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16. Abstract

Local governments have steadily increased their initiative to address global climate change, and many present their proposed strategies through climate action plans (CAPs). This study conducts a literature review on current local approaches to greenhouse gas (GHG) reduction strategies by assessing CAPs in California and presents common strategies in the transportation sector along with useful tools. One identified limitation of many CAPs is the omission of quantitative economic cost and emissions data for decision-making on the basis of cost-effectiveness. Therefore, this study proposes a framework for comparing strategies based on their life cycle emissions mitigation potential and costs. The results data can be presented in a marginal abatement cost curve (MACC) to allow for side-by-side comparison of considered strategies. Researchers partnered with Yolo and Unincorporated Los Angeles Counties to analyze 7 strategies in the transportation and energy sectors (five and two, respectively). A MACC was subsequently developed for each county. Applying the life cycle approach revealed strategies that had net cost savings over their life cycle, indicating there are opportunities for reducing emissions and costs. The MACC also revealed that some emissions reduction strategies in fact increased emissions on a life cycle basis. Applying the MACC framework to two case study jurisdictions illustrated both the feasibility and challenges of including quantitative analysis in their decision-making process. An additional barrier to using the MACC framework in the context of CAPs, is the mismatch between a life cycle and annual accounting basis for GHG emissions. Future work could explore more efficient data collection, alternative scopes of emissions for reporting, and environmental justice concerns.

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April 2020

A Research Report from the National Center for Sustainable Transportation

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National Center for Sustainable Transportation

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NCST

Greenhouse Gas Reduction Opportunities for Local Governments: A Quantification and Prioritization Framework

A National Center for Sustainable Transportation Research Report

April 2020

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AB	Assembly Bill
ADT	Average daily traffic
AFV	Alternative fuel vehicle
B100	100 percent biodiesel
B20	biodiesel blended with petroleum diesel at a ratio of 20:100
BAU	Business-as-usual
CAP	Climate action plan
CAPCOA	California Air Pollution Control Officers Association
CARB	California Air Resources Board
CCA	Community choice aggregation
CCDB	Caltrans Cost Data Book
CH_4	Methane
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
CR	County road
E85	Ethanol blended with gasoline at a ratio of 85:100
EIA	Energy Information Administration
EO	Executive Order
EPA	Environmental Protection Agency
GGE	Gasoline gallon equivalent
GHG	Greenhouse gas
GREET	Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation Model
HDT	Heavy duty truck
HMA	Hot mix asphalt
ILG	Institute for Local Government
LCA	Life cycle assessment
LCC	Life cycle cost
LCCA	Life cycle cost analysis
LCI	Life cycle inventory
LDT	Light duty truck
LPB	Liquid petroleum gas
MT	Metric ton (tonne)
N_2O	Nitrous Oxide
PC	Passenger car
PCC	Portland cement concrete
PG&E	Pacific Gas and Electric
PTW	Pump-to-wheel
SB	Senate Bill
SGCE	Southern California Gas and Electric
SUV	Sport utility vehicle

UN	United Nations
VCE	Valley Clean Energy
VMT	Vehicle miles travelled
WTP	Well-to-pump
WTW	Well-to-wheel

Greenhouse Gas Reduction Opportunities for Local Governments: A Quantification and Prioritization Framework

EXECUTIVE SUMMARY

Through a series of bills and executive orders, California has set greenhouse gas (GHG) emissions reduction targets, outlined statewide plans, and tasked local and state agencies with developing their own plans to reduce emissions. In response, many local governments across the state have outlined their emissions reduction targets and strategies in climate actions plans (CAPs). These typically include a GHG inventory of emissions (conducted on an annual basis), an emissions reduction target and proposed GHG mitigation strategies across various sectors (e.g. energy use, transportation, waste management, etc.) to meet these targets. To better understand current approaches, a review of over 40 CAPs across the state was conducted, as well as a review of tools and methods used by jurisdictions. Particular attention was paid to proposed mitigation strategies in the transportation sector. The review found that a significant portion of CAPs lack quantitative information related to the cost and mitigation potential of the proposed strategies. Even fewer considered life cycle emissions and the life cycle costs of implementation. Thus, there is a need for practicable framework that quantitatively compares mitigation strategies to assist in mitigation strategy prioritization.

To address the lack of a quantitative approach to estimating life cycle cost-effectiveness, this project explores how a marginal abatement cost curve (MACC) could be developed at the local government scale. The life cycle perspective accounts for emissions and costs that occur at the outset of a strategy's implementation (e.g. purchases, construction, etc.), the operation and maintenance, and the end-of-life. For some strategies, it is possible that the monetary value of benefits outweighs the costs, resulting in cost savings while still reducing greenhouse gas emissions. Presenting this data in a MACC enables the side-by-side comparison of the GHG mitigation potential and cost of considered strategies. This framework is applied to proposed strategies in the transportation and electricity sectors of two California jurisdictions: Yolo County and Unincorporated Los Angeles County. The assessed strategies for Yolo County are: additional procurement of renewable energy through its community choice aggregation agency, new intercity bike lanes, converting intersections to roundabouts, installing solar canopies over county parking lots, and alternative pavement rehabilitation methods. The assessed strategies for Unincorporated Los Angeles County are: electrified transit bus fleet, and alternative fuel vehicles for the county fleet.

The study found that two of the five mitigation strategies considered by Yolo County, intercity bike lanes and alternative pavement rehabilitation options, produce net increases in emissions over their life cycle. The remaining three strategies provide potential emission reductions of approximately 800,000 tonnes CO_2e at a zero or negative life cycle cost-effectiveness (i.e. cost savings), largely resulting from new procurement of renewable electricity. However, the emissions reductions from electricity procurement changes do not necessarily lead to real

changes in the electricity generation mix on the grid. As such, the bulk of the projected emissions reductions for Yolo County may be on paper only, and not actual changes to GHG emissions. Both strategies analyzed for Unincorporated Los Angeles County provide emission reductions over their life cycle, but at significant costs. The findings for each community are unique to their conditions, so findings cannot necessarily be generalized for other jurisdictions.

While the MACCs developed for each jurisdiction make it easy to compare strategies by their cost-effectiveness and mitigation impact, these are by no means the only important variables to consider. For example, co-benefits, such as reduced criteria pollution, and equitable distribution of costs and benefits across communities, may be important considerations. Future work is needed to address the challenges to data collection, the mismatch between life cycle emissions accounting and the annual GHG inventory reporting conducted by jurisdictions, and environmental equity concerns.

1. Introduction

1.1. Background

Global warming caused by anthropogenic emissions of greenhouse gases (GHGs, dominated by CO_2, CH_4, and N_2O) and the resulting climate change effects of warming is perhaps the "defining" issue of our time (United Nations 2019). California has been a leader in the U.S. and globally in the development of policies for reducing GHG emissions from all sectors, including the transport sector. A suite of Executive Orders (EOs) and Assembly bills (ABs) have motivated GHG mitigation targets for the state, starting in 2005 with the Governor's EO S-3-05 which required a reduction of GHG emissions to 1990 levels by 2020, and a reduction to 80 percent below 1990 levels by 2050 (Schwarzenegger 2005). California's 2006 Climate Change Solutions Act (Assembly Bill (AB) 32) made the 2020 reductions law, and tasked many government entities, including local governments and government agencies, with helping to meet those goals (California Assembly 2006). Since then additional policies have enhanced or expanded these targets; for example EO B-30-15 (Brown Jr. 2015) requires a reduction of 40 percent below 1990 levels by 2030, which was codified into law with Senate Bill (SB) 32 in 2016, and EO B-55-18 (Brown Jr. 2018) targets carbon neutrality for the state by 2045.

Of particular relevance to California counties and cities, 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 order to ensure that jurisdictions are integrating GHG reduction targets in the development of regional plans, SB375 directs the California Air Resources Board to set regional targets for GHG reductions (California Senate, 2008). As a result, local jurisdictions in California must develop climate action plans (CAPs) that identify these GHG reduction targets and the specific actions to achieve them. Today, many local governments are developing updated CAPs, some of which include policies, standards and specifications for transportation infrastructure and its use.

The transportation sector is a major contributor to GHG emissions in the U.S., causing 28 percent of total GHG emissions (Environmental Protection Agency 2018). In California, the contributions from transport are even more dominant, comprising 41% of statewide emissions (California Air Resources Board 2018). Thus, it is not a surprise that transportation is one of the key sectors identified in most CAPs and targeted for reduction. Reducing motorized travel (vehicle miles traveled or 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 opportunities, have not previously been evaluated.

1.2. Problem Statement[1]

A review of some jurisdictions' CAPs shows that a number of actions proposed or undertaken, perhaps even the majority, have not actually been quantified with respect to costs and GHG mitigation; they are assumed to contribute to achieving reductions without clear quantitative analysis (e.g., see the city of Emeryville's CAP). 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 (i.e., those that occur throughout a project or technology's life cycle as well as throughout the supply chains that support it) are captured. One important consideration for life cycle accounting is the risk of double counting emissions or mitigation. Given that CAPs are geographically bounded, but supply chains are not, careful consideration of this risk of double-counting is required.

This project's goal is to deliver a decision support framework for assessing the expected life cycle GHG mitigation and life cycle cost (LCC) of mitigation actions. The result is a GHG marginal abatement cost curve (MACC), where the expected LCC and total scale of GHG mitigation is represented for a comprehensive set of possible actions related to hardscapes. The MACC can also integrate some qualitative benefits where it appears that co-benefits (e.g., improved environmental, economic or mobility/accessibility outcomes) are likely and where these are likely to occur in disadvantaged communities. 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 provision of this tool could lead to increasing mitigation targets or achieving existing targets at less cost. Stakeholders including local governments, their consultants, and community organizations, will be engaged throughout this project to review, provide feedback, and suggest ideas that might be tested in the framework. This research will complement similar work proposed for Caltrans' operations, which would apply similar methods to develop a GHG MACC.

1.3. Approach and methodology

The ultimate goal of this research is to present a decision-making framework for GHG mitigation strategy selection for local governments based on the development of life cycle GHG MACC. This approach offers the ability to combine the impacts and cost-effectiveness measurements of numerous GHG mitigation options at the same time. 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), as can be seen in Figure 1. 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

[1] We previously used the term GHG mitigation supply curve, instead of MACC. Thus, some materials, such as those referenced in the Appendix, use the term supply curve in lieu of MACC.

and decreasing cost-effectiveness as additional actions are taken. This approach also uses life cycle, rather than direct, emissions accounting. Life cycle GHG 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. The goal of life cycle assessment (LCA) typically includes anticipating unintended consequences, positive or negative, of a product, policy or action.

The example shown in Figure 1 is adapted from Lutsey's (2009) first-order assessment of alternative actions in the transportation sector versus those in other sectors to reduce GHG emissions in the California economy. The figure shows initial cost and life cycle cost. All actions have an initial cost to make the change, however some of the changes will result in life cycle cost savings. Those actions not only reduce GHG emissions but also improve the efficiency of the economy.

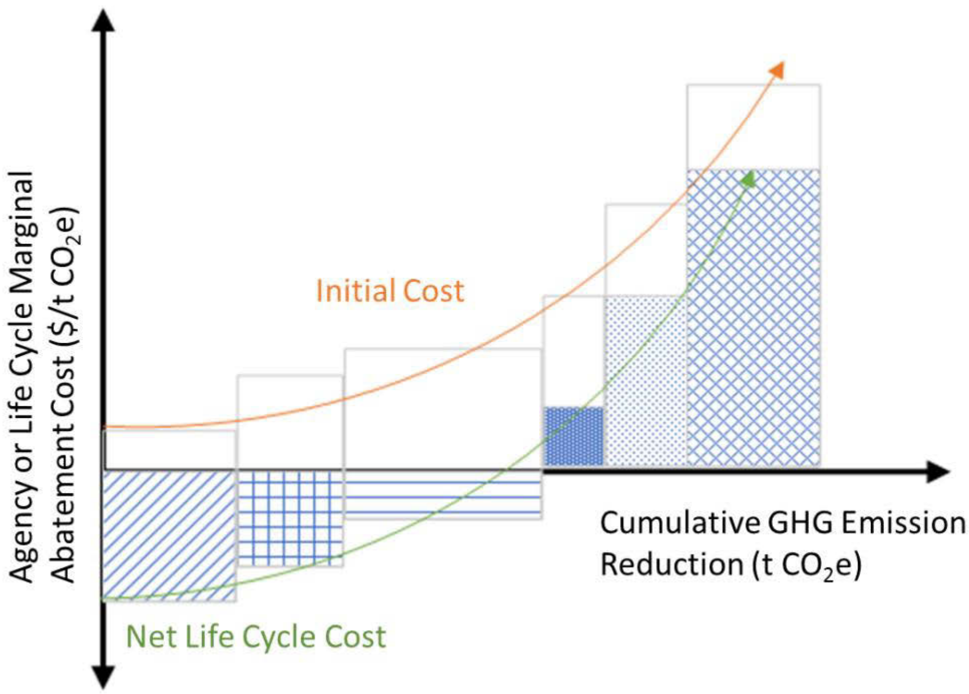

Figure 1. Generic MACC considering initial cost and life cycle cost

There are a number of research tasks required to achieve the goals of this project. The first is to understand the potential actions that can be integrated into a GHG MACC by critically reviewing existing CAPs and relevant tools. The goal of this review is to catalogue potential strategies for GHG mitigations based on measures already identified by jurisdictions. The second is translation of exemplar strategies into an initial MACC (Task 2), identification and outreach to stakeholders to identify local governments interested in partnering to provide data for the development of initial MACCs tailored to their conditions (Tasks 2 and 3). These tasks and their results are described in the subsequent sections of this report. Appendices to this report include documentation and additional detail on the Critical Review of CAPs and Tools.

1.4. Review of proposed GHG mitigation measures from transportation in existing CAPs

The jurisdictions responsible for developing CAPs in California include metropolitan planning organizations (MPOs), cities, and counties. There is no single repository for CAPs, so a number of resources were used to identify CAPs and select a subset for closer review. The Institute for Local Government has a comprehensive list, which has not been updated since 2014, and internet searches were conducted for jurisdictions that were expected to have well-developed CAPs (California Institute for Local Government 2015). This list was supplemented with California local governments that have joined The Global Covenant of Mayors for Climate & Energy, an international coalition of local governments who intend on supporting and promoting actions that combat global climate change and support long-term sustainability (GCM, 2019). California local governments were selected from among all North American cities and local governments.

The preliminary list of target jurisdictions contained 34 local governments. However, not all of them had relevant CAPs, since they either: (1) had yet to release a CAP, (2) had not updated a CAP despite publicizing a past-due update (meaning they have outdated CAPs), or (3) did not have a valid CAP for other reasons [e.g., a lawsuit against San Diego's CAP resulted in a ruling late last year that required the CAP to be revised because it allowed parties to purchase out-of-region carbon credits (Jones, 2018)]. Ultimately, 30 CAPs were read and reviewed (see Appendix 1 for a list of the reviewed CAPs). Listed below are 10 frequently proposed strategies for GHG mitigation from the transport sector.

- **Alternative fuel vehicle fleet:** GHG emissions reductions can be achieved by switching from gasoline and diesel vehicles to less carbon-intensive fuels like natural gas, electricity, and hydrogen. Cities propose changes to passenger fleets, public transit fleets, taxi fleets, and more. While alternatives are definitely cleaner during the use phase, they can have carbon intensive upstream impacts or require carbon intensive infrastructure.
- **Electric vehicle infrastructure:** As a subset of the alternative fuel vehicle movement, a particular idea is to add electric vehicle infrastructure to promote adoption. The question becomes how much GHG reduction can be attributed to each additional charging station, especially when considering the emissions generated to install the charging station in the first place.
- **LED street and traffic lights:** This strategy switches traditional incandescent lightbulbs with brighter and more efficient light-emitting diodes (LEDs). The benefits are twofold: LEDs produce a single-color light and therefore do not need any filters, and they also consume significantly less energy than their incandescent counterparts. However, a study by Lim et al. (2011) found that some LEDs, particularly red ones, have also been found to contain high lead and arsenic content, which if not handled properly can have significant negative effects on human health. Additionally, there are concerns with the intensity of lighting, as it can affect people's circadian rhythms and, in extreme cases, cause retinal damage.

- **Improved road maintenance and/or increased use of recycled materials:** Improperly maintained roads cause vehicle damage while also increasing fuel consumption. There are studies that have determined that optimal road roughness at which maintenance should be made, which balances the cost of maintenance with the fuel consumption benefits achieved by a smoother road. Some CAPs also call for increased use of recycled asphalt pavement in road construction and maintenance, which decreases material use and therefore GHG emissions.
- **Parking pricing:** By charging drivers for parking spaces, there are many ways that emissions could be reduced. The first is by encouraging less driving as more people may opt to use active modes (walking or cycling), take public transportation, or use ride sharing services (note that the use of ride *hailing* services in lieu of driving may not decrease and could even increase miles travelled) to reach their destination. Higher parking pricing also promotes parking space availability, which reduces the time vehicles spend searching for parking spots and reduces both congestion and emissions. San Francisco explored this idea as early as 2011 with its SF*park* program (Chatman, 2014).
- **Idling ordinances:** Idling ordinances restrict vehicle engine idling while parked or otherwise stopped. Idling a truck while occupied may be done for climate control or other energy-demanding services. An ordinance could also affect the idling of unattended vehicles.
- **Ridesharing:** Ridesharing can reduce GHG emissions in two main ways. The first is through carpooling, which reduces vehicles miles traveled (VMT) as passengers no longer drive individual vehicles, while also reducing congestion which in turns results in fewer emissions. The second is through the use of ride-sharing programs (like Zipcar), which alleviates the public's need to purchase personal vehicles, thereby decreasing vehicle production and the corresponding emissions. There is also some potential for a decrease in transit use or non-motorized modes of transport, which could increase emissions.
- **Increase bicycle travel:** Providing infrastructure that supports bicycling can reduce motorized VMT, but may also provide co-benefits, such as for public health.
- **Increase public transit ridership:** While there is no consistent strategy used to increase public transit ridership, doing so results in reduced VMT in personal vehicles, while also (ideally) providing a better return on investment for public transit infrastructure and operation.
- **Telecommuting:** Telecommuting strategies rely on increased flexibility from employers that allows employees to work from home for a certain number of days a year instead of driving to work. The goal is to reduce VMT, thereby reducing GHG emissions. Unfortunately, recent studies have shown that human behavior may reduce or eliminate VMT reductions from telecommuting: those who telecommute see no decrease in VMT, and often even increase their VMT (particularly if telecommuting enables employees to live further away from their workplace) (Chakrabarti, 2018). This exemplifies the need for comprehensive and consequential analysis of a strategy's effectiveness.

A subset of these are further explored in this report; they include alternative fuel vehicle fleets, improved road maintenance and/or increased use of recycled materials, and increasing bicycle travel through provision of bicycling infrastructure. These were selected through collaboration with case study jurisdictions. Additional strategies that were not commonly included in CAPs, including photovoltaic (PV) canopies and the source of low carbon electricity are also explored further in this report.

While all reviewed CAPs listed potential GHG mitigation strategies, there were certain factors that made particular CAPs stand out. Particularly robust CAPs not only listed potential strategies, but also: (1) provided expected emissions reduction per strategy, (2) provided expected cost of implementation per strategy, (3) listed parties responsible for strategy implementation, (4) listed co-benefits, and/or (5) explicitly outlined sources of funding. Appendix 1 of this report provides a review of selected CAPs that were particularly robust.

1.5. Review of tools and methods in use by jurisdictions

In addition to reviewing CAPs developed by California jurisdictions, potentially relevant tools and methodologies that could support quantification of GHG mitigation or mitigation strategy costs have been explored. Many California agencies, such as CARB and Caltrans, have previously developed quantification methods. Some of these have even been rigorously reviewed as part of the California Climate Investments program, or other programs that require quantification of GHG mitigation strategies (CARB, 2019). The following list contains tools and methods that are publicly accessible (or can be requested), and either directly provide emissions quantification methods for relevant strategies or provide information that can be useful in the emissions quantification of strategies.

Benefits Calculator Tool for the Low Carbon Transit Operations Program (Source: CARB, 2019): This calculation tool is an Excel-based model that estimates the expected GHG emissions reductions and the reductions per dollar of investment for transit-related projects; it requires total expected funds and project specifications. Some project categories included in the model are: replacement or additional zero-emissions vehicles and/or infrastructure, installing renewable energy or fuel for transit facilities, and free or reduced fares for transit riders. This tool also calculates changes in VMT attributable to each project and summarizes multiple co-benefits, including $PM_{2.5}$ and NO_X emissions.

California Transportation Commissions Active Transport Program Quantification Method (Source: CARB, 2019): This Excel model provides GHG emissions reductions associated with the installation of bicycle-pedestrian infrastructure and/or bike sharing programs, and can be applied to counties across the state. However, it does not provide information on co-benefits.

CalEEMod (Source: California Air Pollution Control Officers Association (CAPCOA), 2019): The California Emissions Estimator Model determine the changes in vehicle miles traveled achieved by land use and transportation-related strategies. It also includes data on expected vehicle trips, vehicle emissions, and fleet mix to determine subsequent changes in GHG emissions. This information, if not the whole model, could be used to quantify the effects of various strategies that affect VMT.

City of Los Angeles VMT Tool (Source: Los Angeles Department of Transportation (LADOT), 2019): This tool estimates how changes in parking availability, transit use, bicycle infrastructure, and more, affect VMT in predefined areas. This tool could be useful in quantifying the effects of many considered mitigation strategies on VMT, even if it is used for strategies outside the Los Angeles area. Cobenefits are not mentioned in this tool.

SPARC with INDEX (Source: Criterion Planners, 2014): A robust scenario planning tool that compares current community conditions and future alternative scenarios to determine differences in energy use and GHG emissions; these outputs are combined with GIS data. This model allows the user to compare different land use and transportation scenarios.

Quantifying Greenhouse Gas Mitigation Strategies (Source: CAPCOA, 2010): This report provides methods to estimate GHG emissions reductions for 50 transportation-related projects. For each strategy (which includes adding ridesharing programs, limiting parking spaces, providing bike parking near transit facilities, and more), the report provides an explanation, the model equation, an example calculation, and references. Many strategies included in the reviewed CAPs are also included in this report.

2. Selection of Case Study Cities and Stakeholder Engagement

Case study sites were identified through outreach to contacts at candidate sites. The initial list of candidates included the City of San Jose, due to its well-developed CAP and its urbanized landscape, Yolo County due to its largely rural/agrarian landscape and proximity to UC Davis and existing contacts, and the County of Los Angeles due to its varied landscape (urban, suburban and even rural). Outreach began with the provision of a short summary of the project and tentative agenda (See Appendix 2). This outreach led to case study site selections of Los Angeles County and Yolo County. The process for engagement included an initial meeting for the UC Davis team to present the proposed approach and listen to the local government's thoughts on what they are interested in and whether partnering with the UC Davis team would be of interest, and a second meeting to determine the specific actions they would like to see quantified in the MACC framework. Table 1 summarizes the meetings with the two case study counties, as well as meetings with other stakeholders. Appendix 2 documents meeting materials and meeting minutes in greater detail.

Table 1. Meeting Schedule and Descriptions

Stakeholders engaged	Meeting Purpose	Meeting Date	Additional information
Janet Dawson (Chief Consultant for the California Assembly Transportation Committee – Retired), Constance Robledo (Yolo County)	To understand SB375 and CAPs in the context of SB375, and more broadly the policy landscape and process relevant to the proposed framework	February 11, 2019	This was a largely unstructured meeting where the UC Davis listened after providing a brief introduction to the project (see 1-pager in Appendix 2.1)
Yolo County	Initial meeting with Yolo County	July 10, 2019	See Appendix 2.2 for meeting participants and notes
Los Angeles (LA) County	Initial meeting with LA County	August 13, 2019	See Appendix 2.3 for meeting participants and notes
LA County	Discussion of selected strategies for further research.	September 24, 2019	LA County participant Caroline Chen. Result was the development of data request letters to provide to relevant LA County departments or agencies provided in Appendix 2.3
LA County Internal Services Department (ISD)	Research data request, LA County ISD	October 21, 2019	ISD participants included Randy Martin, Daniel Martinez, Minh Duc Quan

The resulting interactions and exchanges led to the selection of the following actions for inclusion in GHG MACCs for each county:

- Los Angeles County chose to move forward with quantification of two strategies;
    1. The implementation of alternative fuels for their fleet of vehicles, and
    2. Transit bus electrification, which is being undertaken by Foothill Transit, a transit agency that serves not just the unincorporated regions of LA County, but also incorporated regions.

- Yolo County chose to move forward with quantification of six strategies;
    1. Emissions reductions from electricity as a result of switching from Pacific Gas and Electric (PG&E) to a community choice aggregation (CCA) entity, Valley Clean Energy (VCE).
    2. Bike lanes connecting other cities in Yolo County to Davis for employees not living in Davis.
    3. Solar panel canopies installed for electricity generation for electric vehicle charging and lighting on county parking lots.
    4. Intercity electric bus/transit system
    5. Changes to start and stop, roundabouts, and speed limits in Yolo County affecting vehicle fuel economy.
    6. Full depth reclamation versus conventional pavement rehabilitation methods.

Due to delays in the provision of data, the actions for Los Angeles County have not been fully quantified and are not included in this report but will be included in the final report associated with this project. Four of the six actions for Yolo County are included; actions 1, 2, 3, and 5.

3. Yolo County MACC Development

3.1. Transition from Pacific Gas & Electric to Valley Clean Energy

3.1.1. Background

While the scope of this project focuses on quantification of transportation-related actions for GHG mitigation, Yolo County's CAP looked to transitioning the purchased electricity fuel mix to lower carbon sources through the adoption of a CCA for 45% of its total mitigation, and thus we chose to include this action in the MACC. Its inclusion in the MACC provides a benchmark for cost-effectiveness and presents interesting questions about the reliability of different mitigation measures to ensure real reductions in emissions.

Across California and the United States, communities are transitioning from purchasing their power from large utilities to smaller CCAs. Their primary purpose is to provide more control over the sources of power generation a community uses, and typically provide lower rates to their customers as well. In 2018, parts of Yolo County made the transition from the investor-owned utility PG&E to their newly formed CCA, VCE. This section examines the changes in GHG emissions and costs that are predicted to occur due to this change over the next 25 years.

3.1.2. Methodology

The life cycle emissions of electricity are the combination of emissions produced in the creation of the power sources (e.g., primary fuels and generation technologies), conversion of fuels or renewable resources to electricity, and the distribution of the electricity to customers. As is the case for many CCAs, the transition from PG&E to VCE changed the community's control over procurement of electricity, but distribution of that electricity remains on PG&E infrastructure.

Therefore, the difference in life cycle emissions for delivered electricity is simply the difference in the resources used to produce the electricity.

To identify the change in electricity resource mix, the power content labels of PG&E and VCE were compared, and outside references were used to determine the average life cycle emissions per kWh of electricity produced under each scenario. These power mixes, as well as the average California mix, are provided in Table 2 (PG&E 2018, VCE 2019).

Table 2. Resource Mix for PG&E, VCE and California (CAMX)

	PG&E Mix 2017	VCE Standard Mix 2018	California Mix 2018
Biomass	4%	0%	2%
Geothermal	5%	0%	5%
Hydro	3%	0%	2%
Solar	13%	0%	11%
Wind	8%	48%	11%
Coal	0%	0%	3%
Large Hydro	18%	37%	11%
Natural Gas	20%	0%	35%
Nuclear	27%	0%	9%
Unspecified	2%	15%	11%
SUM	100%	100%	100%

The fuel pathway life cycle emissions for each power source were acquired from the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation Model (GREET) 1 1 (Argonne National Laboratory 2018), with the exception of wind and solar (Nugent 2014), large hydro (Flury 2012), and geothermal (Sullivan 2010). GREET data accounts for transmissions and distribution losses of 4.9 percent while the other data sources do not. Therefore, non-GREET values were subjected to the same loses as those in GREET. The life cycle GHG intensity of each generation pathway is provided in Table 3.

Table 3. The life cycle emissions per kWh for various power sources.

	Biomass	Geothermal	Natural Gas	Nuclear	Wind	Solar	Hydro
GHGs (g CO_2e/kWh)	78.20	24.13	545.41	9.01	35.78	52.36	11.33

As evident in Table 2, a significant fraction of VCE and California electricity is unspecified. Unspecified power is electricity bought from the market whose source is unknown, and therefore cannot be categorized. This study assumes that electricity from unspecified power has a carbon intensity of 428 g CO_2e/kWh, the emissions factor used by CARB (Weissman 2018). The final emissions per average kWh for the PG&E and VCE power mixes are provided in Table 4.

Table 4. Life cycle GHG emissions intensity

	PG&E Mix 2017	VCE Standard Mix 2018
GHGs (g CO_2e/kWh)	136.48	85.72

To estimate the change in emissions over time, these values were compared to the forecasted emissions of the California grid provided in the U.S. Energy Information Administration's (EIA's) Annual Energy Outlook, which projects through the year 2050 (Energy Information Administration 2018). The year-to-year changes in the EIA's projection are proportionally reflected in the PGE and VCE mixes. That is, if the EIA projects that emissions will decrease by 2% from one year to the next, the PG&E and VCE mixes will also produce 2% fewer emissions the following year. This is not necessarily a trajectory that PG&E or VCE, but without utility or CCA-specific projections, we use the state's trajectory as a guide.

The total difference in emissions can be calculated by multiplying the annual emissions per kWh by the total provided electricity. In its first year of operation, VCE provided approximately 682 GWh to its nearly 162,000 customers. According to the U.S. Census Bureau, Yolo County's population was just over 219,000 in 2018. VCE intends to continue growing until it provides to all of Yolo County. Therefore, they are projected to have a maximum load of approximately 926 GWh per year. This study assumes that it will reach maximum capacity after 5 years.

Finally, according to VCE's rate table, their residential rates are identical to PG&E's. Also, because VCE is not currently installing any additional power sources, but only managing their procurement, there are no additional costs. Therefore, it is assumed that there is no change in consumer cost when transitioning from PG&E to VCE.

3.1.3. Assumptions and Limitations

An implicit assumption by CCAs or other entities that reduce emissions through procurement of more renewable electricity in the absence of installing new renewable or low carbon generation capacity is that these procurement choices actually change the emissions intensity of the grid as a whole. Currently, VCE procures power from different sources across the state, such that 85% of their standard mix power is considered "carbon-free" (by consisting of wind and large hydro energy). However, across the state, there is not necessarily a causal change in the quantity of produced renewable energy, so the statewide mix remains constant (or changes as a result of other state policy or market forces unrelated to VCE's procurement choices). While VCE can claim a higher proportion of renewable energy, other electricity providers would then claim less. Thus, the only way that VCE will reduce GHG emissions compared to PG&E is if it explicitly funds or installs new renewable energy generation capacity, or if its demand for renewable power in the market eventually spurs new development of renewables that would otherwise not have occurred, and which is difficult to confirm.

Based on personal communication with the Director of VCE, they are planning to invest in large quantities of solar in the future. Under this scenario, their specific power mix would change, as would the statewide availability of renewable energy.

However, to advance this study given the information that is available and in the absence of broader understanding about how procurement choices can lead to real changes in the emissions intensity of electricity, MACC calculations were based on the reported, procured fuel mix for VCE and PG&E. The following is a list of other limitations in this study.

- Life cycle emissions of large hydroelectric: A study by Pacca (2004) found that the decommissioning of large hydroelectric dams could produce significant emissions, from 35 up to 380 g CO_2e per kWh depending on the rate of mineralization of sediment organic carbon. This is much larger than the emissions rate used for hydroelectric power in this study (10.8 g CO_2e/kWh), which means emissions for hydroelectric could be underestimated in this study.
- Changes in emissions over time: It is already hard to predict future changes in emissions rates. Some California-focused studies assume that the grid will be 100% renewable by 2045, a goal set by Gov. Jerry Brown in 2018. However, even in this scenario, life cycle emissions are not zero, as there are emissions associated with the commissioning, maintenance, and decommissioning of renewable energy sources. As stated previously, a 2% per year reduction in fossil fuels is assumed.

3.1.4. Results

Over 25 years, the resulting change in emissions in switching from PG&E-procured electricity to VCE is -703,000 tonnes CO_2e, a net decrease. The time-adjusted warming potential (TAWP) is also calculated, which accounts for the timing of emissions changes and calculated their present value (Kendall 2012). The TAWP of this scenario is -637,000 tonnes CO_2e. Because no costs were associated with this scenario, the cost-effectiveness is $0/tonne CO_2e reduced (in other words, they are free).

3.2. Yolo county bike lanes connecting cities

3.2.1. Background

The addition of bike lanes or other bike infrastructures are often anticipated to move some drivers from their cars onto bikes, thereby reducing vehicle trips and consequent GHG emissions from vehicles. The development of new bike infrastructure requires construction processes that demand new material investment and require equipment operation. Thus, to understand the net life cycle GHG emissions from bike lanes and other bike infrastructure development, the initial construction and maintenance of the infrastructure must be modeled, and their effect on trip generation for vehicles must be modeled to estimate the potential consequences for VMT.

This study relies on the *County of Yolo Bicycle Transportation Plan,* published in March of 2013, to determine the existing and proposed/planned bicycle transportation network (Yolo County

Transportation Advisory Committee, 2013). Yolo County has nearly 56 km (35 miles) of bike lanes and 10.5 km (6.5 miles) of bike paths already in place; however, in the bicycle transportation plan, they include an additional 187.6 (116.6 miles) of bike lanes, 30.6 km (19 miles) of bike paths and 40 km (25 miles) of bike route to be added to the existing bikeways. The plan would better connect some key cities within the county including Woodland, Davis, West Sacramento, and Knights Landing. In this study, bike paths connecting Woodland, Davis, and West Sacramento are considered.

Bike infrastructure has three main classifications. A bike path, or a class I bikeway, is defined as a trail/track separated from roads and streets that supports two-way bike traffic and which excludes motor vehicles. The minimum paved width of travel for a two-way bike path is either 2.44 m (8 ft) or 3.05 m (10 ft). A bike lane, or a class II bikeway, on the other hand is the paved edge of a wide street or road separated using white stripes on each side of the road. Bike lanes are designed as 1.2 (4 ft) wide. Finally, a bike route, or a class III, bikeway is a road or street shared by bicyclists and motorists and is designated by signs to provide continuity to the bikeway system; however, routes are without bike paths or bike lanes. No improvements to the roads are made for bicyclists; this study focuses on bike paths and bike lanes.

The goal of this study is to evaluate the strategy of bikes replacing vehicles to achieve a reduction in GHG emissions by providing communities living in Yolo County with active transportation means such as the bike infrastructure. The existing bike lanes and paths are not evaluated in this study; only the proposed new projects of bike infrastructure are evaluated.

3.2.2. Methodology

In LCA a functional unit is often defined for the purposes of calculating a reference unit. This reference unit can then be scaled to represent the system being studied. For this study, the functional unit is construction and maintenance of 1 km of bike path and bike lane for an analysis period of 25 years. The scope of this analysis includes construction of new bike infrastructure and use phase effects of the infrastructure on vehicle trips.

The construction impacts are a function of the bike path and bike lane designs. In this study, the width of the bike path is 3.05 m (10 ft). The thickness of asphalt concrete over the subgrade for the bike path is assumed to be 0.115 m (4.5") which lasts for around 15 years (Bicycle Plan, 2011). In the Yolo County bicycle transportation plan, the shoulders of the existing roads are extended to include a 1.22 m (4 ft) bike lane on both directions of the road. The thickness of the bike lanes is typically the same as that of the road and in this project, they are considered to be 0.152 m (6") thick. In both cases of bike path and bike lane, only conventional asphalt concrete (6% binder and 94% aggregate) is considered for construction and maintenance purposes. Only one-time maintenance (maintenance stage) activity is required in the 25 year analysis period which in this project is considered as milling of 0.045 m (1.8") of surface layer and overlaying of a 0.06 m (2.4") thick asphalt layer. UC Pavement Research Center (UCPRC) reference life cycle inventories (LCIs) were used to perform LCA for the bike infrastructures (Saboori et al. 2020). The Caltrans Cost Data Book (CCDB) online tool was used to estimate the costs of materials, construction and maintenance (Caltrans, 2018). An adjusted unit price value was selected based on the average of several projects as shown in Table 5.

The use phase impacts are a function of how much vehicle-related travel could be replaced by bike travel. While there is significant debate about how to estimate the effects of bike infrastructure on travel behavior, CARB has developed a calculator for the California Transportation Commission Active Transportation Program to estimate the direct GHG impacts of bike infrastructure (CARB 2016a). The calculator is used here to infer the effect of bike infrastructure on driving. This calculator used the GHG reduction quantification methodology based on the reduced VMT due to the proposed bike lanes and paths (CARB 2016b). One key input required by the tool is the average daily traffic (ADT) for the roads (in both directions) parallel to the proposed bike lane or path. The ADT data for proposed bike lane/paths connecting to Davis were taken from the city of Davis traffic count map (City of Davis 2019), the city of Woodland traffic count for Woodland (City of Woodland 2015) and the city of West Sacramento for West Sacramento (City of West Sacramento 2017). For all the projects, it was assumed that the roads are used 200 days annually.

3.2.3. Assumptions and Limitations

The following list describes the key assumptions that were made during the calculation of life cycle GHG emissions for intercity bike infrastructure in Yolo County.

- *County of Yolo Bicycle Transportation Plan*
    - The transportation plan was published in 2013 and no information was available regarding any improvements or construction of bike lanes or paths since then. Yolo County stakeholders agreed with this assumption.
    - All the projects shown in the plan have been evaluated and assumed that all is constructed in year 0.
    - Google maps® was used to calculate the length of the proposed bike infrastructure in the bicycle transportation plan.
    - In most cases, no data were available for ADT of county roads on which bike lanes were proposed. In the absence of other data, traffic counts for the cities of Davis, Woodland and West Sacramento roadway ADT close to the proposed bike infrastructure were used. The ADT data might be under-estimated.
- Bike infrastructure
    - It is assumed that the land is already prepared for the bike infrastructure to be laid onto it. No sub-structure construction or maintenance impacts are considered.
    - Other road fixtures such as rest benches, signals, sign boards, lighting, etc., are also not considered in the analysis.

- Costs
    - In order to calculate the total fuel savings, it is assumed that the average vehicle mileage is about 12.75 km/liter gasoline (30 mpg). The VMT reduction is then used per project to determine the fuel savings in liters as shown in Table 8.
    - The cost of fuel on average for California is assumed to be $0.83 per liter ($3.15 per gallon).
    - No increase in traffic growth is assumed.
    - A discount rate of 4% was applied to the materials and maintenance at year 15 and to the annual cost savings from VMT reduction.

The costs per lane km and the LCA (per functional unit) of bike lane and bike path are presented in Table 5 and Table 6, respectively.

Table 5. Cost in dollars per km of bike lane and bike path

Life Cycle Stages	**Caltrans Codes**		**Cost per unit ($/unit)**	**units**	**Price in $ per functional unit**	
					Bike Path	**Bike Lane**
Material and Construction	390132	Hot mix asphalt (HMA)	533.5	tonne	449116	474891
Maintenance	398001	Remove asphalt concrete pavement	76.10	m^2	232108	185686
	390132	HMA	533.5	tonne	195268	156214

Table 6. LCA of bike path and bike lane per functional unit of 1 km

Life Cycle Stages	**Bike path**	**Bike lane**
	tonne CO_2e	**tonne CO_2e**
Material Stage	50.9	53.9
Transportation	0.309	0.327
Construction Stage	3.49	3.69
Maintenance Stage (at year 15)	29.7	23.8

3.2.4. Results

The reduction in annual VMT using the tool was calculated to be almost 273,886 with a total GHG emission reductions of 2,668 metric ton (MT; tonne) as shown in Table 7. The GHG emission reductions reported in Table 3 are based on a well-to-wheel (WTW) approach which means the reductions reported consider the total fuel cycle (CARB 2016b). While bike paths and bike lanes have a potential to reduce GHG emissions from vehicles (due to VMT reduction), the construction and maintenance of the infrastructure for the bicycles will add GHG emissions. An LCA of the bike path and lanes also needs to be performed for a 25 years analysis period to determine if the net GHG reductions are still negative. The results shown in Table 7 suggest that there are more emissions produced due to construction of bike lanes and paths compared to the GHG benefit from reduction in VMT (almost 15,237 tonnes more CO_2e emissions). A key factor for this outcome is the low ADT on the sections where bike paths or lanes are planned. If ADT substantially increases over time, along with concurrent increases in bike travel that averts some ADT growth, the current calculations underestimate the potential benefits of bike lane infrastructure.

Table 7. Life cycle emission reduction from different proposed projects in Yolo County of bike paths and bike lanes for analysis period of 25 years.

Bike lane/path lengths in Master Plan (km)	**Pedestrian or Bicycle Facility Type**	**Average Daily Traffic (ADT)**	**Adjustment Factor (A)[1]**	**Activity Center Credit (C)[2]**	**Average VMT Reduced**	**GHG Emission Reductions (tonne CO_2e)**	**Material, construction and maintenance GHG emissions (tonne CO_2e)**
30.6	Bicycle Paths Class 1	2,000	0.0038	0.0020	104,400	41	2,583
43.5	Bicycle Lanes Class 2/Class 4	15,588	0.0207	0.0030	3,324,920	1,296	3,548
5.8	Bicycle Lanes Class 2/Class 4	7,725	0.0038	0.0010	333,720	130	473
19.3	Bicycle Lanes Class 2/Class 4	6,388	0.0038	0.0010	275,962	108	1,577
33.0	Bicycle Lanes Class 2/Class 4	7,330	0.0038	0.0005	283,671	111	2,694
34.3	Bicycle Lanes Class 2/Class 4	3,724	0.0038	0.0005	144,119	56	2,799
14.8	Bicycle Lanes Class 2/Class 4	12,293	0.0027	0.0010	409,357	160	1,209
16.9	Bicycle Lanes Class 2/Class 4	4,000	0.0038	0.0010	172,800	67	1,380
10.5	Bicycle Lanes Class 2/Class 4	6,000	0.0207	0.0015	1,198,800	467	854
9.7	Bicycle Lanes Class 2/Class 4	3,000	0.0207	0.0015	599,400	234	788
	Total Sum				**6,847,149**	**2,668**	**17,905**
	Net GHG Emissions (positive value means excess emissions)					**15,237 tonnes**	

[1] Adjustment Factor (A) is a factor that depends on the length of the bike project, average daily traffic (ADT) and human population. The A Table can be accessed from California Air Resource Board (2016a).
[2] Activity Center Credit (C) is a factor that depends on the distance of an activity center (such as bank, church, hospital, university and other community destinations) from the bike project. The C Table can be accessed from California Air Resource Board (2016a).

Life cycle agency and user cost was also calculated for this study and the results are shown in Table 8. The life cycle agency cost to construct bike lanes and paths is higher compared to the savings of GHGs due to VMT reduction. The cost to build bike lane and bike path infrastructure is above $145 million whereas the fuel savings are around half a million dollars. There may not be a payback period in case of GHGs and costs as the infrastructure emissions and costs are too high compared to the benefits from VMT reduction. However, the scope of this analysis does not include the benefits of bike paths and lanes for recreation and potential health benefits, which have not been quantified in this study and which may confer high benefits with respect to externalities.

Table 8. Life cycle cost analysis (LCCA) of the proposed bike path and lane projects.

Bike lane/path lengths from the transportation plan (km)*	**Pedestrian or Bicycle Facility Type**	**Initial Construction Cost (material cost inclusive) per project**	**Maintenance Cost (material cost inclusive) per project Discount rate of 4% applied at year 15**	**Fuel saved in liters annually (average vehicle efficiency 12.75 km/liter gasoline [30mpg])**	**Total fuel cost savings over the 25 years with 4% discount rate applied**
30.6	Bicycle Paths Class 1	$13,732,823	$7,256,228	527	$7,124
43.5	Bicycle Lanes Class 2/Class 4	$20,635,060	$8,249,185	16,780	$226,883
5.8	Bicycle Lanes Class 2/Class 4	$2,751,341	$1,099,891	1,684	$22,772
19.3	Bicycle Lanes Class 2/Class 4	$9,171,138	$3,666,304	1,393	$18,831
33.0	Bicycle Lanes Class 2/Class 4	$15,667,360	$6,263,270	1,432	$19,357
34.3	Bicycle Lanes Class 2/Class 4	$16,278,769	$6,507,690	727	$9,834
14.8	Bicycle Lanes Class 2/Class 4	$7,031,205	$2,810,833	2,066	$27,933
16.9	Bicycle Lanes Class 2/Class 4	$8,024,745	$3,208,016	872	$11,791
10.5	Bicycle Lanes Class 2/Class 4	$4,967,700	$1,985,915	6,050	$81,803
9.7	Bicycle Lanes Class 2/Class 4	$4,585,569	$1,833,152	3,025	$40,901
Total Costs (millions)		$ 102.85	$ 42.88		$ 0.47
Total Life Cycle Agency Cost per Bicycle Transportation Plan (millions)		$ 145.73		**Total Life Cycle User Cost per 25 year VMT reduction (million)**	$ 0.47
Total Life Cycle Cost (LCC) in million dollars					$145.26

* All measurements made using google maps®

3.2.5. Sensitivity Analysis

There were two major assumptions made in the analysis:

- All the bike paths and bike lanes proposed in the *County of Yolo Bicycle Transportation Plan* (218.2 km in total) are built in year 0.
- The county of Yolo has unlimited budget to spend to build the bike infrastructures of very high standards using asphalt concrete (6% binder and 94% aggregate) that is typically used for motorized vehicles transport infrastructures.

Both the assumptions made in the original analysis were very conservative; therefore, a sensitivity analysis was performed. The bike infrastructure project priority characterization provided in the Yolo county bicycle transportation plan was used (Yolo County Transportation Advisory Committee, 2013) in which the projects were further divided into short term projects and prioritized using 'high', 'medium', and 'low' ratings. Table 9 show the details of the projects, their priority rankings, and estimated bike infrastructure length proposed in the plan. An initial estimated cost to complete the projects was also reported per project. For the sensitivity analysis, it is assumed that county of Yolo will be completing the high priority projects only in the first 5 years based on funding limitations.

The second practical assumption is related to the selection of asphalt concrete design and construction and treatment type for the bike infrastructures which includes:

- *Bike paths*: 0.15 m (6 inches) aggregate base with 0.05 m (2 inches) asphalt concrete overlay.
- *Bike lanes*: 0.05 m (2 inches) overlay over the aggregate on the shoulders of the existing CRs.
- *Bike paths and bike lanes*: the first maintenance occurs at year 12 and then every 8 years the infrastructure needs to be maintained. Thus in a 25 years analysis period, maintenance occurs twice; year 12 and year 20. The treatment for the maintenance selected is slurry seal. The slurry seal price was extracted from Caltrans pavement management system, PaveM's database, which was $32,156 lane-km ($51,750 per lane-mile). The GHG emissions for slurry seal treatment were gathered from Saboori et al (2020) which was 2.24 tonnes CO2-e per lane-km.
- Asphalt concrete mix consists of 5.2% asphalt binder (seldom asphalt content goes above 5.5%; in original analysis it was assumed to be 6%).

Table 10 and Table 11 shows the results of the sensitivity analysis in regard to both life cycle environmental and cost spending and savings. The analysis period was kept the same, at 25 years. The cost of aggregates and aggregate base construction was determined to be $36.1 per tonne ($32.76 ton; Caltrans price index 2017) and the GHG emissions were estimated to be kg CO_2e per lane-km (aggregate material and construction). GHG data was based on the LCI's reported for natural aggregate and aggregate base compaction equipment in Saboori et al (2020).

Table 9. Yolo County Bicycle Transportation Plan project prioritization list.

Project	Class	Priority	Estimated project cost ($ million)	Length (km)
Alternative Transportation Corridor (Davis to Woodland)	I	High	9.6	16.1
Davis-Woodland Bikeway (Davis to Woodland)	I/II	High	5.5	10.0
County Road 21A, Esparto	II	High	0.3	0.4
County Road 98, Hutchison Drive to Russell Blvd	II	High	0.4	0.8
County Road 99, County Road 29 to Davis City limits	II	High	1.6	3.2
County Road 102, Davis City limits to 3000' north	II	Medium	0.8	1.0
Russell Boulevard Class 1 Pavement Rehabilitation	I	Medium	No estimates	11.3
South River Road Route, south of West Sacramento	II	Medium	81	43.4
Facility Improvements	n/a	Medium	No estimates	0.0
County Road 98, Woodland to Russell Boulevard	II	Medium	19.7	11.9
County Road 95A, Russell to Solano County	I	Medium	0.9	1.3
County Road 95A, Russell to Solano County	II	Medium	0.6	1.3
County Road 22, Woodland to West Sacramento	I/II	Medium	30	19.3
County Road 104, Davis to Grasslands Park	II	Medium	3	4.8
State Route 113, open to bicycles from CR 27 to Woodland	II	Medium	no capital cost	2.8
County Road 24, Woodland to County Road 90	II	Low	8	12.7
County Road 89, Winters to Madison	II	Low	9.5	15.3
County Road 99/18	II	Low	1.7	4.5
County Road 99W, County Road 18 to County line	II	Low	17.5	28.3
Delta Ecosystem Trail / Great Delta Trail	I	Low	7	22.5
State Routes 128/16	III	Low	No estimates	80.5
Clarksburg Branch Line Rail Trail, West Sacramento to Pumphouse Road	I	Low	No estimates	8.0
Interstate 80 Class I Bicycle Path Improvements, CR105 to West Sacramento	I	Low	No estimates	8.4
Chiles Road Class II Bicycle Lanes	II	Low	3.5	3.6
		***Totals:**	**200.6**	**311.5**

** Note: some of the project costs that have not been estimated in the transportation plan are not in the total costs.*

Table 10. Life cycle emission reduction from Yolo County proposed high prioritized projects of bike paths and bike lanes for the analysis period of 25 years.

Projects	Bike lane/path lengths in Master Plan (km)	Pedestrian or Bicycle Facility Type	Average Daily Traffic (ADT)	Adjustment Factor (A)	Activity Center Credit (C)	Average VMT Reduced	GHG Emission Reductions (tonne CO_2e)	Material, construction and maintenance GHG emissions (tonne CO_2e)
Alternative Transportation Corridor (Davis to Woodland)	16.1	Bicycle Paths Class 1	25,000	0.0104	0.0005	2452500	956	444
Davis-Woodland Bikeway (Davis to Woodland)	10.0	Bicycle Lanes Class 2/Class 4	25,000	0.0104	0.0005	2452500	956	210
County Road 21A, Esparto	0.4	Bicycle Lanes Class 2/Class 4	10,000	0.0019	0.0005	216000	84	8
County Road 98, Hutchison Drive to Russell Blvd	0.8	Bicycle Lanes Class 2/Class 4	3,300	0.0104	0.0030	397980	155	17
County Road 99, County Road 29 to Davis City limits	3.2	Bicycle Lanes Class 2/Class 4	10,000	0.0104	0.0030	1206000	470	67
					Total:	**6.7 million**	**2621**	**747**
	Net GHG emissions reduction (tonnes)						**1874**	

Table 11. LCCA of the county of Yolo proposed high prioritized bike path and lane projects.

Bike lane/path lengths from the transportation plan (km)*	**Pedestrian or Bicycle Facility Type**	**Initial Construction Cost from Transportation plan (material cost inclusive) per project[1]**	**Calculated* Initial Construction Cost (material cost inclusive) per project[2]**	**Maintenance Cost (material cost inclusive) per project Discount rate of 4% applied at year 12**	**Maintenance Cost (material cost inclusive) per project Discount rate of 4% applied at year 20**	**Fuel saved in liters annually (average vehicle efficiency 12.75 km/liter gasoline [30mpg])**	**Total fuel cost savings over the 25 years with 4% discount rate applied**
16.1	Bicycle Paths Class 1	$9,640,000	$3,356,603	$323,361	$236,276	12,377	$167,352
10.0	Bicycle Lanes Class 2/Class 4	$5,500,000	$1,562,142	$200,845	$146,756	12,377	$167,352
0.4	Bicycle Lanes Class 2/Class 4	$300,000	$62,486	$8,034	$5,870	1,090	$14,739
0.8	Bicycle Lanes Class 2/Class 4	$425,000	$124,971	$16,068	$11,740	2,008	$27,157
3.2	Bicycle Lanes Class 2/Class 4	$1,600,000	$499,886	$64,270	$46,962	6,086	$82,294
Total Costs (million)		**$17.5**	**$5.61**	**$1.06**			**$ 0.46**
Total Life Cycle Agency Cost per Transportation Plan (million)		**$6.67**				**Total Life Cycle User Cost per 25-year VMT reduction (million)**	**$ 0.46**
Total Life Cycle Cost (million dollars)							**6.21**

[1] Initial material and construction cost have been extracted from the Bicycle Transportation Plan () which are estimates of bike projects. These values are not used in the analysis.
[2] Calculated initial material and construction costs are calculated based on the cost data presented in this strategy. Other costs related to overheads, traffic closures, etc are not included in these costs. These are the initial costs that are used in the analysis.

The sensitivity analysis for the 25 years period shows that if the high priority bike lane and path projects are implemented, Yolo County could reduce 1874 tonnes of GHG emissions; however, the county will have to spend almost $6.21 million to achieve this. If the initial project costs stated in the transportation plan (also presented in Table 9 and Table 11) are considered, then county of Yolo is looking at almost $19 million and more.

3.3. Converting intersection configurations from start-stop to roundabouts

3.3.1. Background

Yolo County plans to add roundabouts to three county road (CR) intersections (CR31-CR98, CR32-CR98, and Hutchison-CR98) as shown in the map in Figure 2. Yolo County is considering a fourth option at the CR27-CR102 intersection (which is not included in this study). All the roads are one way in each direction thus the intersection design for all the three proposed projects is assumed to be the same. The plan of the intersection with and without a roundabout is shown in Figure 3.

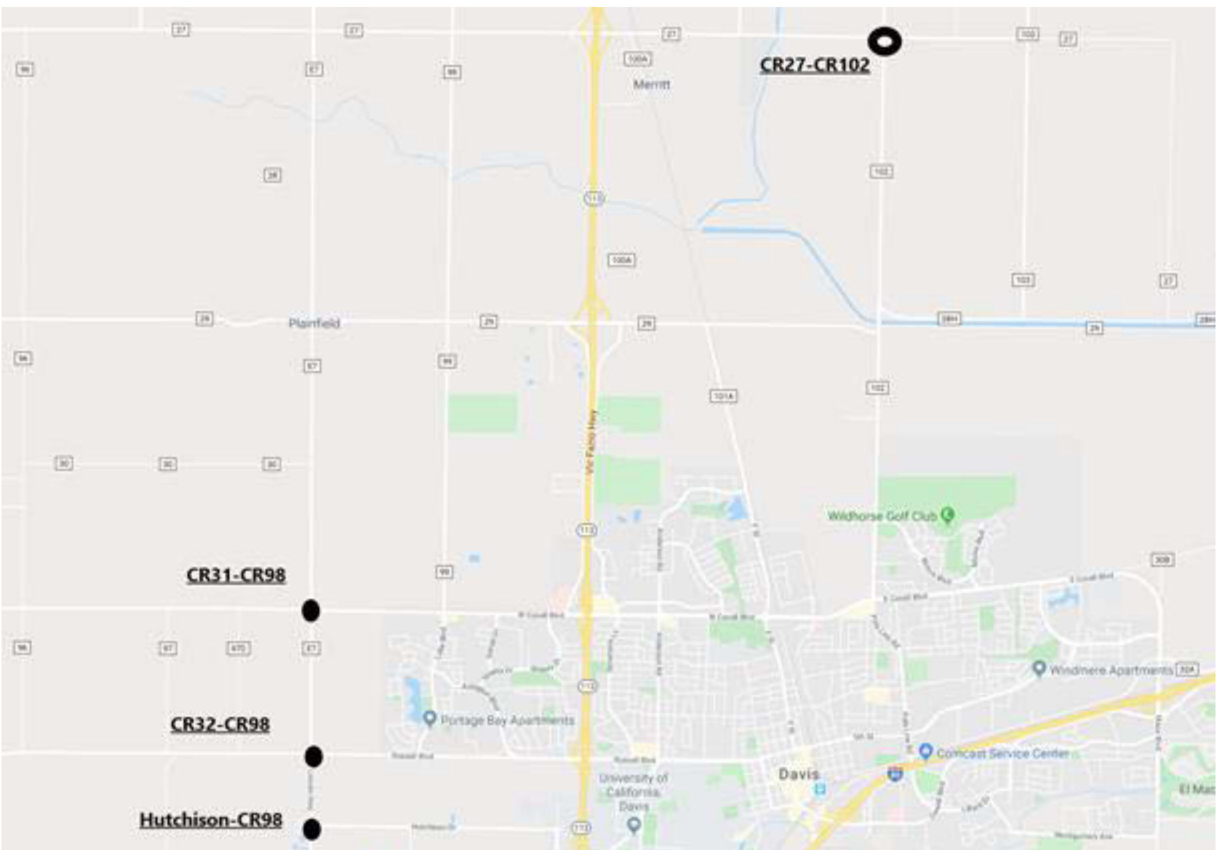

Figure 2. Locations where intersections will be converted to roundabout intersections.

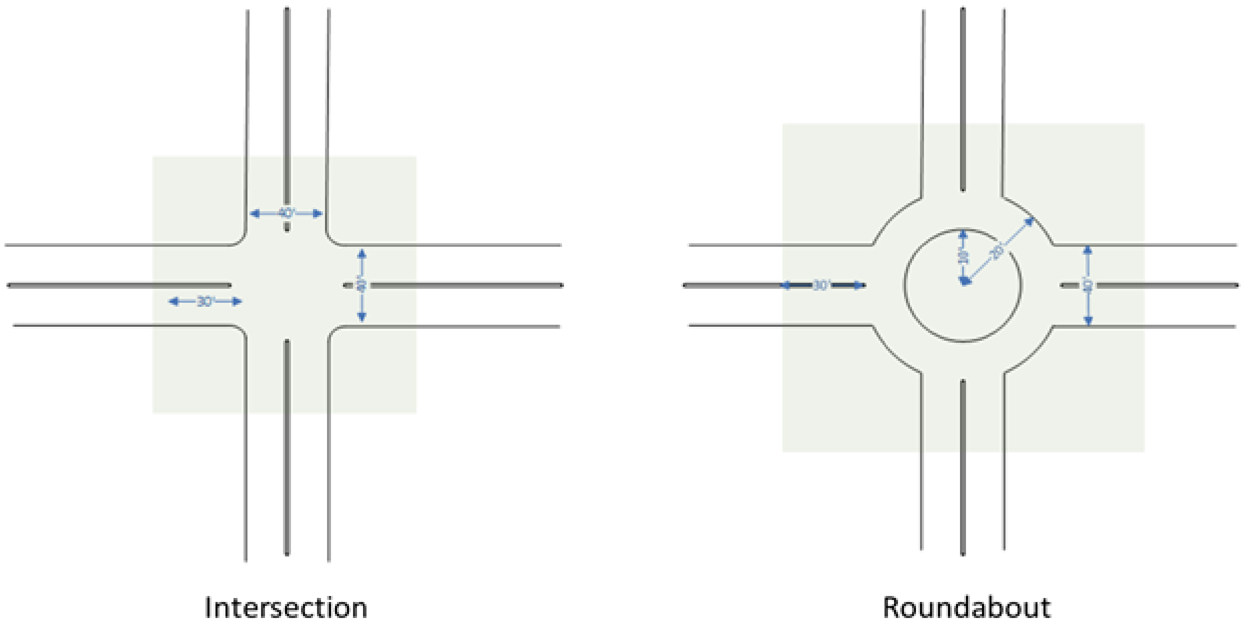

Figure 3. Current intersection (on the left) vs the one with the roundabout (on the right)

3.3.2. Methodology

The functional unit for the study is defined as construction and maintenance of a single intersection analyzed for a period of 25 years. As seen in Figure 3, the width of the two lanes in opposite directions is 12.2 m (40 ft). The intersection approach width does not change for the two type of intersections. The approach length is considered as 9.1 m (30 ft). As there are four roads connected to an intersection, the total area of the existing intersection (as shown on the left in Figure 3 is calculated to be 594.6 m^2 (6400 ft^2). The proposed intersection (on the right in Figure 3) has a roundabout with a radius of 3 m (10 ft) and a single lane 3 m (10 ft) wide around it. It is assumed that the roundabout will be built of Portland Cement Concrete (PCC) of 0.15 m (0.5 ft) thickness whereas the traffic lane will be constructed of hot mix asphalt (HMA) having lane thickness of 0.06 m (0.2 ft). It is assumed that the HMA lane will require maintenance every 7 years during the analysis period of 25 years. 'Mill and overlay' is the treatment being analyzed for this case. It is assumed that the conventional asphalt concrete (6% binder and 94% aggregate) is considered for construction and maintenance purposes and PCC used for minor construction is used for the one-time construction of the roundabout. No secondary cementitious materials are present in the PCC. Milling of 0.045 m (1.8") of surface layer and overlaying of a 0.06 m (2.4") thick asphalt layer is considered for the mill and overlay. UCPRC LCIs were used to perform LCA for the infrastructure (Saboori et al. 2020).

The unit cost of HMA per tonne is $439 ($484/US ton) and that of PCC $5,000 per m3 ($140/ft3). The milling unit cost is considered as $714.3 per m3 ($20/ft3) of material milled. The cost data has been acquired from the Caltrans Cost Data Book (Caltrans 2018).

3.3.3. Assumptions and Limitations

Major assumptions:

- All of the three projects will be constructed in year 0
- No road sub-structure construction or maintenance is required
- Other road fixtures such as signals, sign boards, lighting, etc. are also not considered in the analysis
- The total cost of milling and overlay also includes cost related to engineering, traffic handling, contingency costs (assumed additional 100% of pavement cost for small projects)
- The average cost of fuel for California is assumed to be $0.83 per liter ($3.15 per gallon)
- A 1% traffic growth increase has been included in the study
- A discount rate of 4% was applied to the materials and a maintenance cycle occurs every 7 years.

3.3.4. Results

Table 12 shows the breakdown of the different life cycle stages and their impacts per intersection type. The costs and life cycle GHG impact for the two types of intersections, as shown in Figure 3, are presented in Table 13.

Table 12. LCA of intersections with and without roundabout per functional unit

		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

Table 13. Life cycle agency cost and LCA of the two types of intersections (analysis period of 25 years)

		Life Cycle Agency Costs		Life Cycle Assessment (tonne CO_2e)	
Life Cycle Stages	**Year**	**Intersection**	**Roundabout**	**Intersection**	**Roundabout**
Materials and Construction	0	$130,700	$190,800	5.34	6.58
Materials and Maintenance (4% discount rate applied to costs)	7	$103,300	$69,500	5.55	4.98
	14	$78,500	$52,800	5.55	4.98
	21	$59,700	$40,100	5.55	4.98
Total		**$372,200**	**$353,200**	**22**	**21.52**
Life Cycle Net Savings		**$19,000**		**0.48**	

In order to calculate the life cycle use phase, which includes user costs and impacts, the U.S. Environmental Protection Agency's MOtor Vehicle Emission Simulator (MOVES) was used to determine the pump-to-wheel (PTW) emissions and total fuel use (Environmental Protection Agency, 2015) and Argonne's Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation Model (GREET) was used for the well-to-pump (WTP) emissions for the two fuel types; diesel and gasoline (as shown in Table 14). The drive cycle used for the intersection with and without roundabout is presented in Figure 4. It is assumed that the vehicles approaching the intersection are at 72.4 km/hr (45 mph) speed. In case of a roundabout, the vehicle can freely pass the intersection at 24.1 km/hr (15 mph) speed whereas in case of an intersection with stop signs, the vehicles must stop for few seconds before accelerating again to 72.4 km/hr speed. The average daily traffic (ADT) data for the CR98 has been extracted from the city of Woodland traffic counts (City of Woodland, 2015) for the streets connecting to CR98 whereas that for the other three city roads (connecting to CR98) has been gathered from the traffic counts by city of Davis (City of Davis, 2019). The ADT data for each intersection is presented in Figure 5.

Table 14. Impacts per liter of Fuel: WTP energy and emissions for gasoline and diesel from GREET model

Indicator	**Unit**	**CA Diesel**	**CA Gas**
Total Energy	MJ	42.2	39.1
CO_2e	kg	5.13E-01	6.54E-01

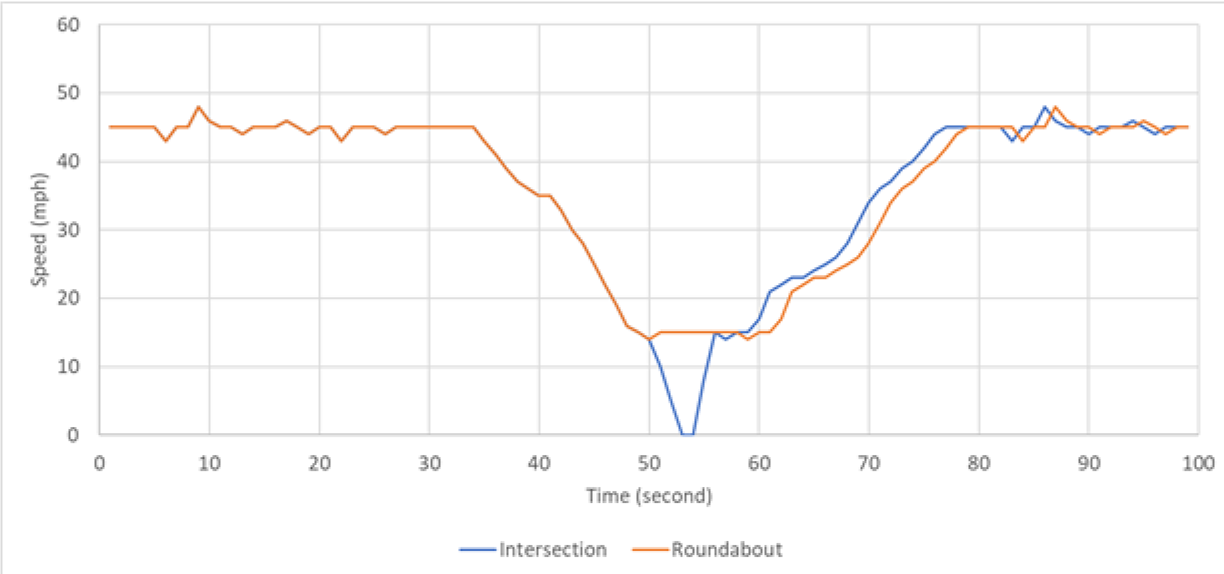

Figure 4. Drive cycle used in MOVES.

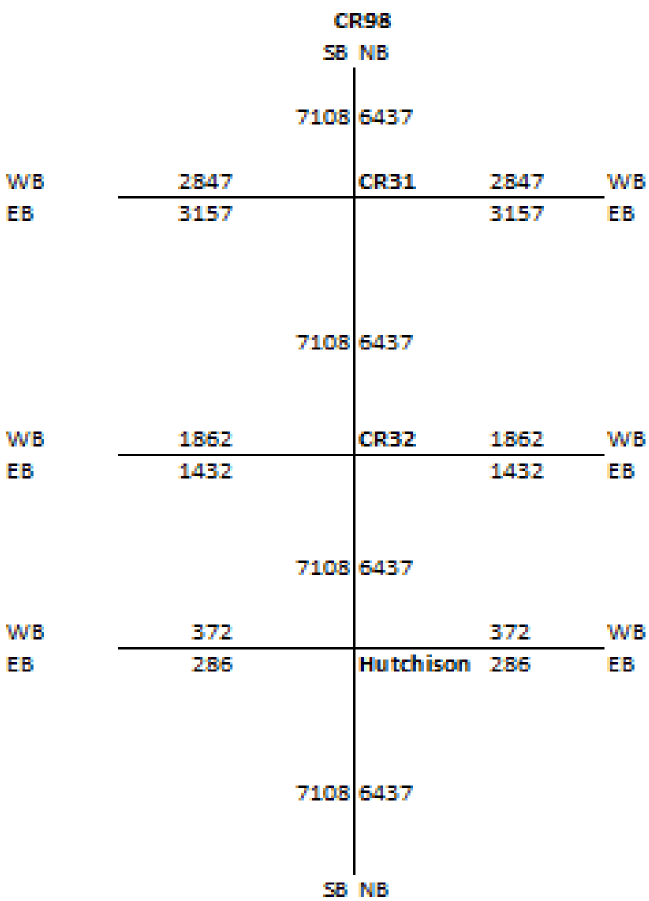

Figure 5. ADT data for the three intersection (NB-Northbound; SB – Southbound; EB – Eastbound; WB – Westbound)

Four classes of traffic are considered for the ADT; passenger car (PC), sport utility vehicle (SUV), light duty truck (LDT) and heavy-duty truck (HDT). PC and SUV are gasoline fueled vehicles whereas LDT and HDT are considered as diesel vehicles. Traffic distribution for all the intersections has been considered as 54% PC, 36% SUV, 5% LDT and 5% HDT. The results show that over the 25 years analysis period, almost 96,987 tonnes of CO_2e emissions can be saved by implementing roundabouts as can be seen in Table 15 . The total net savings in terms of life cycle GHG emissions comes out to be 96,988 tonnes of CO_2e (0.476 tonnes savings from infrastructure LCA results from Table 10). Using the TAWP method from Kendall (2012), the total GHG savings reported in Table 15 will be 82,900 tonnes CO_2e instead of 96,987 tonnes. Table 16 shows a total life cycle user cost savings of $11.4 million can be achieved by implementing the roundabouts at the three intersections. Net life cycle savings (agency plus user) of almost $11.45 million over the 25 years analysis period can be achieved (including the savings from maintenance every 7 years).

Table 15. Use stage well-to-wheel (WTW) vehicle emissions for intersection with and without roundabouts.

	WTW GHG emissions (tonne CO_2e) Intersection without roundabout				WTW GHG emissions (tonne CO_2e) Intersection with roundabout				Annual GHG savings
Year	**CR31-CR98**	**CR32-CR98**	**Hutchison-CR98**	**TOTAL**	**CR31-CR98**	**CR32-CR98**	**Hutchison-CR98**	**TOTAL**	**tonne CO_2e**
1	3,800	3,233	2,854	9,887	3,400	3,000	2,600	9,000	887
2	3,800	3,266	2,883	9,949	3,500	3,000	2,600	9,100	849
3	3,900	3,331	2,941	10,172	3,500	3,000	2,700	9,200	972
4	4,000	3,432	3,030	10,462	3,600	3,100	2,800	9,500	962
5	4,100	3,572	3,153	10,825	3,800	3,300	2,900	10,000	825
6	4,400	3,754	3,314	11,468	4,000	3,400	3,000	10,400	1,068
7	4,600	3,985	3,518	12,103	4,200	3,600	3,200	11,000	1,103
8	5,000	4,272	3,771	13,043	4,500	3,900	3,400	11,800	1,243
9	5,400	4,626	4,084	14,110	4,900	4,200	3,700	12,800	1,310
10	5,900	5,060	4,466	15,426	5,400	4,600	4,100	14,100	1,326
11	6,500	5,589	4,934	17,023	5,900	5,100	4,500	15,500	1,523
12	7,200	6,236	5,504	18,940	6,600	5,700	5,000	17,300	1,640
13	8,200	7,026	6,202	21,428	7,400	6,400	5,700	19,500	1,928
14	9,300	7,997	7,059	24,356	8,500	7,300	6,400	22,200	2,156
15	10,700	9,192	8,114	28,006	9,700	8,400	7,400	25,500	2,506
16	12,400	10,672	9,420	32,492	11,300	9,700	8,600	29,600	2,892
17	14,500	12,513	11,046	38,059	13,300	11,400	10,100	34,800	3,259
18	17,200	14,820	13,082	45,102	15,700	13,500	11,900	41,100	4,002
19	20,600	17,727	15,648	53,975	18,800	16,200	14,300	49,300	4,675
20	24,900	21,416	18,904	65,220	22,700	19,600	17,300	59,600	5,620
21	30,300	26,131	23,067	79,498	27,700	23,900	21,100	72,700	6,798
22	37,400	32,204	28,427	98,031	34,100	29,400	26,000	89,500	8,531
23	46,500	40,085	35,384	121,969	42,500	36,600	32,300	111,400	10,569
24	58,500	50,393	44,483	153,376	53,400	46,000	40,600	140,000	13,376
25	74,300	63,985	56,482	194,767	67,800	58,400	51,600	177,800	16,967
TOTAL	**423,400**	**364,517**	**321,770**	**1,109,687**	**386,200**	**332,700**	**293,800**	**1,012,700**	**96,987**

Table 16. Life cycle user costs at the three intersections

	Current Intersections			Roundabout Intersections			Life Cycle User Cost savings (thousand dollars)	
Year	PTW Energy (MJ)	Total Fuel (million liters)	Fuel cost (million)	PTW Energy (MJ)	Total Fuel (million liters)	Fuel cost (million)		***4% discount rate applied***
1	1.12E+05	2.82	$2.34	1.02E+05	2.57	$2.14	$203	**$203**
2	1.13E+05	2.85	$2.36	1.03E+05	2.60	$2.16	$205	**$197**
3	1.15E+05	2.90	$2.41	1.05E+05	2.65	$2.20	$209	**$194**
4	1.19E+05	2.99	$2.48	1.08E+05	2.73	$2.27	$216	**$192**
5	1.23E+05	3.11	$2.58	1.13E+05	2.84	$2.36	$225	**$192**
6	1.30E+05	3.27	$2.71	1.18E+05	2.99	$2.48	$236	**$194**
7	1.38E+05	3.47	$2.88	1.26E+05	3.17	$2.63	$251	**$198**
8	1.48E+05	3.72	$3.09	1.35E+05	3.40	$2.82	$269	**$204**
9	1.60E+05	4.03	$3.35	1.46E+05	3.68	$3.05	$291	**$213**
10	1.75E+05	4.41	$3.66	1.60E+05	4.03	$3.34	$318	**$224**
11	1.93E+05	4.87	$4.04	1.76E+05	4.45	$3.69	$351	**$237**
12	2.15E+05	5.43	$4.51	1.97E+05	4.96	$4.12	$392	**$255**
13	2.43E+05	6.12	$5.08	2.22E+05	5.59	$4.64	$442	**$276**
14	2.76E+05	6.97	$5.78	2.52E+05	6.36	$5.28	$503	**$302**
15	3.17E+05	8.01	$6.65	2.90E+05	7.31	$6.07	$578	**$334**
16	3.69E+05	9.30	$7.72	3.36E+05	8.49	$7.05	$671	**$373**
17	4.32E+05	10.90	$9.05	3.95E+05	9.95	$8.26	$787	**$420**
18	5.12E+05	12.91	$10.72	4.67E+05	11.79	$9.79	$932	**$478**
19	6.12E+05	15.45	$12.82	5.59E+05	14.10	$11.70	$1,115	**$550**
20	7.39E+05	18.66	$15.49	6.75E+05	17.04	$14.14	$1,347	**$639**
21	9.02E+05	22.77	$18.90	8.24E+05	20.79	$17.25	$1,643	**$750**
22	1.11E+06	28.06	$23.29	1.02E+06	25.62	$21.26	$2,025	**$889**
23	1.38E+06	34.93	$28.99	1.26E+06	31.89	$26.47	$2,521	**$1,064**
24	1.74E+06	43.91	$36.44	1.59E+06	40.09	$33.27	$3,169	**$1,286**
25	2.21E+06	55.75	$46.27	2.02E+06	50.90	$42.25	$4,024	**$1,570**
TOTAL	1.26E+07	317.60	$263.61	1.15E+07	289.98	$240.69	$22,923	**$11,433**

3.4. Solar Canopies on County Parking Lots

3.4.1. Background

To increase the quantity of renewable energy on the grid, Yolo County is considering the installation of solar canopies on parking lots. Also known as solar carports, these structures support a layer of solar panels that produce electricity while also providing shade to the parking spaces below. This study examines various parking sites that the County owns and operates, and considers the costs, emissions, and renewable energy generation associated with installation of solar canopies on these sites.

3.4.2. Methodology

To determine the quantity of solar canopies that could be installed, a list of potential installation sites was determined. The primary list was provided by the Yolo County Department of General Services and was substantiated by the locations of additional county-owned facilities. Adequate sites for installation were those that had limited tree cover to avoid the environmental impacts of plant removal, as well as to reduce the additional cost of this process. Most of the potential installation sites were double row parking spaces (such that two rows of parked cars faced each other) since most single lane parking spaces were on the perimeter of the parking lot, and therefore had more trees.

The considered solar carport structure has vertical support beams every three parking spaces and is two parking spaces wide. In other words, this structure spans six parking spaces. The canopy consists of a grid of solar PV panels, which produce electricity from sunlight. The example structure used for this study’s model is shown in Figure 6 below.

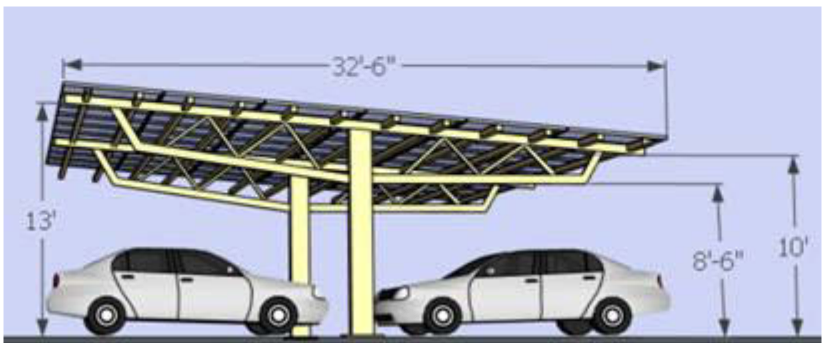

Figure 6. A solar canopy design showing approximate dimensions of the structure (Structural Solar, 2013). Note that the width is not specified but the structure can accommodate a total of six cars.

When assessing sites, the address and number of adjacent spaces that could accommodate a double row solar canopy were noted. A primary building was also included. The final list of sites is summarized in Table 17.

Table 17. This table notes the number of parking spaces per row at a site, as well as how many times that row size appears.

Address	Parking spaces per row	Primary building
600 A St, Davis	15	Yolo County Health and Human Services Agency
25 N Cottonwood St, Woodland	17x2	Social Services Department
137 N Cottonwood St, Woodland	21x4	County of Yolo Health and Human Services Agency
500 Jefferson Blvd, West Sac	10x2, 9, 8	Yolo County Health and Human Services Agency
140 Tony Diaz Dr, Woodland	19, 18, 15, 10x2	Yolo County Juvenile and Detention Centers
292 Beamer St, Woodland	16, 11, 9x3, 6	Yolo County Department of Community Services
1000 Main St, Woodland	18, 12, 9	Yolo County Traffic Division

Ultimately, these sites could accommodate a combined 104 six-space solar canopies (a total of 624 parking spaces covered). Each solar canopy can hold 48 solar panels that measure 39.7 by 26.7 inches and have a rated capacity of 100 watts (W). This results in a rated solar capacity of 0.71 MW across all installations. A 1 kW panel in California can produce approximately 4.5 kilowatt-hours (kWh) per day on average (Sendy 2017). Additionally, multiple studies found that solar panels have lifetimes between 20 and 30 years, so this study assumes a lifetime of 25 years; additionally, a 0.5 percent annual performance degradation rate is assumed (Hsu et al., 2015).

Studies on the life cycle emissions of solar PV often present results in grams of CO_2e per kWh, but can have assumptions about technology efficiency, irradiance, lifetime, and other factors. A study by Hsu et al. (2012) harmonized the GHG values from several studies and found the life cycle GHG emissions per unit energy produced to be 52 g of CO_2e per kWh. By combining this result with the harmonization assumptions made in the study, it was determined that solar panels produce 276 kg CO_2e per meter-squared of panel.

The emissions associated with the support structure also must be estimated. Carport Structures Corporation (2019) provided a material specification sheet that states all supporting beams are steel. This study combines this specification sheet with Structural Solar's model previously seen in Figure 6 to determine the material needed. One addition to the model was a cement concrete base that is two and a half feet tall to protect the structure from vehicular damage. The vertical support beam was shortened accordingly. The LCIs for materials are from the following sources: steel from the EcoInvent database (Wernet 2016), and concrete from Saboori et al. (2020).

The cost of installation was obtained from the listed prices provided by Solar Electric Supply (2019), a California-based company. The prices for installations between 50 and 250 kW was \$1.30 to \$1.50 per kW. This study assumed the median price of \$1.40 per kW.

Finally, correspondence with representatives at Valley Clean Energy confirmed that these installations are highly likely to qualify for monthly net metering. This means that the electricity produced by these solar canopies is credited to the bill and offsets any charges, as long as the solar panels do not produce more electricity than is consumed (which is unlikely to happen). Therefore, the value of this electricity is the price that is paid for electricity. This can vary based on the size of the nearest facility and the rate plan that is chosen, so this study assumed an average annual electricity price of $0.10 per kWh. While the produced electricity will be within the jurisdiction of VCE, it will offset production emissions at the statewide level. Therefore, the California average electric grid carbon intensity was considered to be displaced. The carbon intensity of the California grid over the 25-year time horizon of analysis was determined by combining the projected grid mix provided by the EIA Annual Energy Outlook with the emissions values of each fuel source as reported in the GREET 1 model (ANL 2018).

3.4.3. Key Assumptions and Limitations

The following list describes key assumption and limitations of this analysis

- Additional time required for designing, planning, and permitting. Designs and plans for each site would need to be created and the appropriate permits would need to be obtained. These processes could take from a few months to over a year. However, this study begins its analysis after these processes have been completed, and subsequently considers only the installation rate of the technologies.
- Removing trees and shrubbery not only decreases the amount of natural carbon capture, but it also requires additional planning and costs. While it was largely avoided, sites will still require some landscaping before installation and this was not accounted for in the analysis.
- Effects on afternoon ramp loads were not incorporated. Solar energy production during daytime hours results in decreased output of fossil fuel-powered plants. Increased solar capacity has led to decreased demand from these plants during the daytime, which in turn results in decreased carbon emissions. However, in the afternoon and early evenings, total electricity demand rises sharply as people return home. These times coincide with decreased solar energy production output. As a result, plants that were previously non-operational during the day must quickly ramp up to meet the demand that is no longer met by solar energy. Particularly, it leads to a decreased operation efficiency of the plants as well as the reliance on carbon-intensive “peaker plants.” Adding more solar energy to the grid could therefore exacerbate this steep ramp-up of demand that must be met by plants, and unintentionally results in higher carbon-intensity electricity being generated in the evenings. If this were to occur, it would reduce the net benefit of supplying solar power as compared to a scenario where the solar is not installed (and therefore less ramp up is required since more plants are already operational). While potentially negligible due to the relatively small capacity of installation in this study, it should be noted that this consideration was not included in the analysis in this study and may be more important over time as solar generation capacity in the state continues to expand.

- Time-of-day pricing. Some utilities, including VCE, charge different rates for electricity that depend on the time of day it is consumed. For example, rates are higher on summer weekdays from 5 to 8 PM than the rest of the day. This strategy is meant to minimize the afternoon ramp load (explained above). However, this also means that electricity produced in the late afternoon and early evening is more valuable than electricity produced during the rest of the day. This could affect the payback of the installations. However, this pricing structure was not considered, and instead a slightly lower flat rate was assumed.
- Change in price of electricity over time. The rate at which the price of electricity will presumably increase over time was not accounted for. However, with an increasing number of renewables and a better levelized cost of electricity (LCOE), it was uncertain exactly how electricity prices will shift; this in turn would affect the calculation of the return on investment in this energy generation method. These effects were not considered in the analysis.

3.4.4. Results

The assumed installation would provide a total rated capacity of 0.73 MW. Full capacity is reached after two years. The installation would have a net present cost of $979,000 and generates 2,400 tonnes of CO_2e in GHG emissions. Considering the emissions reductions benefits achieved by selling the generated electricity to VCE, this strategy would achieve net emissions reductions of 2,508 tonnes of CO_2e, and a net present value of profits of $770,000. The time adjusted warming potential (TAWP) is 2,122 tonnes CO_2e. The initial cost-effectiveness is $390 per tonne reduction, and the life cycle cost-effectiveness is -$307 (net savings) per tonne reduction.

3.5. Assessment of FDR Options for the South River Road Rehabilitation Project

3.5.1. Background

Roads deteriorate under traffic load, aging, and climate impacts. The conventional option for asphalt pavements after they reach their end of service life is to mill the old pavement and put in new pavement materials (mill-and-fill). The old pavement milled from a section is then transferred to local plants for recycling or is disposed in landfills. In-place recycling (IPR) techniques are becoming increasingly more popular among local and state governments to avoid hauling the materials back to the recycling plant, reduce consumption of new pavement materials, and expedite the construction process. Two main types of IPR are cold in-place recycling (CIR) and full-depth reclamation (FDR).

IPR processes typically include three main stages:

- In-place material recycling, which includes pulverizing the old pavement and mixing it with additives (to improve the stiffness and load-bearing performance of this new layer)
- Putting the recycled materials mixed with additives back on the track and compacting them

- Adding a wearing surface on top which could be an asphalt overlay or lighter surface treatments such as chip seals. The type and thickness of this wearing layer depend on the traffic levels and other considerations.

The main difference between the CIR and FDR is that in the CIR the full depth of the old section is not recycled, while in FDR the full depth plus at least 2 inches of the layer underneath the pavement is pulverized and fully mixed with additives. CIR is mostly used for sections with less traffic and pavements that are not heavily deteriorated; therefore, the amount of additive and the thickness of layers used in CIR is typically lower than the ones used in FDR. Additives used for IPR are typically portland cement, foamed asphalt, asphalt emulsion, or a combination of these. Figure 7 shows the construction process for an FDR project (Van dam et al., 2015), and Figure 8 shows the equipment details taken from one of the manufacturer's catalog (Wirtgen, 2012).

3.5.2. Methodology

Yolo County is planning to conduct a rehabilitation project on South River Road from the West Sacramento city limit to south of Freeport bridge, as shown in Figure 9. The project is a 2-lane road (24 ft. width) stretching along a 5.2 miles length (using Google Maps, as shown in Figure 9 and Figure 10).

Three alternatives are considered for this project:

- 4-in. asphalt overlay on 2-in. milling (mill-and-fill)
- FDR with a 2.5-in. asphalt overlay and 3 percent portland cement (FDR+PC)
- FDR with a 2.5-in. asphalt overlay and 2.5 percent foamed asphalt and 1 percent portland cement (FDR+FA+PC)

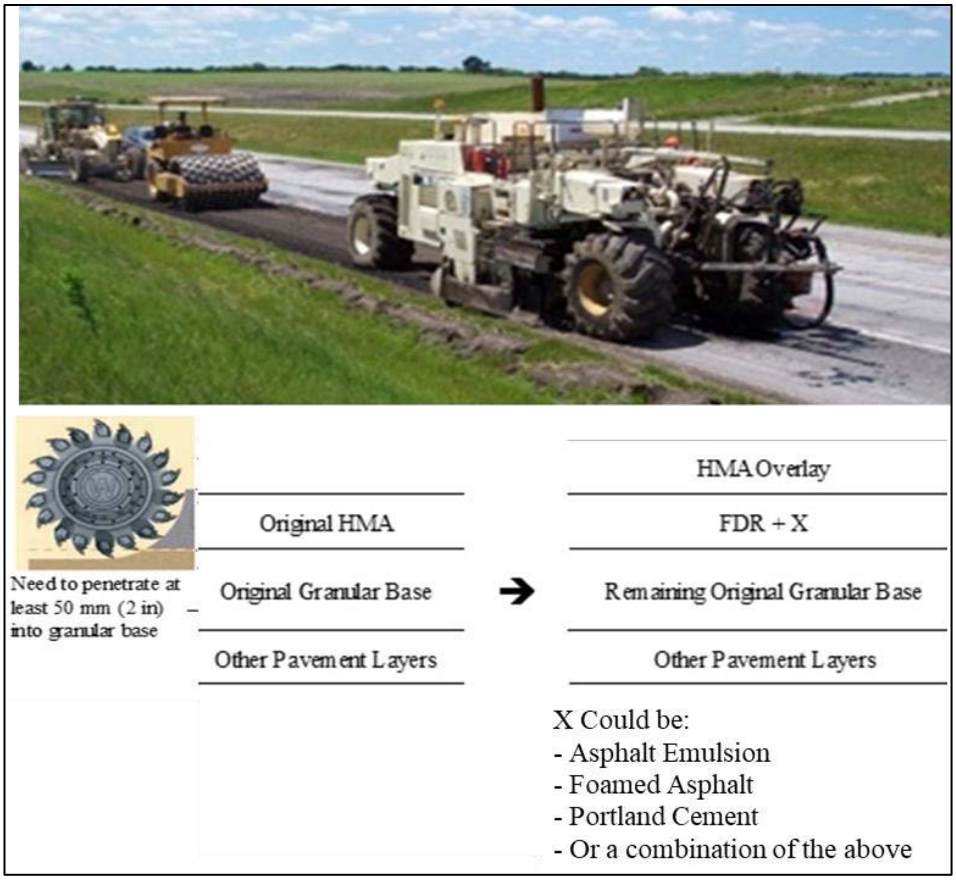

Figure 7. FDR construction process (Van Dam et al., 2015)

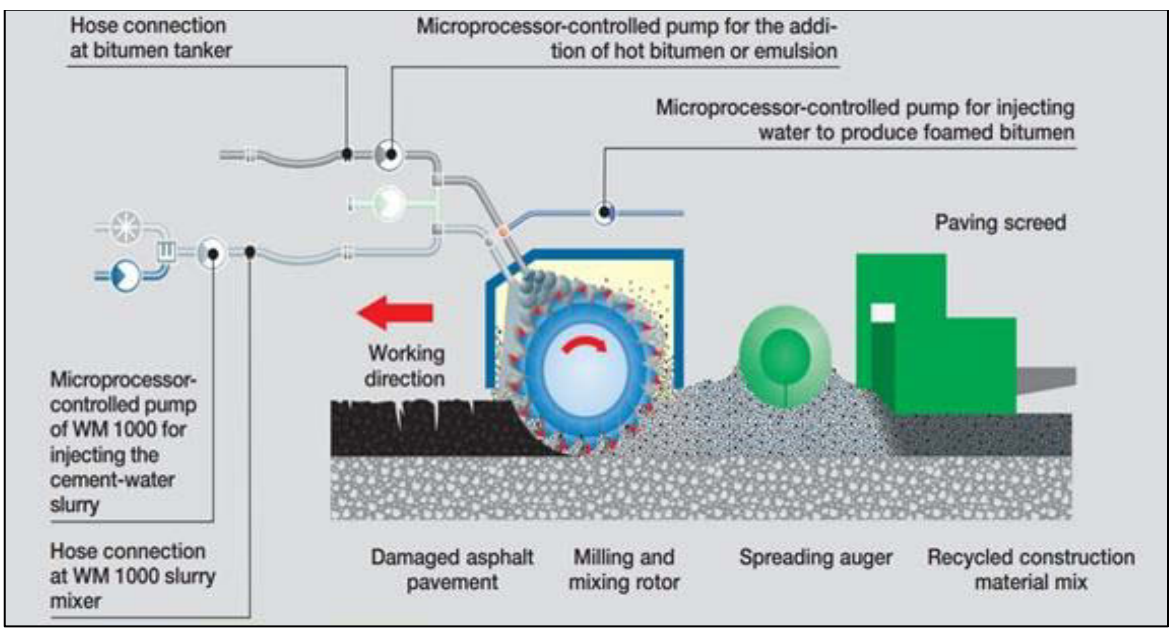

Figure 8. FDR equipment (Wirtgen, 2012).

LCA methods are used to quantify the energy and material consumption of the alternatives considered for this project following the Federal Highway Administration (FHWA) guidelines for conducting pavement LCA (Harvey et al., 2016). The following details show how the analysis will be conducted.

The goal of this LCA comparison study is to compare three end-of-life (EoL) alternatives for the South River Road project. The system boundary for the FDR options include the material production stage, transportation to the site, and construction activities. For the conventional alternative, mill-and-fill, the impacts of transportation of the materials at their EoL to the plant or landfill were also included in the system boundary. All the transportation distances were assumed as 50 miles. For the FDR cases, transportation of the overlay materials and additives were included.

The functional unit is defined as the 2-lane road between the two defined endpoints (West Sacramento city limit to the south of Freeport Bridge), which results in a 24-ft wide and 5.2-mi long pavement section. The analysis period is 25 years. It is assumed that all three alternatives will have the same service life of 10 years and the same treatment is applied at the end of the service life. It was also assumed that all alternatives show similar performance during the analysis period.

For the asphalt overlay, the following mix design was assumed for the hot mix asphalt (HMA): 80.3 percent virgin aggregate, 15 percent reclaimed asphalt pavement (RAP), and 4.7 total binder content (4 percent of which is virgin binder and 0.7 percent comes from the binder recovered from RAP).

For life cycle cost calculations, a typical 4 percent discount rate was assumed, and the cost of treatments were taken from Caltrans data taken from PaveM. The cost of mill-and-fill was assumed at $151,800/lane-miles, and for FDR with overlay, it was assumed $1,651,000/lane-mile.

The CCDB was used to compare the cost of construction among the alternatives (Caltrans 2017), as shown in Table 18, for items that exact matches were not available, proxy items from the cost data book were selected as shown in the table.

Table 18. Cost Items Taken from CCDB using 2017 values (Caltrans 2018)

CCDB Item	Item was used as a proxy for	Unit	Unit Price ($)
Replace asphalt concrete surfacing	Mill-and-Fill	CY	379.06
Asphalt-rubber binder	Foamed Asphalt	TON	458.57
Full-depth reclamation-cement	FDR Process	SQYD	8.25
Cement (full-depth reclamation-cement)	Portland Cement	TON	210.00
Hot mix asphalt (type a)	Overlay	TON	96.13

The life cycle inventories (LCIs) for each of the life cycle stages selected for this study were taken from the UCPRC LCI Database (Saboori et al., 2020).

3.5.3. Key Assumptions and Limitations

There are three main assumptions for this study:

- The three alternatives will perform similarly during the analysis period.
- The system boundary only includes cradle to laid (material production, transportation to site, and construction activities)
- At the end of service life for each alternative, the same treatment is repeated with the same service life and performance during the use stage.

However, depending on the conditions, a significant portion of the cost and environmental impacts of a pavement project may happen during the use stage, which is not included in the scope of study. In-place recycling techniques may save virgin materials and cost and impacts of hauling old materials off the site, but the performance of the sections built using FDRs are not fully understood as they are comparatively new compared to the conventional method of asphalt overlays. There can be multiple maintenance and rehabilitation (M&R) activities during the analysis period, and in case the performance of the alternatives are not the same, the whole initial differences in environmental impact and costs may get reversed due to more frequent M&R needed during the use stage.

Another issue to consider is the pavement roughness and how it will change with time and traffic loading after the initial construction. Pavement roughness directly impacts the fuel consumption in vehicles and if the performance of the EoL alternatives differs dramatically in terms of roughness changes with time, changes in vehicle fuel consumption can also result in significant changes in final results.

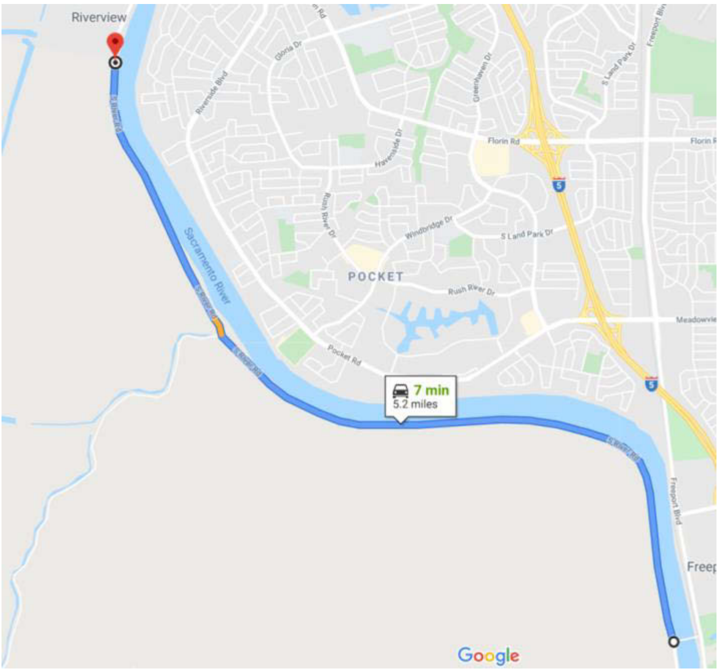

Figure 9. South River Road from West Sacramento City Limit to Freeport Bridge

Figure 10. Aerial Photo of the Intersection of the South River Road with the Freeport Bridge

3.5.4. Results

Table 19 shows results calculated in units of CO_2-equivalent (CO_2e) based on 100-year global warming potential (GWP), using FDR options will increase greenhouse gas (GHG) emissions compared to the conventional method of mill-and-fill. This is due to the high GWP intensity of regular portland cement considered in this study. Use of portland cement with supplementary cementitious materials, such as fly-ash or slag can dramatically reduce the GWP of portland cement depending on the amount of regular portland cement displaced.

Both FDR cases result in decreases in transportation impacts compared to mill-and-fill. Mill-and-fill requires significant tonnage of virgin materials while the FDR cases require significantly less, as evident in Table 19.Table 20 shows the construction costs for each case. The (FDR+PC) and (FDR+FA+PC) cost about 4.34 and 4.72 million dollars, respectively, significant reductions compared to mill-and-fill at 7.80. Table 21 shows the summary comparison of costs and GHG emissions across the three cases as percent changes. The mill-and-fill case is referred in this table as business-as-usual (BAU).

Table 19. Comparison of Environmental Impacts of the Alternative Cases in This Study

Case	Life Cycle Stage	GHG (kg CO_2e)
FDR, 0% Foamed Asphalt, 0.03% Portland Cement, 2.5 in Overlay Thickness	Materials	2.38E+6
	Transportation	1.57E+5
	Construction	2.28E+5
	Total	2.76E+6
FDR, 0.025% Foamed Asphalt, 0.01% Portland Cement, 2.5 Overlay Thickness (in)	Materials	2.11E+6
	Transportation	1.58E+5
	Construction	2.28E+5
	Total	2.50E+6
Mill & Fill, 0% Foamed Asphalt, 0% Portland Cement, 4 in Overlay Thickness	Materials	1.83E+6
	Transportation	4.74E+5
	Construction	1.42E+5
	Total	2.44E+6

Table 20. Comparison of Construction Costs

Case	Item	Unit	Amount	Cost (Million $)
FDR, 0% Foamed Asphalt, 0.03 Portland Cement (%), 2.5 in Overlay Thickness	Mill & Fill	CY	0	0.00
	Foamed Asphalt	TON	0	0.00
	FDR	SQYD	183,040	1.51
	Portland Cement	TON	1,560	0.33
	Asphalt Overlay	TON	26,004	2.50
	Total	**-**	**-**	**4.34**
FDR, 0.025% Foamed Asphalt, 0.01% Portland Cement, 2.5 in Overlay Thickness	Mill & Fill	CY	0	0.00
	Foamed Asphalt	TON	1,300	0.60
	FDR	SQYD	183,040	1.51
	Portland Cement	TON	520	0.11
	Asphalt Overlay	TON	26,004	2.50
	Total	**-**	**-**	**4.72**
Mill & Fill, 0% Foamed Asphalt, 0% Portland Cement, 4 in Overlay Thickness	Mill & Fill	CY	20,569	7.80
	Foamed Asphalt	TON	0	0.00
	FDR	SQYD	0	0.00
	Portland Cement	TON	0	0.00
	Asphalt Overlay	TON	0	0.00
	Total	**-**	**-**	**7.80**

Table 21. Changes in Cost and GHG Emissions versus the Mill-and-Fill Case (BAU)

Case	Cost (Million $)	Change vs BAU	% Change vs BAU	GHG (tonne CO_2)	Change vs BAU	% Change vs BAU
Mill-and-Fill (BAU)	7.80	0.00	0%	2.44E+3	0.00E+0	0%
FDR+PC	4.34	-3.46	-44%	2.76E+3	3.17E+2	13%
FDR+FA+PC	4.72	-3.08	-40%	2.50E+3	5.69E+1	2%

3.6. Summary of the Yolo County GHG abatement Strategies

The results of all the strategies evaluated for the Yolo County are summarized in Table 22. Figure 11 presents the abatement curve and highlights the life cycle agency cost-effectiveness and emissions reduction potential of key strategies. Strategy 3 (converting stop-starts to roundabouts) in the MACC is the most cost-effective strategy, resulting in net savings when agency and user costs are considered, followed by Strategy 1 (transitioning from PG&E to VCE) and Strategy 4 (solar canopies on parking lots). Strategies 3 and 1 are clear winners, with negative or zero cost, while Strategy 4 which has substantial initial costs, in fact leads to net profit (i.e., a negative abatement cost), when the value of generated electricity is considered. Notably, Strategy 2 (bike lanes connecting cities) and Strategy 5 (FDR options on the South River Road rehabilitation project) have been excluded from the figure because both strategies resulted in net generation of GHG emissions over their life cycle.

Table 22. Summary of the LCCA and LCA results for each strategy evaluated for Yolo County

Strategies	Life cycle agency cost	Life cycle user cost	Life cycle infrastructure GHG emission reduction	Life cycle user GHG emission reduction	GHG emission reduction	Life Cycle Agency Cost-effectiveness	Life Cycle Cost-effectiveness
	Million $		*tonnes*		*tonnes*	*$/tonne GHG reduction*	*$/tonne GHG reduction*
1. CCA	0	0	0	1,034,000	1,034,000	0	-
2. Bike Study	146	-0.470	-17,905	2,668	-15,237	9,582	9,551
3. Roundabout	-0.019	-11.430	0.476	96,987	96,988	-0.2	-118
4. Solar Carport	0.979	-1.75	-2,400	4,908	2,508	390	-307
5. FDR	-3.08	-	-60	-	-60	51,333	-

(-) negative means cost saving and net positive emissions

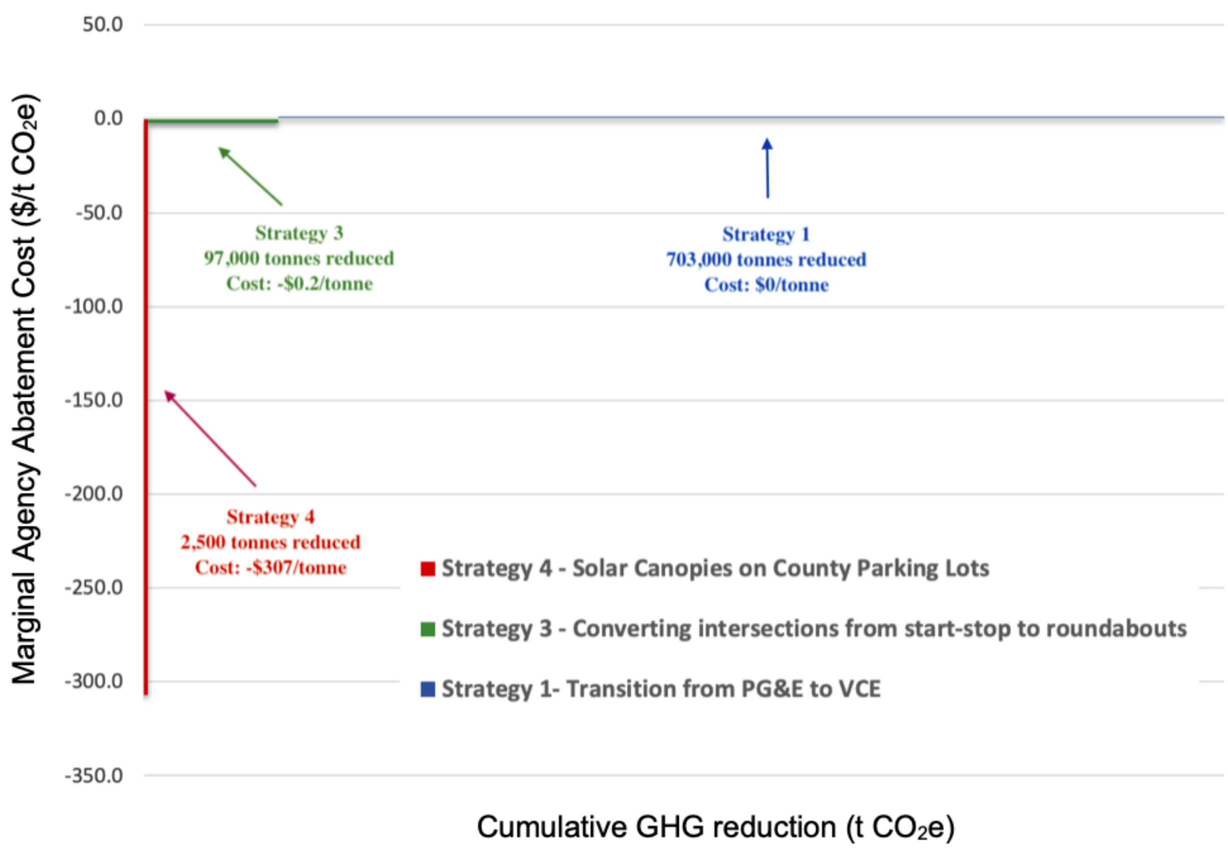

Figure 11. MACC or the Yolo County Strategies

4. Unincorporated Los Angeles County MACC Development

4.1. Electrifying the Foothill Transit Bus Fleet

4.1.1. Background

Foothill Transit has two bus yards, located in Pomona and Arcadia. This study examines the transition of completely electrified transit from a fleet that is currently fueled predominantly by compressed natural gas (CNG). Electric buses (E-Buses) generate fewer emissions during the use-phase, and this is the reason for the push to electrify fleets. This study aims to quantify not only the difference in emissions between electric and CNG buses during the use phase, but also during the production and maintenance phases. Further, these emissions values are paired with cost values to determine the cost-effectiveness of this strategy in reducing GHG emissions. Ultimately, the goal of this study is to compare the net changes in emissions and cost in transitioning to an electric fleet as compared to relying solely on CNG buses.

4.1.2. Methodology

This report builds on the findings of the In Depot Charging and Planning Study conducted by Burns & McDonnell Engineering Company, Inc. (B&M, 2019) for Foothill Transit. The consulting firm assessed Foothill Transit's fleet and infrastructure to determine the costs associated with a transition to a fully electric fleet. Relevantly, they consider the purchase of new E-buses and the associated charging infrastructure needs, maintenance of the vehicles, and the installation of solar PV to fulfill some of the increase in electricity demand. They also provide values for the expected electricity use (reported in kilowatt-hours, kWh) of the electric bus fleet. Overall, their study estimates that Foothill will reach an electric fleet size of 320 buses. The type, location, and specifications of the considered buses are presented in Table 23.

Table 23. A summary of the buses that are purchased in the B&M electrification model

	Battery Capacity (kWh)	Quantity in Pomona Yard	Quantity in Arcadia Yard	Cost
40-foot bus	540	130	160	$900,000
43-foot double-decker bus	864	0	30	$1,380,000

Reference LCIs track the material inputs and outputs of processes and are used to quantify the resulting net changes GHG emissions. The LCIs for electric and CNG buses were acquired from GREET. These LCIs accounted for the glider of both types of buses as well as the batteries of electric buses. The resulting emissions values were supplemented by LCI data from an economic input-out life cycle assessment (EIO-LCA) model (Weber et al. 2009) based on the methodology presented by Ercan et al. (2015). An EIO-LCA uses estimates of the total environmental impacts of a sector and then linearly relates these to the economic value of activities in the sector. Thus, the costs of an activity can be used to estimate the impacts of an activity. In this study, EIO-LCA was used to estimate engine repair emissions of CNG buses, represented by data for automotive repair and replacement for 2002 CNG buses. GREET and EIO-LCA values were used to determine the emissions generated during the production and maintenance phases of the vehicle gliders, powertrains, batteries for electric buses, and engines for CNG buses. As per the B&M report, it is assumed that E-Bus batteries need to be replaced every 6 years. CNG buses would need major overhauls or engine replacement after 6 years as well. GREET-derived values for batteries were used to determine emissions that result from battery replacement.

There were no studies on the production-phase emissions of the double-decker bus gliders. Therefore, emissions data for 60-foot buses was used instead. To justify this, buses produced by BYD, an E-bus company, were compared, since they produce both 45-foot double decker-buses and 60-foot single deck buses. The two designs have similar curb weights (47,000 and 50,100 pounds, respectively), and suggest that substituting production emissions of a 60-ft bus for a double-decker is reasonable (BYD 2019a, 2019b). BYD is not necessarily the provider of the buses in this study.

Chargers are installed annually as the electric fleet grows and are replaced every 12 years. Emissions for a 100W charger were determined in a study by Bi et al. (2018). Under the adoption model designed by B&M, the required charging stations are rated for 325W. Because most of the materials needed for a charger scale linearly with charging capacity (Bi et al. 2018), it is assumed that the produced emissions scale linearly as well.

B&M estimates the total annual electricity consumption given the number of E-buses in the fleet. They also distinguish between electricity generated on-site by installed solar PV and electricity that needs to be purchased from the local utility, in this case Southern California Edison. This study addresses this distinction in two steps. First, it accounts for the emissions associated with the production of the solar panels. The PV production emissions values were acquired from Hsu et al. (2012), which harmonized the GHG values from several studies. Second, it uses the emissions rate of the average California grid to estimate the emissions produced from the purchased electricity. These emissions values were based on the California fuel mixes reported in the U.S. Energy Information Administration's Annual Energy Outlook (2018), and supplemented by GREET values for this mixes to determine the life cycle emissions per kWh of electricity. These resulting LCIs were used to calculate the use-phase emissions of electric buses.

Use-phase emissions were also calculated for CNG buses. While the B&M report did not explicitly state the assumed annual mileage for the examined period, they provided the expected annual energy use of the electric buses. Using the average annual energy purchases for electric buses and an assumed average E-Bus fuel economy of 3 kWh per mile (derived from B&M reported fuel economies of 2.94 and 3.3 kWh per mile for single and double deck buses, respectively), it was estimated that the annual mileage was 19 million. The mileage for a given year was based on the relationship between the electric buses available that year and the average electric buses over the analysis period. The emissions generated by CNG buses were taken from the Mobile Source Emission Inventory (EMFAC) released by the California Air Resources Board (2017). The values used were reported in grams of CO_2e per mile driven for an urban transit bus traveling at an average speed of 20 miles per hour (mph).

4.1.3. Key Assumptions and Limitations

- Higher discount rate: The B&M study uses a 5 percent discount rate as compared to the 4 percent discount rate used for all other GHG mitigation strategies assessed in this study. Because of how data and results were reported in the referenced study, it was not possible to recalculate using a 4 percent discount rate. This means that in the life cycle cost assessment, future costs are slightly smaller in present day value than they would be under a 4 percent assessment. In other words, the reported cost could underestimate the true cost, at least compared to the other studies in this project.
- Use-phase emissions for CNG buses: EMFAC emissions rates are reported by average bus speed, where the emissions produced and average bus speed are inversely related. In a 2019 progress report, Foothill reported that the average CNG bus speed for the latter half of 2018 was 17.6 mph (Eudy 2019). This means that the true emissions rate of CNG buses could be higher than the EMFAC value used in this study, since buses may travel slower than 20 mph on average.
- Effects on afternoon ramp loads were not incorporated. See S4.4.3.
- Time-of-day pricing was not incorporated. See S4.4.3.
- Change in price of electricity over time was not incorporated. See S4.4.3.

4.1.4. Results

The net emissions reduction achieved by Foothill Transit's transition from CNG buses to E-Buses is 664,000 tonnes CO_2e over 25 years, based on GWP_{100}, or 582,000 tonnes CO_2e based on $TAWP_{100}$. As reported by B&M, the difference in costs between the two scenarios assuming no subsidies is just over $217 million. However, there are currently three relevant subsidies available: the Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project (HVIP), the SCE 50% charger rebate program, and California Low Carbon Fuel Standard (LCFS) credits. If these subsidies continue over the 25-year analysis period, the increase in costs of E-Buses compared to CNG buses would be $88.6 million. The cost assuming no subsidies is $327 per tonne reduction CO_2e (GWP_{100}). If subsidies are applied, the cost is $133 per tonne reduction CO_2e (GWP_{100}).

However, 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 under Unincorporated LA County. Those numbers were 1,935 and 260, respectively, as shown in Figure 12. 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, accounting for the number of routes that stop at each bus stop would decrease this proportion to nearly 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. Thus, the net emissions reduction that can be claimed is between 66,000 and 89,000 tonnes CO_2e over 25 years, with a midpoint value of 78,000 tonnes CO_2e. The range in additional costs is \$21 to \$29 million (midpoint of \$25 million), with a subsidized additional cost of \$8.9 to \$11.9 million (midpoint of \$10.4 million). The cost of GHG abatement remains unchanged after scaling, since a linear relationship is assumed.

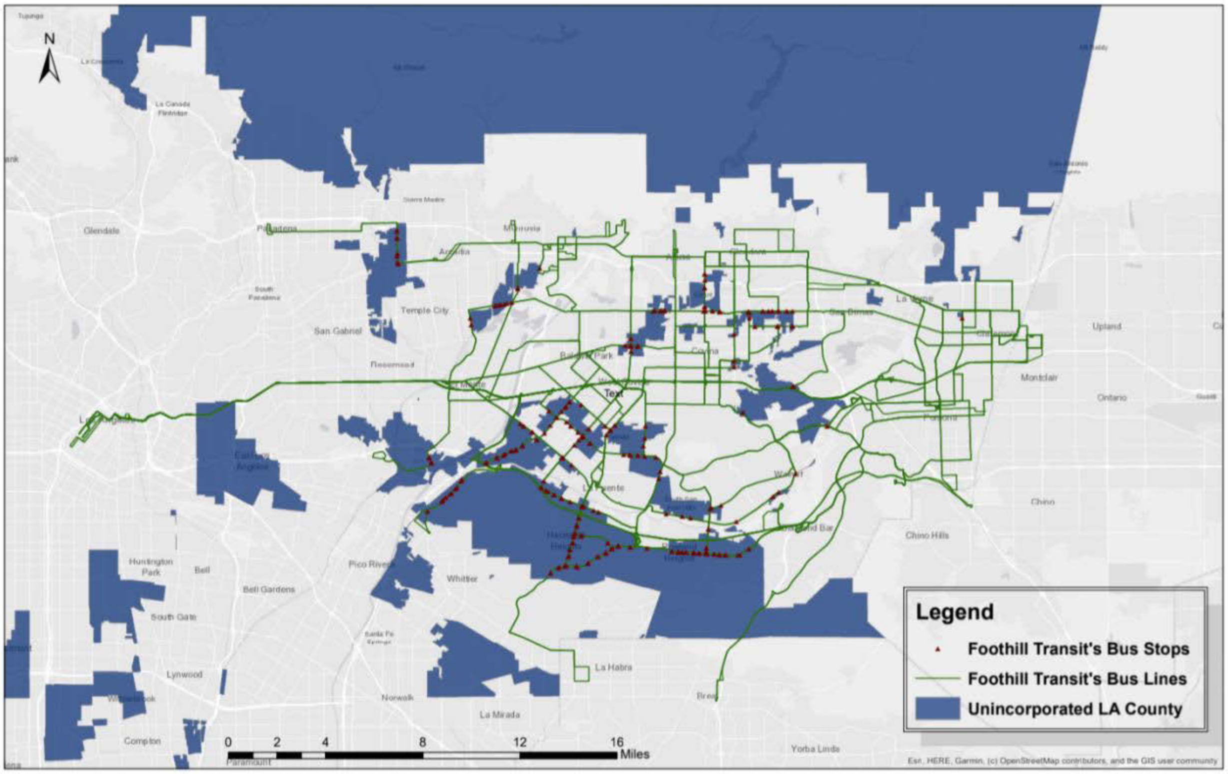

Figure 12. Foothill Transit Bus Stops in Unincorporated LA County (personal communication Transit Planner Lourdes Alvarez at Foothill Transit, 14 January 2020)

4.2. Alternative Fuel Vehicles for the LA County fleet

4.2.1. Background

One potential mechanism to reduce LA County's GHG emissions is the use of alternative fuel vehicles (AFVs) for their fleet. This scenario compares the emissions from the current fleet with those from conversion, where feasible, to vehicles using electricity and biodiesel. The goal of this case study is to examine different pathways for adoption of AFVs in the LA County fleet and calculate the net life cycle GHG emissions and economic costs.

4.2.2. Methodology

The study scope covers the environmental impacts and cost implications of the complete life cycle of all the vehicles in the LA County fleet. Vehicle emissions and costs are divided into two categories:

- Vehicle cycle emissions:
    - vehicle production stage: which includes all the processes from raw material extraction to delivery of the vehicle to end user,
    - vehicle EoL: the vehicle is either recycled, landfilled, or transferred to a third party for which salvage value is assigned.

- Use stage emissions:
    - fuel cycle emissions and costs including:
    - all the upstream impacts of fuel production (well-to-pump), and
    - fuel consumption in the vehicle (pump-to-wheel),
    - maintenance and repairs

Data on the current LA County fleet were provided by The Internal Services Department (ISD) of LA County.[2] The data included the model year, make, fuel type, lifetime accrued miles, fiscal year (FY) 2018-2019 miles, fuel dispensed, fuel economy (if known), FY 2018-2019 maintenance and repair costs, and department of use. Based on this data gross vehicle curb weight was estimated.

4.2.3. Key Assumptions and Limitations

The model developed for this study was run under three different scenarios for the replacement schedule of fleet vehicles, all with an analysis period of 25 years (2019-2044):

- Business as Usual (BAU) Assuming no changes in the fleet composition (vehicle type and fuel combination) through the end of the analysis period
- Gradual Transition: Assuming vehicles are replaced with AFVs at the end of their service life. The service life is determined according to the Department of General Services (DGS) policy for vehicle replacement based on age and mileage, as shown in Table 24 and conversion to AFVs are done according to Table 25.
- All-at-Once: changing all vehicles to AFVs in the year 2019.

The model uses actual annual vehicle miles travelled (AVMT) based on data provided by ISD.

The salvage value for vehicles in service at the end of the analysis period for both vehicle costs and vehicle cycle GHG emissions were calculated based on remaining useful life of each vehicle (explained in detail in subsequent sections in this report).

A discount rate of 4 percent was considered for life cycle cost calculations.

[2] Data were provided November 27, 2019 by Randy Martin <RMartin@isd.lacounty.gov>

Table 24. DGS Policy for Changing of the Fleet Vehicles

Vehicle Type	Change Age (years)	Change Mileage
Auto-Subcompact	6.0	65,000
Auto-Compact	6.0	65,000
Auto-Midsize	6.0	65,000
Auto-Full-size	6.0	65,000
SUV-LD	7.0	85,000
Pickup-LD	5.0	65,000
Pickup-MD	6.0	70,000
Van-LD	8.0	80,000
Van-MD	5.0	65,000
Truck-LD	6.0	70,000
Truck-MD	11.0	115,000
Truck-HD	11.0	115,000

LD: Light Duty
MD: Medium Duty
HD: Heavy Duty

Table 25. AFV substitutes chosen for various vehicle types in LA County fleet

Vehicle Type	AFV Substitute 1
Auto-Sub	ELEC
Auto-Comp	ELEC
Auto-Mid	ELEC
Auto-Full	ELEC
SUV-LD	ELEC
Pickup-LD	ELEC
Pickup-MD	DSL-R100
Van-LD	E85
Van-MD	E85
Truck-LD	E85
Truck-MD	DSL-R100
Truck-HD	DSL-R100

Elec: Electricity
E85: High-Level Ethanol-Gasoline Blends (up to 85%)
DSL-R100: 100% Renewable Diesel

4.2.3.1. Vehicle Fuel Efficiency

Historical data for vehicle fuel efficiency were collected from the Environmental Protection Agency (2019) and Energy Information Administration (EIA) (2019a). These data were used to estimate the fuel consumption based on AVMT assigned to each vehicle currently in the LA County fleet. The future projected vehicle fuel efficiency data were taken from the EIA, as they provided more granular data for fuel efficiency projections based on vehicle type and fuel combinations. The collected data is available in the data management document for this project.

4.2.3.2. Fuel Costs

Historical prices for alternative fuels were collected from the Alternative Fuels Data Center (2019). The prices are expressed in units of dollars per gasoline gallon equivalent (GGE). The data in this section will be later combined with vehicle fuel efficiency values in miles per gallon (MPG) to calculate the cost of one mile traveled for each vehicle-fuel combination. Liquid petroleum gas (LPG), B100 (100 percent biodiesel), and E85 (ethanol blended with gasoline at 85 percent) have been consistently the most expensive fuels among all alternative fuels since 2013 while electricity has been the least expensive.

The Alternative Fuels Data Center reported that they decided not to report the price of diesel from renewable sources (RD100 which is 100 percent renewable diesel) due to lack of a reliable data source, even though RD100 has been available in the California market for several years. Because the literature survey and internet research did not yield much reliable cost data for RD100, it was represented by prices for B100. This might underestimate the cost of RD100 given the competitive market for it.

Projections of future fuel prices were also taken from the EIA. EIA only provides price projections for regular diesel; therefore, historical data were used to calculate the price ratio of B100 and B20 (biodiesel blended with petroleum diesel at 20%) over regular diesel in the past three years. The calculated price ratios were then applied to EIA's projections of regular diesel prices to obtain price projections for B20, B100, and RD100. The results showed that on average B20 was priced at 95 percent of regular diesel since 2016 in the U.S. market while B100 was about 39 percent more expensive. The RD100 price was assumed to be the same as B100 diesel due to lack of better data, as explained in the previous section.

Historical data were collected to account for differences in energy prices in California versus national averages, and correction factors were applied for the price of gasoline, diesel, electricity, and natural gas.

4.2.3.3. Vehicle Costs

The DGS website for reporting years 2011-14 provided historical data on vehicle purchase prices for all state agencies. Data were selected from DB2011-14 data from reporting year 2014 for vehicles purchased after 2004. The selected data were used to conduct linear regression and develop equations for vehicle price versus age for each of the vehicle types in the model. Price projections for every vehicle fuel combination used in this study were obtained from EIA (Energy Information Administration 2018).

4.2.3.4. Salvage Value

Regardless of the vehicle replacement schedule, there is salvage value in vehicles that are traded before the end of their useful service life. This salvage value needs to be accounted for, both in terms of monetary value and the environmental impact from the vehicle cycle. This section explains the calculation methodology used for estimating vehicle salvage values in the model. There are two possible approaches for considering salvage value in the analysis. One approach is using historical data available through DB2011-14 and the other approach is to use industry-wide accepted rates of vehicle depreciation with time.

4.2.3.5. Vehicle Production Impacts (Vehicle Cycle Impacts)

Vehicle cycle impacts include all the energy consumption and emissions due to vehicle production from raw material extraction all the way to delivery of the new vehicle to the end user. Furthermore, the processes at the end of the vehicle service life (either being dumped in a landfill or transported and recycled in a facility) should be included in this cycle. The other items that are included in the vehicle life cycle are fluids, batteries, and tires used during the vehicle life cycle. Almost all the data used for vehicle cycle impacts in this study were collected from the GREET model (Argonne 2018), unless stated otherwise.

The vehicle cycle impacts are reported in four main categories: 1) components, 2) assembly, disposal, and recycling (ADR), 3) batteries, and 4) fluids. The components category consists of the following items: body, powertrain, transmission, chassis, traction motor, generator, electronic controller, and hydrogen storage.

To account for changes in vehicle weights during the 25-year analysis period of this study, weight projections by vehicle type were taken from EIA (Energy Information Administration, 2018). However, there were two challenges to address: a) EIA does not provide weight projections for different fuel technologies and only has data based on vehicle type. b) Vehicle cycle GHG emissions of trucks were not available in any major sources.

4.2.3.6. Fuel Use Impacts (Well-to-Wheel (WTW) Impacts)

Fuel use impacts are typically conceived of as pre-combustion and combustion impacts and are categorized in the following way:

- Fuel production stage impacts capture the energy consumption and environmental impacts of all the upstream processes conducted for producing the fuel and making it available at the pump, called well-to-pump (WTP) impacts. The terminology was coined based on conventional petroleum-based fuels which originate from crude oil extracted from wells, but is used to refer to the entire fuel cycle for electricity and biofuels as well.
- Fuel combustion in vehicles refers to the emissions from fuel combustion during by vehicles in the use stage. This stage is referred to as pump-to-wheel (PTW).
- The collective impacts of WTP and PTW are referred to as well-to-wheel (WTW) impacts. WTW impacts are expressed in grams of CO_2e per mile of travel.

The LCIs used to characterize fuel use impacts were taken from the GREET WTW Calculator too (Argonne National Laboratory 2018). The fuels considered include 2018 California electricity, along with biofuel pathways (ethanol and biodiesel pathways at different blend levels with gasoline and diesel, respectively) available in GREET 1.

4.2.3.7. Study Gaps and Limitations

The analysis presented in this report has the following limitations and gaps that need to be evaluated in future stages of this research:

- The study does not include the cost and environmental impacts of building and maintaining fueling infrastructure.
- California is aggressively moving towards decarbonization of the electricity sector with measures such the Renewable Portfolio Standard outlined in Senate Bill 100 (California Senate 2018) which mandates 60 percent renewable electricity in California grid mix by 2030 and 100 percent clean energy by 2045. Therefore, one fuel pathway which is expected to have major reductions in WTP impacts is electricity. However, these expected reductions in WTP are not implemented in this study, mainly due to the limited time and thus scope of this initial study. However, more than 80 percent of the state fleet consists of medium-duty pickups and trucks for which an EV option is not currently available. Thus, the potential effect of omitting this change is not particularly significant; electricity cannot play a large role in meeting AFV goals.

4.2.4. Results

The results of the case studies are shown in Table 26 to Table 28 and Figure 13 to Figure 15. Figure 13 compares LCC across all four cases, Figure 14 focuses on GHG emissions at various stages of the vehicle and fuel cycles, and Figure 15 compares the fuel consumption with time for each of the cases.

The data in Table 26 shows that the total LCC of the BAU case, without considering the registration fees and insurance cots, has a net present value (NPV) of $738 million compared to $911 and $914 million for Gradual and All-at-Once respectively which is equivalent to 23 and 24 percent increases versus BAU for the two cases.

Looking at the GHG emissions data in Table 27, total GHG emissions during the analysis period of 2019 to 2044 reached close to 0.736 million metric tonnes of CO2e for the BAU case while the results for the Gradual and All-at-Once were approximately 0.619 and 0.618 million metric tonnes. These numbers show savings 16 percent in total GHG emissions versus BAU for both cases. The BAU Scenario results show that consequences of inaction in the adopting AFVs by LA County and maintaining the current mix of vehicle technology and fuel.

The total fuel consumption by fuel type for each case is presented in Table 28. Transition to AFVs can result in more than 1.6 million gallon-equivalent of fuels compared to BAU when a gradual approach to replacement is taken, which equals an 8.6 percent decrease in total fuel consumption during the analysis period.

The negative well-to-pump values over the analysis period shown in Table 27 are because of the use of AFVs. These values include the emissions from the production of electricity used in California, as well as the liquid fuels. The increasing use of bio-based diesel results in net carbon sequestration for WTP. Table 29 shows the breakdown of GHG emissions for cases with negative GWP values for WTP. The fuel in these cases are either E85 from corn or 100 percent renewable diesel from forest-residue and the negative GWP for WTP is only due to the fuel feedstock across all cases, after inclusion of processing and transportation to the pump. The values for fuel cycle presented in this table are taken directly from the 2018 Excel based model GREET 1 (rather than the WTW calculator), to permit further exploration of the fuel cycle emissions. For the specific case of renewable diesel from forest-residue, the GREET pathway seems to have largely been based on Jones et al. (2013). The background, assumptions, and calculations methods used to calculate the fuel cycle impacts of all different vehicle fuel combinations provided in GREET and used in this study are available in Cai et. al (2017), Elgowainy et al. (2016), Cai et al. (2015), and Elgowainy et al. (2010).

Table 26. Comparison of life cycle cost (in million dollars) across cases

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**

* without registration and insurance

Table 27. Comparison of total GHG emissions between 2019 and 2044 (Tonnes of CO_{2e}) and cost of GHG abatement (dollar per Tonne of CO_{2e} abated)

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 28. Comparison of total vehicle on-board liquid fuel consumption (in 1000 of gasoline or diesel gallon equivalent [GGE or DGE]) between 2019-2044)

Fuel Type	BAU	Gradual	All at Once
CNG	117	12	12
DSL	435	60	51
DSL-B20	0	0	0
DSL-R100	0	6,648	6,693
DSL-HPR	0	0	0
E85	1	5,810	5,931
ELEC	11	2,468	2,484
GAS	16,799	1,988	1,788
HEV	1,134	119	95
HYD	0	0	0
LPG	0	0	0
PHEV	245	21	20
Total	**18,744**	**17,126**	**17,074**

Table 29. Breakdown of GHG emissions for cases with negative WTP

Fuel	Fuel Full Title in GREET	Fuel + Vehicle Combinations in GREET Excel Model-1	Feed-stock (g CO_2 / mile)	Fuel (g CO_2 / mile)	WTP (g CO_2 / mile)	PTW (g CO_2 / mile)	WTW (g CO_2 / mile)
DSL-R100	Forest Residue-based RDII 100	CIDI Heavy Heavy-Duty Vocational Vehicles: Forest Residue-based RDII 100	-1,263	410	-853	1,343	490
DSL-R100	Forest Residue-based RDII 100	CIDI Medium Heavy-Duty Vocational Vehicles: Forest Residue-based RDII 100	-1,126	365	-761	1,198	437
DSL-R100	Forest Residue-based RDII 100	CIDI Light Heavy-Duty Vocational Vehicles: Forest Residue-based RDII 100	-925	300	-625	985	360
E85	E85, Corn	SI Light Heavy-Duty Vocational Vehicles: E85, Corn	-563	443	-119	1,140	1,021
E85	E85, Corn	SI Medium Heavy-Duty Vocational Vehicles: E85, Corn	-475	375	-101	964	863
DSL-R100	Forest Residue-based RDII 100	CIDI Heavy-Duty Pick-Up Trucks and Vans: Forest Residue-based RDII 100	-449	146	-304	480	177
E85	E85, Corn	SI Heavy-Duty Pick-Up Trucks and Vans: E85, Corn	-235	185	-50	479	429

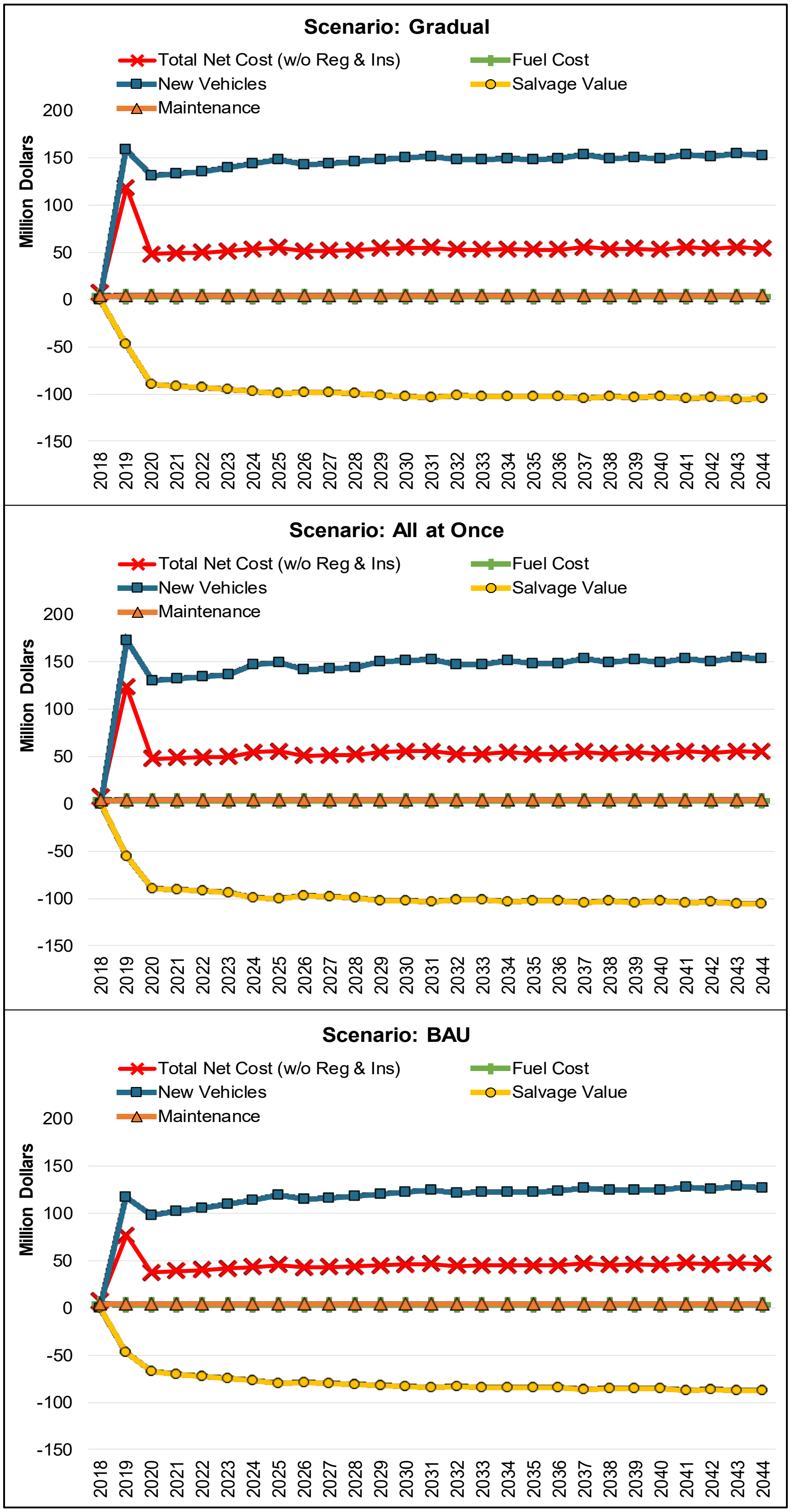

Figure 13. Comparison of life cycle cash flow across three scenarios

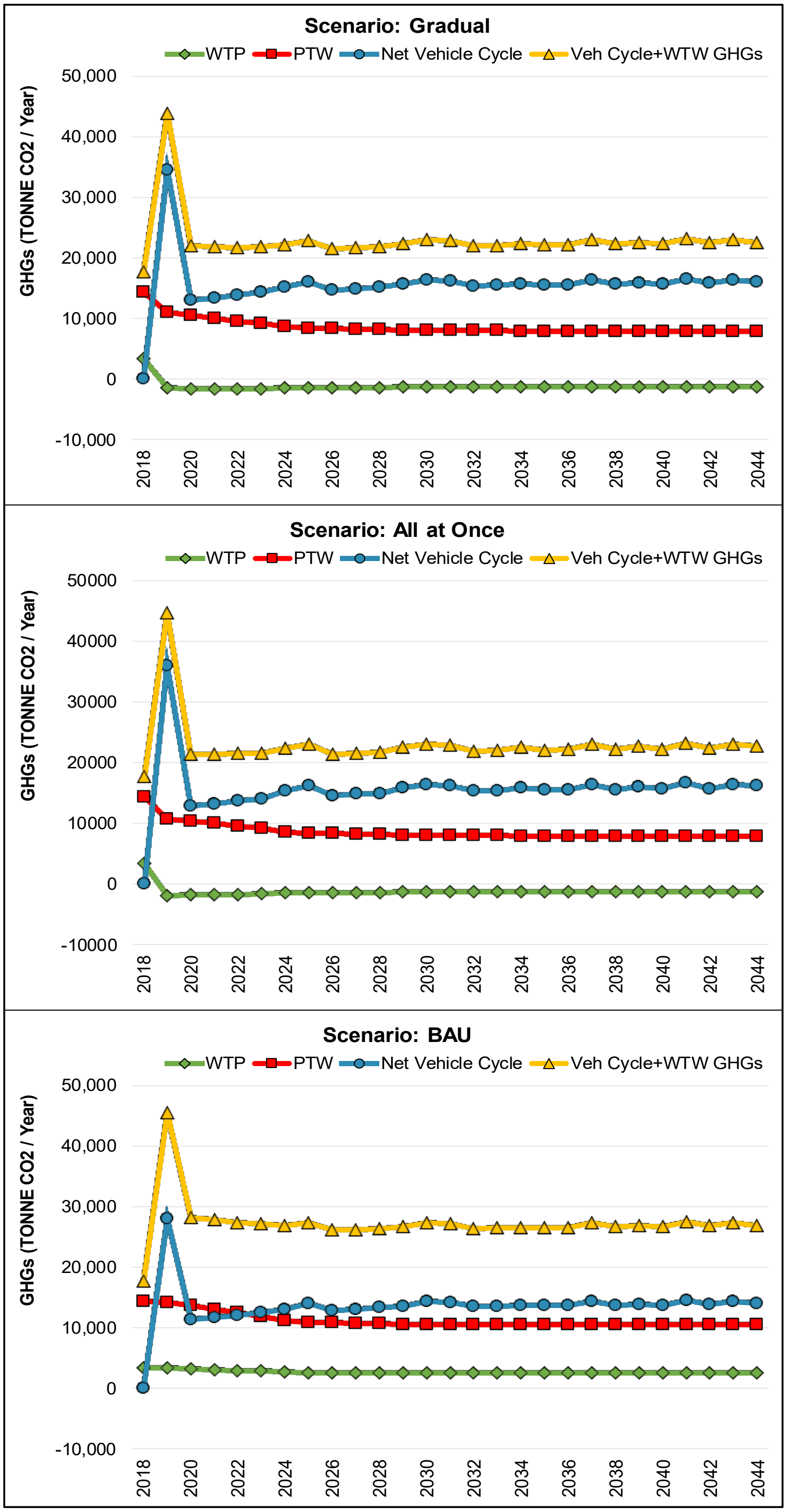

Figure 14. Comparison of GHG emissions across three scenarios: total GHG emissions, vehicle cycle emissions, and emissions due to various fuel life cycle stages (WTP, PTW, and WTW)

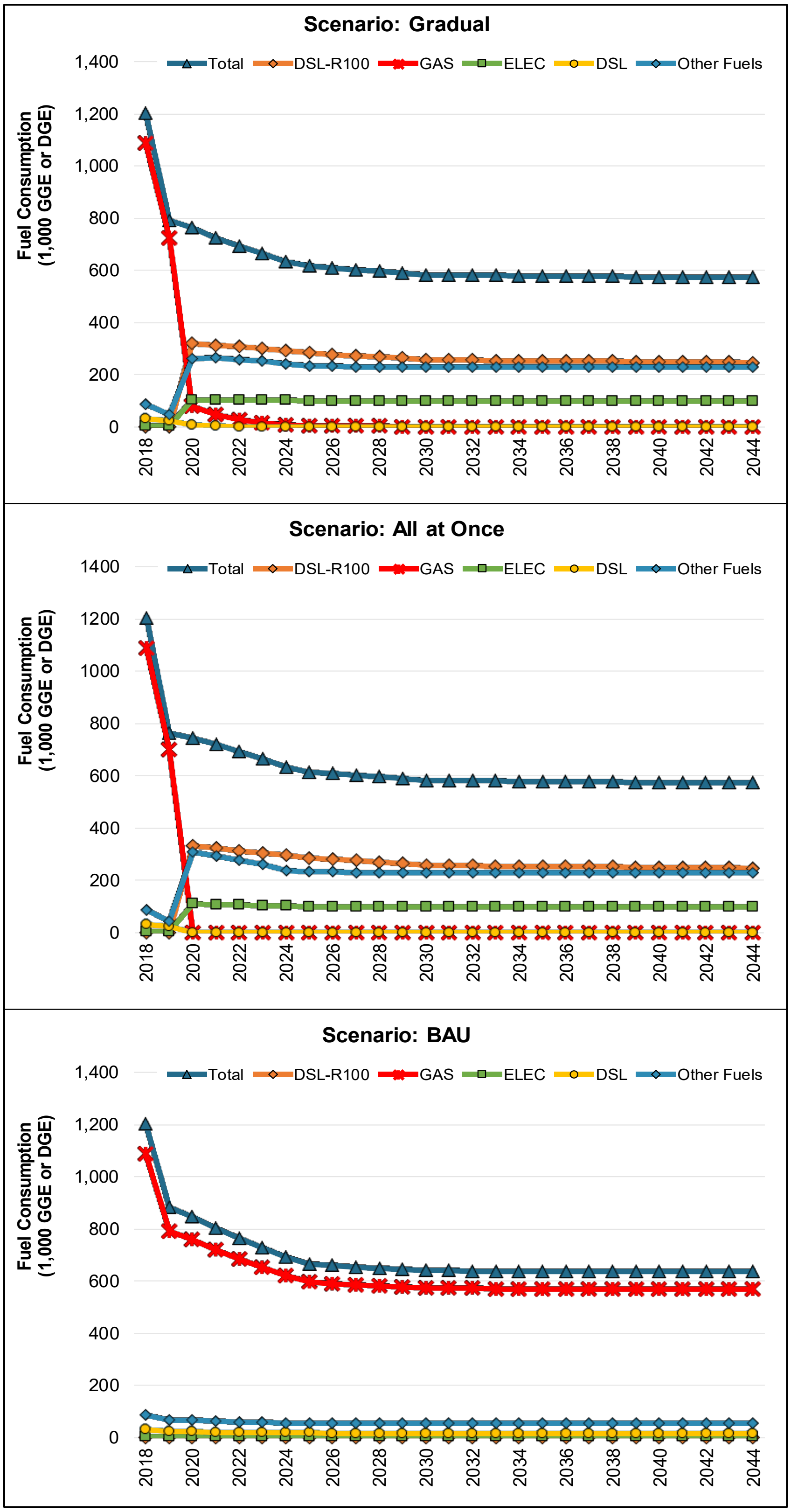

Figure 15. Comparison of fuel consumption across three scenarios

4.3 Summary of the LA County GHG abatement Strategies

The MACC for unincorporated LA County can be seen in Figure 16. This figure highlights the life cycle agency cost-effectiveness and emissions reduction potential of the only two considered strategies. Both the strategies showed GHG reduction potential; however, the abatement comes with some additional costs to the agency: the agency cost-effectiveness to bring down 1 tonne of GHG emission for Strategy 1 (Foothill bus fleet electrification) was less compared to the Strategy 2 (alternative fuel vehicles for county fleet), indicating that bus electrification may be prioritized over conversion of the county fleet. However, in both cases, the cost of GHG mitigation is high relative to other measures of mitigation cost. For example, in California's Cap-and-Trade program, carbon allowance prices (the price to emit one tonne of CO_2e) from 2018 through the close of 2019 has never exceeded $19/tonne CO_2e (California Air Resources Board 2020).

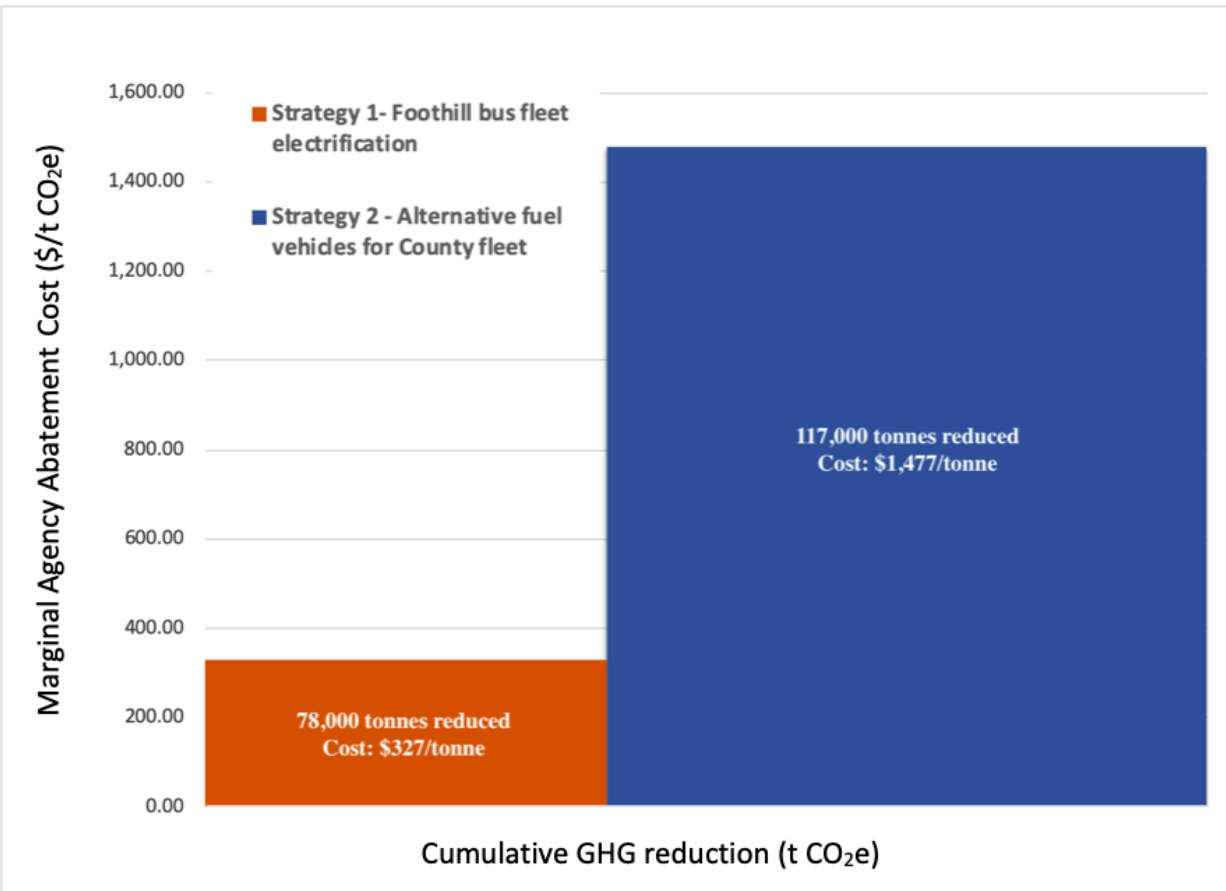

Figure 16. MACC for the LA county Strategies

5. Conclusions

The MACC approach shown in this report for Yolo and LA counties demonstrates the ability to quantify GHG reductions for full-scale implementation of considered strategies and prioritize them based on their cost-effectiveness. In addition, during the quantification process, a number of strategies considered for Yolo County, such as bike lanes, showed increased emissions relative to BAU, indicating that they did not abate emissions at all. However, these conclusions, and others, should be interpreted with care. 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. In addition, the benefits of 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. 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.

There are a number of challenges and opportunities that emerged through the research and review process for this report.

Challenges:

- The two case studies illustrated the challenge of data collection from the multiple divisions and agencies required to complete a MACC. Implementation of this MACC for local governments will require engagement by multiple divisions and agencies.
- 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 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.
- 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 GHG inventories. These inventories are not life cycle based (nor consumption-based) GHG estimations and thus the MACC estimates don’t translate directly to the annual inventories. Thus, the decision-making basis—the MACC—is not directly related to how emissions are report.

Other co-benefits not considered, but potentially of great importance, are co-benefits for air quality. For example, while E-buses may not immediately stand out as highly cost-effective measures, mitigation of air quality emissions through electrification may have significant benefits to air quality and 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 presents an opportunity for further enhancing the scope of environmental benefits considered in prioritization of GHG mitigation strategies at the local scale. Additionally, this study did not consider the distribution of the costs and benefits of implementation across communities. Environmental justice concerns should be considered in the decision-making process along with costs and other impacts.

Future research should pursue solutions to these identified 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 with respect to identifying and quantifying CAP strategies.

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Data Management

Data management activities include the redundant backing up of relevant data and research on two cloud-computing services, Google Drive and Box, and backing up of Box on Crashplan, as described in our proposed data management plan. The research team is archiving the relevant data used for evaluating the strategies with appropriate descriptions and metadata in the UC Davis Library system’s data repository called the Dryad. Previously, DASH was the data archiving system used but now the open source Dryad is the current data archiving system being used. Datasets published in Dryad can be cited in other publications and can be versioned at any time.

Products of Research

This research included the development of case studies for marginal greenhouse gas (GHG) abatement curves for two California counties, Yolo and Los Angeles, each with a number of strategies quantified. In general, each strategy needed to have a business as usual (BaU) condition identified, and then costs and emissions reductions quantified for any implemented strategy.

Los Angeles County

Strategy 1: Electrifying the Foothill Transit Bus Fleet

- Electric and conventional (e.g., diesel hybrid and natural gas) bus costs
- Bus and battery production GHG emissions
- GHG emissions for bus life cycle, charging station production, and solar panel production

Strategy 2: Implementation of alternative fuel vehicles for LA County Fleet:

- Data collection from the county’s Internal Services Department on the current fleet (vehicle type, age, fuel type, etc.);
- Historical data on miles per gallon (mpg) of different vehicle categories and model years; projections of mpg for different categories between 2020 and 2050;
- Projected fuel prices
- The cost of maintenance and repairs for each vehicle category and fuel type combination
- Vehicle and fuel cycle GHG emissions

Yolo County

Strategy 1: Transition to Community Choice Aggregation for Yolo County

- PG&E and Valley Clean Energy (VCA) current electricity fuel mix
- GHG intensity of each fuel pathway

Strategy 2: Yolo county bike lanes connecting cities

- Yolo county bicycle plan to identify bike lanes
- Road daily travel (to estimate possible displacement of vehicle miles)
- Life cycle GHG data on bike infrastructure construction and repair

Strategy 3: Converting Intersection configurations from start-stop to roundabouts

- Collection of construction cost and material and equipment use for intersection conversion, similar to strategy 1
- Estimation of fuel use change by on-road vehicles due to the intersection conversion

Strategy 4: Solar Canopies on county parking lots

- Total parking lot area owned by county and feasibly installed
- GHG emissions for solar panels and canopy structure (including selection of a canopy design)

Strategy 5: Full-depth reclamation versus conventional pavement rehabilitation methods

- The unit prices for all pavement treatments
- The geometric dimensions of the project (length and width)
- The GHG emissions of materials and construction operations

Data Format and Content

All data and calculations are provided in Excel (.xlsx) files. The following is a list of all the files and the strategy they correspond to:

Los Angeles County

Strategy 1: Electrifying the Foothill Transit Bus Fleet

- Bus and battery production data is presented in Excel file "BusProductionLCI.xlsx".
- Total emissions data is compiled and processed in Excel file "Foothill_Electrification.xlsx".

Strategy 2: Implementation of alternative fuel vehicles for LA County Fleet:

- This study consists of 4 Excel files, 3 main Excel files for each of the scenarios, and one file summarizing the results of all the scenarios to develop comparison charts and tables. These files are titled as:
    - The summary file: "AFV for LA Fleet, Summary.xlsx"
    - The model file for the first scenario: "1_AFV for LA, BAU.xlsx"
    - The model file for the second scenario: "2_AFV for LA, All at Once.xlsx"
    - The model file for the third scenario: "3_AFV for LA, Gradual Transition.xlsx"

Yolo County

Strategy 1: Transition to Community Choice Aggregation for Yolo County

- All the data used for analyzing this strategy and the resulting output can be found in Excel file "PG&E_to_VCE.xlsx".

Strategy 2: Yolo county bike lanes connecting cities

- All the data used for analyzing this strategy and the resulting output of the analyses are listed below and could be found in Excel file "2019_Bike_Study.xlsx".

Strategy 3: Converting Intersection configurations from start-stop to roundabouts

- All the data used for analyzing this strategy and the resulting output of the analyses are listed below and could be found in Excel file "2019_Intersections_Study.xlsx".

Strategy 4: Solar Canopies on county parking lots

- All the data used for analyzing this strategy and the resulting output can be found in Excel file "Yolo_Solar_Canopy.xlsx".

Strategy 5: Full-depth reclamation versus conventional pavement rehabilitation methods

- All the data, assumptions, and modeling approaches are available in Excel file titled "FDR_Local Govs.xlsx".

Data Access and Sharing

These data are available for download on Dryad (https://datadryad.org/stash) at the following DOI: https://doi.org/10.25338/B84615

Reuse and Redistribution

These data are all published using the Creative Commons – CC0 1.0 Universal license. Thus, the only requirement for Reuse and Redistribution is attribution and may be cited as:

Kendall, A., Harvey, J.T., Butt, A.A., Lozano, M.T., Saboori, A. and Kim, C. (2020) Greenhouse Gas Reduction Opportunities for Local Governments: A Quantification and Prioritization Framework. UC Davis, Dataset, https://doi.org/10.25338/B84615.

Appendix 1. A Closer Look at CAPs

Table A.1. List of Reviewed CAPs

#	City/Local Government	Year of CAP	Caltrans District	Source
1	Benicia	2009	4	http://www.sustainablebenicia.org/files/cap/Transportationandlanduse.pdf
2	Berkeley	2009	4	https://www.cityofberkeley.info/uploadedFiles/Planning_and_Development/Level_3_-_Energy_and_Sustainable_Development/Berkeley%20Climate%20Action%20Plan.pdf
3	Chula Vista	2017	11	https://www.chulavistaca.gov/home/showdocument?id=15586
4	Cupertino	2015	4	https://www.cupertino.org/our-city/departments/environment-sustainability/climate-action
5	Emeryville	2016	4	https://www.ci.emeryville.ca.us/DocumentCenter/View/9328/Emeryville-CAP-2016-Implementation-Plan?bidId=
6	Fremont	2012	4	https://fremont.gov/DocumentCenter/View/19837/Climate-Action-Plan
7	Hayward	2009	4	https://www.hayward-ca.gov/services/city-services/climate-action
8	Humboldt	2012	1	https://humboldtgov.org/DocumentCenter/View/1347/Draft-Climate-Action-Plan-PDF?bidId=
9	Lakewood	2015	7	http://www.lakewood.org/SustainabilityPlan/
10	Lancaster	2016	7	https://www.cityoflancasterca.org/Home/ShowDocument?id=32356
11	Los Angeles	2015	7	http://planning.lacounty.gov/assets/upl/project/ccap_final-august2015.pdf
12	Manhattan Beach	2010	7	https://www.citymb.info/home/showdocument?id=16913

#	City/Local Government	Year of CAP	Caltrans District	Source
13	Marin County	2015	4	https://www.marincounty.org/~/media/files/departments/cd/planning/sustainability/climate-and-adaptation/chpt4marincapupdate_final_20150731.pdf?la=en
14	Monterey	2016	5	https://monterey.org/Portals/0/Reports/ForPublicReview/Draft_Climate_Action_Plan.pdf
15	Oakland	2018	4	http://www2.oaklandnet.com/oakca1/groups/pwa/documents/policy/oak069942.pdf
16	Palo Alto	2016	4	https://www.cityofpaloalto.org/civicax/filebank/documents/64814
17	Piedmont	2018	4	www.ci.piedmont.ca.us/climate-action-plan-2-0/
18	Sacramento	2016	3	https://www.cityofsacramento.org/-/media/Corporate/Files/Public-Works/Facilities/CityOfSacramento_1606_ClimateActionPlan_InternalOps_FINAL.pdf?la=en
19	San Francisco	2013	4	https://sfenvironment.org/sites/default/files/engagement_files/sfe_cc_ClimateActionStrategyUpdate2013.pdf
20	San Jose	2018	4	http://www.sanjoseca.gov/DocumentCenter/View/75035
21	San Leandro	2009	4	https://www.ca-ilg.org/sites/main/files/file-attachments/resources__ClimateActionPlan.pdf
22	San Rafael	2017	4	http://cityofsanrafael.granicus.com/MetaViewer.php?view_id=38&event_id=1108&meta_id=132004
23	Santa Barbara	2012	5	https://www.santabarbaraca.gov/civicax/filebank/blobdload.aspx?BlobID=17716
24	Santa Cruz	2012	5	http://www.cityofsantacruz.com/home/showdocument?id=29361

#	City/Local Government	Year of CAP	Caltrans District	Source
25	Solana Beach	2017	11	http://solana-beach.hdso.net/docs/CM_ClimateActionPlan-Draft.pdf
26	Sonoma County	2016	4	https://rcpa.ca.gov/wp-content/uploads/2016/07/CA2020_Plan_7-7-16_web.pdf
27	West Hollywood	2011	7	https://www.weho.org/home/showdocument?id=7949
28	Woodland	2017	3	https://www.cityofwoodland.org/DocumentCenter/View/834/Climate-Action-Plan-PDF
29	Yolo County	2011	3	https://www.yolocounty.org/home/showdocument?id=18005
30	Yountville	2016	4	http://www.townofyountville.com/home/showdocument?id=4864

A.1.1. Examples of Robust CAPs

Lancaster (City of Lancaster, 2016)**:** Lancaster's CAP stands out among other reviewed CAPs because it provides emissions reduction potentials for potential actions and does so considering different time horizons. Like many other CAPs, it also lists co-benefits and a timeline for implementation, but in contrast to Cupertino's CAP it provides cost estimates through a simple indicator, as seen in their Bike Lane Installation strategy in Figure A.1. The listed co-benefits (in rank order) are that the strategy: creates local jobs, improves air quality, improves water quality, and improves public health. The cost is two out of a maximum three dollar signs. While not included in the infographic reproduced in Figure A.2., the supporting text for each strategy includes implementation steps, responsible parties for each step, and progress indicators. A succinct summary of Lancaster's listed Transportation strategies along with their co-benefits can be seen in Figure A.3.

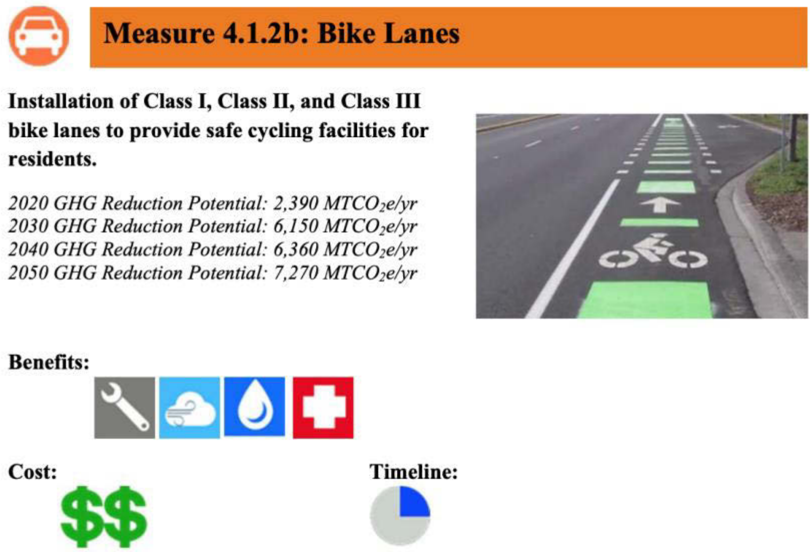
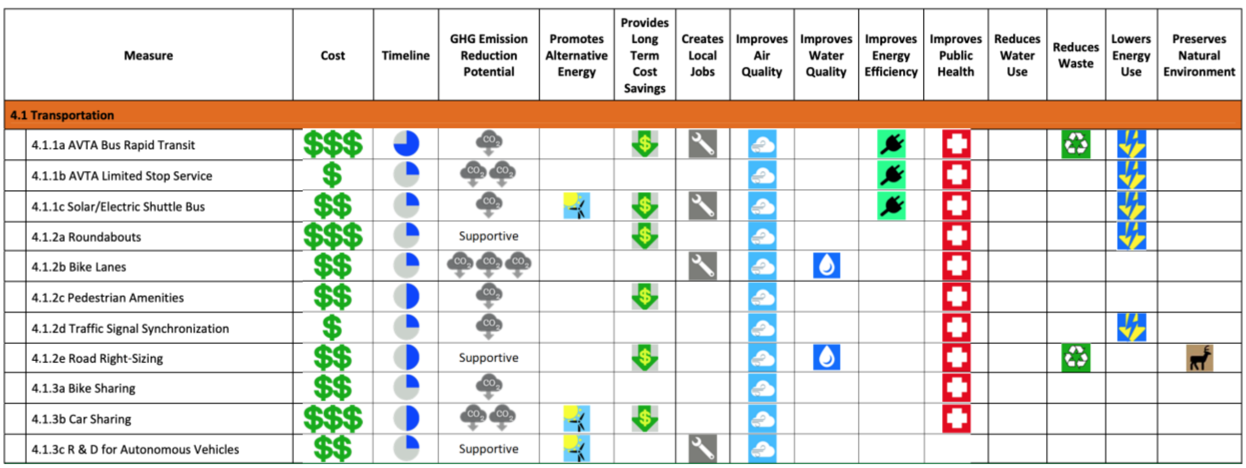


Figure A.1. The indicators used by Lancaster are shown for their strategy to increase the availability of bike lanes (City of Lancaster, 2016, Section 4 page 10).



Measure	Cost	Timeline	GHG Emission Reduction Potential	Promotes Alternative Energy	Provides Long Term Cost Savings	Creates Local Jobs	Improves Air Quality	Improves Water Quality	Improves Energy Efficiency	Improves Public Health	Reduces Water Use	Reduces Waste	Lowers Energy Use	Preserves Natural Environment
4.1 Transportation														
4.1.1a AVTA Bus Rapid Transit	$$$													
4.1.1b AVTA Limited Stop Service	$													
4.1.1c Solar/Electric Shuttle Bus	$$													
4.1.2a Roundabouts	$$$		Supportive											
4.1.2b Bike Lanes	$$													
4.1.2c Pedestrian Amenities	$$													
4.1.2d Traffic Signal Synchronization	$													
4.1.2e Road Right-Sizing	$$		Supportive											
4.1.3a Bike Sharing	$$													
4.1.3b Car Sharing	$$$													
4.1.3c R & D for Autonomous Vehicles	$$		Supportive											

Figure A.2. Summary Table of Transportation Strategies from Lancaster's CAP (City of Lancaster, 2016, Section ES page 3).

Cupertino (Cooke et al., 2015)**:** The CAP developed by the city of Cupertino was one of the most robust reviewed. It included a detailed description of every strategy, which to varying degrees of completeness, reported the following information: implementation steps, status, listed the parties responsible for implementation, progress indicators, reduction potential, co-benefits and implementation timeline—the timeline ranges used are near, medium, and long term. However, it fails to provide a cost estimate, even with simple indicators.

Los Angeles County (Los Angeles CDRP, 2015)**:** Los Angeles County's CAP provided less detailed information for each action or measure compared to other robust CAPs, but still included crucial information on emissions reduction, costs, responsible parties, etc. This CAP also provided the most robust analysis of cost per strategy, listing not only upfront cost, but also the entities responsible for covering the upfront cost, annual net savings or costs per strategy, and entities incurring these annual savings or costs.

Sonoma County (Sonoma County RCPA, 2016)**:** Sonoma County's CAP took a different approach than other county-level (as opposed to city-level) CAPs; for each strategy it provided the expected participation rate of each city within the county. This participation rate informed the reported expected emissions reductions per strategy. Co-benefits were listed per strategy, as were implementation steps, measure commitments, and progress indicators.

San Jose (Romanow at al., 2018)**: The city of** San Jose's CAP is the only one reviewed that included a marginal abatement cost curve (MACC) – which is essentially the same approach proposed in this research and helps demonstrate the feasibility and potentially attractiveness to local governments of this approach. The provided emissions and monetary values were not calculated on a life cycle basis; rather, they were acquired through an extended cost benefit analysis which considered direct emissions reductions and the total cost of ownership. San Jose's MACC is reproduced below in Figure A.3.; note that the strategies span all sectors and not just transportation.

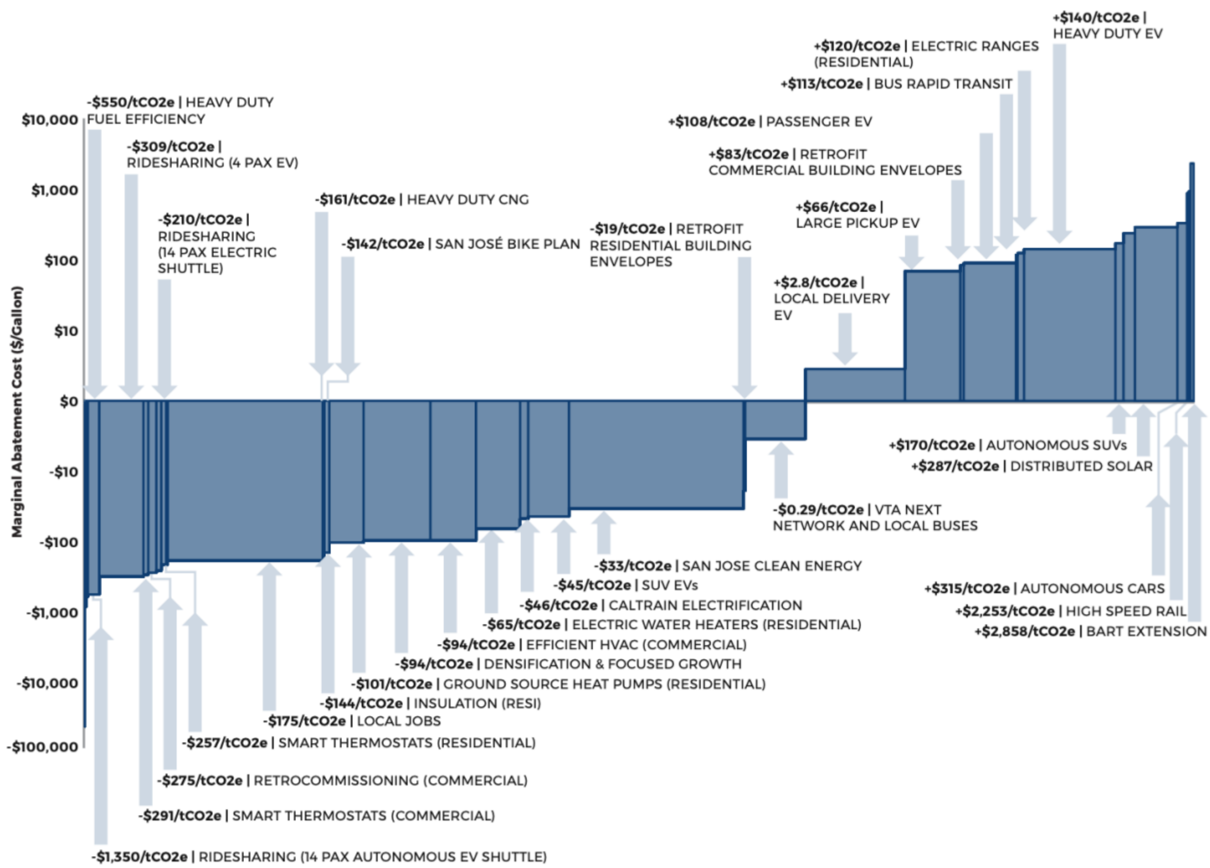


Figure A.3. City of San Jose's MACC showing the abatement costs of the strategies, which can include economic cost savings, such as through job creation; note that the cost axis is logarithmic (Romanow et al., 2018, page 209).

Among the CAPs that listed parties responsible for implementation, it was clear that city departments would be primarily responsible. Lancaster, for example, has multiple departments and services within the city that are responsible for researching, planning, and implementing project ideas; some of these include Development Services, Traffic Engineering, and Economic Development. Other responsible parties include the Antelope Valley Transit Authority, Lancaster Choice Energy (utility), contractors, and consultants. Similarly, the county of Santa Cruz's CAP listed many of its own departments as responsible parties for implementation; these included Fleet and Facilities Operations, Energy Management Office, Transportation, Planning, and Public Works. Los Angeles County also indicated that the local government would incur the costs for most strategies, with the exceptions being (1) the costs of bicycle infrastructure born by businesses adding those facilities, (2) transportation signal synchronization which is eligible for grant funding, (3) car-sharing programs at least partly covered by the program operator, and (4) idling reduction goals implemented by vehicle owners.

Appendix 2. Documentation of stakeholder outreach and discussions

This appendix includes documents related to stakeholder engagement and data collection from case study local governments.

A.2.1. Outreach

The following text was provided as a 1-page document was provided during initial contact with selected local governments:

National Center for Sustainable Transportation, University of California Davis, Research Project:

Greenhouse gas (GHG) reduction opportunities for local governments: A quantification and prioritization framework

Background Local governments are increasingly looked to as key actors and stakeholders in greenhouse gas (GHG) reduction goals. Transportation and transportation assets are important contributors to GHG emissions but are also potential sources for reductions needed to meet state reduction goals. Local governments need to be able to analyze different alternatives to help them achieve GHG reduction targets, as well as other environmental impacts of concern, and to prioritize them by considering life cycle cost using a consistent and transparent process to support decision-making.

Goals & Scope The project's goal is to deliver a decision support framework and process for assessing the expected life cycle GHG mitigation and life cycle cost of transport-sector mitigation actions for local government, and then demonstrate it with several case studies reviewing climate action plans of California local governments. The result of the process is a GHG mitigation "supply curve," where the expected life cycle cost and GHG reduction from alternative mitigation strategies are quantified, prioritized, and presented as a comprehensive set of possible actions. The project is funded by the California Department of Transportation (Caltrans) through the National Center for Sustainable Transportation at the UC Davis Institute of Transportation Studies.

What We Are Doing To produce the example supply curves this project will calculate the life cycle cost and total mitigation potential of a set of strategies that have been extracted from a wide range of city and county climate action plans (CAPs) and previous research. The list of potential transportation strategies will be reviewed with two case study local governments, and those of potential interest will be scaled for that jurisdiction. Transportation strategies in the jurisdiction's existing CAP will also be included in the example supply curve. The results for these two cases will be used to improve the framework and process. The results will be provided to the participating jurisdictions. A report will be published demonstrating the framework and process, showing the case study results, so that other jurisdictions can assess the usefulness and feasibility of this approach. This research will complement similar work for Caltrans' operations, which applied similar methods to develop a GHG mitigation supply curve.

Summary of what is requested from local government

To make this approach useful, the process needs to be validated and be developed with the needs, ideas, and experiences of local government. The research team at UC Davis will request a meeting to seek feedback on strategies of interest, identification of ideas, data sources and limitations, critique or commentary on the proposed approach, and the utility of this approach for the jurisdiction. Future engagement with the research team can include in-person or virtual meetings and interviews. A tentative agenda for the meeting requested is provided below:

Tentative Agenda

- Introduction of the participants
- Introduce the National Center of Sustainable Transportation funded project and what we have done so far
- Introduction to CAP and implementation plan by Yolo County representatives
- Discuss potential GHG reduction strategies that could be considered for the analyses based on review of other CAPs
- Decide on a plan to assess primary strategies that are relevant to Yolo County
- Identify data needs to scale strategies to be evaluated and how to complete them
- Develop plan for collecting data
- Develop schedule for reporting back to Yolo County to get feedback
- Discuss any other considerations, suggestions, or concerns

Contact: Alissa Kendall (PI) – amkendall@ucdavis.edu

John Harvey (Co-PI) – jtharvey@ucdavis.edu

A.2.2. Los Angeles County-UC Davis Meeting Notes and Letters of Introduction

The following text provides the meeting minutes from the introductory meeting between UC Davis and Los Angeles County, followed by letters of introduction provided by LA County to encourage the provision of data from relevant departments and agencies.

Meeting Minutes from August 13, 2019

<u>**Meeting with Los Angeles County Representatives to discuss NCST project**</u>

Attendees: **UCDAVIS** - John Harvey, Ali Butt, Mark Lozano, Sampat Kedarisetty, Alissa Kendall

LA County - Alejandrina Baldwin, Caroline Chen, two gentlemen from LA county

<u>*General Discussion*</u>

- LA County representatives are part of the Advanced Planning Division of their department.
  - One of their goals is updating LA County CAP
  - Colleagues are working on San Gabriel plan
    - Environmental. justice, mobility, economic development, land use planning, etc. (all in the State goals of GHG reduction) - General plan
- John introduces LCCA & LCA, system analysis, EPD, Data. Discussed marginal abatement curve, supply curve, complete streets, cool pavement.
  - Main goal of this project is to avoid unintended consequences through a thorough, life cycle analysis
- JOHN
  - Piloting the approach with Yolo County and the city of San Jose (potential) which can help in developing CAP, and covers policies/political decision support etc.
  - Can also determine uncertainty, can quantify (guesstimate) two strategies that the County selects
- ALEJANDRINA
  - Have not started discussion on transportation strategies yet
  - 2015 results show that statewide transportation emissions have gone way above expected
  - Static energy and transportation are the focus of LA County
  - Agriculture, waste, and industries are low priorities based on the emission trends
  - BuroHappold Engineering is helping with quantification of emissions for LA County
    - Not known if this is a traditional GHG inventory or life cycle basis for GHG accounting
  - Five guiding principles in general plan used to decide on which strategies to implement. *Mentioned*: Cost, feasibility
  - A methodology will be set up of how to quantify emissions
  - Select strategies by looking at existing projects and move ahead with them if it is working and then look at what else is available
  - Interested in mobility and active transportation
- Deciding on project: look at which of their considered projects are more feasible

Action Items

1. Davis: Share strategies found in CAP review
2. LA County: Have internal meeting and get back to UC Davis team with response on participation. Then select strategies that are of interest for LA County to be analyzed by the UC Davis team.

Action Item 1:

Strategies listed across nearly 40 reviewed CAPs:

- Alternative fuel fleets
- Carsharing
- Promote bicycle riding, such as through bike-sharing programs and increased bike lanes
- Public transit improvements to decrease VMT, such as through electric transit, investment in transit station amenities, universal transit passes, and more
- Anti-idling policies (typically for trucks, heavy-duty diesel, and construction equipment)
- LED lights
- Improved road maintenance
- Revised parking standards and/or pricing to promote foot and bike travel
- Telecommuting (which may increase emissions)
- Replace signals with roundabouts
- Signal synchronization
- Electric vehicle charging stations
- Vehicle to grid
- Alternative work schedules to alleviate traffic
- Create "Spare the Air" alerts (implemented in the Bay Area) to promote alternative forms of or reduced travelling (or eliminate wood burning in the winter); they also partner with local transit agencies to offer free or reduced fares.

Reviewed CAPs:

Benicia, Berkeley, Chula Vista, Cupertino, Emeryville, Fremont, Fresno, Hayward, Humboldt County, Lakewood, Lancaster, Los Angeles County, Manhattan Beach, Marin County, Monterey, Oakland, Palo Alto, Piedmont, Riverside, Sacramento, San Bernardino County, San Francisco, San Jose, San Leandro, San Rafael, Santa Ana, Santa Barbara, Santa Cruz, Shasta County, Solana Beach, Sonoma, West Hollywood, Woodland, Yolo County, Yountville

Other suggested Strategies:

- Smart street lighting system. Motion activated street (pedestrian paths, bike lanes, residential/commercial streets, alleys, etc.) lights running on batteries that are charged by solar energy.
- All parking lots (and potential some County roads) re-build using permeable pavement design methods (collect and preserve stormwater for irrigation as an example) and solar panels canopies installed for electricity generation for electric vehicle charging and lighting.
- Intercity electric bus/transit system
- Does white topping help the County against 'Heat Island Effect'?

- Start and Stop, roundabouts and speed limits in the County affecting vehicle fuel economy.
- Full Depth Reclamation versus conventional pavement rehabilitation methods.
- Target emissions reductions by Community Choice Aggregation/Energy (CCA/CCE)
- Bike lanes connection cities

A.2.3. Yolo County-UC Davis Meeting Notes

Meeting minutes from July 10, 2019 and updates reflecting the choice of strategies on August 20, 2019

Dated: 10jul19

Updated: 20aug2019

Meeting with Yolo County Representatives to discuss NCST project

Attendance: <u>*UCDAVIS*</u> - Alissa Kendall, John T. Harvey, Ali A. Butt, Mark T. Lozano

<u>*YOLO COUNTY*</u> - Constance Robledo, Kimberly Villa, Taro Echiburu

<u>Meeting Minutes</u>

General Discussion of Approach

- We have reviewed a number of existing Climate Action Plans (CAP)s. The review of CAPs showed that they presented a list of strategies to reduce emissions, but they didn't quantify the impacts or the cost.
- This project combines life cycle assessment (LCA) <u>and</u> life cycle cost analysis (LCCA) to analyze potential strategies with an aim to discern which give you the best "bang for your buck"
    - Comment: The current climate doesn't allow disposal of ideas because they're expensive, money spent is seen as investment
- This method looks into the feasibility of "popular" or novel project ideas, such as piezoelectric energy generation
- Identify gaps in data and do sensitivity analysis
- We should choose sites that are different from each other - where you are matters
    - Look at viability of projects under different climates, population densities, etc.
- Proposal: do quantitative analysis of transportation strategies listed in governments' CAPs
    - Didn't want the project to be a CAP review and analysis but it has become one as every region is acting differently

- Comment: CAP plan is not mandatory but reduction of greenhouse gas (GHG) is and county/city can achieve the goals of GHG reduction however they want
- Knowing whose responsible shows accountability for implementing CAP and who's paying for changes identifies who is bearing the impact of the CAP

- Open discussion throughout project, allows opportunity for feedback and critique
- Ultimately, we are doing life cycle not just scope 1 (direct emissions)

Things to Consider

- Scope: What the agency controls directly or what the agency can influence
  - Project scope currently narrowed to transportation sector
  - Emeryville says they have no control on VMTs through their jurisdiction. So, we can look at the question of allocation.
- Yolo County is doing GHG Inventory for Yolo County. In October 2018 they had it prepared by ACCENT
- CCA (Community choice aggregator - alternative to utility, more flexibility in electricity fuel procurement, distribution, etc.) are interesting option; only local governments can create one

Project Steps

1. Walk through strategies
   a. We propose the strategies and Yolo County decides the boundaries/scaling
   Comment: Yolo County stated that they have a target to reduce GHG emissions by 45% through their CCA (Valley Clean Energy). Yolo County interested in pursuing this strategy for the case study.
   b. Yolo County creates a list
   c. We sit together and come up with a unified list
2. Implementation questions
   a) Create final list so that we do calculations.
3. Perform LCA and LCCA using existing info, create supply curve
4. Write the report.
5. Send back to Yolo County for review

Yolo County Interest in Strategies (strategies recommended to be studied by UCD) identified by bold font

1. **Target 45% emissions reductions by CCA.**
2. **Bike lanes connecting other cities to Davis for employees not living in Davis. Concerns with maintenance**

3. Biomass energy plants for farm waste (UCD comment: will be covered to extent possible with existing information as part of 1. Not enough time and information to develop detailed analysis)

Other Proposed Strategies

1. Smart street lighting system. Motion activated street (pedestrian paths, bike lanes, residential/commercial streets, alleys, etc.) lights running on batteries that are charged by solar energy. (UCD comment: not enough street lighting on county roads to be important)
2. All parking lots (and potential some County roads) re-build using permeable pavement design methods (collect and preserve stormwater for irrigation as an example) (UCD comment: not enough applicable locations [urban] in county to be worthwhile)
3. **Solar panels canopies installed for electricity generation for electric vehicle charging and lighting on county parking lots.**
4. **Intercity electric bus/transit system**
5. Does white topping help Yolo County against 'Heat Island Effect'? (UCD comment: county is not urban enough to be worthwhile)
6. **Start and stop, roundabouts, and speed limits in Yolo County affecting vehicle fuel economy.**
7. **Full Depth Reclamation versus conventional pavement rehabilitation methods.**