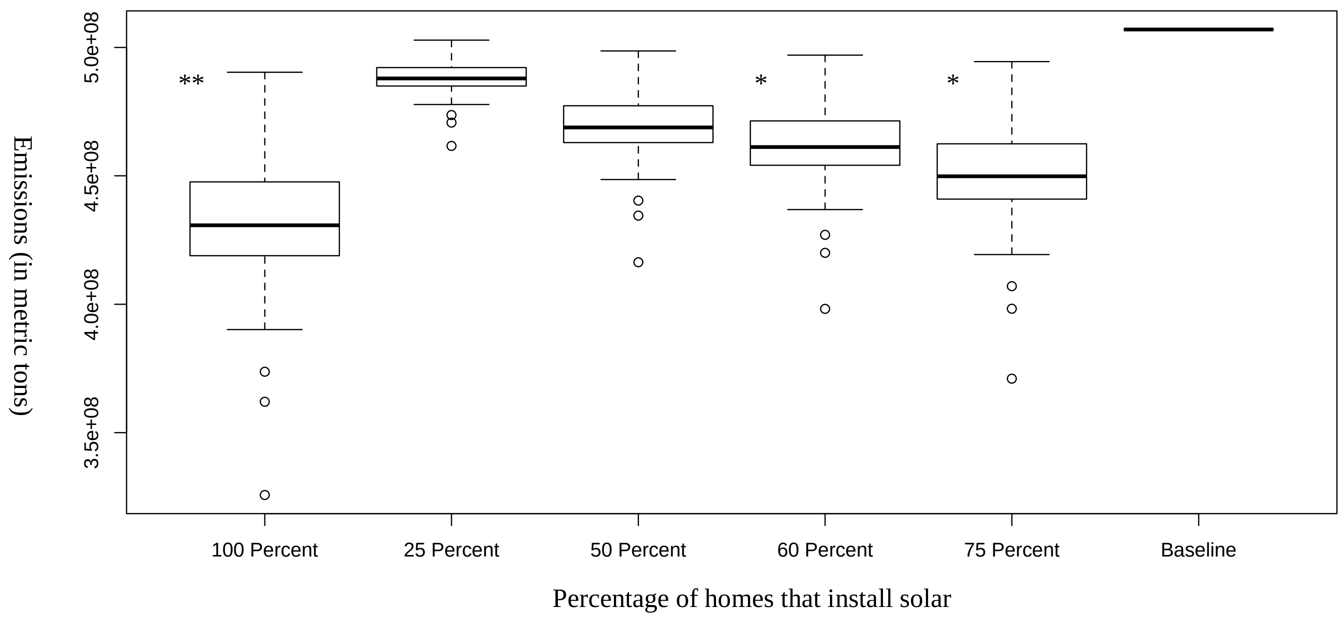

Figure 1. Resulting carbon emissions from all emissions sources if different percentages of homes go solar. Note: * denotes a significant ($p<0.05$) difference and ** denotes a highly significant ($p<0.001$) difference when compared to baseline projected emissions for 2020. At least 60% of homes should install solar for a significant reduction in emissions. The central lines in the boxes depict the median; upper and lower lines represent the quartiles; whiskers represent the minimum and maximum.

Table 3. Remaining carbon emissions if different percentages of homes install solar

Percentage of Homes	**Average Carbon Emissions (million metric tons)**	**Standard Deviation (million metric tons)**
100 **	429.83	26.15
75 *	449.13	19.61
60 *	460.70	15.69
50	468.42	13.08
25	487.71	6.54

Note: * is significant ($p<0.05$) and ** is highly significant ($p<0.001$) when compared to baseline projected emissions for 2020 (507 million metric tons) (CARB 2008). N=58.

Household types that can lead to a significant reduction in carbon emissions by installing solar

If all homes except for rented or low-income homes install solar, then at least 60% of all California homes will still have solar systems; there will be a significant reduction in carbon emissions when compared to baseline emissions. The mean reduction would be 33,891,602 million metric tons CO_2 for low-income (SD: 11,485,437) and 34,512,604 million metric tons CO_2 for rented (SD: 11,695,887). There was a highly significant ($p<0.001$) difference in emissions reductions for both low-income and rented homes when compared to apartments (Fig. 2).

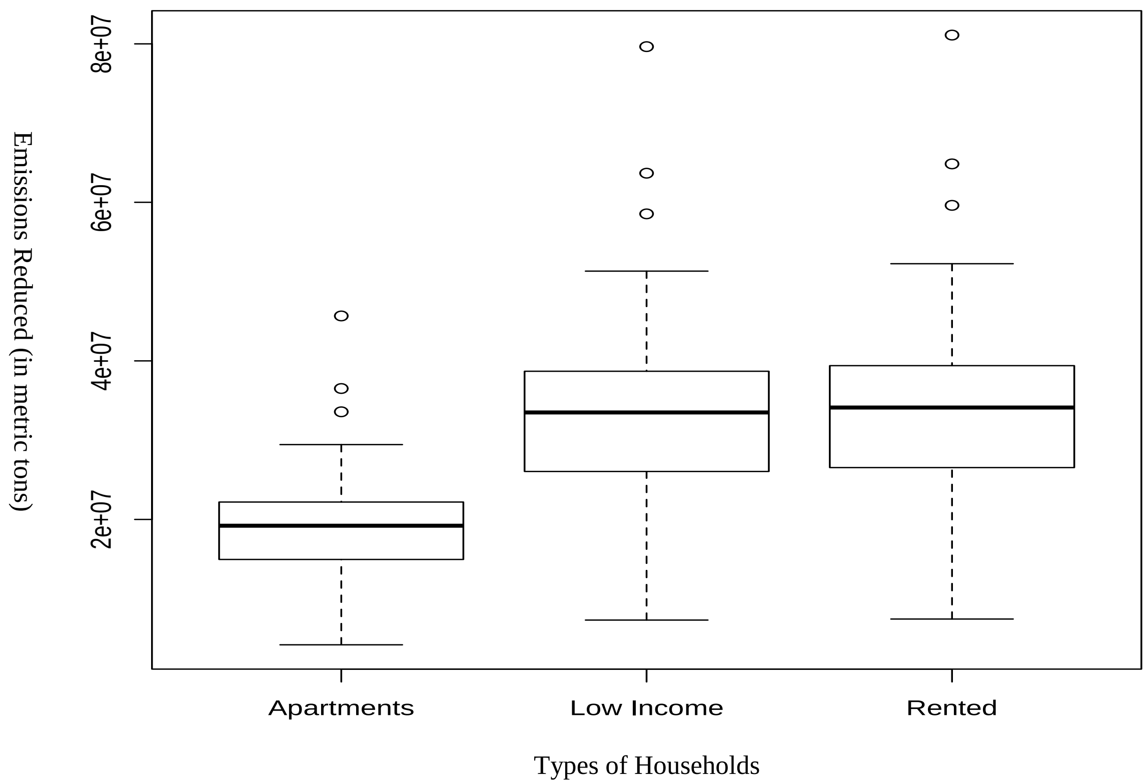

Figure 2. Emissions reductions by household type. There is a highly significant ($p<0.001$) difference in emissions for both low-income and rented homes when compared to apartments.

DISCUSSION

My research focused on a deeper understanding of energy generation and carbon emissions in California and how residential implementation of solar systems can help mitigate those emissions. Currently, there is little known about how renewable energy, especially solar panels, adopted by residential homes can contribute to carbon emissions mitigation in California. Through this research, I have assessed what the situation in 2020 will be like if different percentages of homes install solar and determined the percentage of homes in California that should install solar to significantly reduce carbon emissions. This research determines if the adoption of solar technology is a feasible and practical strategy to help California reach its AB 32 goals.

Current Scenario

The fact that only 0.9% of all California homes have currently installed solar implies that the implementation of solar for the majority of California homes still has some barriers. An important factor to consider is the high cost of solar systems, which can cost an average of $30,000. The cost of a solar system is much greater (about 80%) than the value of electricity that it can produce (Dastrup et al. 2012). In order to overcome this barrier to implementation, the government will likely need to invest more into the research and development of solar technology to make panels cheaper to produce, consequently lowering costs for consumers. Research and development investments can also lead to the production of more efficient solar panels, which can reduce the payback time for their installation (by means of lower electricity bills), and provide consumers more of an incentive to install solar. By overcoming the financial barrier, a higher percentage of consumers are likely to adopt solar; in fact, a much higher percentage than 0.9% of California homes need to install solar systems to result in a significant reduction in carbon emissions.

Alternate Scenarios

I found that 60% of California homes need to install solar systems to completely meet their electricity needs in order to significantly mitigate carbon emissions. The Intergovernmental Panel on Climate Change (IPCC) has stated that 50-70% of current global carbon emissions need to be reduced in order to stabilize carbon concentrations in the atmosphere (IPCC 1995). The IPCC has included all sources of emissions in their statement, while my 60% only includes electricity generation. This implies that we need to go beyond electricity emissions and focus on other sources of greenhouse gas emissions as well, such as transportation.

Sixty percent of all California homes installing solar might be a difficult target to achieve. One policy option that California has planned to adopt is a feed-in tariff (FIT). FITs are contracts between electricity generators (such as homeowners) and the government or public utilities companies. For a set period of time, homeowners are paid a certain price for generating renewable energy and the price is based on the size and efficiency of their system (Couture et al. 2010). This encourages homeowners to invest into solar systems, because they will eventually receive a return on their investments. In addition, homeowners are also encouraged to invest in a system that is efficient and yields a large output. FITs have proven to be effective incentive programs; they have led to aggressive growth in solar system implementation in Canada and Germany (Solangi et al. 2011). Half of the world's solar system installations have actually been due to FITs and Germany, specifically, saw a 142% growth in renewable energy generation between the years 1991 and 2000 ((Solangi et al. 2011, Wustenhagen & Bilharz 2006). Although the program has been initiated in California, it is still in the developing stages and amendments are continuing to be made. In addition, solar systems of 1 MW or more are currently eligible for FITs in California (CPUC 2013). Residential solar systems (around 3 kW) are far smaller, and are therefore not yet eligible for FITs. By accelerating the FIT amendment process and including small solar system sizes, California can be on its way to reaching its AB 32 goal by the year 2020.

The government can also make implementation easier by raising environmental awareness. Generally, more environmentally-conscious communities (ones that are more concerned with climate change) are likely to install solar than the average community (Dastrup et. al. 2012). If government resources are focused on raising awareness about climate change, the effects of carbon emissions, and California's AB 32 goal, then this can be an effective first step to help Californians adopt an environmental mindset as a whole. Another important feasibility issue to consider is that many types of homes in California may be unlikely to install solar because of financial and social impediments.

Different types of households

The government must develop policies aimed at homes that are less likely to install solar in order to promote solar implementation. Both rented and low-income groups make up a large percentage of all California households (44% low-income, 45% rented) (U.S. Census Bureau 2012). My research shows that if all California homes install solar excluding either the rented or low-income groups, California will be at its 60% level of significance. This implies that the government can choose to focus on just one of these groups and still achieve success with carbon emissions reduction. I suggest that policies should be aimed at low-income homes because they are less difficult to incentivize and some programs are already in effect. To help promote solar installation amongst low-income homes, the California Solar Initiative has implemented the Single-Family Affordable Solar Housing (SASH) program. (Go Solar California 2012). This program offers subsidies to qualifying low-income homes and helps homeowners overcome the financial barrier for installing solar. For example, in San Francisco, a low-income SASH eligible home can get an incentive of $9,000 for installing a solar system and incentives can reach up to 95% of the cost of the entire system (SFPUC 2011). For rented homes, this may not be the best policy option; there is not much of an incentive for these landlords as they will not be the ones benefitting from lower electricity bills. One way to encourage solar installation for rented homes would be to adopt a feed-in tariff policy, in which the price for electricity generation through renewables goes to the homeowner, even if he/she has rented it out to someone else.

In contrast to rented houses, promoting solar adoption amongst apartment buildings seems more feasible. Apartment buildings make up a smaller percentage of California homes and they are also generally more energy efficient (U.S. EIA 2009). In addition, the already-established Multi-Family Affordable Solar Housing program (MASH) subsidizes solar systems for buildings that qualify as affordable housing (Go Solar California 2012). Also, apartment buildings include multiple units; by convincing the owner of the building to install solar, the government has essentially guaranteed carbon emissions mitigation for multiple units.

Limitations & Future Directions

The biggest limitation to my study was the amount of assumptions I had to make due to lack of available data, as well as assumptions that were necessary for my results to hold true. I had to assume that all residential solar systems in California are the same size and provide for the electricity needs of the entire household. While this is a valid assumption, my results would have been more accurate if I had specific data regarding solar system sizes and energy consumption in homes that install solar. More research is necessary regarding the sizes of already-installed solar systems.

My findings suggest that more research needs to be done regarding the financial and housing characteristics of households that have installed solar; this can help the government decide where to focus its policies to promote solar. Also, other energy sectors should be researched in order to develop a more accurate scenario of California's energy emissions. My research did not consider energy generation for commercial purposes; further research could add to knowledge regarding the current energy scenario in California and policies could be suggested to promote renewable energy implementation in the commercial sector. Electricity companies and the government should also invest in other sources of renewable energy, as solar energy currently has high costs and faces barriers to implementation. It would be effective to look at other sources, such as wind or biofuels, and their carbon mitigation potential.

Broader Implications

My research shows that there is a great need for the government to make solar technology more accessible in order to reduce greenhouse gas emissions from the residential energy sector. Another implication of this research is that focusing on energy generation is not the only solution; other sources of greenhouse gas emissions must be targeted as well if California aspires to reach its AB 32 goals. Even if 60% of California households manage to install solar by 2020, we will still not have reduced emissions back down to the 1990 levels (Fig. 3). A larger portion of California's greenhouse gas emissions comes from transportation (Fig. 4). If emissions mitigation policies focus on the transportation sector, as well as electricity, then a considerable portion of the state's greenhouse gas emissions can be targeted for reduction.

This research shows that residential solar systems have the potential to significantly reduce carbon emissions; however, California has still not reached that potential due to barriers to implementation. With further research on different sources of renewable energy and with easier access to solar technology, California can overcome a significant portion of its greenhouse gas emissions derived from the energy sector, and hopefully meet AB 32 goals. With a goal to provide 33% of its energy and utilities companies already generating 19.8% of its energy through renewables, California is at the forefront of carbon emissions mitigation (CPUC 2007). By achieving AB 32, California can set an example for other states to follow and contribute to a dramatic reduction in greenhouse gas emissions and help reduce climate change.

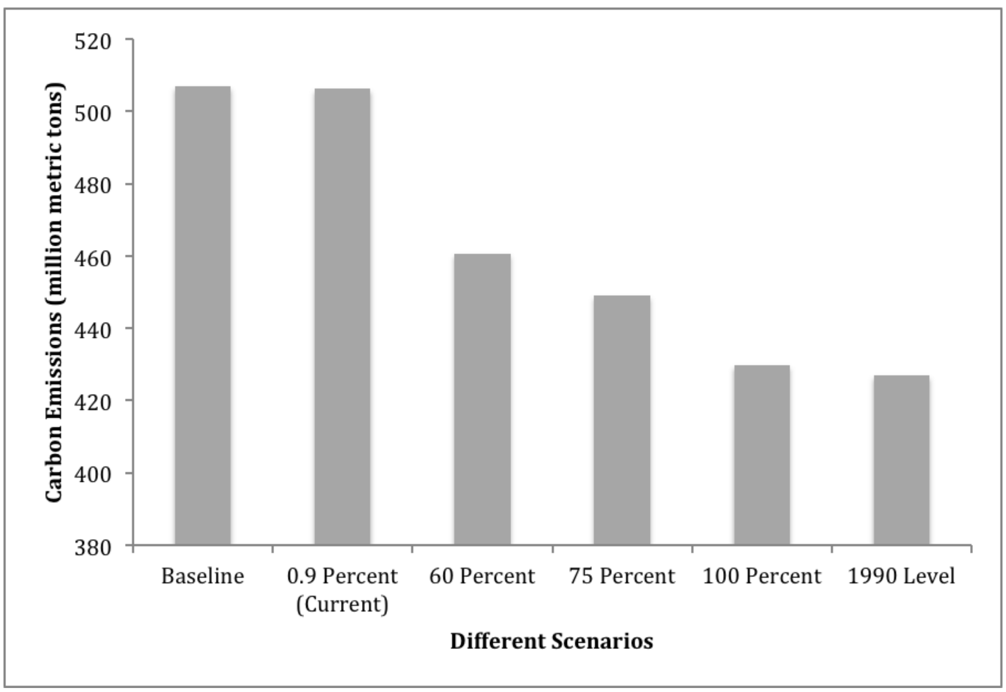

Figure 3. Average carbon emissions if different percentages of homes go solar, current emissions, baseline emissions, and the AB 32 goal. Even if 60% of all California homes manage to install solar, the state will still not have reduced its emissions back down to the 1990 level.

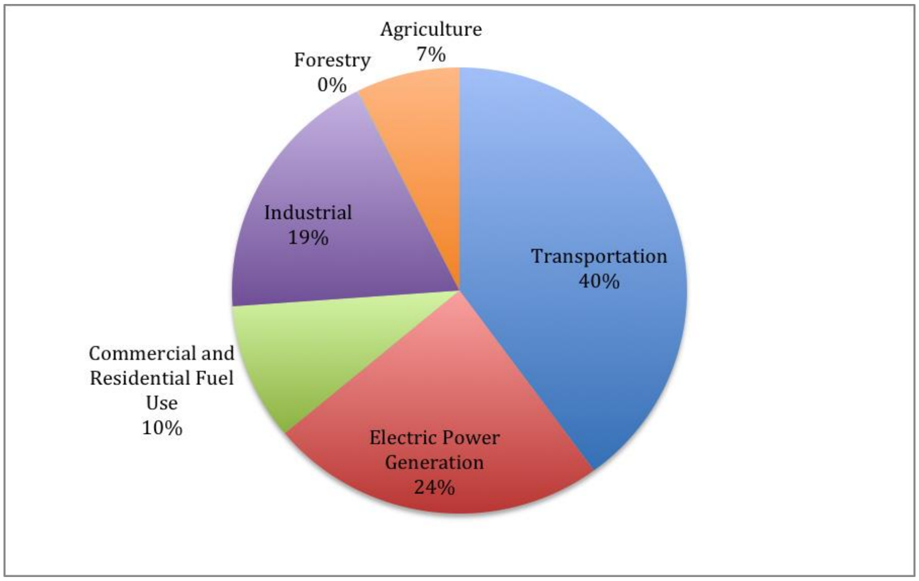

Figure 4. California GHG emissions inventory 2009 (CARB 2009). Transportation comprises a larger percentage of state greenhouse gas emissions; it is also a sector that must be focused on for mitigation strategies if California is to meet its AB 32 target.

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