CO_2 and Cost Impacts of a Microgrid with Electric Vehicle Charging Infrastructure: a Case Study in Southern California

Luis Fernando Enriquez-Contreras

University of California, Riverside

December 1, 2023

Outline

Introduction

Literature Review

Methodology

Results and Conclusions

Introduction

- Electrification of Transportation
  - Electric vehicle (EV) adoption is increasing rapidly, with 25.4% of Q2 2023 vehicle sales being EVs in California
  - California aims to ban the sale of internal combustion engine vehicles by 2035
  - The state is expanding its EV charging infrastructure, with over 13,844 Level 2 and 1,924 Level 3 stations as of November 2023
  - Technological advances allow new EVs to charge up to 80% in 20-60 minutes, making EVs more appealing
  - This rapid charging capability poses challenges for grid operators due to the high electricity demand it creates
- Challenges
  - Two key challenges exist:
    - Providing enough electricity capacity for the growing number of EVs
    - Minimizing the CO_2 emissions associated with battery electric vehicles by ensuring a clean grid
- Solution
  - Microgrids offer a potential solution to both challenges
  - Microgrids can integrate renewable energy sources and EV charging stations, reducing the burden on the main grid and minimizing CO_2 emissions
- Research Focus
  - Further research is needed to understand the economic and environmental impacts of EV charging, especially fast charging, and how microgrids can be effectively utilized to manage EV demand and promote a sustainable transportation future

Contribution

- This research holds significant implications for the advancement of intelligent transportation systems, as it aims to address the economic needs of EV charging infrastructure owners and determine the optimal configuration that benefits both EV owners and the environment by minimizing greenhouse gas emissions
- This paper delves into the impacts of transportation-microgrids equipped with Level 2 and Level 3 charging on the behavior of microgrids, associated electricity costs, and CO_2 emissions within the context of southern California
- The simulations are conducted using OpenModelica, a dynamic modeling and simulation environment
- This study distinguishes itself from previous research in many ways, including employing a higher time resolution for calculating CO_2 emissions that is measured every 15 minutes

Transportation-Microgrids: Key Research Gaps

- Economic Analysis:
  - Current focus on energy charges overlooks demand charges, crucial for fast charging stations
  - A comprehensive approach considering both energy and demand charges is needed
- Impact of EV Charging Demand:
  - Existing research focuses on low-demand Level 2 charging
  - Studies should incorporate a mix of Level 2 and Level 3 charging scenarios for a nuanced understanding
- CO_2 Emissions Assessment:
  - Simplified approaches using average CO_2 emissions neglect time-varying emissions
  - More sophisticated calculations are needed to accurately represent the environmental impact

CO_2 Emissions

- California Independent System Operator (CAISO) CO_2 emission data $\frac{\mathrm{m}^{TON}CO_2 / hour}{Wh}$ with a 15 minute resolution is multiplied with the energy consumed during that period to calculate the amount of CO_2 produced in that time frame
- This gives us an estimate of the amount of CO_2 emissions in $_{\mathrm{m}}TON_{CO_2}$ for every 15 minutes that is summed together to give us the total for the entire period
- When the grid does not pull power from the grid or is sending power, the CO_2 emissions are assumed to be zero since we are using our solar energy

Microgrid Setup in OpenModelica

- Modelica is a programming language designed for dynamic systems simulation
- OpenModelica is an open-source implementation of the Modelica programming language
- OMEdit is the GUI interface for OpenModelica, allowing the user to draw a system for simulation
- The microgrid scenarios are simulated in OpenModelica using the Modelica buildings library
- The Modelica buildings library was created by Lawrence Berkeley National Laboratory for building and district energy and control systems
- The library's capability for energy storage systems, bidirectional inverters, solar, and HVAC modeling makes it ideal for a microgrid simulation setup
- This allows us to create scenarios that do not currently exist in our microgrid, like running a month with solar with the same load or running the BESS control algorithm for different electric rates
- The simulation of our case study microgrid is the grid-connected to the building netload
- The model's net load is broken down into solar power, HVAC demands, regular building demands, electric vehicle chargers, and the BESS

Microgrid Setup in OpenModelica

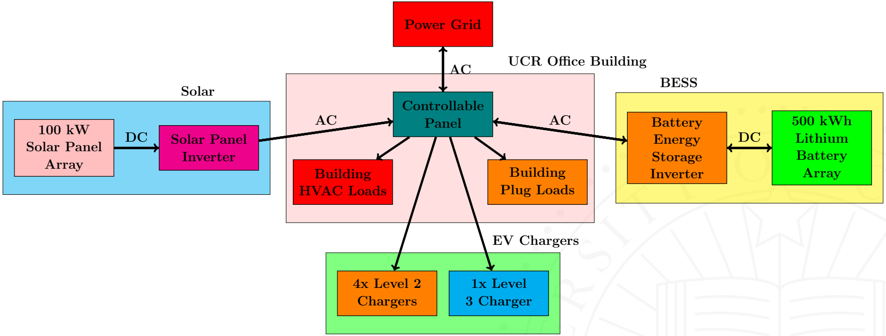

Figure: Microgrid Architecture of our Case Study Example BESS: Battery Energy Storage System

- To ensure that our model accurately portrays our real world system, a year of real world data was used to validate the P_G output . P_G is defined as the power the microgrid sends or consumes from the grid
- The actual data was compared to the simulated with a correlation coefficient of ≈ 0.965087 as shown in Figure 2

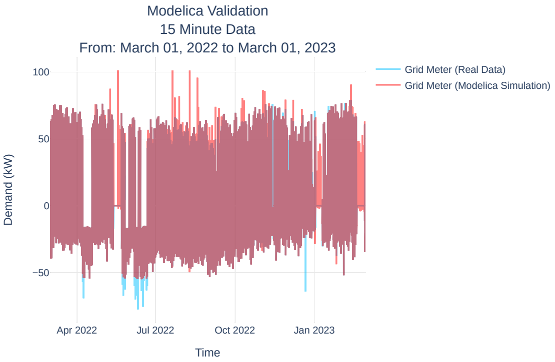

Figure: Whole Year Validation of the Microgrid Architecture in OpenModelica. The bright blue and red is the real data and simulated data respectively. The dark red is the overlap between real and simulated data.

EV Chargers Load

- EV chargers are represented as two models: Level 2 EV chargers, and Level 3 EV chargers.
- The case study microgrid has four Level 2 chargers, so it can have four “steps” of 7.2 kW each, while there is only one “step” of 50 kW with the Level 3 chargers
- Historical data from the Level-2 charger was utilized to determine the parameters for the Poisson random generator, consistent with the typical daily charge probability density function (PDF).
- Analysis of the historical data revealed three distinct peak charging periods occurring at 7:00, 9:00, 13:00, with average number of vehicle arrivals during each peak of 6, 2, and 1 respectively
- A mean charging time of 90 minutes was assumed
- The EV random arrivals function generates random arrival times and durations
- The function employs the NumPy library in Python to create a Poisson random distribution with means centered around the peak times.
- To ensure consistency across different scenarios and prevent any outlier event from the EV charging load disproportionately influencing higher demand events, a random data seed value of 10 was employed to ensure every charging event is the same
- The random arrivals for Level 3 charging are modeled with three peak times at 7:00, 9:00, 13:00, an average vehicle arrival count of 2, 1, and 1, and a mean charging time of 30 minutes

EV Chargers Load

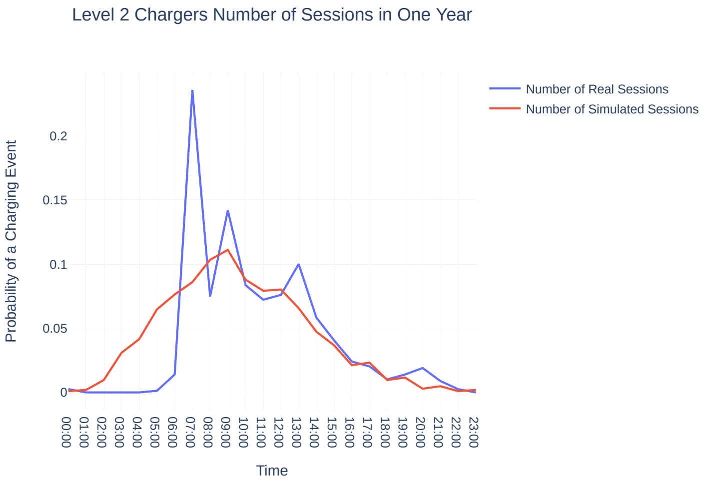

Figure: Validation of the Level 2 EV Charger Stochastic Process that Compares the Probability Density Function of Actual Charging Data to the Poisson Process

EV Chargers Load

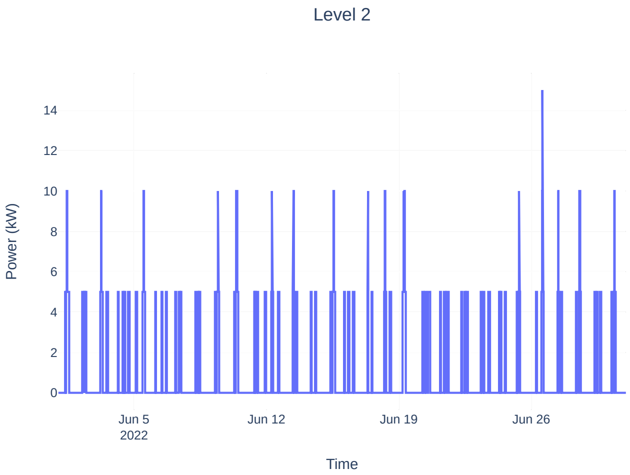

Figure: Example Level 2 Chargers Simulated Power Draw in OpenModelica

Results

- The charging setup is modified in OpenModelica for different layouts and scenarios
- The scenarios are described in Table 1

Table: Simulated Scenarios of the UCR Microgrid using Different Layouts and Electric Pricing Structures

Scenario	
1	Standard Building with no EV Chargers
2	Standard Building with Level 2 and Level 3 Charging
3	Microgrid Building with 100 kW Solar, 500 kWh BESS, No EV Charging
4	Microgrid Building with 100 kW Solar, 100 kWh BESS, Level 2, and Level 3 Charging
5	Microgrid Building with 100 kW Solar, 250 kWh BESS, Level 2, and Level 3 Charging
6	Microgrid Building with 100 kW Solar, 500 kWh BESS, Level 2, and Level 3 Charging
7	Microgrid Building with 100 kW Solar, 1 MWh BESS, Level 2, and Level 3 Charging
8	Microgrid Building with 100 kW Solar, 1 MWh BESS, Level 2, and Level 3 Charging

Results

- The charging setup is modified in OpenModelica for different layouts and scenarios
- Each scenario is run independently of each other, and the power outputs of the different components in the simulation are shown in Figures 5, 6, 7
- Scenarios 1 and 2 are both constantly negative meaning they are constantly pulling power from the grid
- Scenarios 3-8on 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
- 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
- Battery capacity affects the frequency of depletion and the ability to manage low-solar events
- Transportation-microgrids have lower CO_3 emissions than a conventional building, even with EV charging
- Adding EV charging increases CO_2 emissions by 17-45% compared to a microgrid without EV chargers, but these emissions are offset by charging an average of 12 EVs per day

Results

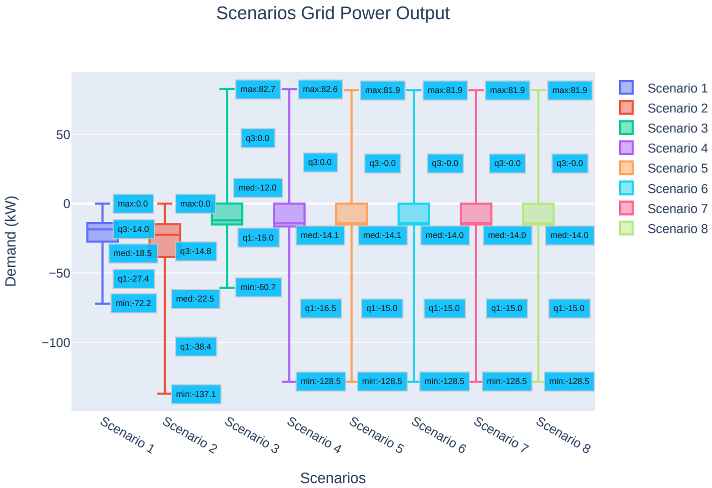

Figure: Power measured from the meter

Results

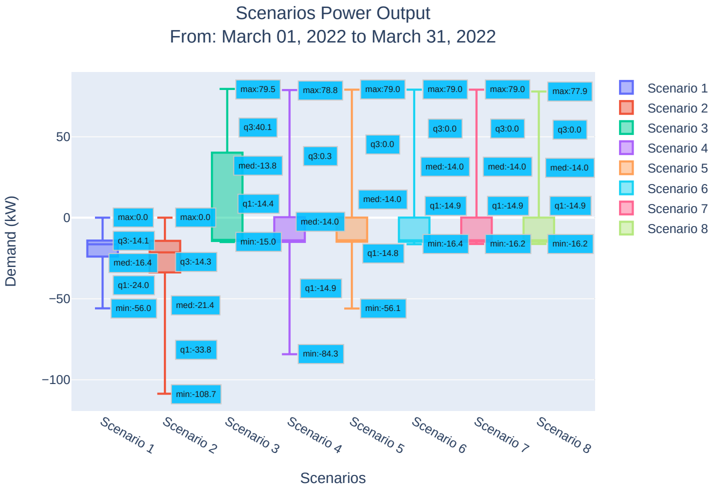

Figure: Power measured from the meter for the month of March

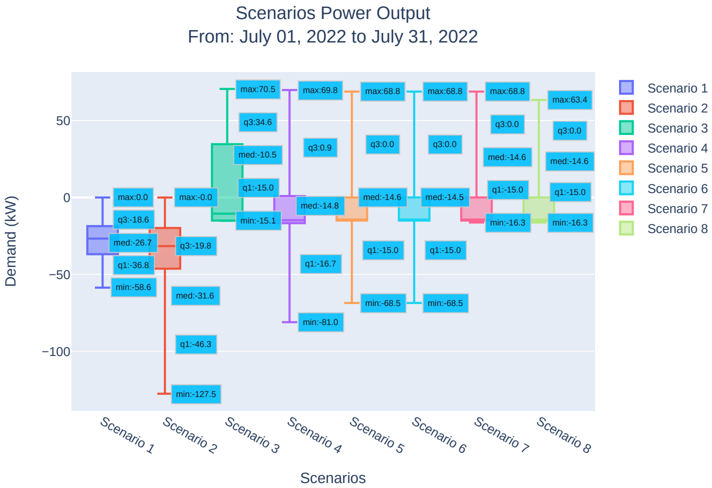

Figure: Power measured from the meter for the month of July

Results

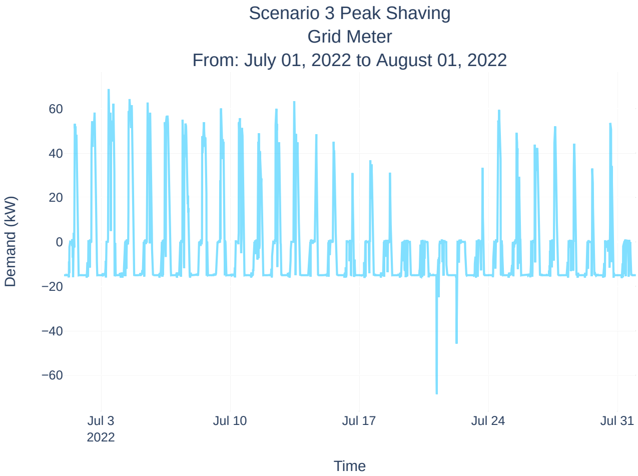

Figure: Peak Shaving Failure after Battery Depletion (500 kWh)

Results

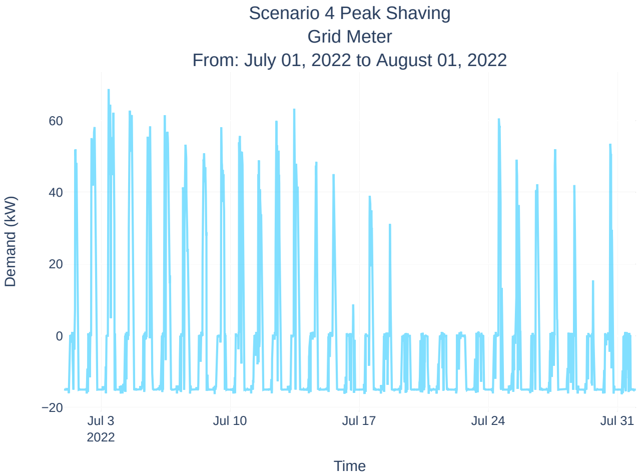

Figure: Peak Shaving Success with 1 MWh battery

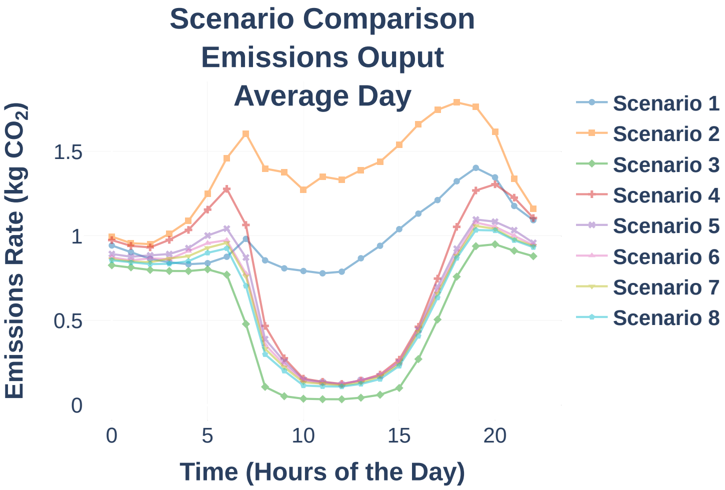

Figure: Microgrid CO_2 Emissions Outputs Averages During Times of Day

Table: Microgrid Utility Prices and CO_2 Emissions Output under Different Pricing Scenarios and Pricing Structures

Scenario	Demand Charges ($)	Energy Charges ($)	Total Cost ($)	CO_2 Emissions ($_m$Tons)
1	7695	22736	30431	34
2	17343	32289	49632	47
3	3904	0	3904	18
4	14341	8209	22550	26
5	13193	8937	22130	23
6	12909	9239	22148	22
7	10835	9418	20253	22
8	9811	9577	19388	21

Results

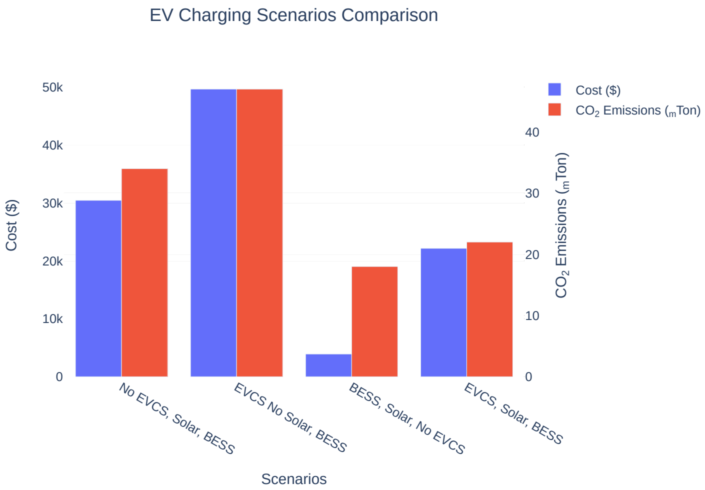

Figure: EV Charging Scenarios Comparison

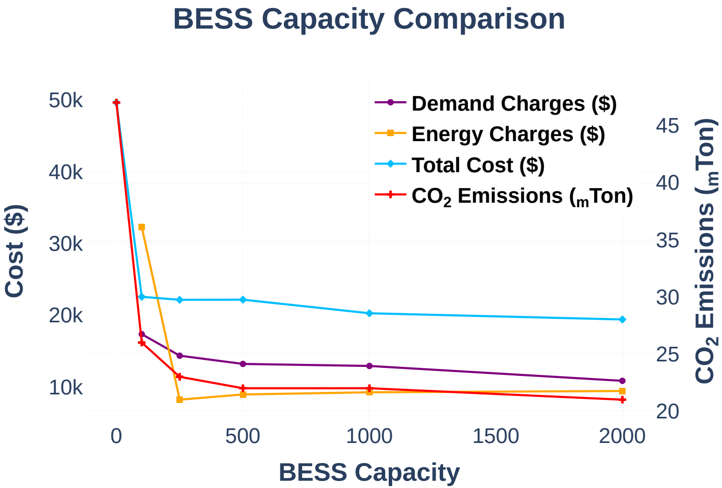

Figure: Cost and CO_2 Emissions for Different Battery Capacities

Conclusion

- Transportation-microgrids offer significant economic and environmental benefits
  - Estimated annual savings of $8,000-$10,000 compared to conventional systems
  - Annual savings of $27,000-$29,000 compared to buildings with EV chargers but no microgrid
  - 24% - 38% reduction in CO_2 emissions compared to conventional buildings
  - 45% - 55% reduction in CO_2 emissions compared to buildings with EV chargers and no microgrid
- Increased battery capacity does not guarantee improved performance
  - Increased capacity improves performance but not proportionally to the cost
  - Large capacity needed for challenging situations may not be cost-effective
- 15 kW demand price floor discourages zero net load
  - Discourages zero net load in peak shaving setups, increasing CO_2 emissions
- Future Work
  - Optimizing electric costs and CO_2 emissions through throttling charging, maximizing solar energy use, and minimizing grid draw during peak CO_2 emissions times
  - Assessing the impact of California's new net energy metering policy