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Incorporating Life Cycle Assessment and Environmental Equity into Local Climate Action

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Incorporating Life Cycle Assessment and Environmental Equity into Local Climate Action

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ABSTRACT

California passed the Global Warming Solutions Act in 2006, establishing greenhouse gas (GHG) emissions reduction goals and requiring local governments and state agencies to take initiative to meet those goal, as well as establishing a state cap-and-trade program. As a result, many local governments began publishing climate action plans (CAPs) to establish jurisdiction-specific goals, whether city-wide, county-wide, or regional, as well as outline the actions they plan to implement to achieve GHG emissions reduction targets. California also passed the Clean Energy and Pollution Reduction Act in 2015, which mandated allocation of cap-and-trade-generated funds towards sustainable projects benefiting and located in disadvantaged communities (DACs). DACs are defined as communities facing above-average social, financial, health, and environmental burden. This bill was passed to promote equity across the state

The main goal of this dissertation was to explore ways to change and improve efforts by local jurisdictions to mitigate climate change. While it focused on the roles of life cycle assessment (LCA) and equity in climate action planning, it also examines the ways that climate action plans consider the impact of community choice aggregators (CCAs) on GHG emissions reduction. Ultimately, this research consisted of four parts:

1. Using life cycle assessment and life cycle cost assessment to prioritize emissions reduction strategies considered in CAPs, with a focus on the transportation sector;
2. Critically reviewing CAPs across California to gauge the extent to which they include emissions, economic, and equity data, and identifying correlations with demographic data, and providing recommendations on how to better include equity in CAPs;
3. Inspired by findings during the CAP critical review, critiquing the assumptions made and calculations undertaken to attribute emissions reduction potential to the transition from an incumbent utility to a community choice aggregator (CCA), and subsequently offering recommendations; and
4. Implementing a survey to better understand how jurisdictions currently approach climate action planning and implementation, with a focus on the roles of life cycle assessment (LCA) and equity, to identify barriers to sustainable action as well as opportunities for change.

In the first chapter, six emissions reduction strategies are analyzed for two jurisdictions, Los Angeles County and Yolo County. Six life cycle assessment and life cycle cost assessments were performed to estimate the life cycle emissions and life cycle cost of each strategy over a 25-year analysis period. Two strategies, intercity bike lanes and full depth recycling options for pavement rehabilitation, were found to produce net positive emissions over their life cycle. The results for the remaining two Yolo County strategies (installation of solar canopies and converting stop-start intersections to roundabouts) and two Los Angeles County strategies (electrifying the Foothill Transit bus fleet and converting the LA County vehicle fleet to alternative fuels) were plotted on a marginal abatement cost curve, which presents the emissions reduction potential and the cost per unit of emissions reduction for each strategy. This case study shows how applying LCA methods to emissions reduction strategies can help compare the environmental impact and life cycle cost of considered strategies, as well as identify strategies that produce net positive emissions over their life cycle.

In the second chapter, a review is conducted of 37 CAPs published by jurisdictions in California which directly affect over half of the state's population. This review uses a developed framework to quantify the extent to which the CAPs include emissions data, cost data, and equity considerations. These values are then coupled with demographic data to see if there are any correlations between the robustness of information included in CAPs, and the demographics of the jurisdictions where they are produced. While results are also presented for each of the three dependent variables, the overall robustness of CAPs is positively correlated with the year of CAP publication (more recent CAPs are more robust) and education level of the jurisdiction (a higher proportion of the population with at least a Bachelor's degree is correlated with a most robust CAP), while it is negatively correlated with poverty rate (wealthier jurisdictions have more robust CAPs) as well as the proportion of white non-Hispanic population (no clear explanation, and thus requires further exploration). Finally, literature is reviewed to compile guiding questions that could promote the discussion of, and planning around, equity themes.

In the third chapter, the research examines the emissions reduction potential that CAPs attribute to CCAs. Some jurisdictions transition from a utility to a CCA, where the CCA exercises additional control over the sources from which they purchase their electricity, leading to many of them (at least in California) offering electricity that is sourced from lower carbon generators than the incumbent utility. Many CAPs will simply attribute emissions reduction potential to a CCA's higher renewable energy content of purchased electricity related to the incumbent utility. Alarmingly, some will assume that when CCAs offer 100% renewable electricity, the jurisdiction produces no carbon emissions through their electricity use, though the reality is not as simple. A review is conducted of the extent to which jurisdictions assign emissions reduction potential to CAPs, the assumptions and methodologies used are summarized, a critique is offered of the potential pitfalls of those assumptions and methodologies, and recommendations are offered regarding how to consider the impact of CCAs. Ultimately, some CAPs refuse to directly attribute emissions reduction potential to their CCAs which is the best course of action. However, jurisdictions that may want to quantify the impact are advised to (1) consider the hourly sources of energy consumption, (2) consider the underlying changes to the larger California grid mix over time, and (3) account for customers that remain with the incumbent utility.

The final chapter implements a survey to assess how jurisdictions currently approach climate action planning and implementation. It was sent to representatives from jurisdictions who play a primary role in the climate action planning or implementation process. The survey found that emissions reduction potential is the most important factor during both planning and implementation, local priorities are more strongly considered during planning than during implementation, and cost is a more strongly considered during implementation than planning. Additionally, it offered insight to the respondents' perspectives on LCA (largely concluding it is a valuable methodology but with some finding it prohibitively resource intensive), equity (funding is key for promoting equitable actions), and equity consideration across an action's lifecycle (difficult to quantify and beyond the control of the jurisdiction). It also offers other key insights to local climate efforts, such as how funding and political will most strongly influence which projects are implemented, and how some jurisdictions are so under-resourced that they depend on free and volunteer work to implement actions and update their CAPs.

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Chapter 1. Introduction

This dissertation examines the efforts taken by local governments to reduce greenhouse gas (GHG) emissions and considers the impacts that climate mitigation actions have on specific individuals and communities. Specifically, the research undertaken presents and applies a methodology to quantitatively assess proposed GHG reduction action, critiques the climate action planning frameworks used by local governments in California, and examines the current state of climate action implementation by local jurisdictions to better propose recommendations.

Climate action has been promoted across all levels of government. Internationally, 196 nations currently participate in the United Nations Framework Convention on Climate Change to establish goals and plans for mitigating climate change. During the 2015 Paris climate conference, the participating nations ratified a legally binding international treaty to limit global warming to below 2 degrees Celsius compared to pre-industrial levels my mitigating GHG emissions (UNFCCC 2015). One focus of the Paris Accord has been the concept of a just transition towards sustainability. Recently, U.S. President Joseph Biden established the Justice40 Initiative, which works to meet the President's promise of having at least 40 percent of benefits from federal investment in in climate and clean energy reach disadvantaged communities (DACs), those that face disproportionate amounts of environmental burden (Biden 2021).

California has been a global leader in climate change mitigation policy and has steadily increased its GHG mitigation goals in recent years. The first major GHG mitigation policy was enacted in 2005 when Governor Schwarzenegger signed Executive Order S-3-05, which set a state goal to reduce GHG emissions to 1990 level by 2020, and to 80 percent below 1990 levels by 2050 (Schwarzenegger 2005). A year later, the Global Warming Solutions Act (Assembly Bill 32) made this a mandate and required that local governments and state agencies help in meeting those goals, notably by creating a statewide cap-and-trade program (California Assembly 2006). In 2015, Governor Brown's Executive Order B-30-15 set a new reduction goal of 40 percent below 1990 levels by 2030 (Brown Jr. 2015). This was then signed into law by Senate Bill 32 in 2016 (California Senate 2016). Governor Brown also signed executive order B-55-18 committing the state to reaching carbon neutrality by 2045 (Brown Jr. 2018). Most recently, Governor Newson signed Executive Order N-79-20 which established dates by which new vehicles sales in the state would consist entirely of zero-emissions vehicles (2035 for all passenger vehicles and 2045 for medium- and heavy-duty vehicles) (Newsom 2020).

The California Environmental Protection Agency sponsored the creation of the state's environmental health screening tool, CalEnviroScreen (CES), to identify the communities that, because of historical decisions and policy making, currently face the highest amounts of burden across the state of California. CES 4.0, the most recent iteration of the tool, considers various indicators when calculating burden, such as exposure to air pollutants, traffic density, proximity to waste sites, predisposition to health issues, and socioeconomic factors (OEHHA 2021). Calculated burden is based on the averages of the percentile score for each of the indicators. That is, for each indicator, values are converted to percentiles for normalization, such that highest score is assigned a percentile of 100 and the lowest score a percentile of 0. The communities, which are split by census tract, in the upper quartile of burden scores are considered disadvantaged communities. For environmental policies, it is CES results that are used to identify disadvantaged communities. These communities are also referred to as priority population communities, since they are sometimes the target of policies that provide funds and promote additional benefits.

Relevantly, the creation of CES was directly caused by the passage of Senate Bill 535 in 2012, which required that 25% of the state's Greenhouse Gas Reduction Fund (generated by the cap-and-trade program) be invested in projects that benefit these priority population communities (OEHHA 2018). This was supplemented by Assembly Bill 1550 in 2016 which amended the requirement so that the projects must actually be implemented in, and not just benefit, DACs. Assembly Bill 617 also tackles environmental inequity by promoting the reduction of air pollution in communities experiencing the highest levels of exposure. These bills promote environmental actions in DACs (which are defined at the census tract level), but they provide little guidance on what actions local jurisdictions should take, or even how to proceed.

The State of California offers funding through loans and grants across various sectors to promote sustainable action and otherwise address environmental problems. A review of funding opportunities published by the state's Environmental Protection Agency reveals funding for training and education about environmental hazards that populations face, vehicle electrification, air pollution reduction, reduction of toxic substance production and leakage, water quality management and protection, and more (CalEPA 2019). It also lists small grants aimed toward environmental justice efforts, including those that provide information about environmental problems, educate communities about the environmental problems they face, or directly address the most significant exposures to pollution (CalEPA 2021).

Climate action by local governments, which is typically centered around reducing greenhouse gas emissions and addressing global warming, in the United States is certainly affected by federal and state policies and funding, but those efforts can also be supported at the international level. Cities can join the Global Covenant of Mayors (2020) or C40 (2020), wherein they commit themselves to achieving emissions reduction and other sustainable goals. These organizations also offer resources to aid local governments in developing plans to guide climate action planning and implementation. One study assessed the impacts of local climate action and concluded that efforts across multiple, decentralized municipalities is indeed a significant driver of emissions reduction (Lutsey and Sperling 2007). While it is encouraging to have local governments opt into such coalitions, some studies argue that local effort must be supported by higher levels of government. Research by Krause (2016) found that state level policy is more effective in promoting local action when it explicitly calls for or demands it. At the local level, a jurisdiction's commitment to sustainability was positively correlated with city size, education of its citizens, and the level of climate action taken by surrounding jurisdictions. These findings are supported by another study that found that the adoption of local climate policy is limited by capacity constraints and is more likely to be developed in states with multilevel governance frameworks that support local climate action (Homsy and Warner 2014). This suggests that top-down policy that calls on action is more effective than simply setting goals and expecting or hoping lower levels of government to act accordingly.

Oftentimes, localities will publish climate action plans (CAPs) to establish emissions reduction targets and to outline the actions they will implement to achieve them. However, the extent to which the proposed actions have been quantitatively assessed varies greatly across CAPs, frequently leading to minimal information on the expected greenhouse gas reduction potential or expected cost of proposed actions. One way to include this information is by implementing life cycle assessment (LCA). LCA is a methodology that considers the emissions impacts, both production and mitigation, across the various phases of a project. These phases may include material extraction, refinement, production, implementation, maintenance, transportation, recycling, disposal, and more. In summary, LCA is a way to holistically consider the impacts of a project beyond simply what occurs during implementation. Just as GHG emissions can be tracked across a life cycle, so too can life cycle cost be calculated by considering costs (and even generated revenue) across the considered life cycle phases. Together, these two pieces of information can help jurisdictions gauge the impact and cost of proposed actions across phases and over a multi-year timeline of implementation.

Quantifying the life cycle GHG emissions reduction and life cycle cost enables the production of a marginal abatement cost curve (MACC), which presents the life cycle emissions reduction and life cycle cost effectiveness per unit of emissions reduction for each considered strategy. Popularized by McKinsey and Co., MACCs have also been developed to assess strategies across various sectors in the US (e.g., Lutsey and Sperling 2009), statewide transportation strategies for a department of transportation (Harvey *et al.* 2019), and transportation strategies implementable by local jurisdictions (Lozano *et al.* 2021). Supply curves are a useful tool to compare various GHG reduction strategies since they visualize the relative cost-effectiveness as well as the total emissions reduction potential of competing strategies.

One shortcoming of MACCs is that the results rely on a number of assumptions, so it is imperative that they are outlined clearly to be useful during decision making. Additionally, MACCs do not consider how implemented strategies interact with the larger system of projects and policies, which some studies say is necessary in a prioritization framework (Givoni et al. 2013, Taeihagh et al. 2013). This is in large part due to the fact that MACCs are two dimensional—they consider only GHG reduction and life cycle cost—so the performance of strategies in other dimensions is not evident. In particular, the effects of GHG reduction strategies on the surrounding communities and potential environmental equity concerns are not captured by current versions of MACCs.

Various GHG emissions reduction efforts focus on electrification: the transitioning from fossil fuel dependency to the use of electricity that is generated by increasing amounts of renewable energy. Therefore, transitioning to cleaner electricity has been at the forefront of conversations surrounding climate action. One of the key contributors to this effort, particularly in California, is the network of community choice aggregators (CCAs). CCAs are not-for-profit entities that allow participating communities to purchase electricity from generators, facilitating purchases of electricity that are cleaner—in other words, generated using fewer fossil fuels—than the electricity generation mix provided by utilities that served them prior to the CCA. CCAs have therefore become a major player in the push to increase renewable energy production across the California electric grid and beyond. Many jurisdictions have compared the power mix used to generate electricity of the larger utility and the new CCA to estimate the expected emissions reduction due to the creation of a CCA. The emissions avoided by the transition to a CCA are often used to achieve a jurisdiction’s emissions reduction target. However, the presumption that purchasing electricity from different generators actually reduces emissions, or increases the total supply of renewable or low-carbon electricity is spurious. The electricity grid and its markets are complex, and this assumption simplifies a very complex process that requires additional scrutiny before being used to achieve GHG mitigation targets.

Especially relevant at the local level is the impact that climate action implementation has on communities, particularly those that are most vulnerable. Historical decisions in the United States have made it so that certain communities face disproportionately larger social and environmental burdens than the rest of the population. Racist policies throughout the country's history (e.g., legalized slavery until 1865, the Trail of Tears during the 1830s, Jim Crow laws that were in place until 1965) have present-day effects on communities of color, such as access to housing, economic opportunity, and political participation (Solomon et al. 2019). Environmental injustices in the US can also be traced back to racial oppression and discrimination (Bell 2015). Environmental equity, defined as the equal access to healthy environmental conditions as well as equal protection from environmental hazards regardless of race, ethnicity, gender, or socioeconomic status (Schlosberg 2013), is a concept that has received an increasing amount of attention and has led to communities focusing on reducing negative costs and increasing benefits for these communities of interest. However, the question remains regarding the extent to which jurisdictions have considered environmental equity, and what can be done to increase it.

By and large, many climate action plans could benefit from additional and more robust quantitative data to have a better understanding of the costs and expected outcomes of proposed actions, prioritize among actions based on quantitative data, and better establish performance goals. Some CAPs also fail to report who is responsible for climate action implementation, how likely it is that an action will be implemented, and who stands to benefit or suffer adverse outcomes from said action implementation. The first sections of this dissertation examine the ways that local governments have approached climate action and propose a way to incorporate additional quantitative data into CAPs and emissions accounting by: using life cycle assessment to better consider emissions reduction potential and cost; considering environmental equity throughout planning and implementation; and reconsidering the roles that CCAs play in emissions reduction.

While critiquing existing plans and proposing frameworks may be helpful, it is irrelevant without framing recommendations within real world context of multiple goals, and complex interactions of different actions and outcomes. For this reason, the final section of this dissertation implements a survey to assess the factors that influence decision making and highlight major hurdles that impede progress towards achieving climate goals, specifically as they relate to the inclusion of life cycle data and equity considerations. In summary, the research questions that are explored in this dissertation can be categorized as follows:

- **Chapter 2. Prioritizing greenhouse gas mitigation strategies for local governments using marginal abatement cost**
  - How can the life cycle perspective be applied to GHG reduction strategies to improve prioritization?
  - Can the necessary information be collected in a timely manner?

- **Chapter 3. Assessment of environment, economy, and equity in Climate Action Plans: The case of California**
    - To what extent to climate action plans include emissions data, cost data, and environmental equity themes?
    - Are there any correlations between the inclusion if this information and the demographic makeup of the jurisdictions?
- **Chapter 4. Potential pitfalls of planning climate action around community choice aggregators**
    - What are key points that a jurisdiction should consider before assigning an emissions reduction potential to a proposed or established CCA?
- **Chapter 5. How do cities approach sustainability? A survey on the importance of life cycle assessment, equity, and funding in local climate action**
    - How strongly are different factors considered in the CAP planning and implementation process, and is there a difference between the two phases?
    - How familiar are jurisdictional representatives with life cycle assessment (LCA), life cycle cost assessment (LCCA), and environmental equity; how likely are they to include them in future CAPs, and what would prevent them from doing so?
    - How much process improvement is included in CAPs, including tracking implementation progress, reporting updates, and modifying the plan accordingly?

Ultimately, the goal of this dissertation is to propose improvements to local climate action initiatives and better outcomes while framing those proposals within the constraints that jurisdictions face.

Chapter 2. Prioritizing greenhouse gas mitigation strategies for local governments using marginal abatement cost curves for the transportation sector

2.1. Introduction

Global warming caused by anthropogenic emissions of greenhouse gases (GHG) and the resulting climate change effects of warming is a defining issue of our time (United Nations 2019). Cities are responsible for the majority of anthropogenic GHG emissions, and as such, cities and other subnational jurisdictions representing urbanized areas have crucial roles to play in mitigating GHG emissions (Fong *et al* 2014). In fact, tens of thousands of cities have joined international compacts, such as the Global Covenant of Mayors (2020) and C40 (2020), to reduce emissions. Many jurisdictions use climate action plans (CAPs) to guide their approach to GHG mitigation. As described in C40's Climate Action Planning framework (the C40 Cities Climate Leadership Group is a network of 100 global cities who have committed to addressing the climate crisis), a CAP serves to set and commit the jurisdiction to emissions reduction targets, present baseline and trajectory emissions, and outline actions that will be implemented to reach the set targets (C40 2020).

California has been a leader in the United States (US) and globally in the development of policies for reducing GHG emissions (California Assembly 2006). In particular, the Sustainable Communities and Climate Protection Act of 2008, or SB375, requires jurisdictions to develop GHG reduction targets and undertake specific actions to achieve them (California Institute for Local Government 2008). In response, many cities and counties in California have developed CAPs that identify GHG reduction targets and specific actions to achieve them. California local governments thus present a ready opportunity to systematically explore GHG mitigation strategies formulated at local jurisdictional scales. California counties are responsible for county-wide services and all services and land use planning in areas not included in incorporated cities. Counties therefore provide services in rural areas, and in urbanized areas between and around incorporated cities, and pockets within cities.

The transportation sector is a major contributor to GHG emissions in the US, causing 28% of total GHG emissions (EPA 2018). In California, the contributions from transport are even more dominant, comprising 41% of statewide emissions (CARB 2018). Thus, it is not a surprise that transportation is one of the key sectors identified in most California CAPs and targeted for reduction. Reducing motorized travel, measured in terms of vehicle miles traveled (VMT), is a crucial element for most reduction targets. However, the infrastructure required for nearly all travel modes includes hardscapes and may present an additional opportunity for GHG mitigation. Many cities and counties, and other jurisdictions such as port authorities, are responsible for managing a significant portfolio of transportation-related hardscapes including roadways, parking lots, airfields, and bike and pedestrian pathways. In the context of CAPs, these surfaces, and the vehicles and equipment that cities and counties operate on them, provide opportunities for directly and indirectly affecting GHG emissions, through changes in their operations, management, design, material selection, and others.

Unfortunately, the actual quantitative analysis of the mitigation potentials, and costs of mitigation for these strategies, have not previously been evaluated. This research examines the extent to which quantitative data have been included in CAPs, then proposes a framework to inform implementation, and applies it to two case studies. The framework uses a life cycle marginal abatement cost curve (MACC) to present the expected costs per unit of emissions reduction and emissions reduction potential of proposed CAP strategies.

A review of 37 California local government CAPs (9 out of 58 counties, and 28 out of 482 cities in the state) was conducted to better understand current approaches to reducing transportation-related emissions at the local level. The reviewed CAPs affect just over 20 million California residents, which is over half of the state's population. In addition to compiling proposed emissions reduction strategies, the review considered whether a CAP quantified the expected emissions reduction and cost of planned strategies. The review found that only half of the reviewed CAPs quantified the expected GHG mitigation of proposed strategies, and even fewer quantified both emissions and costs (Lozano et al 2020; Appendix - Table A1). Beyond simply calculating the GHG reduction potential and direct costs of a strategy, quantifying the life cycle environmental and economic benefits and burdens of actions relative to business-as-usual (BAU) practice would permit prioritization of the most cost-effective mitigation solutions, and ensure that indirect effects are captured.

Many previous studies of CAPs have examined the factors that affect their adoption in the first place (e.g., Pitt 2010; Kraus 2011; Krause 2012; Sharp et al 2011; Reckien et al 2018). While understanding the reason for adoption is important for regions where CAPs are not common, California has policies directing cities and other local jurisdictions to develop CAPs. As such, the more relevant literature for this study focuses on understanding the quality and thoroughness of CAPs and their level of consideration of factors important for their implementation. Tang *et al*

(2010) reviewed CAPs in the US and found that while most showed awareness of the problem of climate change, and the need to address it, they conducted simplified assessments of GHG reduction, did not consider co-benefits or harms, and did a poor job of establishing actionable steps. A more recent study developed a system to rank CAP robustness and found that some US CAPs could greatly benefit from intra-regional collaboration and extra-regional support to improve CAP development and implementation (Deetjen *et al* 2018). However, collaboration between local governments may be hindered by the lack of regulatory frameworks to guide such interactions (OECD 2010). A study of CAPs developed in Brazil also found issues with quality and robustness, and in particular with the completeness and transparency of carbon accounting methods used in CAP development (Baltar de Souza Leao *et al* 2020). Earlier research by Blackhurst *et al* (2011) anticipated this kind of problem, arguing that CAPs should report uncertainty in their emissions inventory, and additionally that they should disaggregate sectors and link emissions to local organizations to increase accountability.

An additional challenge for making CAPs more robust is the lack of consensus on criteria for evaluating CAP strategies, not to mention an accompanying prioritization framework that could be used for evaluation (OECD 2010; Neves 2013; C40 2017). Only one previous study was found that proposes a general framework for use in local government climate action planning. Balouktsi (2019) proposes a multi-criteria decision analysis framework that considers quantitative economic and environmental data, qualitative social and technical data, and stakeholder preferences. Because this framework attempts to integrate many factors that affect decision-making, its application may not be feasible for many local governments. A separate study applied a CAP model that would aid in action prioritization for the City of New York (C40

2017). While this CAP framework includes scoring rubrics for (co)benefits and feasibility, it is apparent that the prioritization relies first and foremost on GHG reduction potential, followed by cost. Unfortunately, this framework for the City of New York (as well as the framework proposed by Balouktsi) did not quantify the life cycle emissions and costs of the proposed actions, specifically by not considering impacts and costs across all life cycle stages of the proposed climate actions.

Given the lack of a quantitative, decision-oriented framework for CAPs and local government climate change mitigation more broadly, the study presented in this paper develops a life cycle-based marginal abatement cost curve framework and applies it to two case studies.
MACCs have previously been used to assess strategies across various sectors in the US (Lutsey and Sperling 2009), internationally across various sectors (Moran *et al* 2010; de Souza *et al* 2018), and in the transportation sector for a state department of transportation (Harvey *et al* 2019). While the MACC approach is limited, insofar as it is two-dimensional (life cycle cost and GHG mitigation potential only), it provides easily interpretable quantitative analysis that can help guide prioritization of climate action strategies. When jurisdictions have limited resources, this can be a first step for including quantitative analysis in deliberations over which strategies to prioritize.

2.2. Problem Statement

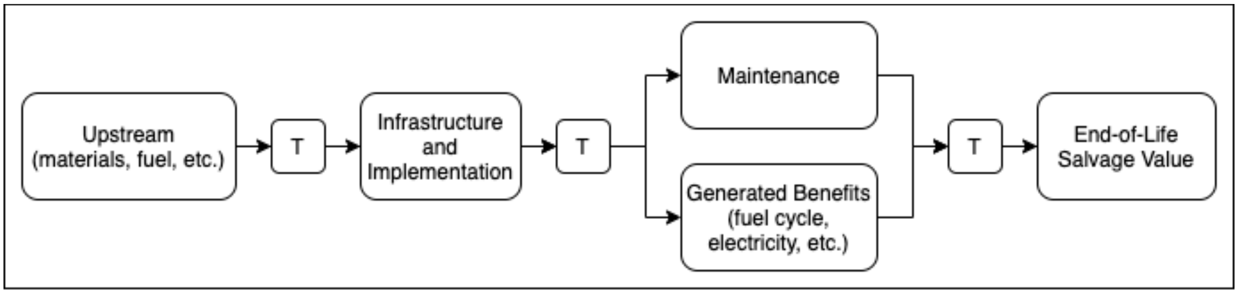
The goal of this research is to deliver a decision support framework for assessing the expected life cycle GHG (LCGHG) mitigation and life cycle cost (LCC) of mitigation actions considered by local governments resulting in a GHG marginal abatement cost curve (MACC). The mitigation actions considered here are limited to the transportation sector, but the framework could in theory be applied across all sectors. The framework and tool will provide two benefits: first a robust method that provides local governments with a set of actions with quantified GHG mitigation values; and second, given constraints on funding faced by all jurisdictions and agencies, the use of this tool could lead to increasing mitigation targets or achieving existing targets at less cost. These advantages are not unique to this particular application of a MACC. However, the vision for replicable MACC decision-support developed for CAPs has not previously been tested. In California, only one CAP-related MACC was identified (Romanow *et al* 2018). More broadly, two transportation-related MACCs were found (Lutsey and Sperling 2009, Harvey *et al* 2019), both focusing on state-level strategies, and only Harvey and colleagues considered emissions on a life cycle basis.

2.3. Materials and Methods

A life cycle GHG MACC offers the ability to combine and compare the impacts and cost-effectiveness of a wide range and large number of GHG mitigation options. Borrowing from economics theory, the MACC approach shows graphically the supply of a given resource (on the x-axis) that is available at a given price (on the y-axis). Depending on the use and derivation of the costs and cumulative emission reduction data, the curves can more aptly be labeled as marginal abatement, incremental cost, cost of conserved carbon, or cost-effectiveness curves. When shown as blocks for the effects of discrete changes, such as from different actions, the curves can show the incremental contribution to achieving a goal and the decreasing cost-effectiveness as additional actions are taken. This approach also uses life cycle, rather than direct, emissions accounting. LCGHG emissions accounting considers emissions generated throughout the supply chain of a product or process, and also typically considers system-wide or consequential effects on emissions as well. A carbon footprint (CF) is a narrow implementation of life cycle assessment (LCA), since LCA typically includes a larger number of environmental impacts in addition to GHGs. The goal of LCAs, especially those implemented to understand the prospective impacts of a policy or technology, typically includes anticipating unintended consequences, positive or negative, of a product, policy, or action.

To test the viability of the framework, it was applied to two case study jurisdictions. After cataloguing potential GHG mitigation strategies pulled from existing CAPs, jurisdictions and stakeholders were contacted to identify local governments interested in partnering to compile data and develop MACCs tailored to their conditions. Two California counties, Yolo County and Los Angeles County, agreed to participate as partner jurisdictions, and were interested in evaluating several GHG mitigation strategies in their respective CAPs. For each selected strategy, the LCGHG emissions and LCC were calculated.

The LCGHG and LCC are calculated over a 25-year analysis period, and life cycle cost calculations include a 4 percent discount rate, a long-term rate typically used in California state government economic analyses. With respect to the LCC, there are costs and savings that apply to the implementing agency as well as other affected parties. Because these results are meant to inform the spending of agencies, the life cycle agency cost is reported, which excludes user and other social costs. A generalized system boundary is provided in Figure 2.1, and equations describing LCGHG calculations and LCC are shown in equations 1 and 2, respectively.



Note: "T" stands for transportation-related impacts between stages.

Figure 2.1. A generalized system boundary that captures the phases of emissions reduction strategies that were analyzed.

$$LCGHG = \sum_{x=0}^{25} Emissions\ produced_x - Emissions\ reduced_x$$

$$LCC = \sum_{x=0}^{25} (Incurred\ costs_x - generated\ benefits_x) * (1 - 0.04)^x - salvage\ value_{x=25}$$

Yolo County prioritized the evaluation of four transportation strategies: intercity bike lanes, converting stop-start intersections to roundabouts, installing solar panel canopies on county parking lots, and full depth recycling (FDR) in lieu of conventional pavement rehabilitation methods. Interestingly, Yolo County's strategies all focused on interventions having to do with pavements and hardscapes. Los Angeles County prioritized two strategies, both of which focused on changing vehicles: electrifying transit buses, and implementing alternative fuels for the county-owned vehicle fleet. The following sections describe the modeling approaches used to represent the strategies and the results of prioritization for each county.

2.3.1. Yolo County strategies

2.3.1.1. Intercity bike lanes

This strategy analyzes the impacts of building new bike paths and lanes between various communities across Yolo County. The new construction is expected to reduce vehicle travel by moving some fraction of drivers out of vehicles and onto bicycles, thereby reducing vehicle travel and associated emissions. In this LCA, the functional unit is defined as the new construction and maintenance of 1 km of bike path or lane over a 25-year analysis period. In addition to the construction and maintenance phases, this analysis also considers the effect of the new infrastructure on vehicle miles traveled.

Bike paths are designed and built to be physically separate from vehicle roadways. Newly constructed paths are 3.05 m (10 ft) wide and 0.115 m (4.5 in) thick and are expected to last 15 years before needing maintenance (Bicycle Plan 2011). Bike lanes not separated from vehicle roadways are assumed to be constructed as 1.22 m (4 ft) wide extensions on both sides of an existing road and are the same thickness as bike paths (Yolo County TAC 2013). Both cases assume conventional asphalt concrete (6% binder and 94% aggregate) is used for construction and maintenance. The maintenance consists of milling 0.045 m (1.8 in) of the surface later and overlaying a 0.06 m (2.4 in) thick asphalt layer at 15 years. The life cycle inventories (LCIs), which track the material inputs and outputs of processes and are used to quantify the resulting net changes GHG emissions, used for the analysis were developed by the UC Pavement Research Center (UCPRC) (Saboori *et al* 2020). The cost of materials, construction, and maintenance were estimated using the Caltrans Cost Data Book (CCDB) (Caltrans 2018). An adjusted unit price value was selected based on the average of several projects.

The net impact of the new bike paths and lanes on GHG emissions is dependent on the change in vehicular travel induced by the availability of bicycle infrastructure which could induce some vehicle trips to be replaced with bicycle trips, thereby reducing motorized vehicle travel. While there is debate surrounding the estimation of this change, this study used a calculator developed by the California Transportation Commission Active Transportation Program through the California Air Resources Board that estimates the impacts of new bike infrastructure based on the expected changes in vehicle miles traveled (CARB 2016a, 2016b). The calculator requires the user to input average daily travel (ADT) in both direction of the roads parallel to the proposed bike infrastructure. The ADT data relevant to the proposed infrastructure were acquired from the traffic count of three cities in Yolo County: Davis (City of Davis 2019), Woodland (City of Woodland 2015), and West Sacramento (City of West Sacramento 2017). Note that the city of Davis is home to the University of California, Davis (UC Davis), a major destination for residents across Yolo County. Davis has extensive bike infrastructure used by permanent and seasonal student residents alike. It is therefore assumed that the roads are used for 200 days annually, which is the average number of annual academic working days. Note, however, that Davis leads the country in commuters traveling by bicycle, at nearly 20% (McKenzie 2014). This calculator may, therefore, underestimate displaced VMT resulting from additional infrastructure in Yolo County. Additional information on the methods, assumptions, specific data, and sensitivity analysis on VMT replacement can be found in Kendall *et al* (2020a, Section 3.2).

2.3.1.2. Full depth recycling compared to conventional pavement rehabilitation methods

Yolo County plans to fund a rehabilitation project on a 5.2-mile-long portion of South River Road, a rural road south of West Sacramento. The considered options are as follows:

- Mill-and-fill that mills 5.1 cm (2 in.) and overlays 10.2 cm (4 in.) of asphalt
- FDR using 3 percent portland cement (FDR+PC) with a 6.4 cm (2.5 in.) asphalt overlay
- FDR using 2.5 percent foamed asphalt and 1 percent portland cement (FDR+FA+PC) with a 6.4 cm (2.5 in.) asphalt overlay

The methodology used follows the Federal Highway Administration (FHWA) guidelines for conducting pavement LCA (Harvey *et al* 2016). The LCA estimates and compares the energy and material consumption of the three rehabilitation options across the material production stage, transportation of materials to the site, and construction activities. The system boundary also includes the transportation of the waste materials to asphalt plants for recycling or landfills when conducting mill-and-fill. All transportation distances are assumed to be 80.5 km (50 miles).

It is assumed that each rehabilitation option must be repeated every 10 years. It is also assumed that the options perform equally (no difference in degradation or effects on travel) throughout the analysis period. The cost of construction was acquired from the CCDB (Caltrans 2018). The life cycle inventories (LCI) used for the analysis were developed by the UC Pavement Research Center (UCPRC) (Saboori *et al* 2019). Additional information on the methods, assumptions, specific data, and sensitivity analysis can be found in Kendall *et al* (2020a, Section 3.5).

2.3.1.3. Converting stop-start intersections to roundabouts

There are busy intersections across Yolo County with stop signs which require vehicles to come to a complete stop before proceeding. This strategy examines the impacts of constructing intersections with roundabouts instead of typical intersections with stop signs. Roundabout intersections reduce the amount of braking and acceleration required, thereby reducing fuel consumption and related emissions. Specifically, this analysis considers the construction and maintenance of each option, as well as the difference in operation of the vehicles, for three intersections along County Road 98 over a 25-year analysis period. It was assumed the roundabout will be constructed using portland cement concrete (PCC) while the traffic lanes will have a hot mix asphalt (HMA) top layer. The central structure is assumed to require no maintenance, whereas the roads will require a "mill and overlay" treatment every seven years, which consists of milling 0.045 m (1.8 in.) of surface layer and overlaying a 0.06 m (2.4 in.) thick conventional asphalt concrete layer. It is assumed that there is enough funding for this frequency of maintenance.

The Caltrans Cost Data Book (CCDB) provided the relevant cost information used (Caltrans 2018). The use stage, which includes user costs[1] and impacts, accounts for well-to-pump (WTP) and pump-to-wheel (PTW) impacts. WTP data were acquired from Argonne National Lab's (ANL) Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation Model (GREET) for diesel and gasoline (ANL 2017). PTW data were estimated using the U.S. Environmental Protection Agency's (EPA) MOtor Vehicle Emission Simulator (MOVES) (EPA 2015). It is assumed that the vehicles approaching the intersection travel at 72.4 km/hr (45 mph). In the case of a roundabout, the vehicle can freely pass the intersection at 24.1 km/hr (15 mph), whereas in case of an intersection with stop signs, the vehicles must stop for few seconds before accelerating again to 72.4 km/hr (see Figure A.2.3). ADT data for County Road (CR) 98 were acquired from the City of Woodland traffic counts (City of Woodland 2015), while that of the three roads connecting to CR98 were acquired from City of Davis traffic counts (City of Davis 2019).

[1] Note that user costs are not included in the results of this report.

2.3.1.4. Installing solar panel canopies on county parking lots

Parking lots can double as electricity production sites through the installation of solar canopies. These structures not only support solar photovoltaic (PV) panels that produce electricity from sunlight, but they also provide shade and protection to the vehicles parked underneath. This strategy assesses the installation of solar canopies in various Yolo County owned parking lots. The scope of installation was determined by assessing a list of potential county-owned sites developed primarily in conjunction with the Yolo County Department of General Services. Sites considered in the assessment had minimal to no tree cover, thereby reducing the environmental impacts and cost of plant removal required for the installation of solar canopies. Within sites, solar canopies were assumed to be installed over double-row parking spaces (where two rows of vehicles are parked facing each other) since single-lane parking spaces were often near the perimeter of the sites and therefore had more nearby plants and trees.

The foundational carport design modeled in this study covers six parking spaces—three rows of cars in double-row parking spaces—and is based on the design published by Structural Solar (2013). Each solar canopy can support 48, 1 kW solar panels with dimensions of 1 by 0.68 m (39.7 by 26.7 in.), and it was estimated that a total of 104 such structures could be installed across all sites. The estimated emissions and cost consider the material requirement for the supporting structure and the solar panels, as well as construction, maintenance, and end-of-life. The approximate solar canopy model and the final list of sites can be found in Kendall *et al* (2020a, Section 3.4.2).

Because studies on the life cycle emissions of solar PV have varying assumptions about efficiency, irradiance, lifetime, and more, a critical study by Hsu *et al* (2012) harmonized results to provide an average emissions factor: 52 g CO_2e per kWh. Using the harmonizing assumptions, these results could also be reported as 276 kg CO_2e per square meter of panel. Combining this with the area covered across all installations results in a total rated solar capacity of 0.71 MW. Using average electricity production values in California, these installations are expected to produce nearly 3.2 MWh of electricity at peak performance (Sendy 2017). It is assumed that the solar panels have a lifetime of 25 years and a 0.5% annual performance degradation rate, consistent with the literature (Hsu *et al* 2012).

The solar panels are supported by the carport structure, the materials of which were modeled after the information published by Carport Structures Corporation (2019). All beams are steel, and the primary load-bearing beams are supported by a portland cement concrete base to protect from vehicular damage. The total material needed was determined by designing solar carport installations for each site and referencing the model developed by Structural Solar. The life cycle emissions of steel were acquired from the EcoInvent database (Wernet 2016), and of PCC from Saboori *et al* (2020). The cost of installation was estimated by referencing the prices listed by the California-based Solar Electric Supply (2019). A median price of installation for projects between 50 and 250 kW (a range which each individual location assessed fell into) was $1.40 per kW.

The electricity produced by the solar carports is added to the grid, and Valley Clean Energy (Yolo County's primary utility) confirmed that the energy would most likely qualify for monthly net metering. That is, the electricity produced would offset the charges of electricity consumed through a monthly credit, as long as the energy produced is not greater than the energy consumed (which is unlikely). This means the electricity is valued at market price, which was assumed to be $0.10 per kWh given the variability in the size of the nearest facility and the chosen rate plan. Due to high uncertainty surrounding electricity price forecasting, the price of electricity is assumed to be constant. This electricity would offset emissions from electricity production at the statewide level. Therefore, this study assumes the displaced emissions are a function of the average California electric grid carbon intensity over the 25-year analysis period, which was estimated using the Energy Information Administration's (EIA) Annual Energy Outlook's projected grid mix (specifically from 2020 onward; the grid mix has been provided in the Appendix) combined with the fuel source emissions values provided by the GREET 1 model (ANL 2017). Additional information on the methods, assumptions, specific data, and sensitivity analysis can be found in Kendall *et al* (2020a, Section 3.4).

2.3.2. Los Angeles County strategies

2.3.2.1. Electrifying the Foothill Transit bus fleet

This strategy examines the electrification of the Foothill Transit bus fleet, which serves incorporated and unincorporated regions of Los Angeles County. This transition to electric buses (E-buses) reduces GHGs compared to compressed natural gas (CNG) buses through reduced use stage emissions. The transition plan was laid out in the In Depot Charging and Planning Study developed by Burns & McDonnell Engineering Company, Inc. (B&M 2019) for Foothill Transit. Specifically, it determined the fleet size, required infrastructure including installation of solar PV to support energy needs, maintenance requirements, expected electric energy needs, and expected cost. The electrification scenario is compared to one where the organization continues relying on CNG buses.

The LCI data used in this analysis were acquired from the GREET model (ANL 2018). This included glider data (the vehicle excluding the powertrain) of both CNG and electric buses, as well as data on batteries for the latter. Though no studies estimated the production-phase emissions of 43-foot double-decker bus gliders, it was deemed justified to assume they produced comparable emissions to 60-foot single deck buses based on a comparison of curb weights. Maintenance-phase emissions were estimated using an economic input-output life cycle assessment (EIO-LCA) model (Weber *et al* 2009), which relates the environmental impacts of a sector to the economic value of sets of activities, thereby allowing one to estimate impact from cost. Using methodology developed by Ercan *et al* (2015), EIO-LCA data on automotive repair and replacement were used to estimate the emissions from engine repair. It was assumed that engine repair or replacement is required every six years. Electric buses were assumed to need battery replacements every six years as well. The resulting emissions were estimated using GREET-derived values.

The report by B&M estimated the annual electricity consumption for the fleet. Additionally, they considered the installation of new solar panels to be installed gradually up to a total capacity of over 1.3 MW. Therefore, the demand would be met partially through on-site solar, with the remainder provided by the local utility. This study considers emissions rates for both sources. The emissions rate for solar and for the average grid were calculated using the same methodology outlined previously in the section "Installing solar panel canopies on county parking lots." The quantity of energy provided by each source was specified in the B&M report, and this information was combined with the calculated emissions rates to estimate the use-phase emissions of the electric bus fleet. As for charging the buses, it was assumed that 325 W chargers are installed annually as the fleet grows and are replaced every 12 years. The emissions rates were taken from a study by Bi *et al* (2018) which provided values for chargers up to 100 W. Bi *et al* argued that charging capacity scales linearly with material required, so this study assumed that environmental impacts scale linearly as well. It was also assumed that the trend can be extrapolated beyond the charging capacity examined by Bi *et al*.

The use-phase emissions for the electric buses were derived from the reported annual electricity use provided by B&M. These data were combined with a model of the annual average carbon intensity of the California electric grid (by combining EIA's projected consumption-based grid mix with GREET's fuel source emissions--as described at the end of Section 3.1.4) to estimate the annual GHG emissions generated through charging. The use-phase emissions of CNG buses are linked to fuel use. B&M did not report current fuel use rates or the annual distance traveled by the bus fleets. Annual distance traveled was derived by combining the reported electricity use of electric buses with an assumed average fuel economy for electric buses. It was assumed that CNG buses and electric buses travel the same distance. This value came out to be 30.6 million kilometers (approximately 19 million miles) traveled by the buses annually. The kilometers driven by either type of bus was estimated by comparing the electric buses available in a given year to the average number of electric buses available over the analysis period. The emissions rate for CNG travel was acquired from the Mobile Source Emission Inventory (EMFAC) released by the California Air Resources Board (2017). This study assumed an average bus speed of 32 km/hr (20 mph). Additional information on the methods, assumptions, and sensitivity analysis can be found in Kendall *et al* (2020a, Section 4.1).

Only part of Foothill Transit's total service affects areas in unincorporated LA County. Therefore, representatives of Foothill Transit counted the number of bus stops across their entire service area, as well as those in Unincorporated LA County. Those numbers were 1,935 and 260, respectively. Approximately 13.4% of Foothill Transit's bus stops are in Unincorporated LA County. Therefore, if bus stops are assumed to be linearly related to the service provided and consequent emissions, 13.4% of total emissions reductions achieved by electrifying Foothill Transit's bus fleet can be attributed to Unincorporated LA County. However, the number of routes that stop at each bus stop is closer to 10%. Thus, an estimate using bus stops finds that between 10 and 13.4 percent of costs and emissions reductions from a transition to E-Buses can be attributed to Unincorporated LA County. An average of 11.7 percent was used.

2.3.2.2. Implementing alternative fuel vehicles for the LA county fleet

This strategy examines the life cycle environmental impacts and life cycle costs of transitioning all 3,913 vehicles in the LA County fleet to alternative fuel vehicles (AFVs): either electric or biodiesel. The study compares the business-as-usual case, a gradual transition to AFVs based on each vehicle's date of purchase, and an all-at-once scenario where all vehicles transition to AFVs within the first year. The analysis is split into two parts: the vehicle cycle, which includes vehicle production (all processes from raw material extraction to delivery of the vehicle to the end user) and vehicle end-of-life (which includes recycling, landfilling, or transferring to a third party for which a salvage value is assigned); and vehicle use, which captures the emissions and cost of fuel production (well-to-pump, or WTP) and combustion (pump-to-wheel, or PTW), as well as maintenance and repairs.

Current information on the LA County fleet was provided by the county's Internal Services Department (ISD)[2]. These data included the model year, make, fuel type, lifetime accrued miles, fiscal year (FY) 2018-2019 distances driven, fuel dispensed, fuel economy (if known), FY 2018-2019 maintenance and repair costs, and department of use. Historical data on vehicle fuel efficiency was compiled from the EPA (2019) and the EIA (2019). This information was combined with data on the annual vehicle miles traveled (AVMT) to estimate the fuel consumption of each vehicle in the fleet. The EIA also provided projections of fuel efficiency according to vehicle and fuel type.

Life cycle cost was calculated by accounting for fuel prices, purchase prices of new vehicles, maintenance, and salvage value of vehicles at the end of the analysis period. The Alternative Fuels Data Center (2019) published historical prices of alternative fuels, reported in dollars per gasoline gallon equivalent (GGE). These values were combined with the previously estimated fuel efficiency data to calculate the cost per mile traveled for each vehicle-fuel combination. While most projected prices for fuels are available through the EIA (2019), they only provide projections for regular diesel. To estimate the projected price of B100 (100 percent biodiesel) and B20 (biodiesel blended with petroleum diesel at 20%), a price ratio of these fuels compared to regular diesel was calculated for the past three years. These price ratios were then applied to the projected price of regular diesel to estimate a projected price for B20, B100, and RD100 (100

[2] Provided on November 27, 2019 by Randy Martin <RMartin@isd.lacounty.gov>

percent renewable biodiesel). Correction factors were determined by comparing historical energy prices of California and the US national average, and subsequently applied to the price of gasoline, diesel, electricity, and natural gas.

Vehicle prices included in this study include both past and future values. Historical purchase price data were acquired from the California Department of General Services, which captures purchases made by all state agencies. Their 2011-2014 database was used to acquire information on purchases made after 2004. Using linear regression, a trend was estimated to relate the vehicle price and age for all vehicle types. Price projections for all vehicle-fuel combinations were provided by the EIA (2018). This information was also used to estimate the salvage value of vehicles at the end of the analysis period given the amount of time before their end of useful service life.

The environmental impacts of the vehicle cycle include the energy consumption and GHG emissions from raw material extraction through delivery of the new vehicle. There are also impacts at the end of the vehicle's service life, particularly from landfilling or recycling. Additional items included in this LCA are fluids, batteries, and tires. Nearly all data used in this portion of the study were compiled from the GREET model (ANL 2017), unless stated otherwise.

The environmental impacts of fuel use considered in this study include pre-combustion (WTP) and combustion (PTW). Combined, these impacts are referred to as well-to-wheel (WTW) and are reported in grams of CO_2e per mile traveled (the scope of each of these categories is depicted in Figure A1). The LCI data needed to characterize fuel use impacts was taken from the GREET WTW Calculator tool (ANL 2018). The fuel mix for the 2018 California grid and the pathways for biofuel production (specifically for different blends of ethanol and gasoline as well as of biodiesel and diesel) were acquired from the GREET model (ANL 2017). Additional information on the methods, assumptions, specific data, and sensitivity analysis can be found in Kendall *et al* (2020a, Section 4.2).

2.3.3. Sensitivity analysis

To understand how results change by varying a number of factors, various sensitivity analyses were conducted. The following are included in the results. For solar canopy installation, a range of installation costs was considered (+/- $0.20 per W), as well as lower solar PV life cycle emissions (24 g CO_2e / kWh, from Fthenakis & Kim 2010). For converting intersections, sensitivity was conducted on the traffic rate (+/- 10 percent) as well as on user fuel cost, but the latter does not affect agency cost so it is not reported alongside the MACC. For alternative fuel vehicles, a range of adoption rates was considered, from gradual implementation to all-at-once.

For electrifying the Foothill bus fleet, the study considered the following scenarios: (i) acquisition of relevant subsidies, and (ii) omitting the assumption that solar panel installation offsets electricity consumption from the grid. In reality, the electricity generated from the installed solar panels is added to the grid through a net-metering arrangement, and the bus fleets therefore still pulls all of its electricity from the grid. Therefore, two methods of electricity accounting are considered: first, in the baseline case, the fleet is modeled as if the solar energy it produces is used to directly charge its buses, and draws the remaining demand for electricity from the grid. In the second case, recognizing that 1.3 MW of solar has only a marginal effect on the GHG intensity of the greater grid mix, the carbon intensity of the electricity consumed by the fleet is essentially unchanged from the projected value and thus the fleet is assigned the average projected grid emissions for all their demanded electricity. Under both scenarios, the fleet is still credited for the monetary benefits generated by net metering from their solar panel installations.

Additional information on the methods, assumptions, specific data, and sensitivity analysis can be found in Kendall *et al* (2020a, Section 3.3). The data for all evaluated strategies can be found in a data repository (Kendall *et al* 2020b).

2.4. Results

Summaries of individual results are followed by

Table 2.1, which reports the results for each strategy evaluated based on net life cycle costs to the agency and net life cycle greenhouse gas emissions over a 25 year analysis period, including a range of values based on relevant sensitivity analyses. Results are then presented in MACCs.

Results for intercity bike lanes show that the strategy fails to achieve GHG reductions and does not lead to agency savings. Emissions associated with the installation and maintenance of the bike lanes and paths were greater than the emissions avoided through reduced vehicle travel. Because only agency costs were considered, and the strategy requires investing in new infrastructure, it was inevitably going to lead to a net increase in cost to the agency. If the scope of this calculation had included user costs, there is some chance that user savings (by reducing costs of vehicle use) could have reduced the net total cost associated with this strategy.

Installing roundabouts also requires a higher initial agency cost for construction than stop-start intersections. However, in a life cycle perspective, almost $19,000 is saved in life cycle agency costs due to lower material needs and subsequent costs during maintenance. About 97,000 tonnes of reduction in life cycle GHG emissions is estimated due to decreases in pavement infrastructure maintenance compared to a stop-start intersection and decreased fuel emissions due to changes in vehicle drive cycles.

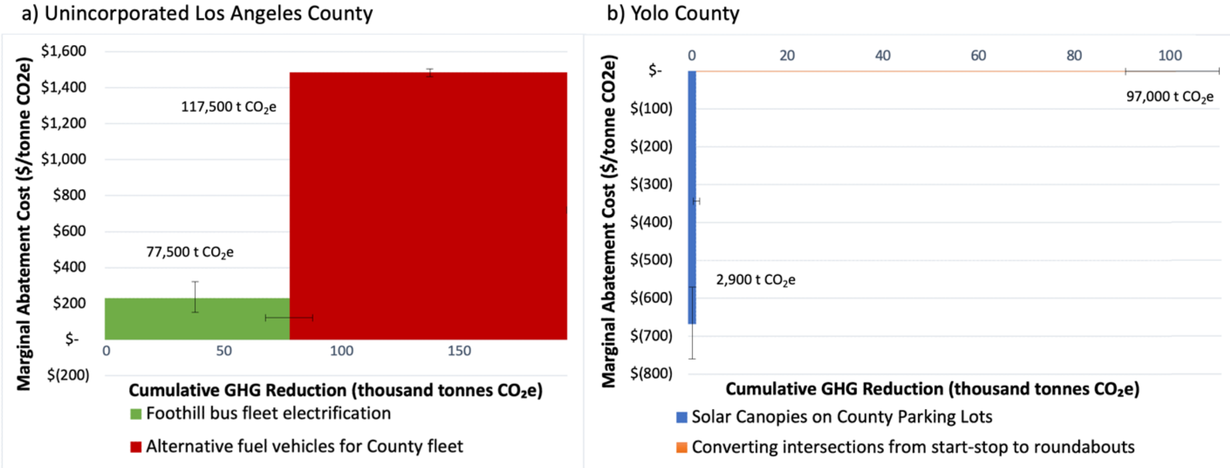
While there is an initial cost associated with the installation and maintenance of the solar canopies, net metering reduces the County's utility costs, leading to a negative life cycle agency cost. The emissions reductions achieved by producing renewable electricity (which reduces the amount of electricity from non-renewable sources) also offsets the positive emissions associated with installing and maintaining solar canopies. Thus, installation of solar photovoltaic on county parking lots provides the dual benefits of life cycle cost savings and emissions savings.

Both types of FDR examined for pavement rehabilitation are cheaper to employ than the traditional mill-and-fill, but they produce a negligible increase in GHG emissions. Therefore, employing either FDR strategy on South River Road would likely save money, but they are not GHG reduction strategies.

Including production, maintenance, use-phase, and end-of-life emissions for bus fleet electrification shows that it would indeed reduce GHG emissions, but at increased cost compared to business-as-usual. The referenced report provides the life cycle cost of this transition but does not clearly lay out what the initial costs (purchase of the buses and required charging infrastructure) would be.

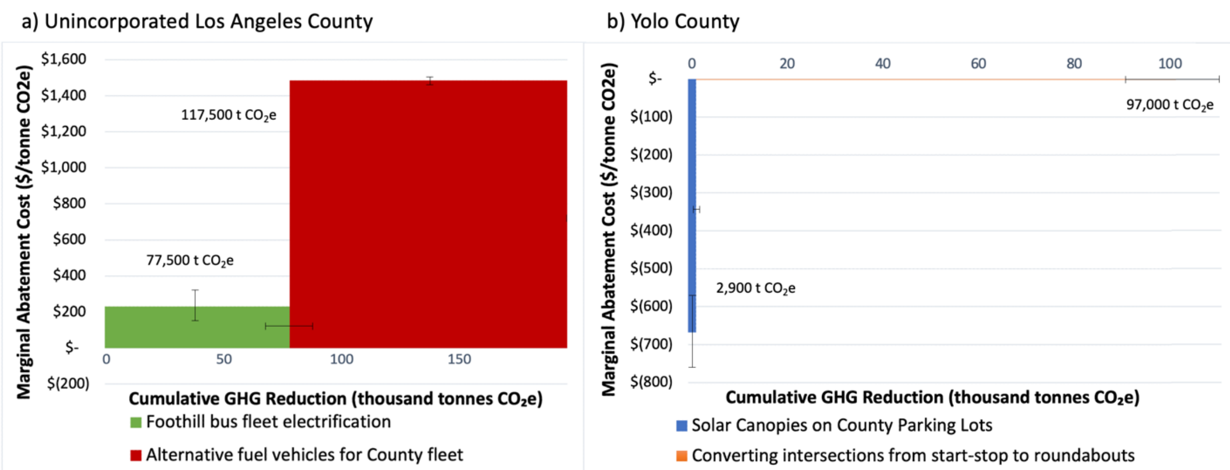
The results show that AFV adoption is a viable path to GHG reduction but at a higher cost than other strategies. The sensitivity of the adoption rate was explored and found that the results were consistent across adoption rates. Both reduced life cycle emissions by about 15.9% and increased life cycle cost by about 23% as compared to the BAU scenario.

The analyses found that of the four strategies analyzed for Yolo County, intercity bike lanes are expected to lead to a net increase in emissions over their life cycle, as do FDR options for pavement rehabilitation (though that increase is negligible). For this reason, the MACC produced for Yolo County includes just two strategies of the four examined (



Note: Error bars have been added to the x- and y-axes to represent the range in emissions reduction and cost, respectively, as determined by the sensitivity analyses.

Figure 2.2a). On the other hand, both strategies assessed for LA County are expected to reduce GHG emissions and are thus included in the MACC (



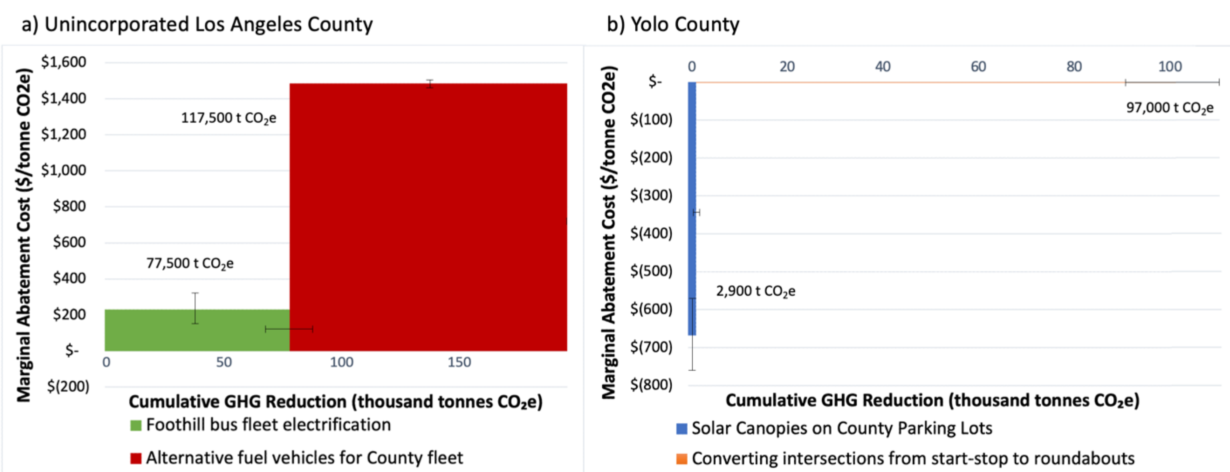
Note: Error bars have been added to the x- and y-axes to represent the range in emissions reduction and cost, respectively, as determined by the sensitivity analyses.

Figure 2.2b). Additional insight on the breakdown of life cycle emissions and costs can be found in the Appendix (Figure A2 – A6, Tables A2 – A8).

Table 2.1. Life cycle GHG mitigation and LCC results of each strategy evaluated.

	Initial Agency Cost	Life cycle Agency Cost	Life cycle Emissions Reduction (tonnes CO2e)	Cost per tonne CO2e reduction
Yolo County				
Intercity bike lanes	$103,000,000	$146,000,000	-15,000	N/A
FDR options for pavement rehabilitation	$(3,080,000)	$(3,080,000)	-60	N/A
Converting intersections	$60,000	$(19,000)	87,000 to 107,000	-$0.2
Solar canopies	$ 979,000	$(770,000)	1,470 to 2,210	-$572 to -$763
Los Angeles County				
Foothill bus fleet electrification	Undetermined	$25,400,000	78,000 to 87,000	$133 to $327
Alternative fuel vehicles	$718,000,000	$173,000,000	117,000 to 118,000	$1,477 to $1,494

NOTE: Parenthetical costs are net savings (negative cost), and negative life cycle emissions reduction values are net positive emissions.



Note: Error bars have been added to the x- and y-axes to represent the range in emissions reduction and cost, respectively, as determined by the sensitivity analyses.

Figure 2.2. a) MACC for Los Angeles County showing the results of the two analyzed strategies. b) MACC for Yolo County highlighting the two viable GHG reduction strategies of the four options analyzed.

2.5. Discussion

The MACC approach presented, and tested for Yolo and LA counties, demonstrates the practicality of quantifying GHG reductions of CAP strategies and prioritizing them based on their cost-effectiveness. An additional benefit of quantification is identification of strategies that may not deliver GHG mitigation. For example, during the quantification process, the bike lanes indicated increased emissions for the assumptions made, while the use of FDR strategy on the county road indicated similar emissions to BAU. However, it must again be emphasized that these conclusions and others should be interpreted with care, and additional work should be done considering sensitivity analysis to help determine the robustness of the prioritization, and areas of where a strategy can be changed to improve its viability. For example, the GHG reduction associated with the bike lanes hinge on their ability to reduce vehicle travel and replacing vehicle travel with bike travel will depend on geographic considerations, such as whether bike lanes are likely to serve commuters. For this reason, site- or corridor-specific data collection of potential users could improve estimates of VMT change due to bike paths and is particularly relevant for Yolo County since UC Davis is its largest employer, and the University and city of Davis, CA have high bicycle mode shares and extensive cycling infrastructure (Lee 2019; City of Davis N.D.). These conditions mean that a site-specific analysis could result in a higher substitution rate for vehicle travel on some bicycle corridors in unincorporated Yolo County, and could reverse the findings presented here. In addition, impacts other than GHG reduction must also be considered. For example, bike lanes may provide other benefits to communities, such as recreation and co-benefits such as improved health, so their failure to reduce emissions does not mean they should not be pursued for other reasons.

Overall, the framework piloted in the studies presented in this paper demonstrated that it provides information that is currently missing from many CAPs: quantification of the effects of a proposed strategy on GHG emissions, and information regarding the cost-effectiveness of alternative strategies for an agency (almost all of which have constrained budgets). This pilot study also identified challenges and opportunities for this approach. It is noted that the expected emissions and costs of a given strategy varies based on the assumptions made, as evidenced by sensitivity analyses conducted. For example, solar canopies can have a net cost under a low price assumption for generated electricity, and net savings under a high price assumption. This highlights the importance of evaluating projects with site-specific conditions prior to implementation.

Discussion is also warranted for the assumptions made regarding the carbon intensity of the electric grid. Interestingly, the two types of electricity-based projects considered—electricity generation (solar canopies) and fleet electrification (Foothill transit and LA County fleet)—have opposite relationships with changes in grid carbon intensity. For solar canopies, a grid with lower carbon intensity than initially modeled means that the emissions offset attributed to solar generation is smaller, so the expected life cycle emissions reduction of the strategy decreases. Conversely, an electricity grid with lower carbon intensity decreases the use-phase emissions of electric vehicles, thereby increasing the expected life cycle emissions reduction of electrifying a fleet (as compared to BAU). There are certainly complications surrounding these strategies, such as considering the marginal emissions rate during times of electricity production (solar canopies) or consumption (charging), not to mention the additional impacts of California's duck curve, which requires massive and inefficient load ramping in the late afternoon and early evening as solar power generation rapidly decreases, and which can lead to the curtailment of solar power (Denholm *et al* 2015). These uncertainties in how to account for electricity generation and consumption arise not just in the quantification of CAP strategies, but a myriad of other policies and practices that attempt to reduce GHG emissions, and merit additional research.

The calculation of a MACC is a snapshot in time. As such, there is a need to update data and calculations over time. For example, if a MACC value is calculated for the year starting 2020, what should that value be if it is implemented in 2025? While some changes could be anticipated, such as the future electricity grid mix, others cannot be and would likely require reanalysis. CAPs are typically updated every 10 years, but it is possible that relevant technologies or other factors change enough in that timeframe to warrant a reassessment. This could potentially be captured with sensitivity analyses, but might otherwise require additional resources to conduct new analyses. Similarly, the case studies in the two counties illustrated the challenge of data collection from the multiple divisions and agencies required to complete a CAP MACC. Implementation of MACCs for local governments will require engagement by multiple divisions and agencies, and thus requires sufficient resources and authority for coordination. There is an additional complication related to reporting. The MACC curve reflects a life cycle perspective, and a total present value of abatement. However, a jurisdiction subject to a CAP is required to submit annual production based GHG inventories. The required inventories are annual, not life cycle (nor consumption based) GHG estimations and thus the MACC estimates do not translate directly to the annual inventories. Thus, the decision-making basis—the MACC—is not directly related to how emissions are reported.

MACCs as used here assume independence of strategies, which is not always a valid assumption. Consideration should be given to interactions with the larger system of projects and policies, which some studies indicate is necessary in a prioritization framework (Givoni et al. 2013, Taeihagh et al. 2013). Further, the current implications of MACCs are limited because they are two dimensional—they consider only GHG reduction and life cycle cost—so the performance of strategies in other dimensions is not evident. Additionally, while the reporting of agency cost is relevant to the implementors of the GHG reduction strategies, a more complete perspective of the impacts would also include other stakeholders (those affected by the approach) and social costs, including consideration of the equity distribution of negative and positive impacts other than GHG reduction. Co-benefits for air quality are of particular relevance for many transportation interventions. For example, while E-buses may not immediately stand out as highly cost-effective measures for GHG reduction, mitigation of air quality emissions through electrification will likely have significant benefits for human health that also confer economic benefits to society such as reduced illness and health care costs (i.e., externalities). This study did not consider these and other co-benefits when calculating cost-effectiveness and is an opportunity for enhancing the scope of environmental benefits considered in prioritization of GHG mitigation strategies at the local scale. In other words, environmental justice concerns should be considered in the decision-making process. Many of the aforementioned shortcomings of MACC have been laid out in Kesicki & Etkins (2011). However, as stated in Eory *et al* (2018), one of the primary purposes of MACCs is to visualize the relative cost and emissions reduction opportunities of considered strategies in order to promote the complex discussion surrounding GHG reduction. Specifically, they are a useful tool when not used exclusively (Kesicki & Strachan 2011).

2.6. Conclusions

The framework presented in this research can be applied across various sectors, locations, and scales. A similar MACC framework was applied to projects in Toronto, specifically those to reduce fossil fuel use in transportation, reduce building energy use, and change the electricity energy supply (Ibrahim & Kennedy 2016). One paper presents the MACC framework applied to the industrial sector, including the hardscape sector, in Brazil, and found various cost-saving emissions reduction strategies over a 15-year analysis period (de Souza *et al* 2018). This framework could also be applied to urban hardscape and water management strategies in the United States, such as by combining with the efforts presented in Butt *et al* (2018). While not all of the aforementioned applications consider the life cycle perspective, their application of a MACC framework to a variety of projects, combined with the results of the study presented in this paper, suggest that life cycle MACCs could be developed for more projects and sectors than just the ones considered herein.

Future research should pursue solutions to challenges and opportunities for improving the MACC framework for CAP development and prioritization, with the ultimate goal of supporting quantification and prioritization for local and regional jurisdictions that face resource constraints and need decision-support for prioritizing CAP strategies.

2.7. Acknowledgements

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2.8. Data Availability

Data can be found on Kendall *et al* 2020b.

Chapter 3. Assessment of environment, economy, and equity in Climate Action Plans: The case of California

3.1. Introduction

The Intergovernmental Panel on Climate Change (IPCC) releases consensus reports documenting the causes and effects of global climate change caused by anthropogenic emissions of greenhouse gases (GHGs), increasingly focused on the tipping points we cannot surpass if we hope to avoid irreversible and existential damages from global warming (IPCC 2019). In fact, the United Nations (2019) declared human-made climate change the "defining" issue of our time. Many nations have committed to reducing their GHG emissions, and discussions center on which strategies will achieve those goals while operating on a limited budget (UNFCC 2021). In addition to emissions and cost considerations, leaders have also been considering the impacts of sustainable actions on individuals and communities, particularly those that are most vulnerable (UKCOP26.ORG 2021). Just sustainable transitions require the active consideration and participation of disproportionately affected communities in the planning and implementation process, all while providing the funding and resources for their environmental health to achieve parity with the rest of the population. While this requires collaboration across all levels of government, many cities and local governments seek guidance on managing intra-jurisdictional climate action by joining international organizations that support GHG mitigation (C40 2020, GCM 2021). While participation in these groups is voluntary, some regions explicitly require local jurisdictions to set their own emissions reduction targets and outline plans to achieve them.

California is examined as a case study on the ways that local governments address climate change and environmental equity. **Equity** refers to the equal and just treatment of all people.

This can refer to social equity, which is the fair treatment across social policy (e.g., education and other public services), racial equity, which focuses on equality across races, and environmental equity, which is the equal access to environmental benefits and impact from environmental hazards. Equitable actions, therefore, are those that promote equity across the population. For example, environmentally equitable actions will provide additional benefits to those who currently experience higher-than-average environmental burdens in order for them to achieve parity with the rest of the population.

Conversations around equity also frequently use the term justice, such as environmental equity and environmental justice. There are different dimensions of justice, with one study (Sovacool *et al.* 2019) referencing the following: **procedural justice**, the fair treatment of individuals under the law, which can manifest itself in planning as well as policy on incentives and regulations, as well as the meaningful participation of constituents in this process; **distributive justice**, the equitable distribution of benefits and burdens across populations, such as monitoring air quality or access to green space; **cosmopolitan justice**, which is the universal respect of human rights and can be pursued by tracking global impacts such as embodied emissions in products; and **justice as recognition**, which highlights the appreciation of vulnerable, marginalized, poor, or otherwise under-represented or disadvantaged populations, such as children, minorities, and indigenous peoples. There is also **geographic justice**, which refers to the sometimes spatial-based distribution of benefits and burdens (Schrock *et al*. 2015). For example, the U.S. has a history of redlining wherein certain communities, namely those with high levels of minority and/or low-income residents, were denied access to loans because they were deemed “high risk”. Over time, this would greatly cripple those communities. As one example of this ripple effect, being denied loans would lead to redlined communities receiving fewer investments and having lower-value homes, which would lower collected taxes, which would then lead to under-funded public education systems. Ultimately, red-lined communities have access to fewer opportunities and have accumulated less generational wealth than non-redlined communities (Perry and Harshbarger 2019). Relatedly, there is also **racial justice**, which consists not only of the absence of discrimination and inequities based on race, but also active efforts to achieve racial equity through proactive and preventative measures (ICMA 2021).

Among its many policies that support GHG mitigation goals, California passed the Sustainable Communities and Climate Protection Act of 2008, or Senate Bill 375, to promote local efforts to meet statewide greenhouse gas reduction goals (California Senate 2008). Specifically, it required regional GHG reduction targets. As a result, local jurisdictions developed climate action plans (CAPs) to set their own emissions reduction goals as well as outline the specific actions they will take to meet them. It also passed Senate Bill 535 in 2012 and Assembly Bill 1550 in 2016 which allocated state funds towards projects that are located in and benefit members of disadvantaged communities (DACs).

There are some studies that have looked specifically at equity in local climate planning. Portney (2003) wrote that most cities at the time did not view equity as a prerequisite for sustainability. Finn and McCormick (2011) reviewed the inclusion of equity in the sustainability documents of three major US cities and found that they tended to only mention equity at a superficial level but failed to include substantive information to guide equitable actions. Another study (Warner 2002) examined the inclusion of environmental justice (EJ) themes in local sustainability documents and found that only five cities (out of 77 examined nationwide) contained any EJ content, which was found almost exclusively in the background information of the document, and not in any policy statements or implementation strategies. A later study by Pearsall and Pierce (2010) conducted a study similar to that of Warner and found that only 31 of 80 reviewed sustainability documents had any mention of environmental justice, and those that happened to measure EJ impacts in their projects largely failed to consider procedural or distributional environmental inequities. A more recent study by Schrock et al. (2015) assessed the CAPs of 28 cities in the US and found that while most did not adequately make social equity a prominent theme in their plans, there was a slight trend in increased consideration over time.

The research in this paper builds on previous research in assessing the quantity and quality of three types of information—emissions, economy, and equity—in the CAPs released by local jurisdictions in California. These types of information can (and perhaps should) take different forms. Emissions and cost information can readily be reported as quantitative information, while equity information may be quantifiable (e.g., distributional and geographic justice), or may be more qualitative or procedural in nature (e.g., related to procedural justice and justice as recognition). Upon examining the state of local climate planning, this paper offers suggestions on ways to promote equity in sustainability documents.

By and large, states do little to provide guidance to jurisdictions on how to produce CAPs. A review of California CAPs found that while they are useful in establishing baseline emissions inventories and setting emissions reduction targets for cities and other local jurisdictions, the quality and quantity of information provided in them varies widely (Lozano et al. 2020). For example, only half of the reviewed CAPs quantified the expected GHG mitigation of proposed mitigation strategies, even fewer quantified both emissions and costs, and many entirely omitted a timeline for implementation, performance measures for the strategies, or explanations on how they will prioritize among the various strategies included. Finally, while CAPs were developed in response to state policy, there is no formal mechanism to verify that the goals and targets in CAPs are being met, or any repercussions when they are not. A large contributor to this issue is the lack of a standard for the collection of quantitative data and other metrics.

Emissions data provide insight to the current GHG emissions and expected impacts of proposed strategies. Some CAPs report a range of emissions reduction potential (low to high) while others provide point estimates. The time periods for emissions reduction estimates are typically between 10 and 30 years and are dependent on the time between publication of the CAP and the year for which emissions reduction targets have been set. For example, a CAP published in 2015 with a target for 2040 would consider a time period of 25 years and may even report expected changes over a shorter time period. Economic information may include not only the expected cost of implementation, but also any long-term costs and benefits, as well as sources of funding. The range in the quality of information is like that of emissions data. Equity themes discuss the need to distribute costs and benefits while considering that some communities face higher levels of burden than others, and they require more resources to achieve equality.

3.1.1. Environmental Equity in the United States

Policies have been passed to promote benefits in historically and presently underserved communities who experience disproportionately high amounts of social and environmental burden. In other words, they aim to advance environmental equity. Inequity in the United States can be indisputably tied to racist policies throughout the country's history. The Center for American Progress provides an excellent resource, the five-part series "Systematic Inequality in America," which examines both the history and present-day effects of policies on communities of color, such as access to housing, economic opportunity, and political participation (Solomon et al. 2019). Environmental injustices in the US can also be traced back to racial oppression and discrimination (Bell 2015). Not surprisingly, the early studies on environmental inequity actually used the term environmental racism (Pellow 2000). Environmental equality became the next predominant term, as it encompasses other factors, such as socio-economic and immigration status. The term equality argues that all populations should be equal (in terms of quality of life, access to opportunities, environmental health, etc.), from which it can be derived that resources should be split equally as well. However, it is important to consider that some populations are initially worse off and therefore need more resources to achieve parity with other populations. Therefore, researchers have shifted to using the term environmental equity, as it stresses the need to provide more support to historically disadvantaged and under-resourced populations to achieve equality.

Equity can be assessed across various scales and sectors. For example, when looking at equity in an urban setting, you may consider environmental equity (e.g., equality of outdoor air quality, water quality and affordability, and vulnerability to climate change impacts), economic equity (e.g., available job opportunities, living wage jobs, and affordability of housing and transportation), transportation equity (e.g., proximity to job centers, availability of public transit, safety of non-motorized modes of transportation), and health equity (e.g., predisposition to health complications, obesity, access to fresh food) (Martin 2011). It may also be helpful to distinguish between environmental equity and environmental justice. Whereas equity is a form of distribution where costs and benefits are allocated such that presently and/or historically disadvantaged communities achieve parity with the more privileged members of the population, environmental justice is a state of society wherein all members are granted equal protections from environmental hazards and each has a voice in the ways the environment is protected, regardless of class, race, or nationality. It is the push for environmental justice that brings about environmental equity.

3.1.2. Relevant Literature

California passed Assembly Bill 1550 which required 25% of funds from the state's Cap and Trade program to go towards sustainable projects that are located in DACs, a clarification over the language in Senate Bill 535 which funded projects that benefit them. While it is certainly impactful to tie funds directly to the location of DACs, there are some limitations to focusing exclusively on the site of implementation. Cushing et al. (2016) looked at the effects of California's Cap and Trade program on communities near GHG-emitting facilities affected by the program. Their study found that many high-emitting facilities met their compliance obligations by purchasing out-of-state offset emissions. Additionally, large emitters were more likely to rely on purchased offsets. As a result, communities near larger emitters were more likely to see increases in emissions than average. These communities were also poorer and had a higher share of people of color than those near facilities that actually decreased emissions. This highlights the importance of assessing the impacts of policies on local communities, with particular focus on the makeup of the affected communities such that low-income and minority communities are not disproportionately burdened. A related study by Fortier et al. (2019) further highlights the concern of impacts beyond the site of implementation by calling out the importance of considering the life cycle of energy systems. Specifically, the authors note that while impacts at the generation stage are certainly noteworthy, it is also important to consider the distribution of impacts across other stages of the energy system, including raw material extraction, transportation, and waste management. This perspective is particularly relevant for electrification efforts (e.g., electrifying buses and stoves), which reduce on site emissions (e.g., along travel routes and in homes, respectively) but may increase generation emissions along with the additional life cycle impacts of the greater electric grid system.

Some previous studies have examined related themes in local sustainability efforts, particularly what factors are correlated with increased sustainable efforts by local governments, such as by passing sustainable policies or committing resources (e.g., funds, personnel, etc.). Hawkins et al. (2015) posit that a city's commitment to sustainability can be affected by six factors: local sustainability priorities, regional governance, climate protection networks, interest group support, local fiscal capacity, and characteristics of the local governing institution. Ultimately, they found that local priorities, membership in climate protection networks, and participation in regional governance were all correlated with commitment of sustainability resources. In fact, participation in regional groups to address climate change was widely studied. Two such groups were of interest: the Mayors' Climate Protection Agreement (MCPA), and the ICLEI-Cities for Sustainability (formerly the International Council for Local Environmental Initiatives). One study (Pitt 2010) finds that cities engaged in regional change efforts have increased adoption of climate change mitigation policies. Krause (2011, 2012) finds that jurisdictions with higher per-capita general revenue are more likely to be part of MCPA and more likely to implement GHG reduction strategies. However, Sharp et al. 2011 found that cities with lower per-capita revenue are more likely to be part of ICLEI, but are also more likely to experience delays in implementation. This suggests that financial health of a jurisdiction, including the socioeconomic status of the population, is positively correlated with sustainable policy adoption, as was also found in Lubell et al. (2009). While intuition, and certainly many studies, suggests that financial health is positively correlated with sustainability efforts, some findings have shown that the relationship is complex. For example, Hawkins et al. (2015) found that per capita own-source revenue (money collected by a jurisdiction through taxes and fees) was not correlated with resource commitment.

There are a few other potential factors of interest. Lubell et al. (2009) found that rural jurisdictions with relatively small populations (less than 50,000) are less likely to adopt sustainability policies. Thus, there is a potential correlation between commitment of resources to sustainable action and both size and location (urban vs. rural). A finding particularly relevant to this work is that prioritization of equity is positively correlated with commitment of resources towards sustainability (Hawkins et al. 2015). Jurisdictions rated their prioritization from 0 (no priority) to 2 (highest priority), and all else equal, a one unit increase in the prioritization of equity led to the jurisdiction being 10% more likely to have a sustainability budget, and 15% more likely to have dedicated staff. This suggests that equity and sustainable efforts are positively correlated, whether it is because jurisdictions who prioritize equity commit more resources, or the availability of resources enables the prioritization of equity.

3.2. Materials and Methods

To assess the inclusion of quantitative data and equity considerations in California CAPs, a standardized approach, or framework, is needed. Because such a framework does not exist, this project develops a framework to calculate a numerical value reflecting the extent to which quantitative data or equity themes are included in a CAP. In prior research on the inclusion of equity in CAPs in major cities across the Unites States, Schrock et al (2015) developed and published a scoring rubric that is immediately relevant to the current research. They developed a qualitative coding scheme (based on work by Miles and Huberman 1994) to assign each CAP a score from 0 to 3 according to prominence and specificity of equity themes included in the plan. The score was dependent on both the quantity and quality of information provided. Each CAP was reviewed by two raters, and they considered three types of equity: procedural, geographic, and social. Their rubric was adapted in this study to include slightly more specificity, and provided inspiration for similar rubrics to quantify the inclusion of emissions data and cost data in reviewed CAPs. The scoring rubric used in this study for the three variables, emissions, cost, and equity, can be found in Table 3.1.

The developed scoring rubric was applied to a total of 33 CAPs across 32 jurisdictions (with one jurisdiction having published two CAPs thus far). A preliminary list of CAPs was compiled in Lozano et al. (2020). At the time, there was no comprehensive, up-to-date list of CAPs in California, so Lozano et al. identified CAPs using several different resources including the Institute for Local Government (for CAPs published through 2014); online searches for jurisdictions expected to have well-developed CAPs; and The Global Covenant of Mayors for Climate & Energy, an international group of local governments committed to combating global climate change and long-term sustainability, requires members to publish CAPs (GCM, 2021). This research used the list of CAPs developed by Lozano et al., and performed an additional search in mid-2021 of jurisdictions already on the list to find if any had published new versions of their CAP. The reviewed CAPs affect just over 20 million California residents, which is over half of the state's population. The distribution of jurisdictions whose CAPs were reviewed is depicted in Figure 3.1.

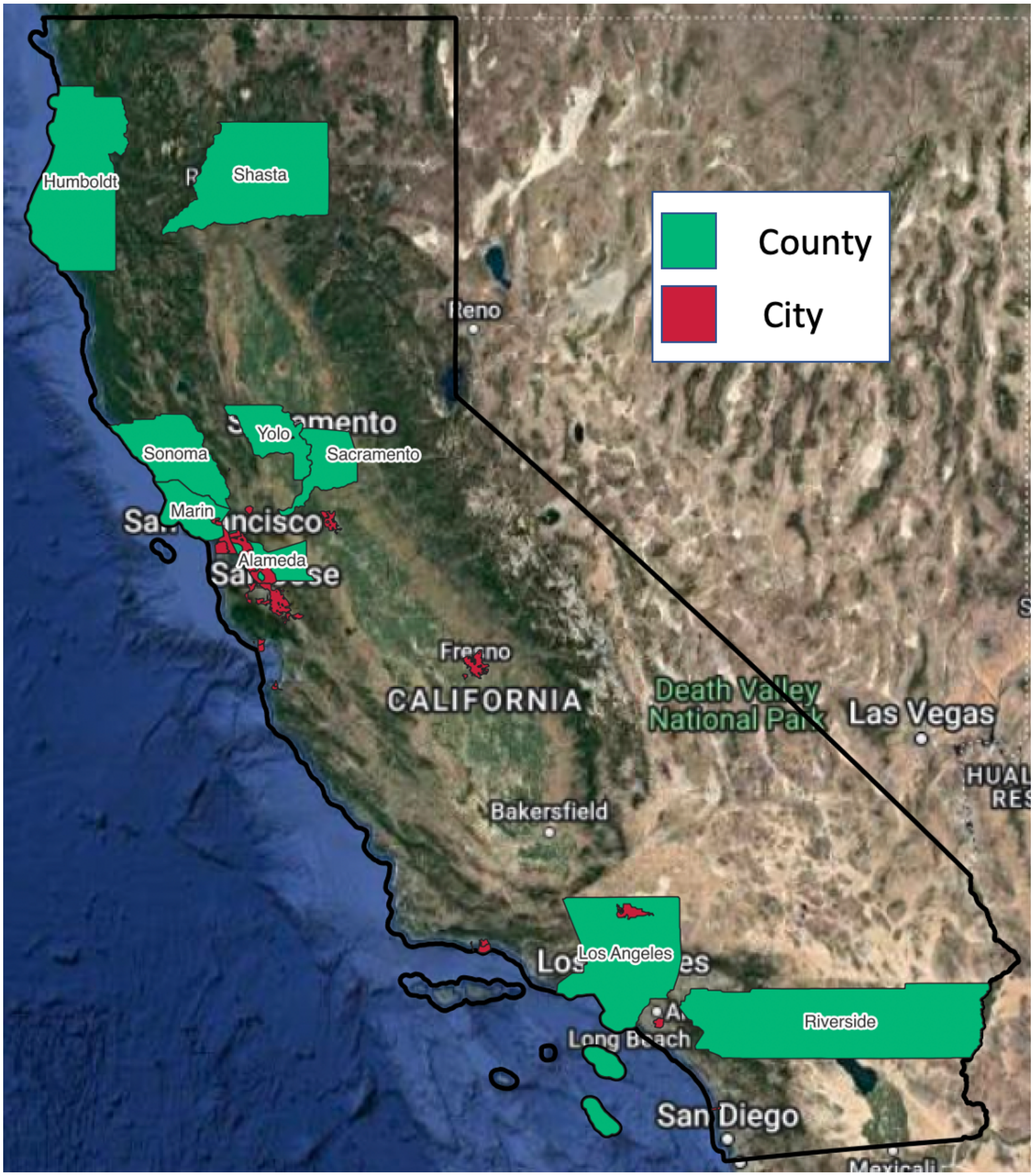


Figure 3.1. A map of the jurisdictions whose CAPs were reviewed for this study.

To assess CAPs for their inclusion of equity, CAP documents were searched for key words, including "equity", "environmental justice", and "disadvantaged community(ies)". Additionally, the introduction sections and the proposed actions were carefully reviewed in case the word-search function missed information (such as information presented in images).

When reviewing for the inclusion of emissions and cost data, researchers checked the information provided for the proposed emissions reduction strategies, the results or summary section (when available, such as in tables), and the supplementary material (when available). The documents were also searched by keywords including “life cycle” or “life cycle”, “emissions”, and “cost” to supplement the manual review. Each CAP was subsequently assigned an Emissions Score, a Cost Score, and an Equity Score according to the rubric presented in Table 3.1.

It may be helpful to give specific examples of scoring, particularly with equity, as that rubric is the most subjective of the three. If a CAP has no mentions of environmental or social equity, it earns a score of zero. A score of one is assigned to CAPs that make minimal efforts to include equity in the document. This may be a single sentence mentioning that there are equity concerns that should be considered when implementing climate actions, or interspersed inclusions of key words (e.g., equity or environmental justice) throughout the document but without much or any elaboration on what they mean or their importance. A score of two is assigned to CAPs that have a paragraph or two dedicated to explaining what equity is and why it is an important theme in sustainability, or those with sparse mentions of equity and environmental justice throughout the document but that also include whether proposed actions can improve equity. A score of 3 is reserved for CAPs that have thorough mentions of equity throughout the document. For example, a document can have an entire section dedicated to explaining what equity is and the reasons that the CAP should spearhead efforts to promote it, as well as including information by sectors or even individual strategies on how implementation is influences by the need to promote equity.

Like the study conducted by Schrock et al., the values determined by the rubric were then compared to demographic data of the jurisdictions that released the CAPs to explore any trends. Except for a CAP's year of publication (which was attained from the CAPs themselves), the collected data were drawn from the U.S. Census Bureau (2021) via their online database, wherein the jurisdiction name is matched with demographic information. Ultimately, the scores assigned by the framework were compared to: (1) year of CAP publication, (2) population of the jurisdiction (as of July 1, 2019), (3) the white non-Hispanic population, (4) the proportion of the population with a Bachelor's degree or more, (5) median household income, (6) poverty rate, and (7) population density. This data is presented alongside other pertinent CAP information in Table 3.1. The correlation between variables and the degree to which the CAPs included equity, emissions, or cost data were calculated using simple linear regression. One linear regression was performed to compare each of the three scores to the demographic data, and the scores were also compared to each other. This was to isolate the three dependent variables and examine how they are each correlated with the demographic data. An additional linear regression was performed on the combination of the three dependent variables to assess how overall robustness of the CAP is correlated with demographic data. After the initial regressions were performed using the previously listed variables, they were performed again including political leaning as an additional explanatory variable[3]. This variable used County-wide political affiliation data, specifically voter registration in 2020 (percent registered with the Democratic party) (CA Secretary of State 2021). Ultimately, eleven linear regressions were performed.

[3] The survey implemented in Chapter 5, which was conducted after the research in this chapter was completed, found that political will was one of the bigger influences on the likelihood of implementation of climate actions. This prompted the consideration of the role of politics in climate action plans. Thus, this work was revisited and the linear regressions were conducted again to include political leaning as a variable. It was decided to keep the original work and substantiate it with the original research, rather than replacing it.

Just as a framework was developed to quantify the inclusion of equity, emissions, and cost data in CAPs, it is easy to envision similar quantification of other important themes, such as the inclusion of co-benefits, stated level of community engagement, and mentions of indigenous communities and tribal lands. All of these themes warrant inclusion in climate action planning, so an additional scoring framework was developed to guide future work, as provided in Table 3.1, alongside the framework for the first three variables.

Table 3.1. A scoring rubric to quantify the extent to which various themes are included in CAPs.

Score	0	1	2	3
Equity	No mention of equity	Mentions of equity concerns or themes with little depth or specificity, or prominence as a plan goal	Mentions were more prominent but with less depth or specificity, or specific but not a prominent goal	There were both prominent and specific themes (i.e., for each proposed strategy)
Emissions	Little to no mention of expected emissions reduction, contextual or quantitative	Includes some sort of language or metric (likely qualitative) to gauge approximate emissions reduction	Has provided a quantitative estimate on expected emissions reduction that can be achieved, but does not consider the project's life cycle OR qualifies for Score 1 but also mentions life cycle impacts throughout the CAP	Life cycle consideration of emissions
Cost	Little to no mention of expected cost, contextual or quantitative	Includes some sort of language or metric (likely qualitative) to gauge approximate cost	Has provided a quantitative estimate on expected cost, but does not consider the project's life cycle AND/OR includes sources of funding for proposed actions	Life cycle consideration of costs
The following were not quantified in this study, but rather serve to guide future work.				
Co-Benefits	No mentions of co-benefits	Mentions of co-benefits with little depth or specificity	Co-benefits are mentioned more prominently but with less specificity (e.g., for the entire CAP)	Co-benefits are a prominent theme and are presented with specificity (e.g., for most or all proposed strategies)
Community Engagement	No mentions of community engagement	Community engagement mentioned with little depth or specificity	Community engagement is mentioned more prominently but perhaps only for one phase (e.g., only during planning)	Community engagement is a prominent theme and occurs across multiple phases of the project (planning, implementation, renewal, etc.)
Indigenous Communities	No mentions of indigenous communities and/or their lands	Indigenous communities are mentioned with little depth or specificity	Indigenous communities and their lands are mentioned more prominently but not thoroughly considered throughout the CAP	Indigenous communities and the importance of their lands are considered throughout the CAP and across proposed strategies

3.3. Results

Results from scoring CAPs with the developed rubric are presented in Table 3.2 by jurisdiction, along with the corresponding demographic data. Score data are also presented visually in the bubble plots seen in Figure 3.2. Each bubble is centered on the average score for that year, and the size of the bubble is proportionate to the number of reviewed CAPs that were published that year. As is evident in Figure 3.2, the cost and equity scores are, on average, generally lower than the emissions scores. Because these are the average of all CAPs from a given year, the variability within each year is not evident.

Examining the average score and year of publication is insufficient for understanding trends or patterns in high and low scores for equity, cost and emissions. To do this, the scores assigned to each CAP were compared to the year of publication and various demographic data (see Table 3.2) using simple linear regression. Additionally, the scores were regressed against each other to identify any relationships therein. The linear model tests the null hypothesis that there is no relationship between the response variables (e.g., Equity Score) and the predictor variables. One of the outputs is a t-value, which can be interpreted as a measure of relationship strength between the response and the predictor variable, such that larger t-values suggest stronger relationships. The p-value can be interpreted as the probability that the relationship between the two variables could happen by chance, such that a smaller p-value suggests a smaller probability that the relationship is randomly-occurring. Studies will establish an alpha value (typically 0.05) such that any p-value smaller than the alpha value rejects the null hypothesis, thereby rejecting the idea that there is no relationship between the two variables. The results of the eleven regressions conducted are available in the Supplementary Materials (Figures A.3.1 – A.3.11). The results from the original linear regressions are available in Table 3.3, and those for the regressions that include political leaning as an explanatory variable are available in Table 3.4. Columns contain the response variables and rows contain the explanatory variables. Statistically significant correlations have been highlighted, and the multiple r-squared value, a value from 0 to 1 which measures how well changes in the response variable are explained by changes in the explanatory variables, has been provided for each regression as well.

Table 3.2. Summary of scores and demographic data for each reviewed CAP.

Name	Year	Emissions_score	Cost_score	Equity_score	Population	White_NH	Bachelors_deg	Med_house_income	Poverty_rate	Pop_density	Democrat_registration
Benicia	2009	1	0	0	28,240	65.1%	44.7%	$103,413	7.1%	2088.1	59.6%
Berkeley	2009	1	1	1	121,363	53.3%	73.8%	$85,530	19.2%	10752.6	46.5%
Hayward	2009	1	0	0	159,203	16.2%	27.7%	$86,744	8.4%	3181.3	23.1%
San_Leandro	2009	1	1	0	88,815	23.2%	31.7%	$78,003	9.6%	6366.6	45.4%
Yolo_County	2011	2	0	0	220,500	46.0%	41.4%	$70,228	16.9%	197.9	50.7%
Fremont	2012	2	1	0	241,110	20.2%	57.0%	$133,354	4.3%	2763.9	50.7%
Humboldt_County	2012	0	0	0	135,558	73.8%	30.4%	$48,041	19.1%	37.7	48.1%
Santa_Barbara_city	2012	2	0	0	91,364	55.6%	49.2%	$76,606	12.5%	4541.3	59.6%
Santa_Cruz_city	2012	0	0	0	64,608	61.6%	53.8%	$77,921	20.9%	4705.3	49.8%
Shasta_County	2012	2	0	0	180,080	79.2%	22.2%	$54,667	13.3%	46.9	59.6%
San_Francisco_city	2013	1	0	1	881,549	40.5%	58.1%	$112,449	10.3%	17179.1	59.6%
Alameda_County	2014	2	2	0	1,671,329	30.6%	47.4%	$99,406	8.9%	2043.6	59.6%
Fresno_city	2014	1	0	0	531,576	26.9%	21.9%	$50,432	25.2%	4418.3	60.6%
Stockton	2014	3	3	0	312,697	20.6%	18.3%	$54,614	17.9%	4730.1	59.6%
Cupertino	2015	3	1	2	59,267	25.2%	78.8%	$171,917	6.0%	5179.6	49.8%
Los_Angeles_County	2015	2	2	0	10,039,107	26.1%	32.5%	$68,044	13.4%	2419.6	59.6%
Santa_Ana	2015	2	1	0	332,318	9.4%	15.0%	$66,145	15.7%	11900.6	62.5%
Emeryville	2016	1	0	2	12,086	40.3%	71.5%	$102,725	13.9%	8089.9	49.8%
Lancaster	2016	1	1	1	157,601	30.1%	17.6%	$55,237	21.7%	1661.4	59.6%

Name	Year	Emissions_score	Cost_score	Equity_score	Population	White_NH	Bachelors_deg	Med_house_income	Poverty_rate	Pop_density	Democrat_registration
Monterey_city	2016	2	0	0	28,178	66.7%	52.8%	$80,694	10.9%	3284.9	60.6%
Palo Alto	2016	2	2	0	65,364	54.9%	82.8%	$158,271	6.1%	2696.5	56.2%
Sacramento_County	2016	2	2	0	1,552,058	43.8%	30.9%	$67,151	12.6%	1470.8	49.5%
Sonoma_County	2016	2	2	1	494,336	62.9%	35.5%	$81,018	7.2%	307.1	51.9%
Yountville	2016	2	2	0	2,934	80.2%	41.8%	$63,561	6.4%	1973	46.5%
San_Rafael	2017	2	1	2	58,440	57.0%	52.2%	$91,742	12.2%	3504.1	59.2%
Solana_Beach	2017	2	1	0	13,296	76.2%	68.0%	$108,118	5.3%	3655.4	39.4%
Woodland	2017	2	1	0	60,548	39.3%	27.3%	$69,612	11.2%	3624.6	39.4%
Piedmont	2018	1	1	0	11,135	70.9%	83.4%	$224,659	2.4%	6357	52.5%
Riverside_County	2018	2	1	0	2,470,546	34.1%	22.3%	$67,005	11.3%	303.8	52.5%
San_Jose	2018	3	2	1	1,021,795	25.7%	43.7%	$109,593	8.7%	5358.7	39.7%
Fresno_city	2020	2	1	0	531,576	26.9%	21.9%	$50,432	25.2%	4418.3	43.3%
Marin_County	2020	2	0	2	258,826	71.1%	59.5%	$115,246	6.9%	485.1	40.3%
Oakland	2020	2	1	3	433,031	28.3%	44.0%	$73,692	16.7%	7004	36.6%

Note: The emissions, cost, and equity scores were assigned to CAPs using the scoring rubric presented in Table 3.1. The demographic data, which were used in the linear regressions to identify correlations, were acquired from the U.S. Census Bureau.

Table 3.3. Results from the original linear regressions conducted on the three response variables, Equity, Emissions, and Cost scores, as well as the combined response variable to represent overall CAP robustness.

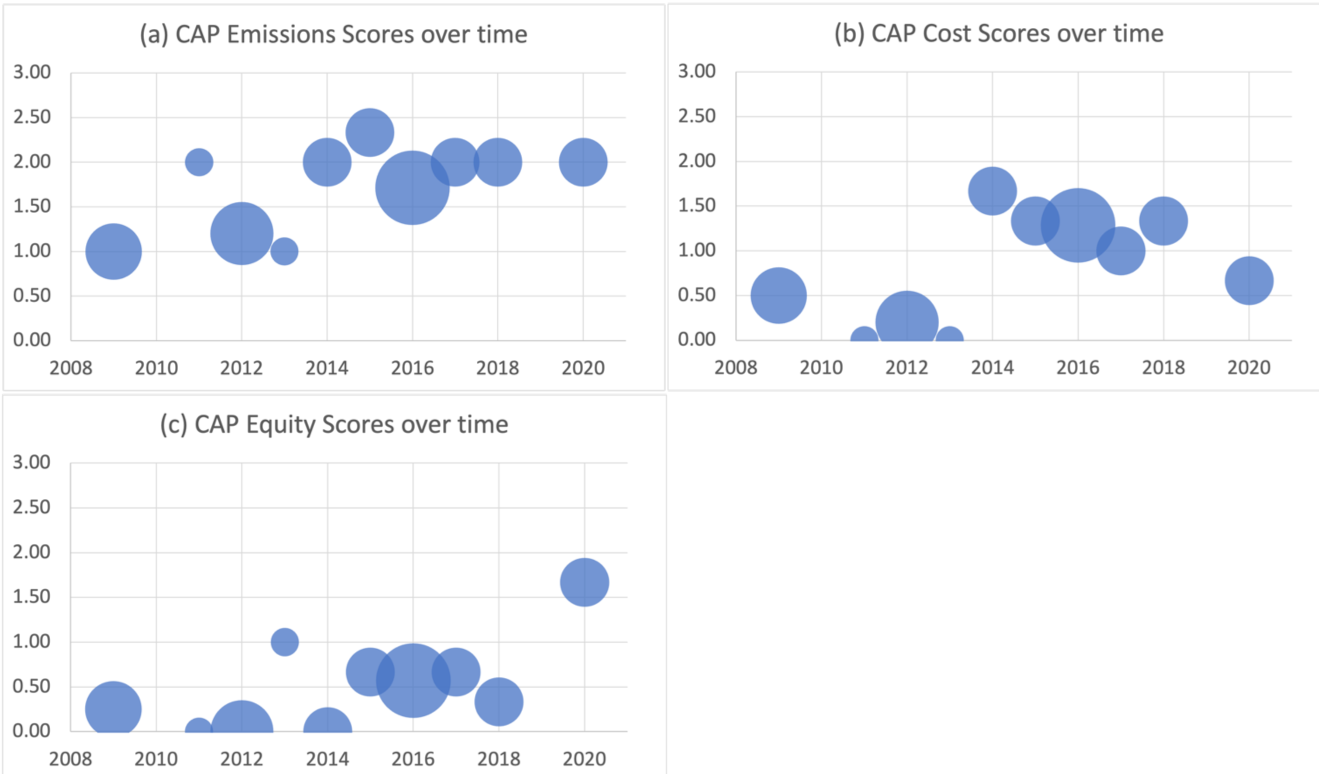
N = 33	Equity		Emissions		Cost		Combined	
	Coefficient	p-value	Coefficient	p-value	Coefficient	p-value	Coefficient	p-value
Equity	-	-	n.s.	n.s.	n.s.	n.s.	-	-
Emissions	n.s.	n.s.	-	-	0.69	<0.001***	-	-
Cost	n.s.	n.s.	0.49	<0.001***	-	-	-	-
Multiple R-squared	0.055		0.354		0.342		-	
Year	0.11	0.014**	0.11	0.005***	0.08	0.093*	0.303	<0.001***
Education	2.66	0.067*	n.s.	n.s.	n.s.	n.s.	4.67	0.061*
Poverty rate	n.s.	n.s.	-7.44	0.011**	n.s.	n.s.	5.66	0.028**
White N.H. population	n.s.	n.s.	-1.83	0.015**	n.s.	n.s.	-4.5	0.005***
Med. house inc.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	~0	0.062*
Population	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Pop. Density	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Multiple R-squared	0.398		0.474		0.298		0.547	
	n.s.: not significant; *: alpha = 0.1, **: alpha = 0.05, ***: alpha = 0.01							

Note: Demographic data with a p-value greater than 0.1 are considered not significant, whereas data with smaller p-values are significant at certain values for alpha, as denoted at the bottom of the table.

Table 3.4. Results from the linear regressions conducted on the three response variables, Equity, Emissions, and Cost scores, as well as the combined response variable to represent overall CAP robustness, that includes political leaning as an additional explanatory variable.

N = 33	Equity		Emissions		Cost		Combined	
	Coefficient	p-value	Coefficient	p-value	Coefficient	p-value	Coefficient	p-value
Equity	-	-	n.s.	n.s.	n.s.	n.s.	-	-
Emissions	n.s.	n.s.	-	-	0.69	<0.001***	-	-
Cost	n.s.	n.s.	0.49	<0.001***	-	-	-	-
Multiple R-squared	0.055		0.354		0.342		-	
Year	0.11	0.008***	0.01	0.002***	n.s.	n.s.	0.3	<0.001***
Education	2.66	0.067*	2.52	0.024**	n.s.	n.s.	5.16	0.063*
Percent Democrat	0.03	0.05**	-0.04	0.002***	n.s.	n.s.	n.s.	n.s.
Poverty rate	n.s.	n.s.	-8.57	0.001***	n.s.	n.s.	-0.136	0.029**
White N.H. population	n.s.	n.s.	-2.44	<0.001***	n.s.	n.s.	-4.71	0.006***
Med. house. inc.	n.s.	n.s.	~0	0.026**	n.s.	n.s.	~0	0.061*
Population	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Pop. Density	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Multiple R-squared	0.480		0.644		0.301		0.551	
	n.s.: not significant; *: alpha = 0.1, **: alpha = 0.05, ***: alpha = 0.01							

Note: Demographic data with a p-value greater than 0.1 are considered not significant, whereas data with smaller p-values are significant at certain values for alpha, as denoted at the bottom of the table.



Note: The size of each bubble corresponds to the number of CAPs reviewed for that a given year.

Figure 3.2. (a) Trend of average emissions scores plotted over time. (b) Trend of average cost scores plotted over time. (c) Trend of average equity scores plotted over time.

3.4. Discussion

This portion of the study sought to identify correlations between the inclusion of data in CAPs and a jurisdiction's demographic data. While the scoring rubric used to quantify the inclusion of data was developed to standardize the quantification of qualitative variables, the scoring process is still subjective. The scores were assigned by a single researcher, and it is possible that another researcher would assign different scores using a different rubric. Correlations between the scores generated and demographic data should be interpreted in this context. Additionally, this study relied on a relatively small sample size of 33, and the results could benefit from a wider review of CAPs, either by reviewing a state with more CAPs or looking at CAPs across states. One could also consider reviewing documents that contain relevant information besides CAPs, such as larger City Plans, though this would necessitate different scoping as well.

There were some demographic data that correlated with the inclusion of emissions, cost, or equity data. Higher emissions scores were positively correlated with the year of CAP publication, suggesting that CAPs have been trending towards more quantitative emissions data over time. A higher emissions score was negatively correlated with both the jurisdiction's poverty rate as well as its white non-Hispanic population. In other words, wealthier jurisdictions and those with a higher proportion of Hispanic residents tended to have CAPs with higher emissions scores. Wealthier jurisdictions may be able to more readily provide the resources to produce more robust CAPs, so the first finding seems intuitive. However, the negative correlation between emissions score and the proportion of the white non-Hispanic population is not expected and warrants more attention perhaps in future work, such as by examining relationships between racial demographics and sustainability efforts. There was a weak relationship between cost scores and the year of CAP release, and no other significant relationships were identified.

Equity scores were positively correlated with both the year of CAP publication as well as the proportion of the jurisdiction's population who earned at least a Bachelor's degree, suggesting that CAPs include more equity themes over time, and that jurisdictions whose resident received higher education push for the inclusion of more equity themes in the document. One interesting trend is that the average Equity score stagnated below 1 for many years, in large part because many CAPs failed to mention equity at all. This is consistent with the findings from a study by Saha & Paterson (2008) which found that equity tends to receive the least attention of the three Es. However, 2020 saw a spike in Equity scores, with three CAPs achieving scores of 0, 2, and 3, respectively. This could be explained by a strong community push to progress social, racial, and environmental justice in recent years. It should be recognized that some jurisdictions concurrently or subsequently release equity-focused documents apart from their CAPs. This could affect results since only CAPs were reviewed to maintain consistency. That being said, climate action and equity are not the same, so even if the equity document is separate, it should at least be referenced in the CAPs moving forward. In particular, a jurisdiction's CAP is the main climate action guiding framework and should be a primary point of contact, so in the best-case scenario, equity priorities would be included in the CAP to understand whether equity has shaped the development of a CAP and to what extent it is part of the planning or implementation process for CAPs.

Upon including political leaning in the linear regressions, the conclusions from the original linear regressions remained largely the same. First, all regressions had a higher multiple r-squared value, which is a measure of how well changes in the response variables can be explained by changes in the explanatory variables. The new regressions found that Emissions scores were positively correlated with the proportion of the jurisdiction's residents who have earned a Bachelor's degree and negatively correlated with higher level of registration with the Democrat party, in addition to still being negatively correlated with the proportion of white non-Hispanic population and the poverty rate. The weak correlation previously found between Cost scores and year of CAP publication was found to be statistically insignificant when political leaning was included as a variable. While the Equity score was still positively correlated with year of CAP publication and a jurisdiction's higher education level, it was also found to be positively correlated with overall registration with the Democrat party. Note that the coefficient for this political leaning was much smaller than that of other variables for all regressions, meaning it has a smaller influence on the three tracked CAP scores.

Finally, both with and without the inclusion of political leaning, the overall robustness of the CAP was found to be positively correlated with the year of CAP publication and a jurisdiction's higher education level, and negatively correlated with the proportion of a jurisdiction's white non-Hispanic population. The multiple r-squared value for both regressions was also nearly identical (about 0.55). As reviewed earlier, it can be reasoned that more recently produced CAPs and those developed by jurisdictions with more highly educated residents can be expected to produce more robust CAPs. However, the correlation between CAP robustness and a more diverse population warrants further exploration. Interestingly, the regression that included political leaning found a negative correlation between robustness and poverty level (coefficient of -0.136, p-value of 0.029), while the regression without political leaning found a positive correlation between robustness and poverty level (coefficient of 5.66, p-value of 0.028).

Among other findings, there is a statistically significant increase in the extent to which equity themes are included in CAPs over time. This warrants exploration into what newer CAPs are doing that older CAPs did not, and what additional themes could be included in future CAPs. The goal was to develop a set of guiding questions for current and future CAP developers that would facilitate the inclusion of equity themes in their planning and implementation processes.

First, CAPs with higher equity scores were examined to identify themes they mentioned that other failed to include. Subsequently, additional literature was reviewed to explore major themes in the overlap between climate action and equity. These included drafts of CAPs that are currently under development, such as the ones by the County of Los Angeles (2020, 2022) and the City of Santa Clara (2022), all of which emphasized equity as one of the central goals of their CAP and further scoped their proposed climate actions with equitable co-benefits (e.g., local green job creation, considering cost and benefit distribution of an action across communities, promoting climate resilience, etc.). These themes and questions were pulled from a variety of metrics, frameworks, and scoring rubrics. These include CARB's "California Climate Investments Co-benefit Assessment Methodologies" (CARB 2020), the CEC's "Proposed Evaluation Criteria for Benefits and Impacts to Low Income and Disadvantaged Communities" (CEC 2019), and NCST's "Framework for Life Cycle Assessment of Complete Streets Projects" (Harvey et al. 2018). These resources, along with a few others, were also used to create metrics in a study that assessed the equity impacts of heavy-duty transportation electrification programs (Bush 2021). Additional literature was reviewed to include equity themes in the agricultural sector (Poulsen 2017, NSAC 2018, Willoughby 2019). After reviewing the aforementioned sources, the following set of questions was generated to guide discussion on the equity impacts of local climate actions:

General Questions

- Co-benefits - Does the strategy:
    - Decrease levels of local pollutants?
    - Generate local jobs (near and/or long term)? Are these sustainable/green jobs?
    - Increase grid reliability?
    - Promote climate resilience?

    - Affect green space?
    - Promote exercise/other health impacts?
    - Provide benefits that are easily and equally accessible?
- What are the upstream impacts of the strategy? Who is affected?
    - E.g., generated emissions, job production?
    - Are any of these impacts beyond jurisdictional borders? State borders? National borders? Who else is a stakeholder?
- What are the downstream or end-of-life impacts? Who is affected?
- Does the strategy impact (i.e. reduce, preserve, or return) native lands?
- Does it affect native flora and/or fauna?
- Across which phases was or will the community be engaged?
    - Design of the climate action plan
    - Implementation of the listed strategies
    - Education and updates on actions and progress
    - End-of-project debriefing
    - Updates to or development of a new CAP
- When engaging the community, how were social, financial, and/or linguistic barriers addressed?

While the above questions broadly explore themes around equity relevant to CAPs, equity issues can also be considered on the basis of specific sectors, and may be more actionable in the context of CAP planning and implementation. A subset of sector-specific questions have been provided below for the energy, transportation, land use, and agriculture sectors. A similar set of questions could be produced for other sectors, such as waste and water management.

Energy Strategies

- Does this strategy increase access to renewable energy in disadvantaged communities (DACs)?
- How are the benefits of building electrification distributed?
- How are costs distributed? What is the particular impact on DACs?
- How transparent is the allocation of energy revenues?
- Does the strategy promote distributed generation and/or microgrids?
- Are there indirect long-term repercussions of electrification? I.e., higher utility bills for using electricity over natural gas; thinking about rates per tier of usage
- Does increase electricity demand affect communities located near power generation plants (e.g., increased pollution), and how is this addressed?
- Does it generate new jobs? Are these jobs local? Who is being hired to fill the positions?

Transportation Strategies

- Does this strategy increase access to clean(er) transportation in DACs?
- Does this affect traffic/congestion?
- Does it increase access to community resources? I.e., proximity or transportation to schools, jobs, other transit hubs?
- Does it promote active transportation modes i.e., walking, biking?
- Does it affect/increase safety for active and transit transportation users?
- Does it promote or improve transit access to people with disabilities?
- How does the travel time between major destinations within the city differ between personal and public modes of transportation?
- Does it generate new jobs? Are these jobs local? Who is being hired to fill the positions?

Land Use Strategies (excluding Transportation)

- Does this strategy increase access to open and green spaces?
- Does new development promote or hinder gentrification? How are existing communities protected from potential increases in costs and rent?
- Are new housing units being developed for varying income levels?
- How frequently have community voices been heard and considered in the shaping of local land use?

- Does proposed development (further?) infringe on historically indigenous lands?

Agriculture Strategies

- Who owns and develops new land? Are minority farmers able to access new opportunities?
- Do working lands conservation programs seek and elevate the voices of farmers of color?
- Does agricultural expansion infringe on historically indigenous lands?
- Do existing loans disproportionately affect lower-income or more vulnerable workers (e.g., through predatory interest rates)?
- Who is getting access to new, more efficient technologies?
- Is the food produced distributed locally? Who has access to this food?

Guiding the development of new CAPs using the questions developed in this section could lead to plans that have considered the broader impacts of strategy implementation on their community, particularly disadvantaged or vulnerable communities. Further considering equity themes that are sector-specific adds context to and understanding of the impacts of individual strategies and not just the broader CAP. It is especially important to note some impacts are outside of jurisdictional borders and this beyond the control of local governance, which highlights the importance of state and even federal planning centered on environmental equity.

Chapter 4. Potential pitfalls of planning climate action around community choice aggregators

4.1. Introduction

Decarbonization of the electric grid has been one of the primary ways that governments have aimed to achieve GHG emissions reduction. This requires a transition away from fossil fuels, primarily coal and natural gas, to lower-carbon technologies like solar, wind, hydro, geothermal, and nuclear energy. Decarbonization of the electric grid is particularly important to the success of electrification strategies (e.g., electrifying bus fleets, replacing gas furnaces with electric furnaces) since they depend largely on the upstream emissions of electricity production to achieve their own reductions. California has passed various policies to promote grid decarbonization. In 2002, Senate Bill 1078 established the state's Renewables Portfolio Standard (RPS) program, which required 20% of the state's electricity to be produced from renewable sources by 2017 (California Senate 2002). This first bill was extended through various sets of additional bills and executive orders, such as Senate Bill 350 which mandated a 50% RPS by 2030 (California Senate 2015). In 2018, California governor Jerry Brown committed the state to achieving carbon neutrality by 2045, which requires vast levels of GHG emissions reduction as well as carbon sequestration programs to offset the remaining emissions, such that the state produces net zero emissions (Brown 2018). Concurrently, Senate Bill 100 was passed which increased SB350's 2030 RPS to 60% renewables and committed the state to producing carbon free electricity by 2045 (California Senate 2018).

The state also passed the Sustainable Communities and Climate Protection Act in 2008 which tasked local jurisdictions with setting and achieving their own GHG emissions reduction goals. Many jurisdictions have since published climate action plans (CAPs) which establish targets and outline the emissions reduction strategies they plan to implement. Many CAPs will include electrification strategies to reduce fossil fuel use. Some examples include electrifying bus fleets and transitioning homes from gas heaters and kitchens to electric alternatives. As a consequence, many jurisdictions also include actions to increase the amount of renewable energy supply on the grid while also decreasing electricity demand when possible. For context, the transportation, electricity, and residential sectors made up 63% of California's total GHG emissions in 2019 (41, 14, and 8 percent, respectively) (CARB 2021).

Utilities play a key role in achieving emissions reduction targets, but the last decade has seen a greater push for electricity oversight by community choice aggregators (CCAs). Some local jurisdictions will develop community choice aggregators to manage their constituents' electricity supply instead of the utility that previously served the jurisdiction. CCAs are locally governed, non-profit organizations that give their customers increased control over their energy make-up and electricity rates, as compared to publicly-owned utilities (Makhyoun and Inskeep 2019). The main role of CCAs is electricity procurement, meaning they decide from which sources their electricity is generated. Therefore, CCAs are responsible for contracting electricity supply from a mix of sources to meet the demands of their customers. Contracts can be short (0-5 years), medium (5-10 years), or long-term (10+ years), with SB350 requiring that at least 65% of energy contracts used to meet RPS requirements be long term (California Senate 2015). However, the incumbent utility remains responsible for the transmission and distribution of the electricity.

Customers who fall under a CCA's jurisdiction are automatically enrolled in its service but can choose to opt out and remain under the incumbent utility. While CCAs have greater control over their prices, many often elect to mirror the rate of the incumbent utility (Makhyoun and Inskeep 2019). The total electricity rate of CCAs in California includes a Power Charge Indifference Adjustment that is paid to the utility the customers departed from, as regulated by the Public Utilities Code (CPUC 2022). This is to ensure that remaining customers aren't financially burdened by taking on contracts the utility had purchased when accounting for customers that they lost to a CCA.

Oftentimes, the CCA will offer an electric mix with more renewable energy than that required by state policy, referred to as voluntary green power. In fact, this is true for all CCAs in California (O'Shaughnessy *et al.* 2019). CCAs will often provide power content labels that highlight their own offered electric mix(es) as well as that of the incumbent utility or greater grid. As an example, Figure 4.1 shows the two electricity mix options offered by the CCA Valley Clean Energy, as well as that of the greater California electric grid (VCE 2020). Currently, 24 CCAs in California offer service to more than 30% of the state's population, 14 of which offer 100% renewable energy as their default grid mix (Trumbull *et al.* 2020). Because of this, many climate action plans will reference the lower-carbon electricity mix of the jurisdiction's CCA, as compared to the mix of the incumbent utility, as a key source of GHG emissions reduction.

Version: October 2020

2019 POWER CONTENT LABEL

Valley Clean Energy

https://valleycleanenergy.org/power-sources/

ENERGY RESOURCES	Standard Green	UltraGreen	2019 CA Power Mix
Eligible Renewable[1]	**45.3%**	**100.0%**	**31.7%**
Biomass & Biowaste	0.0%	0.0%	2.4%
Geothermal	0.6%	0.0%	4.8%
Eligible Hydroelectric	1.2%	33.9%	2.0%
Solar	20.8%	33.4%	12.3%
Wind	22.6%	32.7%	10.2%
Coal	**0.0%**	**0.0%**	**3.0%**
Large Hydroelectric	**31.3%**	**0.0%**	**14.6%**
Natural Gas	**0.0%**	**0.0%**	**34.2%**
Nuclear	**0.0%**	**0.0%**	**9.0%**
Other	**0.0%**	**0.0%**	**0.2%**
Unspecified sources of power[2]	**23.4%**	**0.0%**	**7.3%**
TOTAL	**100%**	**100%**	**100%**
Percentage of Retail Sales Covered by Retired Unbundled RECs[3]		**0.0%**	

[1]The eligible renewable percentage above does not reflect RPS compliance, which is determined using a different methodology.

[2]Unspecified power is electricity that has been purchased through open market transactions and is not traceable to a specific generation source.

[3]Renewable energy credits (RECs) are tracking instruments issued for renewable generation. Unbundled renewable energy credits (RECs) represent renewable generation that was not delivered to serve retail sales. Unbundled RECs are not reflected in the power mix or GHG emissions intensities above.

For specific information about this electricity product, contact:	**Valley Clean Energy** **1-855-699-8232**
For general information about the Power Content Label, please visit:	http://www.energy.ca.gov/pcl/
For additional questions, please contact the California Energy Commission at:	Toll-free in California: 844-454-2906 Outside California: 916-653-0237

Figure 4.1. This power content label shows the breakdown of electricity generation sources used in Valley Clean Energy's Standard Green and UltraGreen options, as well as that of the greater California electric grid.

4.2.Examining the role of CCAs in CAPs

To gauge how jurisdictions assess the GHG emissions reduction potential of implementing CCAs, 28 CAPs were reviewed for jurisdictions who currently have a CCA. This set of CAPs was derived from a larger list of California CAPs (Lozano 2020) by cross-referencing which currently have a CCA option available to them. Some of the CAPs were published before the jurisdiction even considered incorporating a CCA, and others mentioned plans to consider a CCA. Ultimately, 12 CAPs included CCAs as an existing GHG emissions reduction strategy, and

10 provided estimates for their expected impact. These values were then compared to the total expected GHG emissions reduction of implementing all strategies laid out in the CAP. This review found that as much as 84% of total expected emissions reduction was attributed to the introduction of a CCA. The percentage of emissions reduction attributed to transitioning to CCAs ranged from 3% to 84%, with a mean percentage of 31.8% and a median percentage of 31%. Across these CAPs, CCA implementation is estimated to reduce GHG emissions by 1.1 million megatons (MT) CO_2e (carbon-dioxide equivalent) per year, which is just under 2% of California's annual electricity consumption-related emissions of nearly 60 million MT CO_2e (CARB 2021). These findings are summarized in Table 4.1 and depicted in Figure 4.2.

Table 4.1. A list of CAPs that included CCAs as an existing emissions reduction strategy, the expected emissions reduction from transitioning to the CCA, and the proportion of emissions reduction potential the transition is assigned compared to all proposed strategies in the CAP.

Jurisdiction of reviewed CAP	Community Choice Aggregator	Expected emissions reduction (MT CO2e/year)	Proportion of the CAP's total expected emissions reduction attributed to the CCA
Cupertino	Silicon Valley Clean Energy	57,303*	0%
Marin County	Marin Clean Energy	2,744	3%
Placer County	Pioneer Community Energy	0	0%
Riverside	Western Community Energy	0	0%
San Jacinto	San Jacinto Power	0	0%
San Jose	San Jose Clean Energy	500,000	32%
San Mateo	Peninsula Clean Energy	19,840	84%
Solana Beach	Solana Energy Alliance	10,466	14%
Solano County	Marin Clean Energy	23,170	30%
Sonoma County	Sonoma Clean Power	181,793	31%
Sunnyvale	Silicon Valley Clean Energy	152,267	80%
Yolo County	Valley Clean Energy	117,285	31%

* Note: Cupertino estimates an expected emissions reduction, but ultimately lists the CCA as a supporting strategy and assigns it 0 emissions reduction in their summary table.

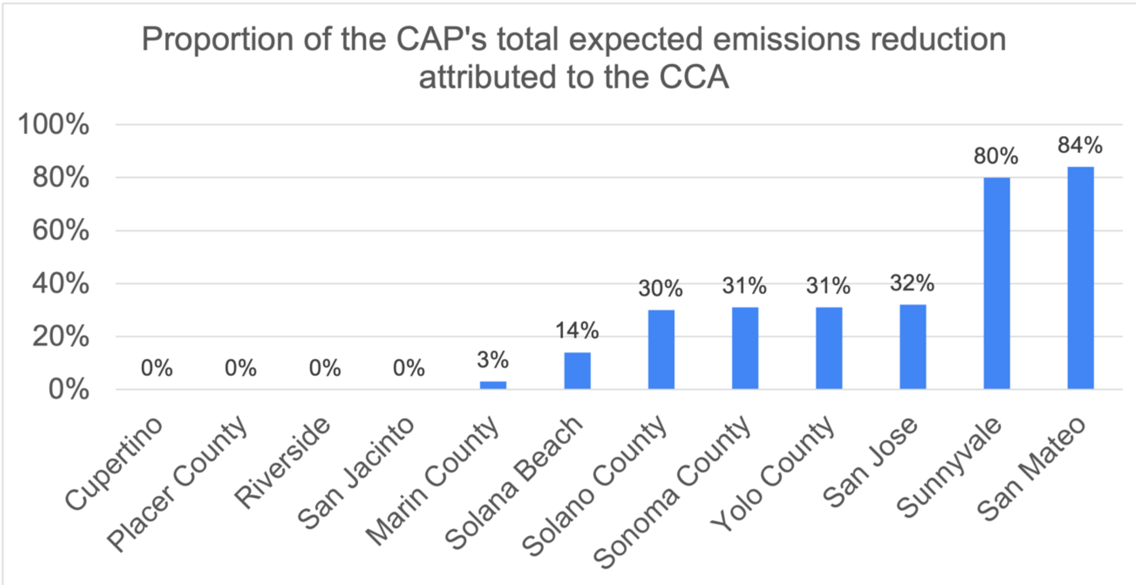


Figure 4.2. This figure shows the range of emissions reduction potential attributed to CCAs by jurisdictions who included them among their considered climate actions.

The emissions reduction potentials reported in CAPs were not all calculated the same way. For example, some regions, like Marin County, assumed increased participation in CCA 100% renewable options (where the share of 100% renewable customers increases from 1% to 5%) and credited a reduction based on the difference between the CCA emissions and the emissions rate of the existing utility (Pacific Gas and Electric, or PG&E) (ICF International 2015). Similarly, San Mateo estimated averted emissions through the transition of customers from the baseline CCA mix to a 100% renewable option (City of San Mateo 2020). Sunnyvale assumed the state would achieve 50% renewables on its average grid mix by 2030, so it attributed an emissions reduction potential by comparing this to its CCA's 100% renewable energy mix (City of Sunnyvale 2019). San Jose also compared its CCA's expected procurement of renewables to the expected mix of PG&E (Romanow *et al.* 2018).

Some CAPs took a more conservative approach to estimating emissions reductions due to CCA-related programs. Sonoma County, for example, assumed that its CCA would help the state achieve its grid mix goals, so it assigned an emissions reduction potential according to the expected impact of state measures (Sonoma County RCPA 2016). Placer County lists its CCA as a supportive strategy but does not assign a corresponding emissions reduction potential (Placer County 2020). However, they separately list new installations of solar as part of the CCA's efforts, which did receive an attributable amount of GHG reduction potential. While Cupertino performed an estimate comparing its CCA's 100% renewable option to the current mix of the existing utility, it ultimately lists it as a supporting strategy and does not assign the CCA an emissions reduction potential in its summary of emissions reduction strategies (City of Cupertino 2015). Finally, Riverside and San Jacinto are both included in the CAP developed for the Western Riverside Council of Governments (WRCOG), which assumed that all electricity providers, whether utilities or CCAs, would meet RPS standards which would subsequently reduce emissions. There was no emissions reduction directly attributed to the CCAs. The various methodologies across all examined CAPs are summarized in Table 4.2.

Table 4.2. A summary of the methodologies used in CAPs to assign a GHG emissions reduction potential to the implementation of a CCA.

Jurisdiction of reviewed CAP	**Methodology used to assess the impact of a CCA on GHG emissions**
Cupertino	Compared the expected CCA grid mix to the current PG&E grid mix. However, it is ultimately listed as a supporting strategy.
Marin County	Assumed that participation in the CCA's 100% renewable (deep green) option went from 1% to 5% and all new customers came from PG&E. Ultimately assigned emissions reduction compared to the current PG&E grid mix.
Placer County	Listed the CCA as a supportive strategy, so no corresponding emissions reduction.

Riverside	The WRCOG CAP assumed all electricity providers would add renewables to their mix in line with California's RPS targets and did not consider the different grid mix options offered by the CCAs. That is, the CCAs were not assigned any additional emissions reduction potential.
San Jacinto	Same as Riverside, see above.
San Jose	Compared their CCA's 100% renewable grid mix to the current mix of PG&E. They do not assume PG&E's renewable energy content changes over time, despite developing a marginal abatement cost curve over a 33 year analysis period.
San Mateo	Compared their CCA's grid mix to that of a PG&E grid mix that changes over time in line with California's RPS targets.
Solana Beach	Compared their CCA's expected grid mix to that of PG&E's grid mix at the time of publication.
Solano County	A bit unclear, but likely a comparison between the CCA's grid mix and the current grid mix offered by PG&E. They establish 2020 targets of having 50% of consumers purchase 65% renewable electricity, and 30% of consumers purchase 100% renewable electricity. These values are likely then compared to the PG&E grid mix.
Sonoma County	A bit unclear, but likely a comparison between the CCA's grid mix and the current grid mix offered by PG&E. They assign emissions reduction to compliance with RPS targets separately, and separately assign emissions reduction to the CCA. Given that they presented a table comparing the CCA's two grid mix options to that of PG&E, it is likely that they assumed participation of their constituents in either of the two options and compared that to the carbon intensity of their electricity had they remained with PG&E.
Sunnyvale	Used the assumption that RPS pushes the 2030 requirement to 50% renewables and their CCA offers 100%. They attribute emissions reductions to that difference.
Yolo County	Assumed 75% of consumers purchase "light green" portfolio comprised of 50% renewable sources; 15% of consumers purchase "deep green" portfolio comprised of 100% renewable sources; and 10% of consumers stay with PG&E portfolio. This is compared to the current PG&E grid mix.

4.3. Exploring potential pitfalls

Estimating the expected emissions reduction of sustainable strategies is complex, and this is certainly true for the transition from a utility to a CCA. This section examines two ways in which assumptions about the operation of CCAs can lead to situations where emissions reduction may be less than expected and provides examples of how these potential pitfalls can and have been addressed. The first is regarding the procurement of renewable energy without necessarily adding renewables to the grid. The second is a mismatch between energy procurement over the year and intra-day energy use, which can lead to situations where the electricity used by customers is produced using fewer renewables than assumed.

Just as CCAs take over customers previously served by an incumbent utility, it is possible for them to take over contracts previously held by utilities as they expire. Since the California grid is connected to a network beyond state borders, it is also possible for CCAs to contract out-of-state renewables. In either scenario, the CCA could meet its own electric mix goals without affecting the overall California grid mix. However, CCAs in California have signed long-term contracts for over 10,000 megawatts of new-build clean energy resources (CalCCA 2022), compared to California's current total renewable energy capacity of 36,000 megawatts (U.S. EIA 2022). Because CCAs contract renewables above the requirements set by the RPS, while also reducing the number of customers previously served by the incumbent utilities, the utilities actually exceed their clean energy targets (Trumbull *et al.* 2020). That is, incumbent utilities have existing long-term contracts for renewables based on predictions for the expected energy needs of their customers, naturally not predicting that they would lose customers to CCAs. After CCAs are established, incumbent utilities serve fewer customers, so their per-customer share of renewables increases. Should CCAs continue to contract more renewable energy than is required to meet the RPS, including the installation of new renewable energy generation technologies, they will certainly be major players in the acceleration of renewable energy adoption in the state.

Issues can also arise due to CCA's claim of 100% renewable electricity. Some CCA's will offer electricity that consists solely of renewable energy, leading customers to believe that the electricity they use is carbon free. Even temporarily ignoring the life cycle carbon impacts of renewable energy technologies, it is almost always inaccurate to say that the electricity customers of CCAs use is 100% renewable. CCAs make this claim because they procure enough renewable energy so that over an entire year, the electricity consumed by its customers is balanced by an equal amount of generated renewable energy. The problem with this is that the two primary forms of renewable energy, wind and solar, are variable energy sources, meaning they do not generate a fixed, predictable, or controllable amount of energy. Solar energy cannot be produced without sunlight (e.g., on cloudy days or at night) and wind energy cannot be produced without wind. Therefore, there are numerous situations on the daily level where electricity is being consumed but renewable energy is not being produced, such that some or all of the demand is met by burning fossil fuels.

One way to interpret this is that the CCA purchases so much renewable energy that at times, it is powering its own customers as well as those in other jurisdictions. At other times, however, the lack of renewable energy production creates a demand that that necessitates the burning of fossil fuels. On a smaller scale, it could be compared to net metering offered to homes with solar panels. The energy produced by the solar panels is sent to the grid, and the utility customers are credited for that energy. Assuming that over the bill cycle they use the same amount of energy that their solar panels produced, they pay nothing to the utility since they technically filled their energy demand with the solar panels. However, these customers still demanded the use of fossil fuels through electricity use during the time that solar energy was not produced. Even if everyone purchased enough solar panels to match their monthly or annual energy consumption, this alone would not make all electricity use 100% renewable.

This can also impact the estimated emissions reduction potential of electrification efforts, such as electrifying stoves to adopting electric vehicles. It can be argued that both are better for the environment than their fossil fuel-based alternatives, but it would be inaccurate to say that using these technologies results in zero emissions when the electricity they use is generated through fossil fuels, such as charging an electric vehicle overnight. Planners should be wary of assuming emissions reduction from supposed 100% renewable electricity when the greater electric grid still depends largely on fossil fuels.

This issue can be addressed by adding forms of energy storage to the grid. By storing excess renewable energy production (e.g., solar produced during midday) and using it when renewable energy is not being produced (e.g., at night), electricity demand can indeed be met by renewable sources. In fact, many CCAs pair contracts for new renewable energy with contracts for storage technologies (CalCCA 2022). One study confirmed the value of battery storage technologies in grid mixes with increases proportions of renewable energy, though the capital cost can sometimes exceed the value of storage (Mallapragada *et al.* 2020). However, storage capacity is limited, and does not fully address renewable supply gaps during longer periods with low energy production (e.g., subsequent cloudy days). In cases where storage is insufficient, firm power sources are needed to fill demand, and this is currently achieved using fossil fuel-powered plants.

4.4. Discussion

Ultimately, attributing causality between CCA renewable procurement programs on emissions reductions is nearly impossible, so jurisdictions should be wary of basing a significant portion of their emissions reduction target on CCA procurement programs alone. Primarily, there is cause for concern with estimates that assume zero attributable emissions when a CCA procures enough renewable energy to cover its customers' total annual energy demand. With that said, despite the challenges to estimating the additional emissions reduction (or renewables generation) that can be credited to CCAs, it is certainly true that CCAs promote the adoption of additional renewable energy on the grid. Even when additional renewable generation is added to the grid, it does not yield straightforward emissions reduction, as there are still problems due to intermittency. With midday overgeneration of solar energy as well as the necessity of fossil fuel-powered "peaker plants" that fill high demand in the afternoon left by decreased renewable energy production (Denholm *et al.* 2015), the actual net emissions reduction is not easy to calculate. This problem can be ameliorated through energy storage technologies, but even that may prove to be insufficient. By overestimating the impact of CCAs on achieving emissions reduction targets, it is possible that jurisdictions may decrease efforts to reduce emissions in other sectors.

This may be similar to issues faced in the world of cap and trade. In cap and trade programs, the overseeing authorities (e.g. national governments, the European Union, the United Nations) set a limit, or cap, on the total allowable GHG emissions which decreases over time to achieve a target. Governments then distribute permits to polluters that allow them to emit a certain amount. However, some entities emit less than their allowable amount while other emit more, so these surplus allowances can be traded in the market such that everyone has sufficient permits for their level of emissions. In certain programs, like the international Clean Development Mechanism developed as part of the Kyoto protocol (UNFCCC 1997), over-polluting entities (in this case, Annex I, or industrialized, countries) can also purchase carbon offset credits from organizations that reduce emissions (in this case, from programs located in non-Annex I countries) to make up for their over-generation. One example is a forest carbon offset program, where an organization either plants new trees, prevents trees from being cut down, or otherwise improves forest management. Under the carbon offset arrangement, entities can pay a fee to receive credit for GHG reduction while making minimal changes to their own pollution-generating processes. However, there is doubt as to whether this effectively reduces emissions. Forest carbon offset programs, for example, have been criticized for failing to prove additionality (that the emissions reduction were only achieved because of the investment) and permanence (the permanent and irreversible removal of carbon emissions from the atmosphere) (Richards and Huebner 2014). In other words, the polluting entities are receiving credit for emissions reductions that may have happened anyway and, even then, may not be long-lasting. Ultimately, then, the carbon offset program allows entities to make minimal changes to their pollution generation processes on the evidently questionable assumption that emissions are being reduced elsewhere. Similarly, local jurisdictions may be lagging on pushing emissions reductions in certain sectors under the assumption that CCAs are reducing sufficient emissions, but this impact may not be as large as they hope it to be.

While there are evidently sources of error in estimating the impacts of CCAs, this can be said of almost all future-facing, assumption-based estimates and should not necessarily deter making those estimates in the first place. After reviewing methodologies and considering potential pitfalls, this research offer the following suggestions for estimating the impacts of a CCA on GHG emissions.

Consider hourly sources of energy consumption

While a CCA may procure 100% renewable energy on an annual basis, it is important to consider the energy generation sources that meet a jurisdiction's energy demand throughout the day, particularly during times of low renewable energy production as discussed earlier. Therefore, it is recommended to estimate how much of the jurisdiction's energy use is, in practice, supplied by the larger utility/grid mix. This calculation would focus on times in a day where energy demand is not met by renewables, and does not directly give credit for the times where renewable energy production exceeds demand. However, this excess renewable energy supply is critical to the decarbonization of the grid as a whole and is part of the greater impact of CCAs towards meetings the state's RPS targets.

A case study could examine a jurisdiction with a CCA and compare the hourly energy production of the CCA's renewable energy sources to the energy demand of the jurisdiction over a one-year time period (or shorter depending on data and resource availability). This may be simpler to perform for CCAs that offer 100% renewable energy, as opposed to those that have multiple and varied sources of electricity supply. The study would seek to identify the frequency of which a jurisdiction's energy demand is not met by renewable energy production or stored renewable energy (if that technology is available), as this would then indicate how much energy demand, in practice, is being supplied by the incumbent utility. For long-term assessment periods, the study could consider technological and numerical advancements in storage technologies that would reduce the amount of energy supplied by the incumbent utility. That is, increased storage capacity would allow CCAs to offer more renewably sourced electricity even when renewable energy isn't actively being produced. One study forecasted that global storage capacity would increase by 56% in the five years between the end of 2020 and the start of 2026 (IEA 2021). Findings like this could inform assumptions on how much storage capacity a CCA could expect to have access to over the analysis period. Estimating the emissions associated with the electricity provided by the incumbent utility requires an assumption on what the grid mix of the incumbent utility will be over time, which leads to the next recommendation.

Consider underlying changes to the larger California grid mix

Some CAPs will compare future scenarios to the situation at the time of publishing because CAPs are structured around targets. That is, a CAP published in 2011 will set an emissions reduction target for 2020 (e.g., to reach 1990 emissions levels), and may therefore compare the expected CCA grid mix in 2020 to the incumbent utility grid mix of 2011—this is what Yolo County did in their CAP. However, the larger California grid mix, and therefore that of incumbent utilities, will consist of more renewables over time to comply with or meet state RPS goals. Therefore, CCA grid mixes should be compared to a changing incumbent grid mix, just as San Mateo did in their CAP. They assumed an annual emissions reduction of 19,840 in 2020, 28,730 in 2030, and 0 in 2050 because it is assumed that the incumbent utility will have achieved

100% renewable energy by 2045 to meet the RPS goal set in SB 100. This was the only reviewed CAP to consider a changing grid mix for the reference case.

Account for customers that remain with the incumbent utility

A good practice is to recognize that some constituents elect to be customers of the incumbent utility instead of automatically opting into the CCA, just as Solana Beach did in their CAP. When calculating the impacts of a CCA, it is important to consider what proportion of the jurisdiction's total energy demand is being met by the CCA.

While these recommendations may lead to better estimates on the impact of CCAs on GHG emissions, they depend on assumptions affected by a larger problem that has recently been identified. In 2021, the agencies responsible for overseeing progress towards the RPS goals set in SB100 (the California Energy Commission, the California Air Resources Board, and the California Public Utilities Commission) issued a report wherein they stated that California would need to add clean electricity generation capacity at a record-breaking rate to achieve its carbon-neutral goal in 2045 (SB 100 Joint Agency 2021). According to their estimates, the state would have to add an average of 6 gigawatts of new solar, wind, and battery storage annually through 2045. Another study confirms this fear, estimating that the state would have to build new renewable energy technologies at 10 times the current rate (Long *et al.* 2021). While this reaffirms the argument that CCAs are unlikely to achieve carbon-free electricity and jurisdictions should be wary of assuming so, this should not deter action or progress towards an electricity grid and electricity services that eliminate direct emissions of GHGs.

Chapter 5. How do cities approach sustainability? A survey on the importance of life cycle assessment, equity, and funding in local climate action

5.1. Introduction

National and international policies have established goals and roadmaps to reduce greenhouse gas (GHG) emissions to combat global climate change. Much of the onus has also fallen to local jurisdictions who, while they may not have as much budget, resources, or authority as larger jurisdictions, are able to operate on a more refined level and implement actions specific to their region. Many local jurisdictions will publish climate action plans (CAPs) that establish emissions reduction targets and outline a set of proposed actions to achieve them. While examining CAPs may provide some insights into the stated priorities of a given jurisdiction (e.g., Lozano 2020), it does not reveal the process of developing a CAP, the reality of implementing stated objectives or plans, or how progress is gauged. For example, are resources available to fulfill stated commitments? Do jurisdictions really use CAPs when deciding on climate-relevant projects or investments? Answering these questions and better understanding the planning and implementation process could provide insight to the priorities of local government policy-makers, allowing them to reflect on their current approaches to setting and meeting emissions reduction goal, and provide information useful to state-level policies intended for local implementation. This research implements a survey to assess the current state of climate action planning and implementation at the local level. While the study in centered in California, the findings may be extrapolated to other local jurisdictions within the United States and even internationally.

Some literature has explored opportunities and barriers faced by localities committing resources to sustainability (e.g., Lubell et al. 2009; Sharp et al. 2010; Krause 2011; Krause 2012; Yi et al. 2017; Hawkins et al. 2018), yet even within this literature, there is little to no information on how jurisdictions prioritize between different proposed sustainability actions. Life cycle assessment (LCA) can play a major role in quantitatively assessing emissions reduction strategies as it considers impacts, such as greenhouse gas emissions and cost, across a large range of time and space. For example, whereas a simple assessment of solar energy would argue that there are zero emissions associated with the production of renewable energy, the life cycle method considers the embedded emissions from the mining, refining, and manufacturing of the materials needed to produce a solar panel and connect it to the grid, maintenance related impacts, and end-of-life impacts that occur once the solar panel is retired. One study has conducted an LCA and life cycle cost assessment (LCCA) of emissions reduction strategies considered by a state department of transportation (Harvey et al. 2019). Similar work was done to assess emissions reduction strategies proposed by two California jurisdictions (Lozano et al. 2021). In both studies, LCA helped identify strategies that may be cost ineffective, or even produce net GHG emissions over their life cycle despite being considered emissions reduction strategies. While there are documented benefits to conducting this type of analysis, it requires additional time and resources, both of which are limited for local jurisdictions. Additionally, it is difficult to predict how stakeholders from local jurisdictions would engage with the proposed life cycle framework without knowledge of how these jurisdictions prioritize among sustainability options and their perceived benefits of life cycle-based accounting.

A similar argument could be made about environmental equity in climate action. Environmental equity refers to the equal distribution of benefits and burdens across communities which is achieved by addressing existing disparities in said distribution. It is linked strongly with environmental justice, which the U.S. Environmental Protection Agency defines as "the fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income, with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies." Several resources examine the history, current state, and best practices of the environmental justice movement both broadly and in the sustainability sphere (Agyeman et al. 2016; Temper et al. 2018; Solomon et al. 2019; Levenda et al. 2021; Litman 2022). The practical difference between environmental equity and environmental justice is that the former is a more quantifiable way of comparing the impacts of emissions reduction strategies on disproportionately burdened communities. It is possible to examine the stated importance that jurisdictions put on equity by reviewing their CAPs, but this does not reveal the ways that equity is considered during implementation. This study also uses the term life cycle-based equity to refer to the impact assessment of a climate action across its life cycle and not just at the point of implementation, specifically considering the distribution of costs and benefits across communities within and beyond a jurisdiction's borders.

5.2. Materials and Methods

It is unclear how local jurisdictions judge the importance of life cycle effectiveness or environmental equity alongside other priorities. To address this, a survey aimed at those responsible for developing and implementing CAPs was developed. Specifically, California jurisdictions that had approved CAPs since the passage of the Global Warming Solutions Act in

2006 were engaged through emails (on their climate action/sustainability website or in the CAP itself), phone calls, and online forms to get in touch with an elected or unelected member who played a primary, if not the primary, role in overseeing the jurisdiction's CAP. Only one response was sought per jurisdiction to be considerate of staff time, though contacted members were invited to fill out the survey in a group if they so desired. A survey was prepared with the goal of answering the following broad questions:

(1) Among various factors that influence climate action planning and implementation, which are the most and least considered, and is there a difference in the amount of consideration received between the two phases?

(2) How familiar are jurisdictional representatives with life cycle assessment (LCA), life cycle cost assessment (LCCA), and environmental equity; how likely are they to include them in future CAPs, and what would prevent them from doing so?

(3) How much process improvement is included in CAPs, including tracking implementation progress, reporting updates, and modifying the plan accordingly?

5.2.1. Survey methods

To develop the survey questions, field-tested and validated survey questions already worded to avoid biases and minimize the range of subjective interpretation were collected from previous studies (e.g., Lubell et al. 2009; Sharp et al. 2010; Krause 2011; Yi et al. 2017). These previous studies used survey approaches to study local adoption of climate mitigation and sustainability plans, and here we extend that work to specifically consider CAPs in California. In addition, the survey scope includes a new dimension, by exploring whether and how local officials consider *life cycle effectiveness* and *equity* in their planning and implementation process. As such, new questions specific to CAPs, life cycle effectiveness, and equity were developed, and mirrored language used in other surveys.

After developing a draft set of survey questions, the survey was piloted with two groups of local agency employees from Yolo and Los Angeles Counties who had previously cooperated with the research team. After the agency employees responded to the survey, the researchers requested feedback on the appropriateness and clarity of questions, developed new questions that arose from conversations about the relevant topics, and subsequently revised the survey.

The finalized survey contained two parts: a set of quantitative questions and a set of free-response questions. At the start of the survey, respondents were asked to identify which jurisdictions' CAPs they have worked on, followed by whether they have been involved in planning, implementation, or both. They were subsequently asked to reflect on the extent to which various factors were considered during climate action planning and/or implementation, with access to one or both sets of questions dependent on their reported experience. Their responses were recorded on a Likert scale, with potential responses ranging from "not at all" (score of 1) to "a great deal" (score of 5). The factors they were asked to consider were: (1) expected GHG emissions reduction potential of proposed strategies, (2) expected cost, (3) improvements to local pollution, (4) the stated priorities of the local community through various forms of engagement (e.g., townhalls, surveys, etc.), (5) impacts on the local community, (6) impacts on other/external communities, (7) effects (positive or negative) on disadvantaged communities (DACs), and (8) expected timeline of implementation of proposed strategies. This combination of factors was based both on previous literature (e.g. Hawkins et al. 2015) and the interests of this research.

Respondents' familiarity with LCA, LCCA, equity, and life cycle-based equity was gauged using a Likert scale like the one used to assess the consideration of factors during CAP planning and implementation. Responses were converted to numerical values (from 1 to 5) to calculate mean familiarity. The survey subsequently offered a brief summary on the topics, intended to educate the respondent. The summary was followed by questions eliciting respondents' opinions about the extent to which they think these topics merit inclusion in local climate planning and implementation. Respondents were also asked about how their jurisdiction funds proposed climate actions, as well as how it funds updates to the CAP. There was also a question that procured information on what affects the likelihood that proposed actions get implemented. Finally, respondents were asked how they gauge CAP efficacy, and how often they report on progress to their constituents. The specific questions asked in both the quantitative and free-response sections are presented in Table 5.1.

Table 5.1. The questions asked in the survey are presented below. Note that the quantitative questions applied to the eight factors listed in the text, with five possible answers on a Likert scale to gauge the level of consideration for each factor.

Quantitative questions
1. When developing a CAP for your jurisdiction, how much did you consider the following?
2. When implementing a CAP for your jurisdiction, how much did you consider the following?
Score: 1 – "Not at all", 2 – "A little", 3 – "A moderate amount", 4 – "A lot", 5 – "A great deal"
Free-response questions
1. Please explain your response to the previous question: What explains the likelihood of using LCA in future climate action planning?
2. Please explain your response to the previous question: What explains the likelihood of using LCCA in future climate action planning?
3. Please explain your response to the previous question: What explains the likelihood of you incorporating environmental equity into future climate action planning?
4. Please explain your response to the previous question: What explains the likelihood of you incorporating life cycle-based environmental equity in future climate action planning?
5. How are the projects proposed in CAPs funded? What are your funding sources for these projects?
6. Specifically, how does your jurisdiction fund updates to the CAP?
7. What explains the likelihood of a project listed in a CAP getting implemented?
8. How does your jurisdiction assess efficacy of implementation of the plan?
9. How often do you report back to constituents on the progress of the CAP? What information is included?

After the final survey received an exemption from the UC Davis Institutional Review Board (IRB), it was published online through the web-based survey platform, Qualtrics. The full survey can be found in the Appendix. Best practices for survey implementation, including multiple reminders in multiple modes (e.g., phone and email), were used to increase the response rate (Dillman et al. 2009; Monroe and Adams 2012). The survey was sent to a set of California cities and counties who had published CAPs, the preliminary list of which had been developed in previous work (Lozano et. al 2020) and was updated through additional searches and resources. Of the 32 jurisdictions invited to complete the survey, a total of 25 responded, resulting in a response rate of 78%. Of these 25 responses, 4 completed the quantitative section of the survey but did not answer the free-response questions. The response rate was compared to various jurisdictional demographic data, namely: (1) year of CAP publication, (2) population of the jurisdiction (as of July 1, 2019), (3) the white non-Hispanic population, (4) the proportion of the population with a Bachelor's degree or more, (5) median household income, (6) poverty rate, and (7) population density. No statistically significant correlations were found. That is, no combination of the reviewed variables could significantly predict the likelihood that a jurisdiction would respond to the survey.

5.2.2. Survey response analysis

Because the purpose of the first part of the survey was to determine the relative importance of factors to each other, responses were normalized for each respondent. That is, for each survey response, the average score of all Likert responses was calculated, and individual responses were normalized accordingly, such that positive scores meant the factor was considered more than average, and negative scores meant that the factor was considered less than average. Note that the Planning and Implementation phases were considered separately, therefore responses were processed accordingly. The normalizing calculation is summarized in the equation below, calculated for factor "X," which is one of the eight factors listed previously, for phase "Y," which is either planning or implementation.

$$Normalized\ Score_{X,Y} = Survey\ Score_{X,Y} - Average\ Survey\ Score_{All,Y}$$

For example, if a respondent assigns "Emissions reduction" a consideration score of 5 in the survey, and the average score of all their responses is 4, then the normalized score for "Emissions reduction" would be +1, meaning that the expected reduction in GHG emissions of the climate actions was considered more than average. Alternatively, a survey score of 3 would lead to a normalized score of -1, meaning the expected GHG emissions reduction was considered less than average.

This method requires the potentially contentious assumption that the ordinal data (qualitative responses) provided by the Likert-scale questions can be converted to equally-spaced interval data (quantitative values from 1 to 5). For example, this method assumes that the difference between “No consideration” and “A little consideration” is the same as the difference between “A little consideration” and “A moderate amount of consideration”, which is also the same as the difference between “A lot of consideration” and “A great deal of consideration”. It is not possible to infer such a perfect distribution in sentiment, so some authors argue that it is incorrect to perform descriptive statistics (i.e., calculating mean and standard deviation) on ordinal data, and instead analysis should be restricted to the rank, median, and range of the data set (Allen and Seaman 2007). Another author notes that while literature tends to frown upon this sort of statistical analysis of Likert data, many peer-reviewed studies do so anyway (Jamieson 2004). Yet another author acknowledges this disparity in theory and practice, and proceeds to advocate for interval analysis of Likert data since the stated drawbacks of such analysis do not outweigh the benefits of getting some understanding of the data, even if it is imperfect (Norman 2010). Having acknowledged the drawbacks of assuming interval distribution from ordinal data, this study still proceeds to do so in an effort to gain a different understanding of the data distribution.

This study also normalized the responses to the quantitative questions by phase (planning or implementation) for each respondent. Normalizing the responses in each phase helps distinguish between the amount of consideration factors receive (according to each individual respondent) compared to the other factors during that phase. For example, consider a jurisdiction assigning a score of 3 to Cost in the planning phase, and 4 in the implementation phase. Comparing these two raw scores would suggest that Cost is considered more during implementation than planning. If we assume the average score during planning was 3, then Cost received a normalized score of 0, suggesting an average amount of consideration. Now, if all other factors received a greater increase in consideration during implementation than Cost did, such that the average score during implementation is greater than 4—say, 4.5—then in fact the *relative* consideration of Cost would have gone down (standardized score of -0.5). In other words, Cost would have received below-average levels of consideration during implementation, though the jurisdiction reported a higher level of overall consideration.

Consider another example where a jurisdiction assigns all factors a score of 3 during planning and a score of 5 during implementation. A comparison of raw scores shows that all factors are more highly considered during implementation than planning, but the difference in consideration between these factors remains constant. That is, no factor is considered more or less than any other across the phases. Since this study aims to highlight the relative consideration of factors in each phase, and not exclusively the difference in reported consideration between the two phases, the scores for factors within each phase were normalized.

A one sample t-test was performed on the normalized scores to determine whether any were statistically non-zero, signifying that it is likely they were considered above or below average. Scores that did not have a significant p-value are indistinguishable from a zero score, signifying that their consideration could be considered average. This analysis was conducted for all eight factors and distinguishes between responses for the planning and implementation phases.

There are four topics from the second section of the survey, comprised of open-ended questions (see Table 5.1), that are highlighted in this report: equity, life cycle equity, funding, and project implementation. Responses to the question(s) for each topic were reviewed and subsequently categorized into broad themes. The broad themes were generated to capture the sentiments and ideas expressed by respondents and were not pre-determined, since the researchers did not know what kinds of responses would be received. The number of responses that fall into each theme is provided in addition to an explanation of the theme and, occasionally, representative quotes.

5.3. Results

The survey can be considered as consisting of two parts: the quantitative response questions, and the qualitative, free response questions. The first sub-section of these results focuses on the quantitative responses, with all subsequent sub-sections presenting information collected from one set of qualitative questions.

5.3.1. Quantitative assessment of factors considered in planning and implementation

Respondents used a Likert scale response to indicate how important various factors were during climate action planning and implementation phases. The range of original responses is presented in Figure 5.1, whereas the range in normalized responses is presented in Figure 5.2. The data is presented in quartiles. The line dividing each box represents the sample median, with a quarter of responses falling between the median and the edge of the box. Each line extending from the edge of the box, a "whisker", encompasses another quarter of responses. Note that normalizing the data was done to focus on the relative consideration of factors according to each respondent, and in doing so, removed a number of outliers present in the non-normalized data.

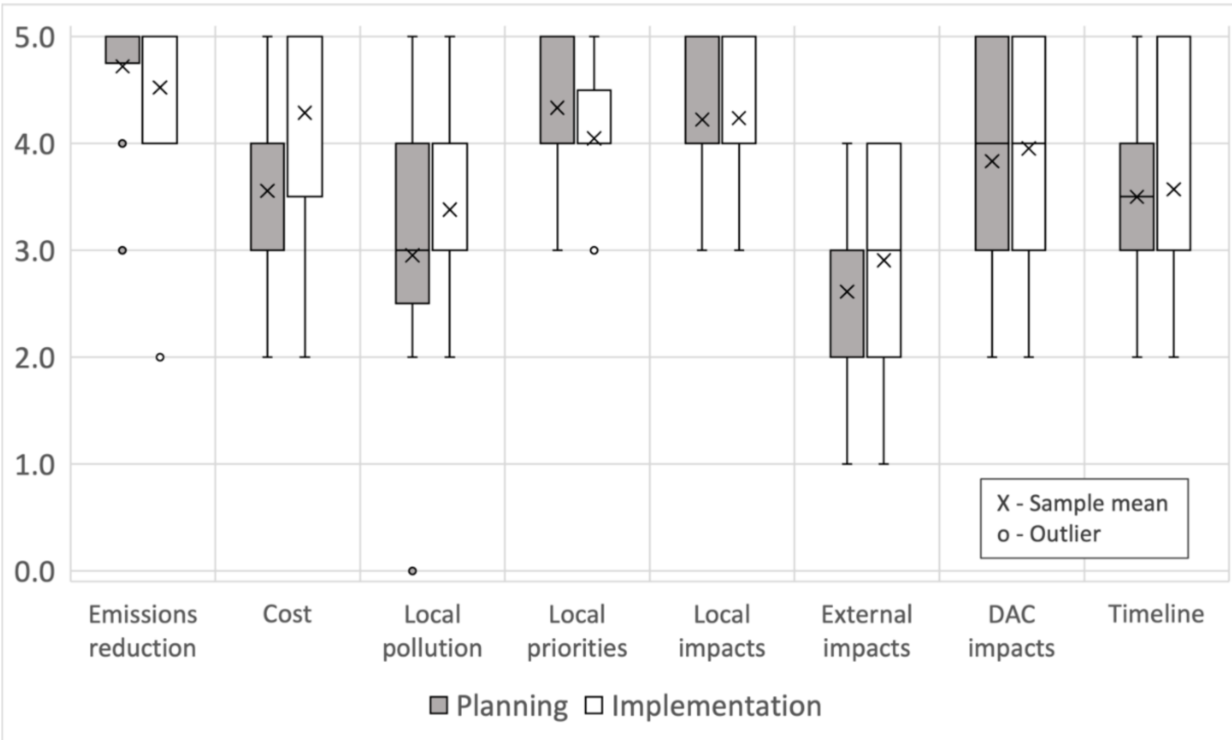


Figure 5.1. This box and whiskers plot shows the range of original consideration scores received by all factors for both the planning and implementation phases.

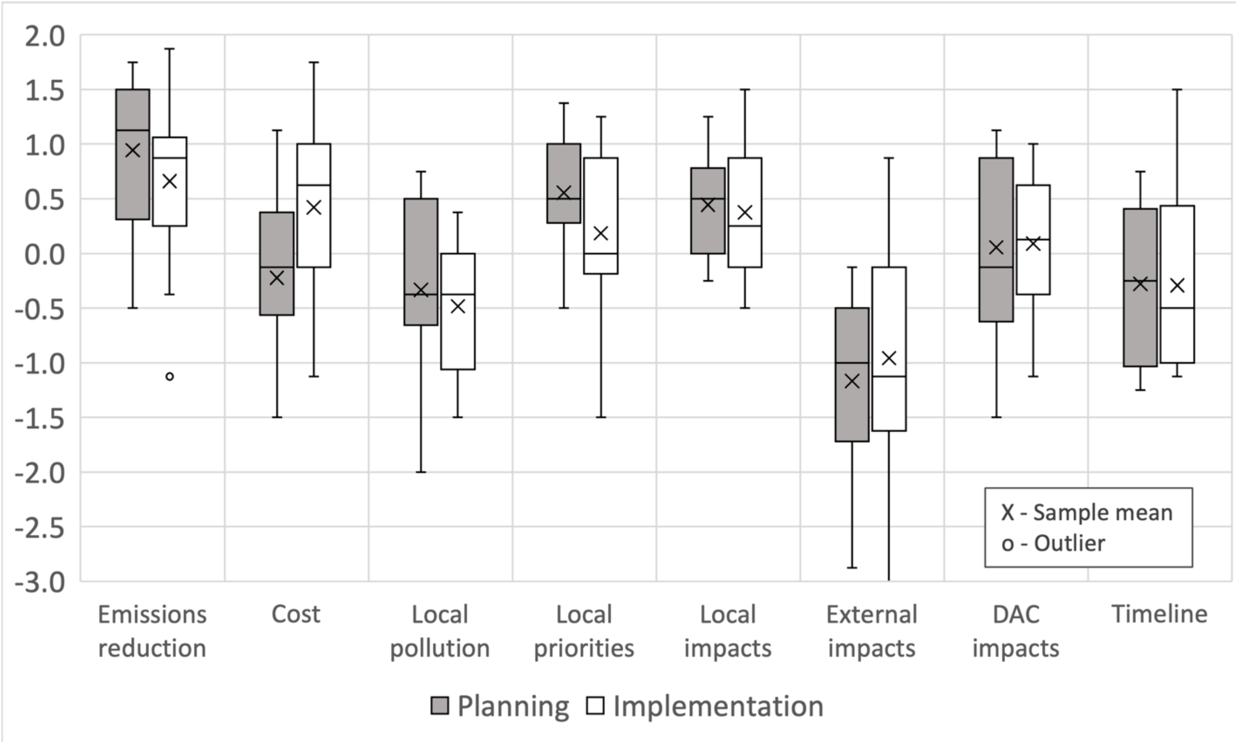


Figure 5.2. This box and whiskers plot shows the range of normalized consideration scores received by all factors for both the planning and implementation phases.

Various sets of t-tests were conducted on the normalized data to determine whether any factors had non-zero values (in other words, had non-average levels of consideration). The results of these t-tests are presented in

Table 5.2. The table includes the sample mean, the 95% confidence interval of the mean, and the corresponding p-value. The p-value determined whether the null hypothesis can be rejected that the mean is equal to zero. P-values smaller than the alpha value (

Table 5.2 shows alpha values of 0.05 and 0.01) reject the null hypothesis, thereby suggesting that the mean is non-zero. This is interpreted as the corresponding factor having a non-average level of consideration.

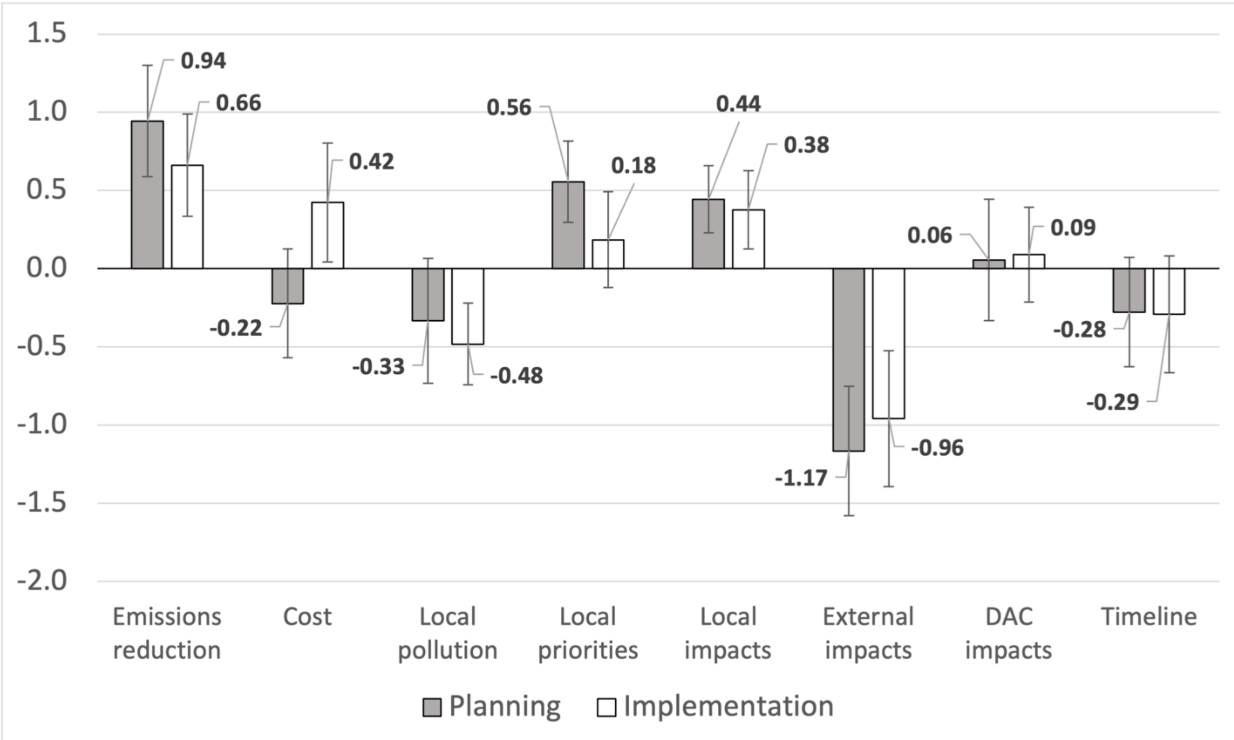
Note: Positive values signify that the factor was considered more important than average during that stage, with the opposite being true for negative values. The error bars show the 95% confidence interval about the mean, which is the range of values for which we are 95% confident that the true mean falls within.

Figure 5.3 highlights the mean normalized score assigned to each factor in addition to the 95% confidence interval of the mean, and is also presented across both phases. Note: The graph also includes the 95% confidence interval for each difference, which is a range of values for which we are 95% confident that the population difference is within. Note that positive values signify that a factor was more important during implementation than during planning, with the opposite being true for negative values. This uses normalized values based on the average consideration of factors per respondent for each phase.

Figure 5.4 graphs the difference in reported consideration between the implementation and planning phases for all factors.

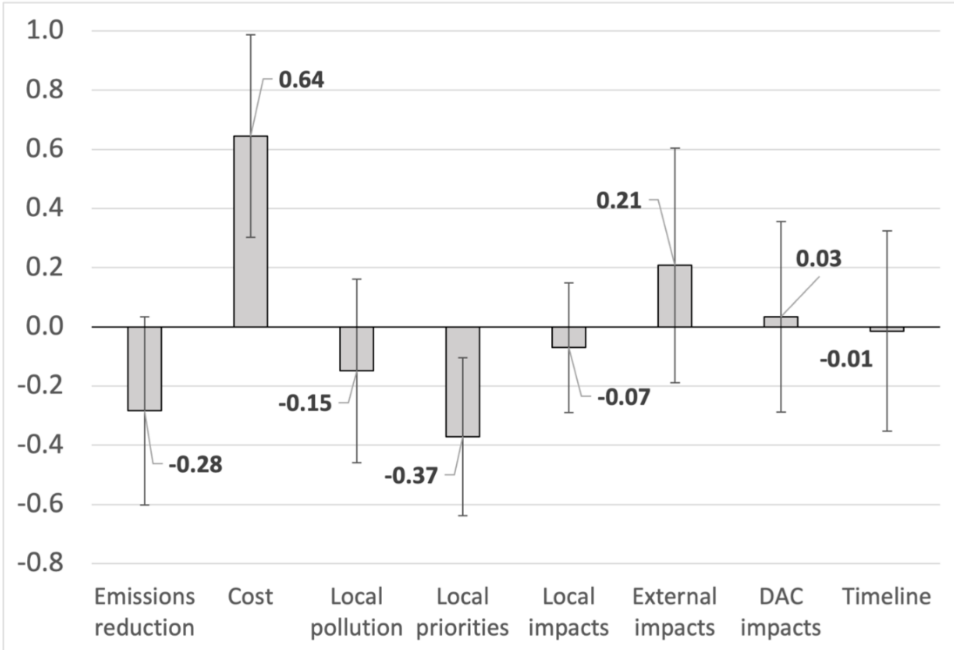
Table 5.2. Results of a one-sample t-test for the reported importance of various factors during the planning and implementation phases of local climate action. This includes the sample mean, the 95% confidence interval of the mean, and the p-value for the null hypothesis that the mean is equal to zero.

	Planning (df = 17)			Implementation (df = 20)		
Factor	Mean	95% C.I.	p-value	Mean	95% C.I.	p-value
Emissions reduction	0.94	0.35	3.10E-05**	0.66	0.33	4.25E-04**
Cost	-0.22	0.35	1.96E-01	0.42	0.38	3.13E-02*
Local pollution	-0.33	0.40	9.63E-02	-0.48	0.26	1.01E-03**
Local priorities	0.56	0.26	3.16E-04**	0.18	0.31	2.23E-01
Local impacts	0.44	0.21	4.16E-04**	0.38	0.25	5.28E-03**
External impacts	-1.17	0.41	1.55E-05**	-0.96	0.43	1.72E-04**
DAC impacts	0.06	0.39	7.67E-01	0.09	0.30	5.45E-01
Timeline	-0.28	0.35	1.11E-01	-0.29	0.37	1.19E-01
Note: *Value is significant for an alpha of 0.05; **value is significant for an alpha of 0.01.						



Note: Positive values signify that the factor was considered more important than average during that stage, with the opposite being true for negative values. The error bars show the 95% confidence interval about the mean, which is the range of values for which we are 95% confident that the true mean falls within.

Figure 5.3. A comparison of the mean reported relative consideration for planning (grey) and implementation (white).



Note: The graph also includes the 95% confidence interval for each difference, which is a range of values for which we are 95% confident that the population difference is within. Note that positive values signify that a factor was more important during implementation than during planning, with the opposite being true for negative values. This uses normalized values based on the average consideration of factors per respondent for each phase.

Figure 5.4. The difference in mean reported relative consideration of various factors during implementation compared to planning is plotted above.

5.3.2. Qualitative assessment of factors considered in planning and implementation

The following sections summarize the responses received for the free-response questions. The questions have been grouped by topic: life cycle emissions and cost, equity, life cycle equity, funding, and project implementation.

Life cycle emissions and cost

Respondents were first asked about their familiarity with life cycle assessment and life cycle cost assessment. On average, familiarity with life cycle assessment was reported to be 3.04 (just about “A moderate amount”; n = 23) while familiarity with life cycle cost assessment was reported to be 2.36 (between “A little” and “A moderate amount”; n = 23). While some responses were hopeful that LCA and LCCA would play roles in future climate planning, responses expressing doubt and limitations were more plentiful and vocal. Note that while the survey asked about the two concepts separately, the responses have been categorized together.

- **Too resource intensive** (n = 13) – Resource limitations and fear that the return on investment isn't justifiable were commonly cited reasons for not including life cycle thinking in local climate action. One jurisdiction shared that their consultants compared different types of greenhouse gas inventory methods, including LCA, and found that the results were "not necessarily more precise for the level of effort required." Similarly, another jurisdiction expressed that people already struggle with developing inventories, so expecting additional data for life cycle considerations may be excessive. One jurisdiction mentioned that their constituents want health impacts incorporated into the overall cost of projects, but that it's "hard to expect this level of data from small governments." Yet other jurisdictions expressed that due to limited resources, they decide to prioritize implementation over more complex planning or tracking progress. By and large, responses in this category may express appreciation for the benefits of life cycle considerations, but all feel that it is not something they have the resources to implement.
- **Life cycle proponents** (n = 12) – Many respondents seem to expect LCA to become more of a mainstay in California climate action planning despite not being required by policy, as more jurisdictions see the benefits of planning around consumption-based GHG emissions inventories over sector-based ones. Respondents also frequently cited LCA as a driving force for promoting electrification projects. Some respondents highlighted that LCCA informs decision making that justifies high initial investment for later, long-term success. This is particularly important since, as one jurisdiction reports,

localities operate with little to no budget, so analyzing the upfront and maintenance costs and monetary value of benefits of climate projects is important. Additionally, one jurisdiction explained how considered projects can find more traction within city staff when they are shown to have environmental and fiscal benefits over their life cycle. Of these responses, two reported using LCA and one reporting using LCCA in their climate action planning.

- **Not under their control** (n = 5) – Some jurisdictions mentioned that the inclusion of life cycle considerations is a decision made by the consulting agency (during planning) or the implementing party. One example provided was that for emissions reduction strategies regarding asphalt, it is not on the jurisdiction to decide what kind of asphalt mix is used. Other examples provided include emissions related to packaging material or refrigerants used in grocery stores: one city could not effectively implement policies that target these items.
- **Not a proven methodology** (n = 4) – Responses in this category were concise and suggested that the relevance of life cycle methodologies to local climate action is unknown, as are the benefits, so they are unlikely to be early adopters. This perspective is likely closely linked to jurisdictions having limited resources.
- **Debate on whether life cycle considerations are relevant or beneficial** (n = 3) – One jurisdiction cited the implementation of consumption-based inventories by other jurisdictions and expressed concern over how this results in the double counting of emissions across boundaries. On the other hand, another jurisdiction mentioned how their constituents are pushing for consumption-based GHG inventories, which track the emissions of products the jurisdiction produces and ships beyond its boundaries in

addition to accounting for the associated emissions of products the jurisdiction imports and/or consumes. Another jurisdiction mentioned that while they acknowledge the benefits of LCA, it is unlikely to motivate any change since their constituents care primarily about direct impacts from and the implementation of climate action.

Equity

Survey respondents were also asked to reflect on equity themes specifically. Respondents were very familiar with the concepts of environmental equity and disadvantaged communities, with both receiving an average familiarity score of 4.64 (between "A lot" and "A great deal"; n = 23). All but one jurisdiction responded that they are "very likely" (maximum score) to include equity themes in future CAPs. Respondents were then asked to clarify what affects the likelihood of including equity in future CAPs, and while some outlooks were generally positive, others expressed doubt on how to proceed. These responses have been categorized and expanded upon below.

- **Communities pushed for equity** (n = 5) – Many jurisdictions mentioned that equity has recently become a central discussion point in meetings held with community members. This could be, in part, because of the nation-wide attention garnered by the Black Lives Matter movement in the Summer of 2020, in response to the killing of George Floyd. One jurisdiction mentioned that the increased awareness of equity issues has made it "easier to plan and consider" equity in climate action. Another clarified that while equity is not explicitly highlighted during CAP development, this community push has led to the development of an equity-centered initiative for the jurisdiction, and that now, "implementation of every action within the CAP is done with an equity lens on it." One county clarified that while equity as a topic is of utmost importance, their jurisdiction did not contain any disadvantaged communities as determined by CalEnviroScreen, California's environmental health screening tool. However, they do have low-income, underserved communities within the county's unincorporated areas that "identify with the importance of and opportunities presented by [environmental justice]", which encourages the inclusion of equity-centered actions in the county's plan.

- **Not explicitly or sufficiently in the CAP** (n = 4) – Several jurisdictions mentioned that while equity is an important theme, it is not included in their climate action plan, but rather in other jurisdictional documents, typically either the jurisdiction's General Plan or a separate document altogether. Others also noted that their CAP could do a better job, as it does not currently include enough detail around equity.
- **Equity-centered funding is key** (n = 2) – Some jurisdictions mentioned that the increased importance placed on equity over the last couple of years has led to state and federal policies that provide funding to programs that promote equity. These policies include SB 535 and AB 1550, which explicitly direct funds to DACs and low-income communities, as well as AB 617, a bill aimed at reducing air pollution in communities experiencing the highest levels of exposure.
- **Doubt about effective implementation** (n = 1) – While acknowledging that equity and the environment should go hand-in-hand, one jurisdiction expressed doubt about meaningfully and impactfully addressing equity issues through implemented measures. The respondent expressed uncertainty on whether it is better to have equity play a role in the CAP development process, or more as a lens through which CAP measures are evaluated during implementation. Compare this to the response of yet another

jurisdiction, which clarified that they are currently doing both: proposed projects, programs, and policies must include an equity impact statement, and climate measures are considered and evaluated through an equity lens (among others).

- **Equity is not in scope** (n = 1) – One jurisdiction explained that the priority of a CAP is to enact jurisdiction-wide change. Therefore, actions are implemented that bring the greatest positive change to the jurisdiction (e.g., air quality improvement) regardless of the individual affected communities.

Life cycle-based equity

Respondents were briefly introduced to the concept of life cycle-based equity, which posits that the equity lens should be applied not just at the point of implementation, but across the life cycle of a proposed action. Particularly, there are impacts that may be outside the jurisdiction's borders, and the question is whether and to what extent these are considered by the jurisdictions who are sponsoring and implementing actions. For example, electrifying transit buses reduces local pollution along the routes of those buses, but it (1) requires the mining of minerals like cobalt for battery production, which generates significant burden in mining communities (e.g., in the Democratic Republic of the Congo), and (2) induces an increased demand for electricity which may generate additional local pollutants in communities near fossil fuel power plants that provide electricity to the grid. Life cycle-based environmental equity attempts to capture local impacts beyond the site of project implementation.

Respondent's sentiments on the inclusion of life cycle equity in CAPs can be separated into three simplified categories: not enough resources (n = 7), not their responsibility (n = 5), and not under their control (n = 3). Generally speaking, respondents acknowledged that there are impacts from decisions made within the jurisdiction that impact communities beyond its borders, but ultimately, local governments have to focus on efforts to improve the state of life within their borders, not outside them. In other words, life cycle equity is outside their scope and not something they could, or even should, pursue. Local jurisdictions feel primarily responsible to their own residents, with one respondent expressing that local governments must show that they "are spending tax payers' dollars on projects and plans that will benefit their immediate life." It was also shared that it is challenging to convince residents to make lifestyle changes for benefits not experienced by them directly (e.g., not purchasing low-emissions vehicles because of impacts in another country). Many respondents suggested that the inclusion of life cycle equity is a change that needs to occur in other areas, such as a change in practices offered by the consulting industry (which is largely responsible for providing the quantitative data that local governments use in their CAPs) or at the state or federal level through policy (e.g., requiring fair trade certifications for materials and products). To paraphrase one response, the inclusion of life cycle equity would require a change in the data provided to jurisdictions, which necessitates a change in the way the industry operates, which in turn could be supported by policy. The most frequently cited barrier, though, was that even if local governments did want to include life cycle equity to some extent, they simply do not have the resources to pursue acquiring the relevant data (e.g., the upstream impacts of various materials, end-of-life considerations) and conducting more complex calculations, especially since there is currently no tool or database that readily provides this. Ultimately, respondents felt that local governments have limited power to change this through the decisions they can make.

Funding

There were two questions in the survey that addressed sources of funding. One was for funding proposed climate actions, and the other was for funding updates to the CAP. Potential funding sources indicated in survey responses are summarized in Table 5.3, which highlights under which circumstance that source was referenced.

Table 5.3. Ways that jurisdictions fund (1) climate actions included in their CAPs, and (2) updates to their CAP.

	Climate Actions	Updates to the CAP
Grant opportunities	X (n = 15)	X (n = 5)
City/County General Fund	X (n = 11)	X (n = 8)
Community generated fees	X (n = 7)	X (n = 2)
Public/private partnerships	X (n = 4)	
Self-generated savings	X (n = 2)	
Developer fees	X (n = 2)	
Bonds	X (n = 1)	
Volunteering/Free	X (n = 1)	X (n = 3)
Unsure moving forward		X (n = 5)

Grant opportunities include state, federal, and private grants (e.g., electric bus purchase subsidies or DAC funds), and were the most frequently cited source of funding for CAP implementation. The City or County's General Fund was another frequently cited source of funding for climate actions. Community generated fees may include increases in electricity rates, air quality fees, recycling funds, and even direct taxes. Some projects may be self-financed through the savings they generate, or those savings may be used to fund different actions (e.g., renewable energy installations that produce savings through electricity generation once the initial investment is recuperated). Many jurisdictions mentioned volunteering and pro-bono work as a major contributor to CAP updates, with some expressing uncertainty on their plan moving forward due to limited resources.

Project Implementation

The final question of the survey asked respondents to reflect on the likelihood that all proposed actions are implemented, and then expand on what affects that likelihood. The developed categories and the number of responses that fell into each are summarized in Table 5.4.

Table 5.4. A summary of how many jurisdictions mentioned that the listed factor affected an action's likelihood of implementation.

	Factor affects implementation
Budget/Cost	n = 16
Political will	n = 8
Community support	n = 5
Ease of implementation	n = 5
Staff capacity/resources	n = 4
State of technology	n = 3
Advances equity goals	n = 1

Many jurisdictions mentioned financial reasons, such as budget limitations and upfront implementation cost. Project-centered factors included ease of climate action involved in implementation and the state of technology (e.g., expected technological advancements, supply chain issues), both of which directly affect the expected outcome of proposed actions. External factors mentioned include political will of those in power and community support of an action (for example, an action with divided community support is electrifying stoves). Successful implementation is also dependent on staff capacity and available resources, which, more often than not, was reported to be insufficient. Only one jurisdiction mentioned that an action's ability to meet equity goals affected its likelihood of implementation. Finally, one jurisdiction commented that a CAP doesn't "give teeth" to any proposed actions, since a plan for implementation is largely determined predetermined by funding and political will. Ultimately, the consensus was that implementation plans depend mostly on available funding and political will, with many new projects being considered only if new funds appear.

Gauging and reporting CAP progress

When reflecting on gauging CAP success, jurisdictions mentioned referencing evaluation metrics or progress indicators, such as quantity of solar panels installed, miles of new bike lanes, or electric vehicles miles traveled. Some jurisdictions tracked progress on an online dashboard. Others rely on updated greenhouse gas inventories to quantify the impacts. Still others answered they were unsure of the best way to quantify progress, or simply know they cannot gauge it.

Frequency of reporting varied widely, as did the method of reporting. One jurisdiction reports at least every other month in City Council meetings and disburses information both in written format (e.g., local news outlets and newsletters) and verbally (e.g., meeting presentations), while others aim to provide updates every four years. The majority of jurisdictions report on progress every 1-2 years, and do so either by referring to pre-determined metrics, or by updating the jurisdiction's greenhouse gas inventory. The range of information that is reported includes: implementation level of actions, estimated emissions reduction, changes to key performance indicators (e.g., energy or water use, vehicle miles traveled, etc.), new or proposed projects, and new partnerships.

5.4. Discussion

In assessing the quantitative results of the survey, we examine three trends: relative consideration of factors in the planning phase, relative consideration of factors in the implementation phase, and the difference in relative consideration between the two phases. During the planning phase, the priorities of the jurisdiction's constituents, the expected GHG emissions reduction of proposed actions, and actions' local impacts receive above-average consideration, with emissions reduction being the most highly considered. At the same time, the external impacts of climate actions receive significantly below-average consideration during the planning phase. Upon examining consideration in the implementation phase, much remains constant: expected emissions reduction and local impacts of actions receive above average consideration (with emissions reduction again being the most highly considered), while external impacts again receive below-average consideration. In addition, change to local pollution was considered below average during implementation, while expected cost (albeit with slightly less significance) received above average consideration. During both planning and implementation, impacts of actions on DACs receive an average amount of consideration, as does the timeline of implementation.

It is unsurprising that expected emissions reduction would be at the forefront in decision-making during both planning and implementation since the primary goal of CAPs is to accomplish just that. It is also unsurprising that external impacts were considered the least across both phases, especially considering responses to the concept of life cycle equity: local governments serve their constituents, and do not have the power or capacity to consider extra-jurisdictional communities in their decision making.

It was also interesting to examine changes in the level of consideration between the two phases. Cost was considered significantly more during implementation than during planning. Note that this held true even using original, non-normalized survey responses (see Figure A.5.2). This is in line with the frequency of which respondents cited cost and resource limitations as reasons they were restricted in their actions. One interpretation of this result is that while the planning phase allows jurisdictions to consider a plethora of different factors, such as impacts on DACs and action co-benefits, at the time of implementation, it becomes a discussion of what is fiscally feasible or what is specifically funded through existing policies and grants. This interpretation is supported by the fact that reported local priorities were considered less during implementation than during planning. The difference in consideration between implementation and planning for all other factors was not statistically different from 0. It may be relevant to note that two jurisdictions lamented their inability to participate in this study's survey because they were under-resourced. That is, while they would have liked to participate, they were behind on planning and/or implementation, and so could not spare the time. This may be true of other jurisdictions that did not respond.

While GHG emissions reduction and cost were reported to be major factors in climate action planning and implementation, life cycle methodologies did not seem to receive much consideration across the board despite the added benefits in estimated environmental and fiscal impacts. Firstly, jurisdictions were not too familiar with the concepts of LCA and LCCA, with the average respondent knowing between "a little" and "a moderate amount" about them. Compare this to familiarity with environmental equity, which was "a great deal" for nearly all respondents. The impression of many respondents was that life cycle methods are too resource intensive, especially for those who were uncertain about the additional benefits provided. A number of responses debated the value of using LCA to develop consumption-based inventories.

While some jurisdictions highlighted the importance of increased emissions tracing, others countered that local jurisdictions have limited control over many products and items, thereby arguing that consumption-based inventories are not relevant for local action. However, few mentioned estimating the expected life cycle emissions and cost of proposed climate projects. Those that did mentioned that life cycle information can be very helpful in promoting projects with high initial costs or those that have long-term benefits.

All jurisdictions expect equity to play a large role in the future, and yet it received average consideration during both planning and implementation, and when asked what affects the likelihood of an action's implementation, only one jurisdiction mentioned equity. One explanation for this is that jurisdictions are under-resourced and under-funded, such that these two factors take priority during implementation, consistent with this study's findings. The quantitative assessment found that the expected cost of actions is considered significantly more during implementation than during planning, and an open-ended question saw cost and budget cited as a major factor that affects implementation twice as much as the next most-important factor (political will).

Additionally, jurisdictions cited outside grants as the most common funding source, suggesting that many jurisdictions are not self-sufficient when it comes to implementing their CAPs. While the state of California has certainly made an effort to promote equity and sustainability through its policies, local governments may in fact need additional support from both the state and federal governments to implement their proposed emissions reduction actions, and even more so if they are to do so equitably. This study compiled questions in Section 4.1. to guide climate action planning and assess implementation, and while this is hopefully a welcome resource, it does little to alleviate the financial barrier that jurisdictions currently face. The fact that some jurisdictions require volunteer work to update their CAP, means they likely do not have the funds to include sufficient data in their CAP to make the best long-term and equitable decisions. This is a systemic problem that requires top-down support.

The results and interpretation of this study are subject to some limitations. First, the relatively small sample size of respondents to the survey (25 total responses, 18 and 21 responses for planning and implementation phases, respectively, and between 16 and 22 responses for the free-response questions) is challenging for quantitative analysis. Though the distribution of the quantitative responses was small enough to yield statistically significant results, the reliability of would benefit from more responses. A similar argument could be made for the free-response questions. It is also possible that the quantitative questions did not list all relevant factors taken into consideration during planning or implementation. One example is political will, which was mentioned frequently in the free-response questions, but was not an option in the survey responses. If this and other relevant factors had been listed, it is possible that respondents would have reported their consideration for other factors differently, thus affecting the findings.

Additionally, it is possible that local impacts, external impacts, and DAC impacts are correlated variables such that they may have had similar response trends, an observation made after the distribution of the survey. This was tested using Cronbach's Alpha, a measure of how closely related items within a group are. Possible values are between 0 and 1, where smaller values signify that there is a lot of similarity between the items. For reference, calculating Cronbach's

Alpha for all 8 variables considered in the survey gave values of 0.59 and 0.69 for the planning and implementation phases, respectively. Calculating Cronbach's alpha for local impacts, external impacts, and DAC impacts, however, yielded values of 0.05 and 0.4 for planning and implementation, respectively. The smaller alpha values support the theory that respondents assessed these three items more similarly than they did all other factors, and in the case of planning, assessed them almost identically. Similar studies in the future should consider a way to distinguish between these three impacts, perhaps by using a separate survey question on the consideration given to impacts on different communities.

While the validity of assuming interval distribution of ordinal data has already been discussed, another question of interest is whether there was a better way to collect data. For example, perhaps the study should have used a 7 point Likert scale instead of a 5 point Likert scale. However, a study by Dawes (2012) showed that there is no difference in the sample mean between these two scales, but that a 10 point Likert scale could yield better results. Both this paper and others (e.g., Jamieson 2004) argue that for this type of data collection, it is better to use a sliding scale than a Likert scale. To simplify an already lengthy survey, a Likert scale was used in this study. However, future studies could use a 10 point Likert or sliding scale and evaluate whether it changes the result.

On the topic of survey length, it may be advisable to focus on fewer topics in a single survey to improve the quality of responses, as (1) jurisdictional representatives have little time to devote to this kind of activity, and (2) a number of responses to open-ended questions in this survey did not answer the entire question, and as is evident by the response rate, some jurisdictions opted to not answer some questions at all.

5.5.Data Availability

Data, as well as the full survey, can be found on Lozano *et al* 2022.

Chapter 6. Conclusion

Summary

This dissertation explored the ways that local climate action can be adjusted for greater impacts and grounded that work in the realities that jurisdictions face when planning and implementing actions. The benefits of life cycle assessment (LCA) and life cycle cost assessment (LCCA) were revealed when applying the methodology to estimate the expected life cycle greenhouse gas (GHG) emissions and life cycle cost of various proposed emissions reduction strategies. These results were presented in marginal abatement cost curves (MACCs) to highlight the relative emissions reduction potential and life cycle cost effectiveness of the assessed strategies. This research also identified proposed strategies that generated net positive emissions.

Subsequently, an assessment of published climate action plans (CAPs) examined the extent to which the documents include emissions, cost, and equity data. A scoring framework was used to quantify their inclusion, and a comparison with relevant variables found that: (1) emissions data tends to be of better quality in more recent CAPs as well as in wealthier jurisdictions and those with a higher proportion of Hispanic residents, and (2) the inclusion of equity themes is positively correlated with the education level of the jurisdiction. A set of general and sector-specific guiding questions is presented to promote the consideration of equity themes across CAP development and implementation.

A critical assessment of the role of community choice aggregators (CCAs) in local climate action warns against assigning too much emissions reduction potential to their cleaner grid mix. Specifically, it is difficult to assign a value to the influence a single CCA has on the installation of new renewable energy on the greater grid, especially since not all CCAs contract for new installations. There is the additional complication that because the primary forms of new renewable energy, wind and solar, have variable energy production throughout the day, there are times where electricity is used that is not from renewable sources. Some CCAs have contracted additional storage to address this mismatch. However, this does not fully address the issue, and also introduces additional emissions over the life cycle of the energy storage technology. A review was conducted of the methodologies used by jurisdictions to estimate the impacts of transitioning from an incumbent utility to a CCA. While it is difficult to accurately assign an emissions reduction potential to this transition, and jurisdictions should be wary about doing so, the research offered recommendations on what should be considered when estimating a CCA's impact on GHG emissions.

Finally, a survey of local jurisdictions revealed much of what influences their planning and implementation, specifically the relative importance of various factors across both phases of climate action. Namely, emissions reduction potential is the most important factor during both planning and implementation, local priorities and more strongly considered during planning than during implementation, and cost is a more strongly considered during implementation than planning. The survey also shed light on what prevents local jurisdictions from incorporating life cycle assessment in their planning, why they are unable to account for the far-reaching impacts of project implementation, the different funding sources jurisdictions rely on, and ultimately what limits their ideal operation.

Conclusions

While this research showed the benefits of developing life cycle marginal abatement cost curves (MACCs), they require time and resources that not many jurisdictions have available. For example, of reviewed climate action plans (CAPs), only San Jose procured a MACC. However, this research showed that life cycle-based MACCs can be developed in a timely manner and can greatly improve the accounting of GHG emissions. This methodology also makes it possible to expose those strategies that may seem to reduce direct greenhouse gas (GHG) emissions, but lead to net positive emissuibs. Additionally, it can be used to justify higher initial costs of proposed strategies if it is shown that they generate net savings over their life cycle. This is in line with the expectations and experiences shared by some survey respondents, and the results of the MACC work address some expressed concerns over the relevancy of life cycle assessment (LCA) and life cycle cost analysis (LCCA) in local climate planning.

Incorporating life cycle accounting in climate action planning occurs at the request of the jurisdictions, but with limited resources, their inclusion would have to be facilitated by other entities. To this end, it could be helpful to develop state policy that supports specific aspects of planning and establishes minimum requirements in the climate action plan development. Such a policy would provide guidance and parameters to support local climate efforts while also allocating additional funds to meet those ends. This investment could be justified due to the benefits of life cycle accounting (as mentioned in Chapter 2) and would address expressed concerns from jurisdictions over the resource intensity demanded by the additional data and expertise required for life-cycle based assessments (as mentioned in Chapter 5).

Estimating expected emissions and tracking resulting emissions reductions would help local jurisdictions better understand their direct impact on meeting climate goals. Because local actions happen in conjunction with intra-jurisdictional, statewide, and national sustainability actions, there is uncertainty around how much local actions directly contribute to emissions reduction goals. Certainly, a number of studies confirm the importance of local climate action (e.g., Lutsey and Sperling, 2007), so it is more a question of how much change can be directly attributed to local action. One study proposed disaggregating emissions by various factors, primarily those not explicitly under the control of the local government (Azevedo and Leal 2021). Some examples include population, transportation habits and regulations, the local economy, and energy prices. Using this methodology, they examined emissions in Porto, Portugal from 2004 and 2015 and found that while total emissions were reduced by 31% in that time frame, the estimated effect of local actions was only 7.2%, less than a quarter of the total emissions reduction. Some of the reviewed CAPs distinguish between state-led emissions reduction strategies and locally implemented ones, but they comprise a minority of CAPs reviewed in this dissertation.

One particular question regarding the impact of local versus regional or state-wide mitigation actions is the efficacy of CCAs to reduce the GHG emissions from electricity. Based on reviewed CAPs, many jurisdictions assigned an emissions reduction credit based on CCA procurement of more renewable energy than the incumbent utility provides. However, many fail to consider the time-of-use of the electricity relative to the availability of renewable energy production, thereby ignoring situations where their constituents still depend on non-renewable sources of energy to meet their electricity demand. Additionally, many failed to consider the fact that the larger electric grid will have more renewables over time to adhere to state renewable portfolio standards, which also reduces the difference in carbon intensity between the two options.

It may be more practical to qualitatively credit CCAs with pushing the entire state's electric grid towards having more renewables and meeting RPS goals without necessarily assigning them an independent emissions reduction potential. However, some jurisdictions may feel the need to report to their constituents the direct impacts of actions that have been taken to address climate change, such as transitioning to a CCA that procures high levels of renewables. If jurisdictions feel compelled to estimate their impacts, this research recommends (1) considering the hourly sources of energy consumption, (2) considering the underlying changes to the larger California grid mix over time, and (3) accounting for customers that remain with the incumbent utility when calculating energy use that is affected by the CCA.

The survey of local government officials responsible for CAP development (Chapter 5) confirmed that GHG emissions reduction and cost are of primary importance to climate action planners, but so are the stated priorities of the jurisdiction's residents and the impacts of climate action on the local community. While MACCs consider the first two factors, decision making is evidently influenced by the latter two as well. Therefore, a framework that combines these factors, such as using multi-criteria analysis could support such decision-making. One previous study considered job creation and ease of implementation in addition to emissions reduction potential and cost effectiveness to rank different climate actions and found that there is indeed a difference in rank order (de Melo *et al.* 2013). Assessments of local climate action could confirm with local representatives a list of priority factors and use those in combination with MACC information to provide a more holistic rank order of the projects. An even more holistic evaluation would include overlap between actions (e.g., primary actions vs supporting actions). In practice, however, the implementation of such methodologies is unlikely since even developing MACCs requires more resources than most local governments are able or ready to provide.

It may be important to also contextualize that decision-making is sometimes tied directly to the sources of funding that support mitigation actions. The survey conducted in this dissertation confirmed that grant opportunities, which typically have predetermined goals or purposes, are more commonly referenced as funding sources for climate action implementation than city funds, which can be spent with more flexibility. For example, an assessment may find that electrifying a California city's bus fleet is not the most impactful emissions reduction strategy, but the city may opt to purchase electric buses anyway due to the availability of funds through the state's Hybrid and Zero-Emission Truck and Bus Voucher Incentive Program (HVIP), which subsidized the purchase of low emissions trucks and buses at the point of purchase. The decision to implement bus fleet electrification as a mitigation strategy is spurred by state fund availability, and not necessarily because the jurisdiction deemed it a priority. In other words, decision-making may be more opportunistic than driven by an assessment of all available strategies and their expected impact. This may also be true with environmental equity-centered decisions. While some grants are earmarked broadly for projects that support environmental justice, others, such as federal Urban Waters Small Grants or Diesel Emissions Reduction Act Grants (US EPA 2022), may be geared towards more specific sectors or purposes. Additionally, since many funding sources (e.g., those supported by Justice40 at the national level or SB 535 in California) are meant for projects that directly benefit disadvantaged communities, some jurisdictions may not have access to equity-centered funding because their population is not among the most disadvantaged across the state or country.

While this research found that equity is receiving more attention during the planning and writing phase over time in reviewed CAPs, as is evident in the stated intentions of climate action plans currently under development, it is imperative that equity be considered during implementation. Survey results found that equity received significantly less importance during implementation than planning. Thus, the importance of community environmental justice organizations and other grassroots groups cannot be understated. This external accountability beyond the planning phase is necessitated if organizations are to implement emissions reduction strategies with equity in mind. Accountability to equity priorities within jurisdictions and their CAPs can be accomplished by establishing equity-specific performance measures (e.g., job creation, affordable housing units, local pollutant concentrations, etc.) and reporting updates in regular intervals. Additionally, jurisdictions should commit time and resources to regularly engage with and report to their constituents, not only during the planning process. Because there are impacts that reach beyond the boundaries of individual jurisdictions, the state should promote collaboration between multiple jurisdictions in addressing climate change, perhaps through regional climate action plans.

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Appendix

A.2. Chapter 2

Table A.2.1 summarizes relevant information that was collected when reviewing CAPs across California. It provides the name of the jurisdiction, the year of final CAP release, whether the CAP includes any quantitative data (emissions and/or cost), and the accessed link. It is specified whether the CAP provides emissions and/or costs, whether the data it considered a "scaled" value (i.e. high, medium, or low expected emissions reduction), as well as whether information is provided for each strategy or summed across all strategies.

Table A.2.1. Documentation of Reviewed Climate Action Plans (CAP)

Jurisdiction	Year of CAP	Source
Benicia	2009	http://www.sustainablebenicia.org/files/cap/Transportationandlanduse.pdf
Berkeley	2009	https://www.cityofberkeley.info/uploadedFiles/Planning_and_Development/Level_3_-_Energy_and_Sustainable_Development/Berkeley%20Climate%20Action%20Plan.pdf
Chula Vista	2017	https://www.chulavistaca.gov/home/showdocument?id=15586
Cupertino	2015	https://www.cupertino.org/our-city/departments/environment-sustainability/climate-action
Emeryville	2016	https://www.ci.emeryville.ca.us/DocumentCenter/View/9328/Emeryville-CAP-2016-Implementation-Plan?bidId=
Fremont	2012	https://fremont.gov/DocumentCenter/View/19837/Climate-Action-Plan
Fresno	2014	https://www.fresno.gov/darm/wp-content/uploads/sites/10/2016/11/F-2-Greenhouse-Gas-Reduction-Plan.pdf
Hayward	2009	https://www.hayward-ca.gov/services/city-services/climate-action
Humboldt County	2012	https://humboldtgov.org/DocumentCenter/View/1347/Draft-Climate-Action-Plan-PDF?bidId=
Lakewood	2015	http://www.lakewood.org/SustainabilityPlan/
Lancaster	2016	https://www.cityoflancasterca.org/Home/ShowDocument?id=32356
Los Angeles County	2015	http://planning.lacounty.gov/assets/upl/project/ccap_final-august2015.pdf
Manhattan Beach	2010	https://www.citymb.info/home/showdocument?id=16913
Marin County	2015	https://www.marincounty.org/~/media/files/departments/cd/planning/sustainability/climate-and-adaptation/chpt4marincapupdate_final_20150731.pdf?la=en
Monterey	2016	https://monterey.org/Portals/0/Reports/ForPublicReview/Draft_Climate_Action_Plan.pdf
Oakland	2018	http://www2.oaklandnet.com/oakca1/groups/pwa/documents/policy/oak069942.pdf

Palo Alto	2016	https://www.cityofpaloalto.org/civicax/filebank/documents/64814
Piedmont	2018	www.ci.piedmont.ca.us/climate-action-plan-2-0/
Riverside County	2018	https://planning.rctlma.org/Portals/14/CAP/CAP_071717.pdf
Sacramento	2016	https://www.cityofsacramento.org/-/media/Corporate/Files/Public-Works/Facilities/CityOfSacramento_1606_ClimateActionPlan_InternalOps_FINAL.pdf?la=en
San Bernardino County	2014	https://www.gosbcta.com/plans-projects/plans-greenhouse.html
San Francisco (City and County)	2013	https://sfenvironment.org/sites/default/files/engagement_files/sfe_cc_ClimateActionStrategyUpdate2013.pdf
San Jose	2018	http://www.sanjoseca.gov/DocumentCenter/View/75035
San Leandro	2009	https://www.ca-ilg.org/sites/main/files/file-attachments/resources__ClimateActionPlan.pdf
San Rafael	2017	http://cityofsanrafael.granicus.com/MetaViewer.php?view_id=38&event_id=1108&meta_id=132004
Santa Ana	2015	https://www.santa-ana.org/sites/default/files/Documents/climate_action_plan.pdf
Santa Barbara	2012	https://www.santabarbaraca.gov/civicax/filebank/blobdload.aspx?BlobID=17716
Santa Cruz	2012	http://www.cityofsantacruz.com/home/showdocument?id=29361
Shasta County	2012	https://www.co.shasta.ca.us/index/drm_index/aq_index/programs/RCAP/Draft_RCAP.aspx
Solana Beach	2017	http://solana-beach.hdso.net/docs/CM_ClimateActionPlan-Draft.pdf
Sonoma	2016	https://rcpa.ca.gov/wp-content/uploads/2016/07/CA2020_Plan_7-7-16_web.pdf
Stockton	2014	http://stockton.granicus.com/MetaViewer.php?view_id=48&clip_id=5016&meta_id=418169
West Hollywood	2011	https://www.weho.org/home/showdocument?id=7949
Woodland	2017	https://www.cityofwoodland.org/DocumentCenter/View/834/Climate-Action-Plan-PDF
Yolo County	2011	https://www.yolocounty.org/home/showdocument?id=18005
Yountville	2016	http://www.townofyountville.com/home/showdocument?id=4864

Figure A.2.1. outlines which aspects of a fuel's life cycle are considered well-to-pump, pump-to-wheel, and well-to-wheel. Figures A.2.2 through A.2.7 and Table A.2.3 provide additional information on the breakdown of emissions determined as determined by this research. Table A.2.5 provides the projected California consumption-based electric grid mix that is referenced for a number of strategies. Tables A.2.2, A.2.4, and A.2.6 through A.2.9 provide a breakdown of the cost for the strategies.

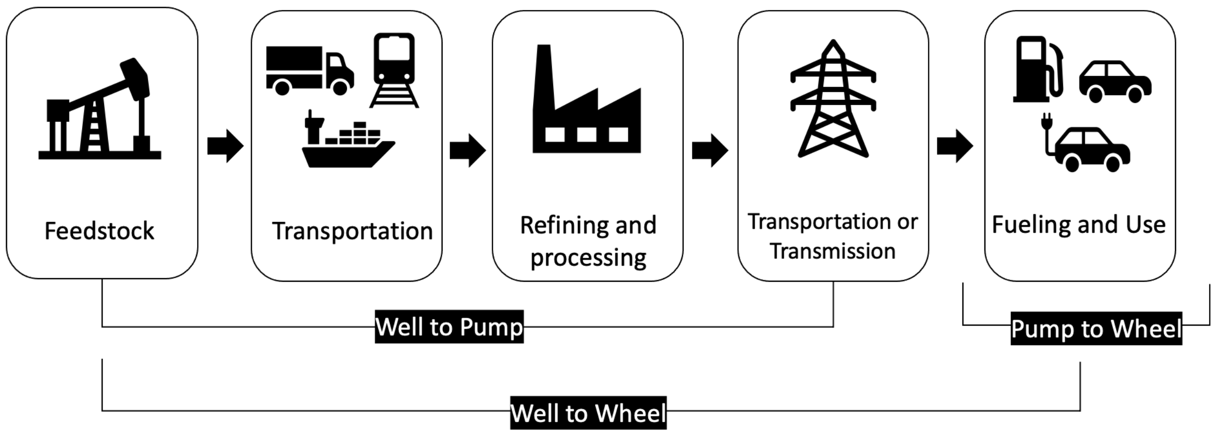


Figure A.2.1. A system diagram of fuel-related emissions.

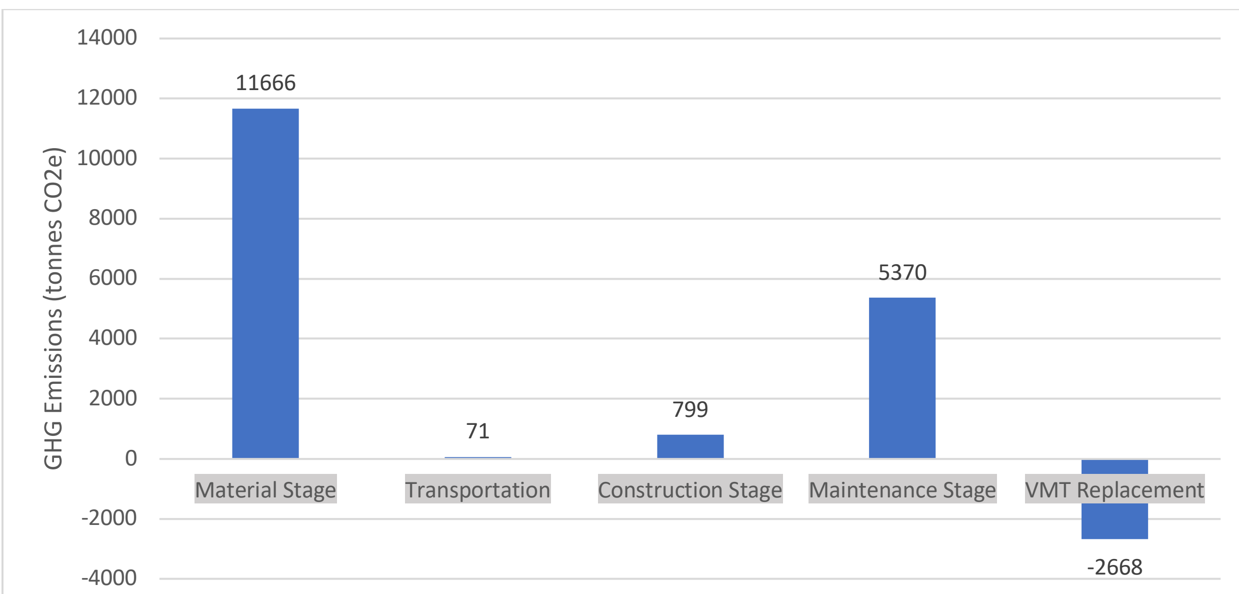


Figure A.2.2. A breakdown of the emissions generated to produce bike paths and lanes, as well as the expected emissions reduction achieved through vehicle VMT reduction.

Table A.2.2. A breakdown of costs associated with bike lane construction and maintenance.

	Bike Path	Bike Lane	Total cost
Cost per lane-km	$ 449,116	$ 474,891	-
Initial cost	-	-	$ 102,845,710
Maintenance (discounted)	-	-	$ 42,880,486

Table A.2.3. A breakdown of emissions associated with producing the two types of intersections, as well as the difference in emissions of the drivecycle associated with driving through each intersection. Note that drivecycle emissions are five orders of magnitude larger than pavement-related emissions.

		Current Intersection	**Intersection with a Roundabout**
	Life Cycle Stages	**tonne CO_2e**	**tonne CO_2e**
Conventional HMA	Material Stage	4.97	4.46
	Transportation	0.03	0.027
	Construction Stage	0.34	0.305
	Maintenance Stage (at every year 7)	5.55	4.98
Cement Concrete for Minor Concrete (without secondary cementitious materials)	Material Stage	-	1.54
	Transportation	-	0.229
	Construction Stage	-	0.0147
Use Phase (drivecycle)	WTW emissions	1,109,687	1,012,700

Table A.2.4. A breakdown of costs associated with producing the two types of intersections.

	Stop-start Intersection	Roundabout
HMA-A	$ 92,308	$ 108,418
PCC	$ -	$ 43,960
Milling	$ 38,400	$ 38,400
Maintenance (every 7 years)	$ 130,708	$ 87,953

Note: The maintenance costs repeat three times. The real time cost is as listed, but they are discounted to present day values depending on when maintenance occurs.

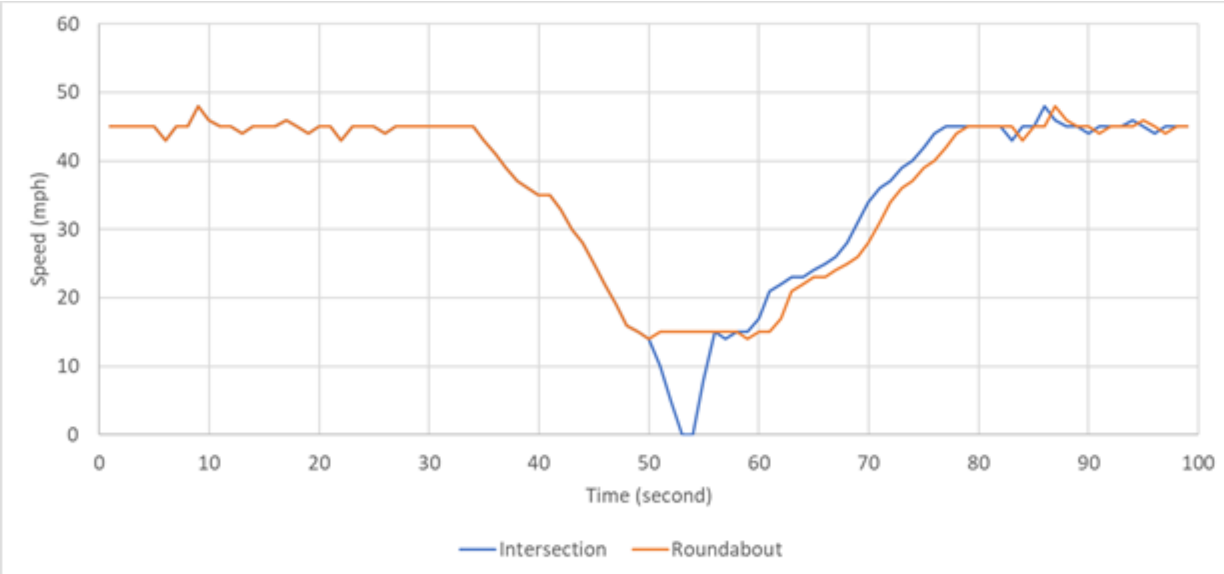


Figure A.2.3. Drive cycle used in MOVES.

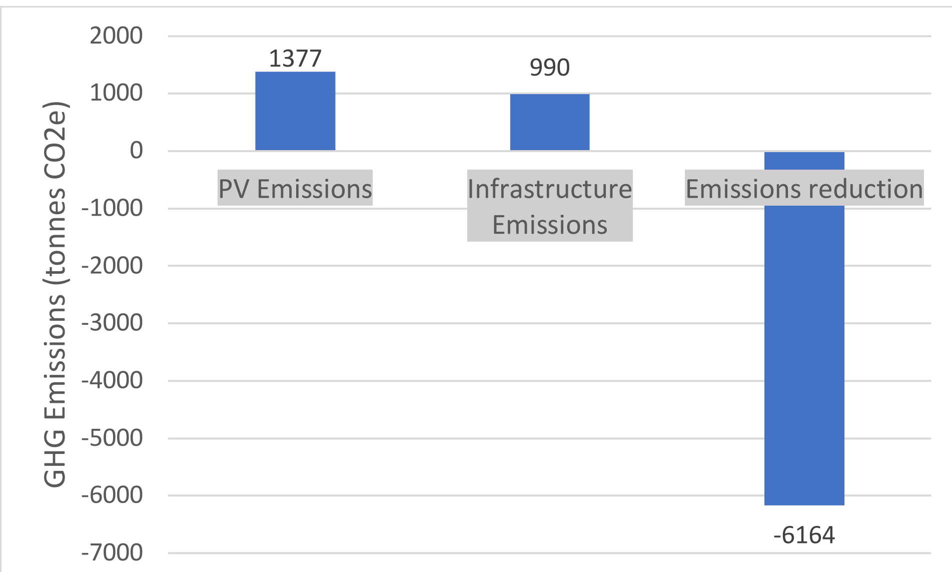


Figure A.2.4. This figure shows the life cycle emissions of the solar PV and infrastructure required to build solar canopies, as well as the emissions reduction achieved through the electricity that is generated.

Table A.2.5. The projected California grid mix based on consumption, acquired from the EIA, is provided in the table below.

CAMX Grid Mix	2020	2025	2030	2035	2040	2045
Coal	4%	0%	0%	0%	0%	0%
Petroleum	0%	0%	0%	0%	0%	0%

Natural Gas	33%	30%	27%	22%	20%	19%
Nuclear	10%	5%	0%	0%	0%	0%
Renewables	53%	65%	73%	78%	80%	81%

Table A.2.6. A cost breakdown for solar canopy installation. Benefits are generated from electricity production.

Installation Cost	$ 979,200.00
Benefits Generated	$ (1,749,418.07)

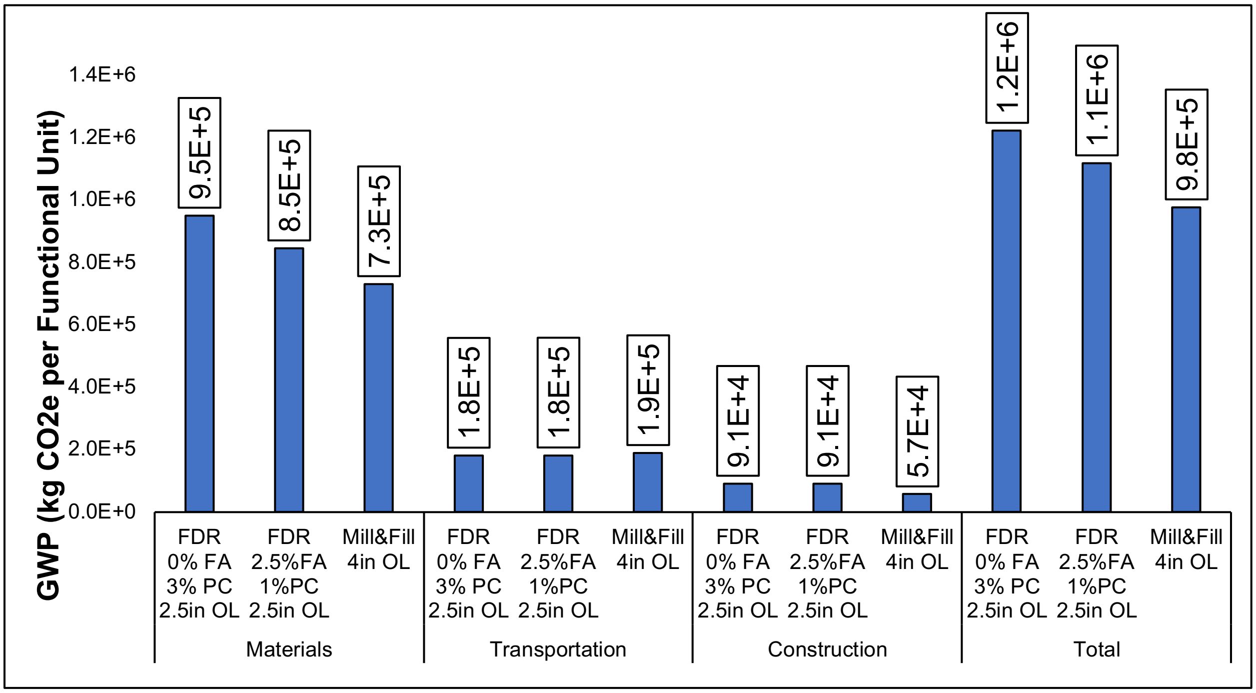


Figure A.2.5. The emissions breakdown of three pavement rehabilitation methods, categorized by materials, transportation, and construction related emissions.

Table A.2.7. The cost breakdown for the three pavement maintenance options considered.

Case	Item	Unit	Amount	Cost (Million $)
FDR, 0 Foamed Asphalt (%), 3 Portland Cement (%), 2.5 Overlay Thickness (in)	Mill & Fill	CY	0	0.00
	Foamed Asphalt	TON	0	0.00
	FDR	SQYD	73,216	0.60
	Portland Cement	TON	624	0.13
	Overlay	TON	10,402	1.00

	Total	**-**	**-**	**1.74**
FDR, 0.025 Foamed Asphalt (%), 0.01 Portland Cement (%), 2.5 Overlay Thickness (in)	Mill & Fill	CY	0	0.00
	Foamed Asphalt	TON	520	0.24
	FDR	SQYD	73,216	0.60
	Portland Cement	TON	208	0.04
	Overlay	TON	10,402	1.00
	Total	**-**	**-**	**1.89**
Mill & Fill, 0 Foamed Asphalt (%), 0 Portland Cement (%), 4 Overlay Thickness (in)	Mill & Fill	CY	8,228	3.12
	Foamed Asphalt	TON	0	0.00
	FDR	SQYD	0	0.00
	Portland Cement	TON	0	0.00
	Overlay	TON	0	0.00
	Total	**-**	**-**	**3.12**

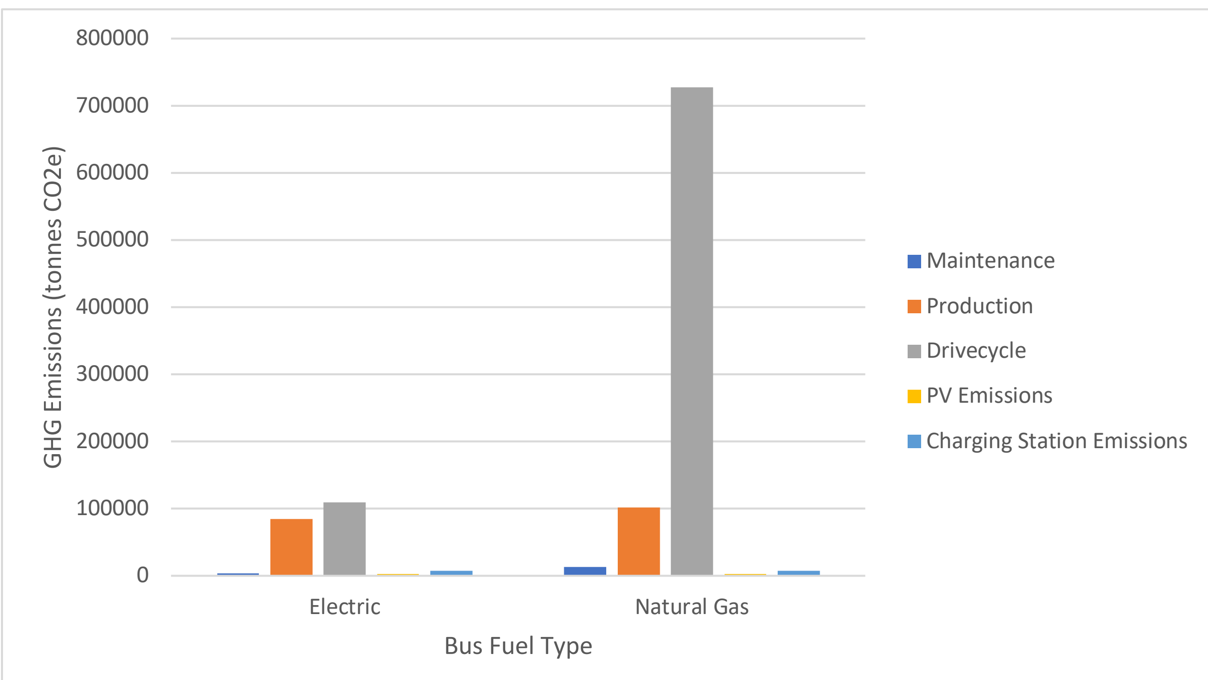


Figure A.2.6. An emissions breakdown for the various life cycle stages of the two buses analyzed for Foothill Transit's transition to electric buses.

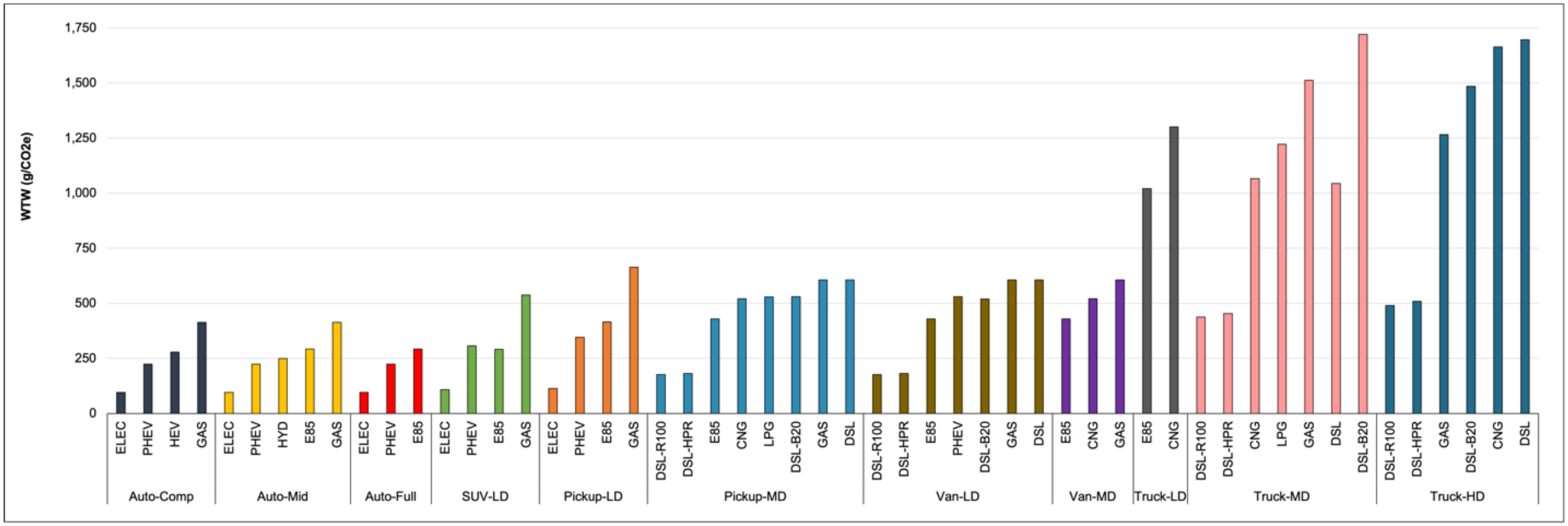


Figure A.2.7. The per-vehicle well-to-wheel emissions over 25 years of the various vehicle types considered in Los Angeles County's transition to alternative fuel vehicles.

Table A.2.8. A comparison of emissions across the three considered scenarios.

GHGs (Tonne CO_2e)		BAU	Gradual	All at Once
WTP		70,233	-32,739	-33,744
PTW		301,732	232,874	232,343
WTW		371,965	200,135	198,599
Net Vehicle Cycle		364,054	418,577	419,374
Total GHG Emissions		736,019	618,713	617,973
Change in GHG Emissions vs BAU	-		-117,306	-118,046
Percent Change vs BAU	-		-15.9%	-15.9%
Abatement Cost ($/Tonne CO_2)	**-**		**$1,477**	**$1,494**

Table A.2.9. A breakdown of costs associated with transition the LA fleet to alternative fuel vehicles.

Item	BAU	Gradual	All at Once
Fuel Cost	76.4	73.7	73.6
New Vehicles	3,105.0	3,827.0	3,837.9
Reg & Fees	0.0	0.0	0.0
Insurance	0.0	0.0	0.0
Maintenance	108.4	113.2	113.2
Salvage Value	-2,098.0	-2,564.0	-2,571.4
Total Net Cost	1,191.8	1,450.0	1,453.2
Net Present Value	737.9	911.3	914.3
Total Net Cost (w/o Reg & Ins)*	1,191.8	1,450.0	1,453.2
Net Present Value (w/o Reg & Ins)	**737.9**	**911.3**	**914.3**

A.3. Chapter 3

```
lm(formula = Equity_score ~ Year + Population + White_NH + Bachelors_deg +
    Med_house_income + Poverty_rate + Pop_density, data = data)

Residuals:
    Min      1Q  Median      3Q     Max
-0.9466 -0.4456 -0.2842  0.3358  1.5968

Coefficients:
                   Estimate Std. Error t value Pr(>|t|)
(Intercept)      -2.218e+02  8.363e+01  -2.652   0.0137 *
Year              1.104e-01  4.159e-02   2.655   0.0136 *
Population       -7.207e-08  7.826e-08  -0.921   0.3659
White_NH         -1.088e+00  8.532e-01  -1.275   0.2139
Bachelors_deg     2.656e+00  1.386e+00   1.916   0.0668 .
Med_house_income -9.375e-06  7.993e-06  -1.173   0.2519
Poverty_rate     -6.378e-01  3.302e+00  -0.193   0.8484
Pop_density       1.612e-05  4.253e-05   0.379   0.7078
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.7295 on 25 degrees of freedom
Multiple R-squared:  0.3408,    Adjusted R-squared:  0.1562
F-statistic: 1.846 on 7 and 25 DF,  p-value: 0.1223
```

Figure A.3.1. Linear regressions testing correlations between CAP equity scores and demographic data (not including political leaning).

```
lm(formula = Emissions_score ~ Year + Population + White_NH +
    Bachelors_deg + Med_house_income + Poverty_rate + Pop_density,
    data = data)

Residuals:
     Min       1Q   Median       3Q      Max 
-0.83727 -0.28282 -0.03222  0.22104  1.27854 

Coefficients:
                   Estimate Std. Error t value Pr(>|t|)   
(Intercept)      -2.098e+02  6.845e+01  -3.065  0.00516 **
Year              1.061e-01  3.404e-02   3.118  0.00454 **
Population       -2.223e-08  6.406e-08  -0.347  0.73152   
White_NH         -1.831e+00  6.984e-01  -2.621  0.01469 * 
Bachelors_deg     1.093e+00  1.134e+00   0.963  0.34467   
Med_house_income -1.031e-05  6.542e-06  -1.575  0.12774   
Poverty_rate     -7.438e+00  2.703e+00  -2.752  0.01087 * 
Pop_density      -3.735e-05  3.481e-05  -1.073  0.29351   
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.5971 on 25 degrees of freedom
Multiple R-squared:  0.4747,	Adjusted R-squared:  0.3276 
F-statistic: 3.228 on 7 and 25 DF,  p-value: 0.01404
```

Figure A.3.2. Linear regressions testing correlations between CAP emissions scores and demographic data (not including political leaning).

```
lm(formula = Cost_score ~ Year + Population + White_NH + Bachelors_deg +
    Med_house_income + Poverty_rate + Pop_density, data = data)

Residuals:
     Min       1Q   Median       3Q      Max 
-1.22287 -0.50253 -0.07381  0.28326  2.04682 

Coefficients:
                   Estimate Std. Error t value Pr(>|t|)  
(Intercept)      -1.576e+02  9.156e+01  -1.721   0.0975 .
Year              7.945e-02  4.553e-02   1.745   0.0932 .
Population        8.772e-08  8.567e-08   1.024   0.3157  
White_NH         -1.356e+00  9.341e-01  -1.452   0.1590  
Bachelors_deg     2.297e-01  1.517e+00   0.151   0.8809  
Med_house_income -4.329e-06  8.750e-06  -0.495   0.6251  
Poverty_rate     -5.023e+00  3.615e+00  -1.389   0.1770  
Pop_density      -2.307e-05  4.656e-05  -0.496   0.6245  
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.7986 on 25 degrees of freedom
Multiple R-squared:  0.2984,	Adjusted R-squared:  0.102 
F-statistic: 1.519 on 7 and 25 DF,  p-value: 0.2065
```

Figure A.3.3. Linear regressions testing correlations between CAP cost scores and demographic data (not including political leaning).

```
lm(formula = Equity_score + Emissions_score + Cost_score ~ Year +
    Population + White_NH + Bachelors_deg + Med_house_income +
    Poverty_rate + Pop_density, data = data)

Residuals:
    Min      1Q  Median      3Q     Max
-2.0481 -0.8635 -0.2900  0.6455  3.0401

Coefficients:
                   Estimate Std. Error t value Pr(>|t|)
(Intercept)      -5.892e+02  1.497e+02  -3.937 0.000583 ***
Year              2.960e-01  7.442e-02   3.977 0.000525 ***
Population       -6.570e-09  1.400e-07  -0.047 0.962957
White_NH         -4.275e+00  1.527e+00  -2.800 0.009716 **
Bachelors_deg     3.978e+00  2.480e+00   1.604 0.121286
Med_house_income -2.401e-05  1.430e-05  -1.679 0.105677
Poverty_rate     -1.310e+01  5.910e+00  -2.216 0.035996 *
Pop_density      -4.430e-05  7.611e-05  -0.582 0.565719
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 1.306 on 25 degrees of freedom
Multiple R-squared:  0.5151,    Adjusted R-squared:  0.3794
F-statistic: 3.794 on 7 and 25 DF,  p-value: 0.006139
```

Figure A.3.4. Linear regressions testing correlations between overall CAP robustness (all scores) and demographic data (not including political leaning).

```
lm(formula = Equity_score ~ Year + Population + White_NH + Bachelors_deg +
    Med_house_income + Poverty_rate + Pop_density + Democrat_Registration,
    data = data)

Residuals:
    Min      1Q  Median      3Q     Max
-0.7939 -0.4523 -0.1023  0.3476  1.4366

Coefficients:
                        Estimate Std. Error t value Pr(>|t|)
(Intercept)           -2.354e+02  7.953e+01  -2.960  0.00683 **
Year                   1.163e-01  3.951e-02   2.944  0.00708 **
Population            -7.551e-08  7.416e-08  -1.018  0.31871
White_NH              -6.006e-01  8.456e-01  -0.710  0.48439
Bachelors_deg          1.514e+00  1.436e+00   1.054  0.30229
Med_house_income      -7.029e-06  7.665e-06  -0.917  0.36829
Poverty_rate           2.715e-01  3.162e+00   0.086  0.93230
Pop_density            1.351e-05  4.031e-05   0.335  0.74038
Democrat_Registration  3.256e-02  1.658e-02   1.964  0.06121 .
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.6911 on 24 degrees of freedom
Multiple R-squared:  0.4321,    Adjusted R-squared:  0.2427
F-statistic: 2.282 on 8 and 24 DF,  p-value: 0.05644
```

Figure A.3.5. Linear regressions testing correlations between CAP equity scores and demographic data (including political leaning).

```
lm(formula = Emissions_score ~ Year + Population + White_NH +
    Bachelors_deg + Med_house_income + Poverty_rate + Pop_density +
    Democrat_Registration, data = data)

Residuals:
     Min       1Q   Median       3Q      Max
-0.84714 -0.28906 -0.01575  0.29496  1.14511

Coefficients:
                        Estimate Std. Error t value Pr(>|t|)
(Intercept)           -1.928e+02  5.772e+01  -3.340 0.002734 **
Year                   9.874e-02  2.868e-02   3.443 0.002121 **
Population            -1.792e-08  5.382e-08  -0.333 0.742030
White_NH              -2.440e+00  6.137e-01  -3.976 0.000561 ***
Bachelors_deg          2.520e+00  1.042e+00   2.417 0.023591 *
Med_house_income      -1.324e-05  5.563e-06  -2.379 0.025638 *
Poverty_rate          -8.574e+00  2.295e+00  -3.735 0.001026 **
Pop_density           -3.409e-05  2.926e-05  -1.165 0.255380
Democrat_Registration -4.068e-02  1.203e-02  -3.381 0.002472 **
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.5016 on 24 degrees of freedom
Multiple R-squared:  0.6442,    Adjusted R-squared:  0.5256
F-statistic: 5.431 on 8 and 24 DF,  p-value: 0.0005702
```

Figure A.3.6. Linear regressions testing correlations between CAP emissions scores and demographic data (including political leaning).

```
lm(formula = Cost_score ~ Year + Population + White_NH + Bachelors_deg +
    Med_house_income + Poverty_rate + Pop_density + Democrat_Registration,
    data = data)

Residuals:
    Min      1Q  Median      3Q     Max
-1.1656 -0.4998 -0.1358  0.3195  2.0278

Coefficients:
                        Estimate Std. Error t value Pr(>|t|)
(Intercept)           -1.552e+02  9.363e+01  -1.657    0.110
Year                   7.839e-02  4.652e-02   1.685    0.105
Population             8.834e-08  8.730e-08   1.012    0.322
White_NH              -1.443e+00  9.955e-01  -1.450    0.160
Bachelors_deg          4.334e-01  1.691e+00   0.256    0.800
Med_house_income      -4.748e-06  9.024e-06  -0.526    0.604
Poverty_rate          -5.185e+00  3.723e+00  -1.393    0.177
Pop_density           -2.261e-05  4.746e-05  -0.476    0.638
Democrat_Registration -5.808e-03  1.952e-02  -0.298    0.769

Residual standard error: 0.8136 on 24 degrees of freedom
Multiple R-squared:  0.301,     Adjusted R-squared:  0.06797
F-statistic: 1.292 on 8 and 24 DF,  p-value: 0.294
```

Figure A.3.7. Linear regressions testing correlations between CAP cost scores and demographic data (including political leaning).

```
lm(formula = Equity_score + Emissions_score + Cost_score ~ Year +
    Population + White_NH + Bachelors_deg + Med_house_income +
    Poverty_rate + Pop_density + Democrat_Registration, data = data)

Residuals:
    Min      1Q  Median      3Q     Max
-2.0514 -0.8886 -0.2522  0.6682  2.9944

Coefficients:
                        Estimate Std. Error t value Pr(>|t|)
(Intercept)           -5.833e+02  1.527e+02  -3.819 0.000831 ***
Year                   2.935e-01  7.588e-02   3.868 0.000736 ***
Population            -5.097e-09  1.424e-07  -0.036 0.971746
White_NH              -4.484e+00  1.624e+00  -2.761 0.010865 *
Bachelors_deg          4.467e+00  2.758e+00   1.620 0.118349
Med_house_income      -2.501e-05  1.472e-05  -1.699 0.102194
Poverty_rate          -1.349e+01  6.073e+00  -2.221 0.036061 *
Pop_density           -4.319e-05  7.741e-05  -0.558 0.582104
Democrat_Registration -1.393e-02  3.184e-02  -0.437 0.665722
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 1.327 on 24 degrees of freedom
Multiple R-squared:  0.519,     Adjusted R-squared:  0.3586
F-statistic: 3.237 on 8 and 24 DF,  p-value: 0.01214
```

Figure A.3.8. Linear regressions testing correlations between overall CAP robustness (all scores) and demographic data (including political leaning).

```
lm(formula = Equity_score ~ Emissions_score + Cost_score, data = data)

Residuals:
    Min      1Q  Median      3Q     Max
-0.7291 -0.5383 -0.3475  0.6045  2.4617

Coefficients:
                Estimate Std. Error t value Pr(>|t|)
(Intercept)      0.06184    0.35704   0.173    0.864
Emissions_score  0.33364    0.23334   1.430    0.163
Cost_score      -0.19082    0.20163  -0.946    0.352

Residual standard error: 0.7933 on 30 degrees of freedom
Multiple R-squared:  0.06463,   Adjusted R-squared:  0.002271
F-statistic: 1.036 on 2 and 30 DF,  p-value: 0.3671
```

Figure A.3.9. Linear regressions testing correlations between CAP equity scores and the other assigned scores.

```
lm(formula = Emissions_score ~ Equity_score + Cost_score, data = data)

Residuals:
    Min      1Q  Median      3Q     Max 
-1.1615 -0.3395 -0.1482  0.3451  0.9626 

Coefficients:
             Estimate Std. Error t value Pr(>|t|)    
(Intercept)    1.1615     0.1678   6.921  1.1e-07 ***
Equity_score   0.1912     0.1337   1.430 0.163087    
Cost_score     0.4934     0.1260   3.915 0.000483 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.6006 on 30 degrees of freedom
Multiple R-squared:  0.3624,	Adjusted R-squared:  0.3199 
F-statistic: 8.526 on 2 and 30 DF,  p-value: 0.00117
```

Figure A.3.10. Linear regressions testing correlations between CAP emissions scores and the other assigned scores.

```
lm(formula = Cost_score ~ Equity_score + Emissions_score, data = data)

Residuals:
    Min      1Q  Median      3Q     Max 
-1.1858 -0.5005 -0.1858  0.6514  1.1289 

Coefficients:
                Estimate Std. Error t value Pr(>|t|)    
(Intercept)      -0.1848     0.3169  -0.583 0.564195    
Equity_score     -0.1519     0.1605  -0.946 0.351510    
Emissions_score   0.6853     0.1751   3.915 0.000483 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.7078 on 30 degrees of freedom
Multiple R-squared:  0.3387,	Adjusted R-squared:  0.2946 
F-statistic: 7.682 on 2 and 30 DF,  p-value: 0.002024
```

Figure A.3.11. Linear regressions testing correlations between CAP cost scores and the other assigned scores.

A.5. Chapter 5

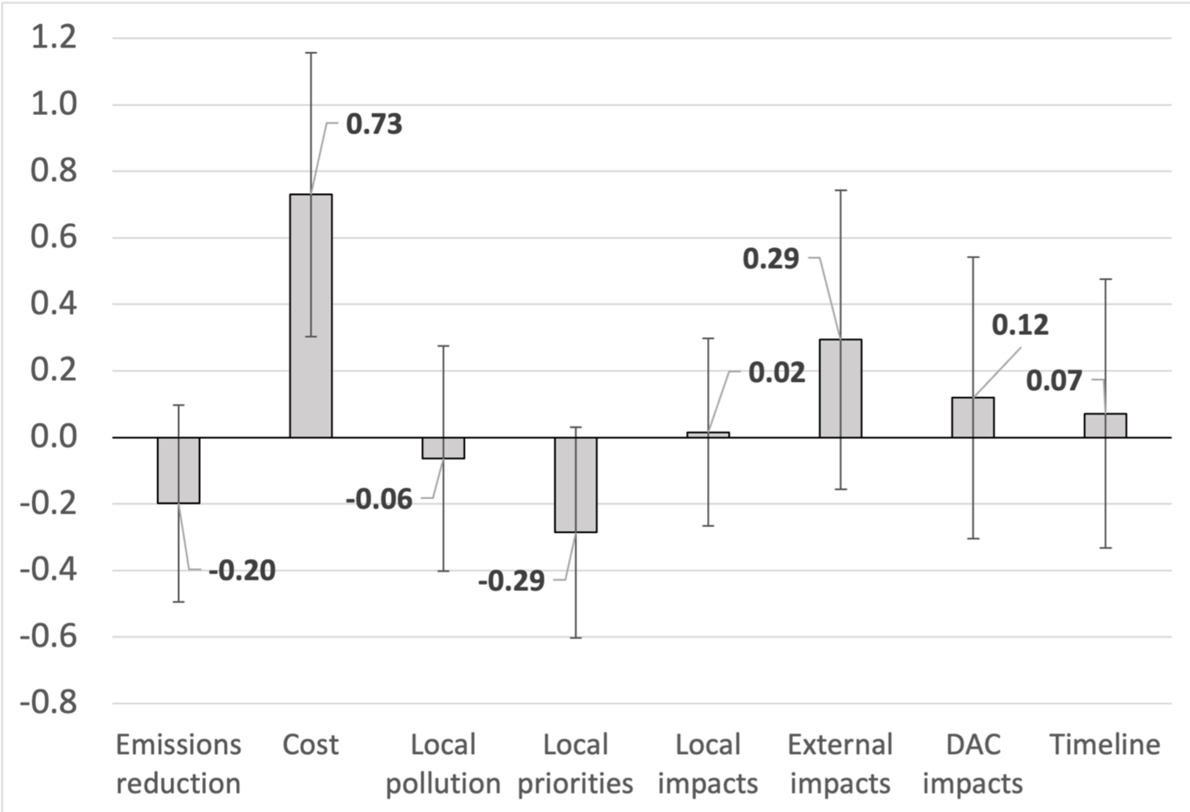
```
lm(formula = Response ~ Year + Population + White_NH + Bachelors_deg +
    Med_house_income + Poverty_rate + Pop_density, data = data)

Residuals:
    Min      1Q  Median      3Q     Max
-0.8729 -0.5431  0.1937  0.3155  0.4523

Coefficients:
                   Estimate Std. Error t value Pr(>|t|)
(Intercept)       4.566e+01  5.540e+01   0.824    0.418
Year             -2.237e-02  2.755e-02  -0.812    0.424
Population        5.194e-08  5.184e-08   1.002    0.326
White_NH         -3.593e-01  5.652e-01  -0.636    0.531
Bachelors_deg     7.708e-01  9.180e-01   0.840    0.409
Med_house_income -8.020e-07  5.294e-06  -0.151    0.881
Poverty_rate      2.520e-01  2.187e+00   0.115    0.909
Pop_density      -1.141e-05  2.817e-05  -0.405    0.689

Residual standard error: 0.4832 on 25 degrees of freedom
Multiple R-squared:  0.1082,    Adjusted R-squared:  -0.1415
F-statistic: 0.4332 on 7 and 25 DF,  p-value: 0.872
```

Figure A.5.1. Linear regressions testing correlations between responding to the survey and demographic data.



Note: The graph also includes the 95% confidence interval for each difference, which is a range of values for which we are 95% confident that the population difference is within. Note that positive values signify that a factor was more important during implementation than during planning, with the opposite being true for negative values. This uses original survey response values that have not been normalized.

Figure A.5.2. The difference in mean reported consideration of various factors during implementation compared to planning is plotted above.