California is committed to reducing greenhouse gas emissions through various approaches. However, the two largest contributors to greenhouse gas emissions in California are transportation and electricity generation. In California, 25.4 \% percent of Q2 2023 vehicle sales were electric, \cite{ev\_sale\_percentage} and the state plans on banning the sale of internal combustion engine vehicles by 2035 \cite{ice\_ban}. At the same time, California is increasing the number of charging stations in the state, having over 13,737 stations \cite{ev\_stations\_CA}. Electric vehicle technology has improved, and new vehicles can charge in 20-60 minutes \cite{ev\_stats}. This is due to Level 3 charging, which can be as high as 350 kilowatts (kW), as opposed to Level 2 charging, which is capped at 19 kW \cite{ev\_stats}. While this innovation has led to a higher practicality for electric vehicles, it also leads to more difficulty for the owners of these chargers since they can create a tremendous amount of loads very quickly. Most Level 2 chargers consumers use are similar in load to an air conditioner. While California tries to increase clean energy penetration, it also needs to reduce the amount of GHG emissions produced by transportation through electrification. This leads to two conundrums: how will California add enough capacity for electrified transport, and how clean is the grid to minimize the amount of emissions associated with battery electric vehicles? One proposal to mitigate the strain on the grid is to keep electricity production and EV charging local by using microgrids. A microgrid is defined by the Department of Energy(DOE) and the Institute of Electrical and Electronics Engineers (IEEE) as: “‘a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid. A microgrid can connect and disconnect from the grid to enable it to operate in both grid-connected or island-mode.” \cite{mivrogrid\_def}. As microgrids and EV chargers become ubiquitous, it is crucial to study the economic and environmental impacts EV charging, in particular fast charging, will have on microgrids. EV charging various from other building loads since they almost instantaneous ramp un to the max levels based during random intervals based on human behavior. An outlier event where multiple people charge at the same t

This paper's analyzes the impacts transportation microgrids with Level 2 and Level 3 charging have on the behavior of microgrids and the associated electric costs and CO\textsubscript{2} emissions in southern California. The simulation is run in open Modelica rather than being a purely calculated model. This paper also uses a higher time resolution data than most to calculate the CO\textsubscript{2} emissions every 15 minutes.

California has adopted various strategies to reduce greenhouse gas emissions from different sectors. However, two large sources of greenhouse gas emissions in California are transportation and electricity generation. In California, electric vehicles (EVs) accounted for 25.4 % of Q2 2023 vehicle sales, \cite{ev\_sale\_percentage} and the state aims to ban the sale of internal combustion engine vehicles by 2035 \cite{ice\_ban}. Concurrently, California is expanding the number of charging stations in the state, reaching over 13,737 stations \cite{ev\_stations\_CA}. EV technology has advanced, and new vehicles can charge in 20-60 minutes \cite{ev\_stats}. This is enabled by Level 3 charging, which can deliver up to 350 kilowatts (kW), compared to Level 2 charging, which is limited to 19 kW \cite{ev\_stats}. While this innovation has increased the attractiveness of EVs, it also poses a challenge for the owners of these chargers, as they can generate a large amount of load quickly. Most Level 2 chargers consumers use have a similar load to an air conditioner. As California strives to increase the share of clean energy in its electricity mix, it also needs to reduce the GHG emissions from transportation by promoting electrification. This leads to two conundrums: how will California provide enough capacity for electrified transport, and how clean is the grid to minimize the emissions associated with battery electric vehicles? One proposal to alleviate the pressure on the grid is to localize electricity production and EV charging by using microgrids. A microgrid is defined by the Department of Energy (DOE) and the Institute of Electrical and Electronics Engineers (IEEE) as: “a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid. A microgrid can connect and disconnect from the grid to enable it to operate in both grid-connected or island-mode.” \cite{mivrogrid\_def}. As microgrids and EV chargers become more widespread, it is essential to study the economic and environmental impacts of EV charging, especially fast charging, on microgrids. EV charging differs from other building loads, as it can rapidly ramp up to the maximum levels at random intervals based on human behavior. An outlier event where multiple people charge at the same **time** can cause a significant peak in the load.

This paper analyzes the impacts of transportation microgrids with Level 2 and Level 3 charging on the behavior of microgrids and the associated electric costs and CO\textsubscript{2} emissions in southern California. The simulation is run in OpenModelica, which is a dynamic modeling and simulation environment. This paper also uses a higher time resolution data than most studies to calculate the CO\textsubscript{2} emissions every 15 minutes.

The charging setup is modified in OpenModelica for different layouts and scenarios. The scenarios are described in Table \ref{tab:scenarios}. Scenarios 2 is the baseline case where only the building loads such as the air conditioners, appliances, and lights are connected to. Scenarios 2 is the case where a building installs four Level 2 and one Level 3 charger. Scenario 3 represents a transportation microgrid that has solar power and a BESS for peak shaving. Each scenario is run independently of one other, and the power outputs of the different components in the simulation are shown in Figure \ref{fig:scenariospoweroutputboxplot}. Scenario one and two are both constantly negative meaning we are constantly pulling power from the grid. Scenario 3 on the other hand it's mostly positive or limit it to -15, meaning it's either exporting power to the grid or it's consuming very only 15 kilowatts. The reason for the 15 kilowatt floor is because with the utility companies electric rate a minimum of 15 kilowatts is charged for the demand meaning that a zero demand microgrid will not make financial difference for the user. While the peak shaving algorithm should limit the amount of power consumed at anytime to be limited to 15 kilowatts, there are still sometimes when the BESS cannot supply the building with power. This happens when the BESS is too depleted, and there is little to no solar power to replenish it as shown in Fig 7 . The two main reasons for these events that happen are multiple cloudy days and electrical faults. During the winter months is when most of the low solar power event occur since that is when most of the rain falls in southern California. Figures 5, 9, and 10 show box plots of the power output. Figures 5 is for the entire year while figures 9 and 10 show selected months. The box plots show that all three figures mean and 75th percentile are almost identical at 15 kW. This implies that peak shaving is functioning correctly most of the time. However, the outlier shows when the BESS fails to keep the power pulled from the grid at 15 kW. Just one outlier will change the demand charge for the entire billing month. In some months, the maximum demand peak of scenario 2 and 3 are similar since they have the same load, but for most of the months, it is reduced significantly which is reflected on the reduced demand charges of the building. Each scenario’s power pulled from the grid is juxtaposed in Figures \ref{fig:scenariosmgloadoutputboxplot} \ref{fig:netloadscenariocomparisonsummer}. The different amounts of loads produced by each charging is shown in Figure \ref{fig:scenariosevpoweroutputboxplot}. The average of daily CO\textsubscript{2} emissions from each scenario is shown in Figure \ref{fig:emissionsscenariocomparison}. Scenario 2 with its increased charging events shows about a 47 \% increase of CO\textsubscript{2} emissions during day hours compared to scenarios 1 and 3. The CO\textsubscript{2} emissions from the transportation microgrid are lower than a conventional building even with the additional load coming from the EV chargers. The emissions and electric price amounts of each scenario are shown in Table \ref{tab:emissions}.

The charging setup is modified in OpenModelica for different layouts and scenarios. The scenarios are described in Table \ref{tab:scenarios}. **Scenario 1** is the baseline case where only the building loads such as the air conditioners, appliances, and lights are connected to **the grid**. **Scenario 2** is the case where a building installs four Level 2 and one Level 3 charger. Scenario 3 represents a transportation microgrid that has solar power and a BESS for peak shaving. Each scenario is run independently of **each other**, and the power outputs of the different components in the simulation are shown in Figure \ref{fig:scenariospoweroutputboxplot}. Scenario **1 and 2** are both constantly negative meaning **they are** constantly pulling power from the grid. Scenario 3 on the other hand **is** mostly positive or **limited** to -15, meaning it’s either exporting power to the grid or it’s consuming **only** 15 kilowatts. The reason for the 15 kilowatt floor is because with the utility companies electric rate a minimum of 15 kilowatts is charged for the demand\*\*,\*\* meaning that a zero demand microgrid will not make **a** financial difference for the user. While the peak shaving algorithm should limit the amount of power consumed at **any time** to be limited to 15 kilowatts, there are still **some times** when the BESS cannot supply the building with power. This happens when the BESS is too depleted, and there is little to no solar power to replenish it as shown in **Figure** 7 . The two main reasons for these events that happen are multiple cloudy days and electrical faults. During the winter months\*\*,\*\* **most of the low solar power events occur** since that is when most of the rain falls in southern California. Figures 5, 9, and 10 show box plots of the power output. **Figure** 5 is for the entire year while **Figure** 9 and 10 show selected months. The box plots show that all three figures mean and 75th percentile are almost identical at 15 kW. This implies that peak shaving is functioning correctly most of the time. However, the **outliers** show when the BESS fails to keep the power pulled from the grid at 15 kW. Just one outlier will change the demand charge for the entire billing month. In some months, the maximum demand peak of scenario 2 and 3 are similar since they have the same load, but for most of the months, it is reduced significantly which is reflected on the reduced demand charges of the building. Each scenario’s power pulled from the grid is juxtaposed in Figures \ref{fig:scenariosmgloadoutputboxplot} **and** \ref{fig:netloadscenariocomparisonsummer}. The different amounts of loads produced by each **charger** are shown in Figure \ref{fig:scenariosevpoweroutputboxplot}. The average of daily CO\textsubscript{2} emissions from each scenario is shown in Figure \ref{fig:emissionsscenariocomparison}. Scenario 2 with its increased charging events shows about a 47 % increase of CO\textsubscript{2} emissions during day hours compared to scenarios 1 and 3. The CO\textsubscript{2} emissions from the transportation microgrid are lower than a conventional building even with the additional load coming from the EV chargers. The emissions and electric price amounts of each scenario are shown in Table \ref{tab:emissions}.

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Transportation microgrids will have a significant impact on the electric costs and emission levels of an EV charging setup. Compared to the user having a conventional system, a transportation microgrid offers \$8,000 in savings a year or \$80,000 in a 10-year battery lifetime, even with additional demand. The savings compared to a building that installs EV chargers are even more dramatic, with a savings of \$27,000 a year or \$270,000 in a 10-year battery lifetime. This means that for a 100 kW 500 kWh transportation microgrid system, the overall savings are tripled compared to savings from switching from a conventual building. The CO\textsubscript{2} emissions are more than halved from the conventional building and only about a third of the emissions if the microgrid was not feeding the building clean energy. The user has an economic and environmental incentive to adopt a transportation microgrid. Doubling the battery capacity does eliminate some peaks from a couple of cloudy days as seen in the month of July in Figures . However, the \$2,000 in savings a year do not justify the cost of doubling the capacity of the BESS. A 15 kW demand price floor negatively effects CO\textsubscript{2} emissions, since it dissuades the user from keeping the net load at 0 in a peak shaving setup.

Future papers will investigate different, more advanced control strategies to decrease electric costs further and CO\textsubscript{2} by preventing users from charging during high peak times, utilizing the clean energy produced by the solar panels, and only pulling power from the grid during low CO\textsubscript{2} times. The increased value of a BESS system in California with the new net energy metering policy in place will also be assessed.

Transportation microgrids are an innovative solution for reducing the electric costs and emission levels of an EV charging setup. A comparative analysis of different scenarios shows that a transportation microgrid can offer significant savings and environmental benefits over a conventional system. For a 100 kW 500 kWh transportation microgrid system, the annual savings are estimated to be $8,000 or $80,000 over a 10-year battery lifetime, even with additional demand from EV chargers. Compared to a building that installs EV chargers without a microgrid, the annual savings are even more substantial, reaching $27,000 or $270,000 over a 10-year battery lifetime. This implies that the transportation microgrid can triple the savings from switching from a conventional building. Moreover, the transportation microgrid can reduce the CO\textsubscript{2} emissions by more than 50% compared to the conventional building and by about 67% compared to the scenario where the microgrid does not supply the building with clean energy. Therefore, the user has a strong economic and environmental incentive to adopt a transportation microgrid. However, increasing the battery capacity does not necessarily improve the performance of the microgrid. As shown in the month of July in Figures **X and Y**, doubling the battery capacity can eliminate some peaks from a couple of cloudy days, but the additional savings of $2,000 per year do not justify the cost of the extra capacity. Furthermore, a 15 kW demand price floor has a negative impact on CO\textsubscript{2} emissions, as it discourages the user from maintaining the net load at zero in a peak shaving setup.

Future research will explore different, more advanced control strategies to optimize the electric costs and CO\textsubscript{2} emissions of the transportation microgrid. These strategies will include preventing users from charging during high peak times, maximizing the use of the clean energy produced by the solar panels, and minimizing the power drawn from the grid during high CO\textsubscript{2} times. The effect of the new net energy metering policy in California on the value of the BESS system will also be assessed.