Carbon Free Housing and Dining:
A UCSB Electrification Study


Photo: Glen Beltz

Authored By:
Drew Andersen, Logan Babcock, Daija Odom,
Marco Palombo, Emily Pelstring

Faculty Advisor: Kyle Meng

UC SANTA BARBARA
Bren School of Environmental Science & Management

UCSB Sustainability

March 2023

A Group Project submitted in partial satisfaction of the requirements for the degree of Master of Environmental Science and Management for the Bren School of Environmental Science & Management.

UNIVERSITY OF CALIFORNIA

Santa Barbara

Carbon Free Housing and Dining: A UCSB Electrification Study

A Group Project submitted in partial satisfaction of the requirements for the degree of

Master of Environmental Science and Management

for the

Bren School of Environmental Science & Management

by

DREW ANDERSEN

LOGAN BABCOCK

DAIJA ODOM

MARCO PALOMBO

EMILY PELSTRING

Committee in charge:

KYLE C. MENG

March 2023

As authors of this Group Project, we archive this report on the Bren School's website such that the results of our research are available for all to read. Our signatures on the document signify our joint responsibility to fulfill the archiving standards set by the Bren School of Environmental Science & Management.

____

DREW ANDERSEN

____

LOGAN BABCOCK

____

MARCO PALOMBO

____

EMILY PELSTRING

____

DAIJA ODOM

The Bren School of Environmental Science & Management produces professionals with unrivaled training in environmental science and management who will devote their unique skills to the diagnosis, assessment, mitigation, prevention, and remedy of the environmental problems of today and the future. A guiding principle of the School is that the analysis of environmental problems requires quantitative training in more than one discipline and an awareness of the physical, biological, social, political, and economic consequences that arise from scientific or technological decisions.

The Group Project is required of all students in the Master of Environmental Science and Management (MESM) Program. The project is a year-long activity in which small groups of students conduct focused, interdisciplinary research on the scientific, management, and policy dimensions of a specific environmental issue. This Group Project Final Report is authored by MESM students and has been reviewed and approved by:

____

KYLE MENG

____

DATE

Acknowledgements

Our team would like to thank the following for their time, guidance, support, and continued expertise:

Faculty Advisor

Dr. Kyle C. Meng, Associate Professor, Bren School of Environmental Science & Management

Clients

Katie Maynard, Director of Sustainability, UCSB Office of Sustainability

Jewel Persad, Campus Sustainability Manager/TGIF Grant Manager, UCSB Office of Sustainability

Mark Rousseau, Assistant Director Energy & Environmental Office, UCSB Housing, Dining, & Auxiliary Enterprises

External Faculty Advisor

Sage Davis, Building Manager, Bren School of Environmental Science & Management

External Advisors

Ryan Gardner, Climate Action Program Manager, Rincon Consultants, Inc.

Michael Gialketsis, Vice President Strategic Advisor, Rincon Consultants, Inc.

Faculty Reviewers

Mark Buntaine, Associate Professor, Bren School of Environmental Science & Management

Ranjit Deshmukh, Assistant Professor, Bren School of Environmental Science & Management

Table of Contents

List of Tables

List of Figures

1. Introduction

1.1 Climate Change and Greenhouse Gas Reduction

Global carbon emissions have been increasing worldwide according to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, causing anthropogenic climate change (*Summary for Policymakers*, 2022). Warmer temperatures are causing more severe storms, increased drought, wildfires, rising sea levels, loss of biodiversity, crop failures, displacement, and more. In 2022, the International Energy Agency (IEA) projected carbon dioxide (CO_2) emissions to increase by nearly 300 million metric tons to a total of 33.8 billion metric tons as a result of power generation and global economic recovery from the pandemic (*Defying Expectations, CO2 Emissions from Global Fossil Fuel Combustion Are Set to Grow in 2022 by Only a Fraction of Last Year's Big Increase - News*, n.d.). In the U.S. alone, energy-related CO_2 emissions were approximately 4,872 million metric tons in 2021 (*Frequently Asked Questions (FAQs) - U.S. Energy Information Administration (EIA)*, n.d.), making the country the second largest emitter of global greenhouse gasses (GHG) in the world. The transportation and electric power sectors accounted for the majority of these emissions through the use of coal, natural gas, petroleum, and renewable energy.

1.2 Residential and Commercial Buildings in the U.S.

In 2021, the combined end-use energy consumption by the U.S. residential and commercial sectors were approximately 21 quadrillion British thermal units (BTUs) equaling around 28% of total end-use energy consumption (*Frequently Asked Questions (FAQs) - U.S. Energy Information Administration (EIA)*, n.d.). Electricity and natural gas accounted for the main energy sources. Residential and commercial buildings use significant quantities of energy for heating, cooling, cooking, lighting, and other services. The latest Commercial Buildings Energy Consumption Survey list the number of buildings in the U.S. to be 5,918 thousand (*Energy Information Administration (EIA)- About the Commercial Buildings Energy Consumption Survey (CBECS)*, n.d.). By 2050, approximately two-thirds of these buildings will still exist (*The Capital Stock Turnover Problem for 100% Clean Energy Targets*, n.d.). Efficiency standards for appliances and technologies, along with building codes with stronger efficiency requirements can help significantly improve energy efficiency. This increase in efficiency paves the way for building electrification, which capitalizes on the higher efficiency of electric infrastructure and appliances.

1.3 Decarbonization and Need for Building Electrification

Decarbonizing buildings and other existing infrastructure is a major strategy for reducing carbon emissions. In California, 25% of carbon emissions result from the fossil fuel use and electricity demand of built structures (*Building Decarbonization | California Air Resources Board*, n.d.). In 2020, the California Energy Commission (CEC) calculated commercial buildings to consume the most electricity in the state followed by housing (Robinson, n.d.). Building electrification is an integral component of decarbonization for California. Building electrification describes the shift away from using fossil fuels to, instead, utilizing electricity for heating and cooking services. The California Air Resources Board (CARB) recently released a State Implementation Plan (SIP) aimed at achieving the state's goal of carbon neutrality by 2045 (Hicks, 2022). This SIP includes policy measures that promote decarbonized technology for space and water heating, as well as a zero-emission sales standard with the goal of promoting the deployment of heat pumps and other decarbonized technology for buildings. More than 75% of California's existing commercial buildings were built before the Building Efficiency Standards were developed in 1978 (*Existing Buildings | California Air Resources Board*, n.d.). By retrofitting existing residential buildings with electrified technologies, there is the potential to reduce GHG emissions by approximately 30-60% compared to mixed-fuel buildings (Mahone et al., 2019). Building electrification aims to achieve long-term carbon neutrality goals through clean energy supply and improvements in energy efficiency.

2. Literature Review

2.1 2019 California Energy Efficiency Action Plan

The 2019 California Energy Efficiency Action Plan is the roadmap that covers the problems, opportunities for advancement, and cost savings estimates pertaining to energy efficiency in California's buildings sector. The plan aims to achieve the state's goals of doubling energy efficiency savings by 2030, removing barriers to energy efficiency in low-income, marginalized communities, and reducing GHG emissions from the building sector (Commission, current-date). In combination with the updated *Existing Buildings Energy Efficiency Action Plan* and *Doubling of Energy Efficiency Savings by 2030 Report*, the action plan lays out the components of clean energy systems that will help sustain California.

As a part of the 2019 California Energy Efficiency Action Plan's recommendations, to achieve reduced greenhouse gas emissions in the buildings sector, California needs to pursue a clean energy supply, acquire deep energy efficiency, and have energy demand flexibility (Robinson, n.d.). Electrification is the most viable and least cost pathway to zero-emission residential and commercial buildings (Mahone et al., 2019). The electrification of space and water heating to high-efficiency, demand responsive technologies are key to reducing emissions in the built sector. Time-of-use rates and specific appliances can shift the timing of energy consumption in buildings to sync with peak solar production or when emissions are the lowest. Furthermore, heat pump space and water heating can support integration of renewable energy. By using heat pump hot water heaters as thermal storage, excess renewable generation from midday solar energy can be utilized during late afternoon peak loads occurring after sunset.

The action plan notes that increased market penetration of these systems in the residential and commercial buildings and improved demand flexibility, would pave the way for an eventual transition to a zero-carbon grid, while simultaneously reducing the impacts of rapid electrification on California's grid. The action plan further notes that seven sites across the University of California (UC) and California State University (CSU) systems have partnered with electricity supply company, Southern California Edison, to pilot a performance based GHG reduction program. This program, known as the Clean Energy Optimization Pilot, is a four-year, $20 million program aimed at providing financial incentives to the universities to identify and install clean technologies. UC Santa Barbara is one of the seven sites selected to participate.

3. Background and Significance

3.1 Background

3.1.1 UC Santa Barbara's Path to Carbon Neutrality

In November 2013, UC President Janet Napolitano announced the Carbon Neutrality Initiative (CNI). This initiative stated that all UC campuses shall be carbon neutral by 2025 for Scope I and II emissions (*President Napolitano Proposes Tuition Freeze, New Systemwide Initiatives*, 2013). To achieve this ambitious goal, the UC system needs to expand its energy efficiency efforts, increase its use of renewable energy sources, and eliminate the use of fossil-based natural gas by its buildings and vehicle fleet. According to the National Center for Ecological Analysis and Synthesis (NCEAS) natural gas accounts for nearly two-thirds of the UC's emissions (*Strategies for Replacing Natural Gas to Help Decarbonize the University of California*, n.d.). NCEAS developed a three-part strategy for the UCs to consider, noting that each campus differs and no singular strategy works for all. The strategy is as follows: 1. Reduce energy demand via improved efficiency, 2. Substitute natural gas with renewable biogas, and 3. Electrify all end uses of energy (*Strategies for Replacing Natural Gas to Help Decarbonize the University of California*, n.d.). Reducing energy demand, particularly in campus buildings, results in lower operating costs and energy cost avoidance. This is done through retrofitting existing buildings with current inefficient energy systems and designing new all-electric buildings on campus. Substituting biogas would help gradually wean campuses off natural gas. Biogas is also considered to be climate-friendlier because it is renewable and derived from organic material. Lastly, replacing natural gas with carbon-free electricity and moving towards electrification through innovation and experimentation pushes campuses toward decarbonization. To meet the CNI goal, UC Santa Barbara (UCSB) will need to shift away from water and space heating as well as cooking units that require burning natural gas on-site. These units account for two-thirds of the overall campus energy portfolio, totaling between 10,000 to 13,000 metric tons of carbon dioxide released annually (Davis & Lovegreen). To do so, the university developed the Climate Action Plan and UCSB Sustainability Report.

In August 2009, UCSB developed a Climate Action Plan (CAP) to establish a framework within the institution for the inventorying, annual tracking, and strategic reduction of GHG emissions (Yang et al., 2016). This plan detailed the scope of emissions dating up until 2015, the emissions reductions strategies of Scope I and II in line with the goal for carbon neutrality by 2025, and future emission projections. The 2016 update of the plan continued to quantify and analyze the campus' emissions, while simultaneously evaluating the campus' progress toward meeting the reduction targets of 2020 and 2025. UCSB emissions fell below the 2020 reduction target in 2015 through investment in energy efficiency projects. At the time, those energy efficiency projects accounted for a 20% reduction in total campus emissions and an estimated $13.2 million in cost savings, which accounted for 1% of the campus's annual operating budget. CAP notes while UCSB strives to continue reducing emissions as quickly as possible, it faces financial constraints.

The UCSB Sustainability Report for 2020-2021 outlines a broad summary of the efforts that are being made to sustainability initiatives at the University (*2020-2021 Annual Sustainability Report to the Chancellor*, 2021). In July 2020, UC Santa Barbara joined the UC Clean Power Program, a clean electricity program that allows the main campus to be powered by 100% carbon-neutral electricity by 2025 (*Energy | UCOP*, n.d.). This use of carbon-neutral electricity lowered the campus's operational GHG emissions (Scope I & II) by 50%. The report also outlined that the school was in its first year of a four-year Clean Energy Optimization Pilot (CEOP) with Southern California

Edison & SoCalGas. This $18 million incentive program provides incentives to CSU and UC locations to reduce GHG emissions by prioritizing ongoing carbon reductions through metered GHG emissions as opposed to standard measurements of energy reduction, such as LED fixtures and efficiency upgrades (*Energy | UCOP*, n.d.).

UCSB has additional plans to help reach carbon neutrality aside from those formalized in UCSB's CAP and Sustainability Report. One of these measures is a transition of fuel sourcing. UCSB plans on a fraction of its natural gas procurement to be transitioned to biomethane, a renewable natural gas source from decaying material. This fraction of natural gas will have an added premium cost that UCSB has forecasted costs for. The transition schedule specifies that UCSB will source 20% of its natural gas from biomethane by 2025, with an increase to 40% total biomethane procurement by 2030. This transition schedule is accounted for within analysis, and is an added feature to UCSB's path to carbon neutrality.

3.1.2 Other UC Campus's Progress

As of September 2022, there is a diverse range of decarbonization efforts that are being implemented among other UC campuses.

At UC Berkeley, plans to transition their aging co-generation plant to a central electric heat pump are underway (K. Stoll, personal communication, June 28, 2022). The new electric heat pump will provide hot and chilled water to the campus buildings, edging them away from natural gas use towards electricity. In the area of housing and dining, most electrification efforts are focused on new building construction instead of retrofitting existing structures. The school expects they will need to build more substations on campus to handle this increased demand for electricity.

At UC Davis, the campus-wide effort to transition away from fossil fuels, known as The Big Shift, is being completed in stages in individual neighborhoods (C. Kirk, personal communication, July 6, 2022). The campus will be shifting away from their use of steam boilers to ground-source heat pumps, as the campus has ample land to utilize for this larger installation. The residence halls and dining commons are connected to the campus's central heating and cooling system, and an internal team at UC Davis is looking into what it would require to convert the kitchen equipment from natural gas to electric.

Other campuses, including UC Riverside and UC Irvine, supply hot and chilled water to their buildings using a natural gas central heating system, but do not have any current plans to electrify. With some exceptions, new buildings on every campus are all run on electricity alone.

3.2 Significance

The UCSB Sustainability Department serves as our primary client with the support of the three campus divisions that oversee and use the equipment in question, Facilities Management (FM), Housing, Dining & Auxiliary Services (HDAE), and Student Affairs (SA). These campus entities would benefit from this project because it aids UCSB in meeting the 2013 CNI goal. Currently, UCSB is attempting to reach the 2025 goal without the use of carbon offsets. To accomplish this, this project aims to start the process of mapping the feasibility of electrification through the retrofits of existing infrastructure.

Existing infrastructure will need to be transitioned away from current fossil fuel-based systems, and the range of building types on a campus result in a complex retrofit-based decarbonization approach. Our project provides an approach to decarbonization for three general types of campus buildings (a dining hall, a residence hall, and an apartment complex) that will be replicable for similar campus buildings across the UC System.

This project also identifies the barriers and opportunities to electrifying existing campus infrastructure, and is a learning opportunity for other UC's in assessing their own ability to decarbonize through selective retrofits. While UCSB is attempting to reach the 2025 goal without the use of offsets, this project's analysis included the use of carbon offsets in order to compare carbon neutral paths.

Not included in this project's analysis is the Social Cost of Carbon (hereafter referred to as SCC), which is a value that aims to capture the damages to society from an additional unit of GHG emissions. Using the SCC in an analysis would account for the externalities associated with burning fossil fuels, and may present a more robust trade-off analysis for decarbonization. However, the incorporation of offsets in our analysis makes this scenario net zero, eliminating the need for the incorporation of an SCC.

4. Objectives

The objectives of this report are to explain the background of building decarbonization and the approach and reasoning behind the analysis.

4.1 Project Objectives

I. Complete site surveys of dining/housing facilities to take inventory of all natural gas-fueled equipment. Select 1 dining commons, 1 residence hall, and 1 apartment complex for further analysis.

II. Gather data related to building energy demand including fuel consumption, peak demand, energy services, etc. Develop a model to estimate future electricity demand for various energy services based on forecasted input variables.

III. Quantify and compare the net present value of each modeled scenario. Research electrified replacement options and collaborate with UCSB and external advisors to estimate cost and feasibility of meeting forecasted energy service demand.

5. Methods and Data

5.1 Scope

This project determines the cost of operating three buildings (San Miguel Residence Hall, De La Guerra Dining Commons (DLG), and West Campus Family Student Housing (West Campus FSH) for the years 2023-2045, under two carbon neutral scenarios. The first scenario is the continued use of natural gas, with emissions mitigated through purchase of offsets and biomethane. The second scenario is full electrification starting in 2023, which generates no emissions due to the assumption of carbon free renewable electricity purchased through UCSB's energy procurement contract.

UCSB operates a total of 8 residence halls, 5 apartment complexes, and 4 dining commons which are responsible for approximately 10 percent of campus energy consumption (Yang et al., 2016). Each residence hall, apartment complex, or dining commons is fairly similar in terms of appliances and services provided, so one building per type was selected for detailed analysis. San Miguel Residence Hall is one of the two main campus tower residence halls on UCSB's campus and is home to 475 undergraduate students (*San Miguel | Campus Housing*, n.d.). The building consists of 8 floors and 16 halls with single, double, and triple rooms and communal style bathrooms. De La Guerra Dining Commons is one of the four dining halls on campus. It serves approximately 18,000 meals per week ranging from breakfast, lunch, and dinner, Monday through Friday, and brunch and dinner on weekends (*De La Guerra Dining Commons | UCSB Dining*, n.d.). The West Campus Family Student Housing apartment complex is a 2-story apartment style building home to 250 students and their families (*West Campus Family | Campus Housing*, n.d.). Buildings include large fenced in lawn spaces and apartment style bathrooms. San Miguel, DLG, and West Campus each represent a specific style of building; residence hall, dining commons, and apartments respectively.

To profile the natural gas usage of each building, natural gas appliances in each building were identified. The capacity of each appliance was determined and used to select a suitable electric alternative that would fill the same service. A mathematical model was then developed that takes inputs including energy demand, equipment efficiencies, and fuel/capital costs, and outputs yearly cost of operating for each scenario, discounted to 2023 dollars. After all inputs were determined, the model was run for both baseline scenarios. We then ran various sensitivity analyses with alternative input values.

5.1.1 Natural Gas Appliances and Electric Replacements

Natural gas appliances vary within each building. DLG has two steam boilers which provide space/water heating and natural gas kitchen equipment. San Miguel Residence Hall has two hot water boilers which provide space/water heating and natural gas laundry dryers. West Campus has 21 natural gas water heaters which provide water heating, and individual wall furnaces per unit which provide space heating. Electric alternatives with the capability to meet the same demand for energy services were identified for each of these appliances. A summary of natural gas appliances, their electric replacement, and the service they offer is provided in Table 1 below. A more detailed version of this table, including appliance models, kitchen appliances, and efficiencies can be found in Appendix 1.

Table 1. Current technologies and electric alternatives per energy service in De La Guerra, San Miguel, and West Campus.

De La Guerra Dining Commons		
Natural Gas Appliance	Electric Appliance	Energy Service
Steam Boiler	Heat Pump	Hot water and steam for dishwashers
Natural Gas Kitchen	Electric Kitchen	A range of cooking services from grilling, charbroiling, baking, warming, etc.
San Miguel Residence Hall		
Natural Gas Appliance	Electric Appliance	Energy Service
Hot Water Boiler	Heat Pump	Space heating for students dormitories/hot water for communal bathrooms
Natural Gas Clothes Dryer	Electric Clothes Dryer	Clothes drying
West Campus FSH Apartments		
Natural Gas Appliance	Electric Appliance	Energy Service
Water Heater	Electric Water Heater	Water heating
Wall Furnaces	Mini-split Heat Pump	Space heating

Heat pumps can meet demand for space and water heating much more efficiently than other technologies (*Heat Pump Water Heaters*, n.d.). As opposed to conventional natural gas or electric heaters, which convert chemical energy or electrical energy respectively into heat, heat pumps use electricity to move heat via a thermodynamic cycle. This allows heat pumps to achieve impressive efficiencies in excess of 100%. There are some caveats to the high performance of heat pumps, primarily reduced efficiency at extreme temperatures. However, due to the moderate climate of Santa Barbara, heat pumps are a promising electrified option for fulfilling demand for space and water heating. All heat pumps considered in this analysis were selected with equal capacity to the gas appliance they are modeled to replace.

Natural gas appliances within an industrial kitchen are able to be directly substituted with electricity-powered counterparts, with a few exceptions. Direct substitution of appliances, however, may not be the most efficient way to make the transition from a natural gas to an electric kitchen, and is examined further in the Discussion section.

5.2 Simulated Model

The simulated model used for this project takes in a variety of inputs specifying a given building's use of natural gas, efficiencies of considered natural gas and electric appliances, yearly prices of natural gas and electricity, and cost of capital equipment along with the years the capital equipment is purchased. The model outputs the costs of meeting services with considered appliances for a scenario of solely natural gas use with current natural gas technology and a scenario of complete electrification starting in 2023 (beginning of considered time series). Costs are made available as yearly totals discounted relative to 2023 at a 5% discount rate and overall totals for the simulated time period of 2023-2045 discounted yearly relative to 2023 at a 5% discount rate. There is one model for each building considered.

The simulated model performs several fundamental functions; portioning of the total building natural gas use to considered appliances (Natural Gas Portioning), conversion of a quantity of natural gas required to fulfill a given service with a natural gas appliance to a quantity of electricity required to fulfill that same service with an electric appliance (Gas to Electricity), determination of emissions by a natural gas appliance due to the combustion of natural gas (Combustion), cost determination using pricing of applicable fuel or carbon offset (Electricity Price/Natural Gas Price/Offset Price), and discounting and summation of total prices for a given year and scenario (Discount). The flow of information through these functions for a given year can be found below in Figure 1.

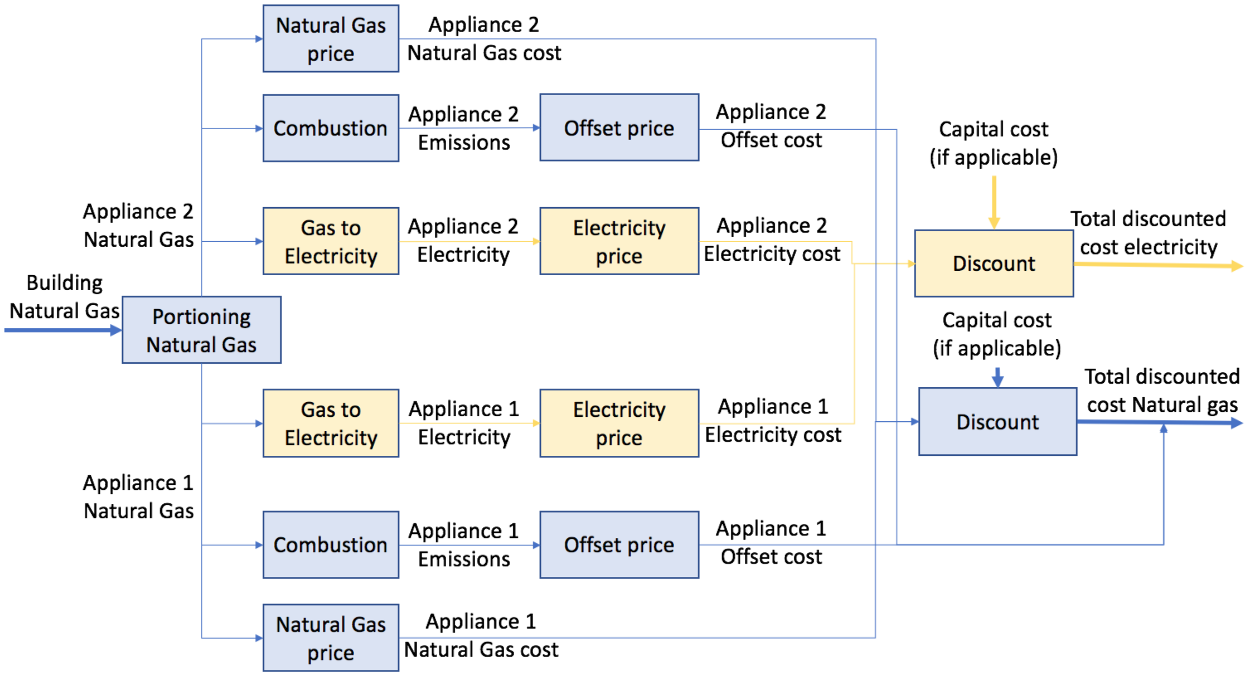

Figure 1. *Flow chart of top-level operations per building model.*

Natural Gas Portioning

Natural gas use is assumed to be constant at 2019 levels for each building for each simulated year. 2020 was not used as a baseline year due to the large changes in housing as a result of the COVID-19 pandemic. As of 2022, each building is at or near its housing capacity, which matches the housing capacity in 2019. Metered data only exists at building level, meaning there is no data regarding what share of gas goes to specific appliances. Each model considers all appliances using natural gas and makes assumptions regarding what ratio of gas goes to each. San Miguel assumes 99% of natural gas goes to the natural gas boiler and the remaining 1% goes to the laundry machines, per client specification. De La Guerra assumes 83% of natural gas is used by boilers per data gathered via time lapse camera footage of boiler gas meters. West Campus assumes 50% of natural gas is used by space heaters per client specification.

Gas to Electricity

To obtain the amount of electricity required to fulfill the same service as a natural gas appliance, the model utilizes natural gas usage, the natural gas appliance efficiency ratio, and an equivalent electric appliance. For heat pumps it is assumed, per industry advisor recommendation, that a heat pump's efficiency is 350% that of the equivalent gas appliance. The equation shown below represents the model's processing.

Equation 1

$$E_{el} = E_{ng} * \frac{efficiency_{ng}}{efficiency_{el}} = E_{ng} * \frac{E_{serv}}{E_{ng}} * \frac{E_{el}}{E_{serv}}$$

Term Definitions:

$$E_{el} = Electrical\ Energy$$
$$E_{ng} = Natural\ Gas\ Energy$$
$$E_{serv} = Service\ Energy$$
$$eff_{el} = Electrical\ appliance\ Efficiency$$
$$eff_{ng} = Natural\ Gas\ appliance\ Efficiency$$

Combustion

It is necessary to account for the amount of emissions generated by the use of natural gas in order to quantify the amount of carbon offsets necessary to make the natural gas scenario carbon neutral. UCSB plans to transition a fraction of its natural gas procurement to biomethane, which is assumed to be carbon neutral. To account for this, the portion of natural gas from biomethane for each given year is removed from the total natural gas used prior to the calculation of emissions. Emissions due to natural gas combustion are determined by multiplying the amount of natural gas used (in therms) by an emissions factor 5.30 E-3 $\frac{tonne\ CO_2}{therm}$ (US EPA, 2015). The mathematical equation for emissions determination can be found below in Equation 2.

Equation 2

$$Emissions = E_{ng} * f_{emiss}$$

Term Definitions:

$$E_{ng} = Natural\ Gas\ Energy$$
$$f_{emiss} = 5.30\ E^{-3}\ \frac{tonne\ CO_2}{therm}$$

Electricity/Natural Gas/Offset Price

Electricity and natural gas pricing were provided by UCSB Sustainability on a yearly basis for the considered time frame of 2023-2045. Once total natural gas and electricity use are determined for a given year, that year's price is multiplied by each total to calculate the total costs. These fuel costs are then passed to the discount function. Offset prices are held constant and non-discounting is applied, it is assumed that price increases at the same rate as discounting.

Discounting

Discounting is applied to applicable future costs using conventional discounting methods, contained in Equation 3.

Equation 3

$$Cost_{discounted} = \frac{Cost}{1 + R^{year}}$$

Term Definitions:

$$Cost_{discounted} = discounted\ cost$$
$$Cost = cost\ prior\ to\ discounting$$
$$R = discount\ rate\ (.05)$$
$$Year = years\ from\ 2023$$

Each building's specific inputs and modeled assumptions are summarized below in Table 2. Space and water heating refer to electric heat pumps and natural gas boilers and appliance #2 refer to all other secondary appliances (kitchen and laundry appliances).

Table 2. *Baseline scenario parameter values. Model inputs of building's use of natural gas, efficiencies of natural gas and electric appliances, yearly prices of natural gas and electricity, cost of capital equipment and the year the capital equipment is purchased for San Miguel, De La Guerra, and West Campus.*

Parameter	Baseline Scenario Parameter Values		
	De La Guerra	**San Miguel**	**West Campus Apartments**
Building			
Building Yearly Gas Demand:	92,461 therms	33,799 therms	88,389 therms
Furnace to Boiler Gas Demand Ratio:	5	99	1
Natural Gas Price (2023):	0.95 $/therms	0.95 $/therms	0.95 $/therms
Electricity Price (2023):	0.14 $/kWh	0.14 $/kWh	0.2 $/kWh
Space & Water Heating			
Heat Pump Capital Cost:	$646,800	$726,000	$1,259,775

Heat Pump Installation Year:	2023	2023	2023
Natural Gas Furnace Capital Cost:	$483,024	$274,659	$361,625
Natural Gas Furnace Installation Year:	2030	2030	2030
Appliance #2			
Electric Appliance #2 Capital Cost:	$264,210	$0	$144,306
Electric Appliance #2 Installation Year:	2023	2023	2023
Electric Appliance #2 Efficiency:	70%	48%	100%
Natural Gas Appliance #2 Capital Cost:	$302,456	$0	$242,550
Natural Gas Appliance #2 Installation Year:	2025	NA	2030
Natural Gas Appliance #2 Efficiency:	48%	43%	85%
Other			
Carbon Offset Price:	$24	$24	$24
Discount Rate	5%	5%	5%

5.3 Data Collection

The data collected for this analysis covers the equipment in each building that could be electrified, and the cost projections for these replacements. Data collection began in Spring Quarter 2022, continued during the Summer Internship, and extended through the conclusion of Fall Quarter 2022. The data collection began with multiple tours of each building (DLG Dining Commons, San Miguel Residence Hall, and West Campus FSH) in Spring Quarter, allowing the team to inventory the existing boilers and other gas burning appliances on each site. Over the summer, the specific technical specifications for each appliance in each building were collected and used to identify electrical replacements that would be able to meet the same demands.

The boilers in DLG are not electronically metered, leading to a gap in data collection. To address this gap, the project used manually collected data to approximate a full week's range of gas consumption. This was completed using a Brinno TLC 2020 time-lapse camera for sample periods of one weekend, consisting of three days, and one week consisting of four days. The boilers in DLG were also assessed to understand the difference in the lead-lag system. Readings were captured on the weekend of October 14, 2022 through October 17, 2022 and the week of October 31, 2022 through November 3, 2022. Boiler readings are not digitized by existing infrastructure, however the manual transcription of boiler readings from the time-lapse camera were taken in 15-minute intervals, which work to convey the daily peaks in gas demand from the boiler.

5.3.1 Additional Sources and Types of Data

In addition to data from the time-lapse camera, multiple databases were provided by the UCSB Sustainability Department and HDAE to provide historical data to characterize natural gas demand for each building. These include:

- *EnergyCAP* - Yearly natural gas consumption of buildings considered and the monthly electric and gas meter bills of San Miguel Residence Hall and DLG Dining Commons
- *SkySpark* - Historical natural gas and electricity energy demand in 15-minute intervals
- *FoveaCAP* - Forecasted utility costs and transition schedule to biomethane procurement

UCSB Sustainability Department and HDAE also provided the capital costs of purchasing and installation of boilers in DLG Dining Commons and San Miguel Residence Hall. This project was unable to obtain a direct quote for heat pump cost from providers; to determine the capital costs of heat pump replacements, data on heat pump sizing and cost from the National Renewable Energy Laboratory (NREL) was utilized. To estimate capital costs of replacements for kitchen appliances and mini ductless heat pumps, multiple websites were used including Energy Star and The Webstaurant Store, the site currently used for UCSB purchasing, which provided direct unit costs.

5.4 Assumptions

Several assumptions were made to handle gaps in data and enable modeling efforts. These assumptions are split into conceptual framework assumptions, which outline the general assumptions used throughout the entire model, and building specific assumptions, which outline the differences specific to each building modeled.

Conceptual Framework Assumptions

- *Utility Costs & Emissions* - The forecasted utility costs for electricity, natural gas, and biomethane premiums are sourced from the UCSB Sustainability Department. It is assumed all these predictions are accurate. It is also assumed that electricity comes entirely from renewable sources per UCSB's purchasing agreement and therefore results in no GHG emissions. Finally, it is assumed that biomethane is carbon neutral, which is expanded upon in the Discussion section 7.1.4.

- *Heat Pump Capital Costs* - Installation costs are assumed to be high due to the high cost of labor in Santa Barbara (*Occupational Employment and Wages in Santa Barbara-Santa Maria-Goleta, May 2013*, n.d.). Capital costs for heat pumps were estimated using NREL's price estimates based on mmBTU ranges (*Industrial Heat Pumps for Steam and Fuel Savings*, 2003).

- *Boiler Capital Costs* - It is assumed current boilers will be replaced at their end of life, which HDAE estimates to be 8-12 years. Capital costs for boilers were provided by HDAE staff using records of past boiler purchases. De La Guerra boilers cost $370,700 in 2018, and San Miguel boilers cost $55,000 each with $115,000 in installation, totaling $225,000 in 2019. These values, which include associated labor costs, are assumed to be accurate and representative of boiler capital costs for UCSB.

- *Efficiencies* - Appliance efficiencies are assumed to be consistent with datasheet specifications. It is assumed that on average a heat pump will perform with 3.5 times the efficiency of its natural gas counterpart. The kitchen was treated as a single entity with an average efficiency determined by a weighted average of the major kitchen appliances.

- *Discounting* - The model assumes a 5% discount rate accurately describes the relative cost of present and future expenses.

- *Carbon Offset Pricing* - The price of carbon offsets was provided by UCSB Sustainability. The model uses a range of $17-30 as recommended by UCSB Sustainability. It is assumed this pricing is accurate and that offsets fully mitigate emissions. Further discussion of offsets' role in emission mitigation can be found in section 7.2.4.

- *Fugitive Emissions* - Natural gas appliances and its supporting infrastructure have the ability to leak methane into the natural environment. These emissions come directly from pipe joints and the un-combusted methane from appliances, and may differ according to a building’s type (Newsom, n.d.). The California Energy Commission estimates that methane emission as a percent of total natural gas consumption ranges from 0.23% to 0.35% in southern California (Newsom, n.d.). Because these values represent less than 0.5% of total emissions and are highly dependent on the age and quality of a given building, these values are considered negligible and are not included in this study.

Building Specific Assumptions:

- *De La Guerra Dining Commons* - It is assumed that neither kitchen operating hours nor meal times will change with electrification. It is assumed that kitchen appliances and equipment can be represented in aggregate with one average efficiency to simplify analysis.
- *San Miguel Residence Hall* - It is assumed that capital costs associated with transitioning to electric laundry services would be paid for by an external contractor, further discussed in section 7.1.2. It is assumed that the boiler to laundry gas use ratio remains 99:1, per specification by HDAE staff. It is also assumed that the number of laundry loads remains constant from year to year.
- *West Campus FSH Apartments* - The gas using appliances (250 wall furnaces and 21 water heaters) in West Campus do not have separate metering. This project thus is unable to differentiate the distribution and use of gas at an apartment level, and assumes the metered use gathered from utility billing records as the general natural gas consumption. We assume the distribution of gas between boilers and apartments used to be 50:50.

5.4.1 Sensitivity Analysis

Various assumptions made about important aspects of this project warrant sensitivity analyses. These sensitivity analyses show the stability of results subject to changes in assumptions made. Results of sensitivity analyses are included in the below results section. Below is a summary of the specific sensitivity analysis parameters considered in this report, reasonings, and relevant sources.

- *Heat Pump Capital Cost* - Our analysis includes a ±15% contingency around our assumed heat pump capital costs, as requested by the UCSB Sustainability client team.
- *Utility Costs* - Utility prices are variable, and a sensitivity analysis helps this project prepare for unforeseen changes in resource availability and energy pricing. The projected fuel costs provided by FoveaCAP were nonlinear, to create bounds for a sensitivity analysis the cost curves for natural gas and electricity rates were fitted to an exponential function. The found growth rate is used as the basis for an ±5% range that this project uses for a sensitivity analysis.
- *Carbon Offset Pricing* - UCSB Sustainability uses a range of $17-30 for carbon offset pricing in their FoveaCAP projections. This project uses the average of $23.50 as a carbon offset price, and uses the lower bound of $17 and upper bound of $30 for the sensitivity analysis.

6. Results

This section outlines the model output operational costs per scenario for De La Guerra, San Miguel, and West Campus. Below, the costs of continued operation of these buildings using natural gas appliances is compared to the cost of electrification. Results are shown on a time series graph for each service (space and water heating, and the secondary appliance for each building), and through a total electrification premium graph, which shows the additional cost of electrification compared to natural gas appliances.

6.1 De La Guerra Dining Commons

Applying the baseline conditions to De La Guerra Dining Commons reveals it is more expensive to electrify both space and water heating and kitchen operations than to continue operating with natural gas appliances.

6.1.1 Space and Water Heating

The initial capital cost of a heat pump starts the electricity cost time series above that of natural gas, as shown in Figure 2. Though the heat pump performs more efficiently than the traditional steam boiler and there is a capital cost of replacing the aged steam boiler in 2030, these factors are not sufficient enough to overcome the relatively low natural gas cost and high heat pump capital cost. At the end of the simulated scenario electrified space and water heating costs $284,976 more than natural gas-fired space and water heating, as shown in Figure 3.

6.1.2 Kitchen

The initial capital cost of electric kitchen equipment starts the electricity cost time series above that of natural gas, as shown in Figure 2. Though electric kitchen equipment performs more efficiently in aggregate than natural gas kitchen equipment and there is a capital cost of replacing the aged kitchen equipment in 2025, these factors are not sufficient to overcome the relatively low natural gas cost and high electric kitchen equipment capital cost. At the end of the simulated scenario electrified kitchen operations cost $391,797 more than natural gas-fired kitchen operations, reference Figure 3.

6.1.3 Total

At the end of the simulated scenario the combined electrified space and water heating and kitchen operations cost $676,773 more than combined natural gas-fired space and water heating and kitchen operations, as shown in Figure 3.

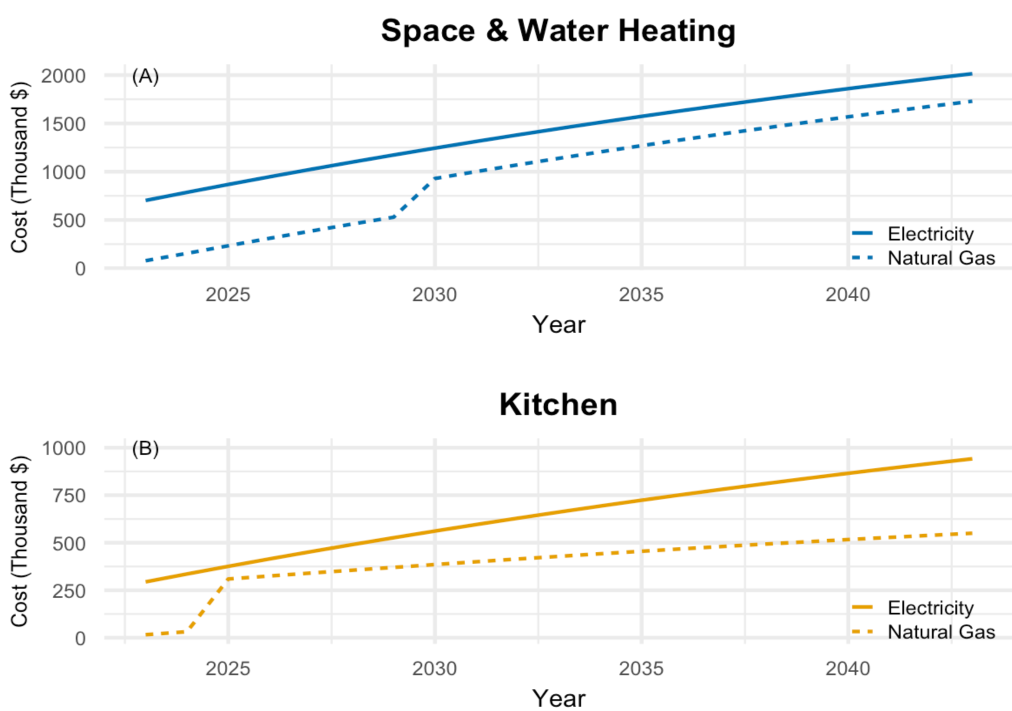

Figure 2. *Time series of net cost (discounted at 4% relative to 2023), including capital equipment purchases, operating De La Guerra space and water heating (top) and kitchen operations (bottom), with electricity (solid line) and natural gas (dashed line).*

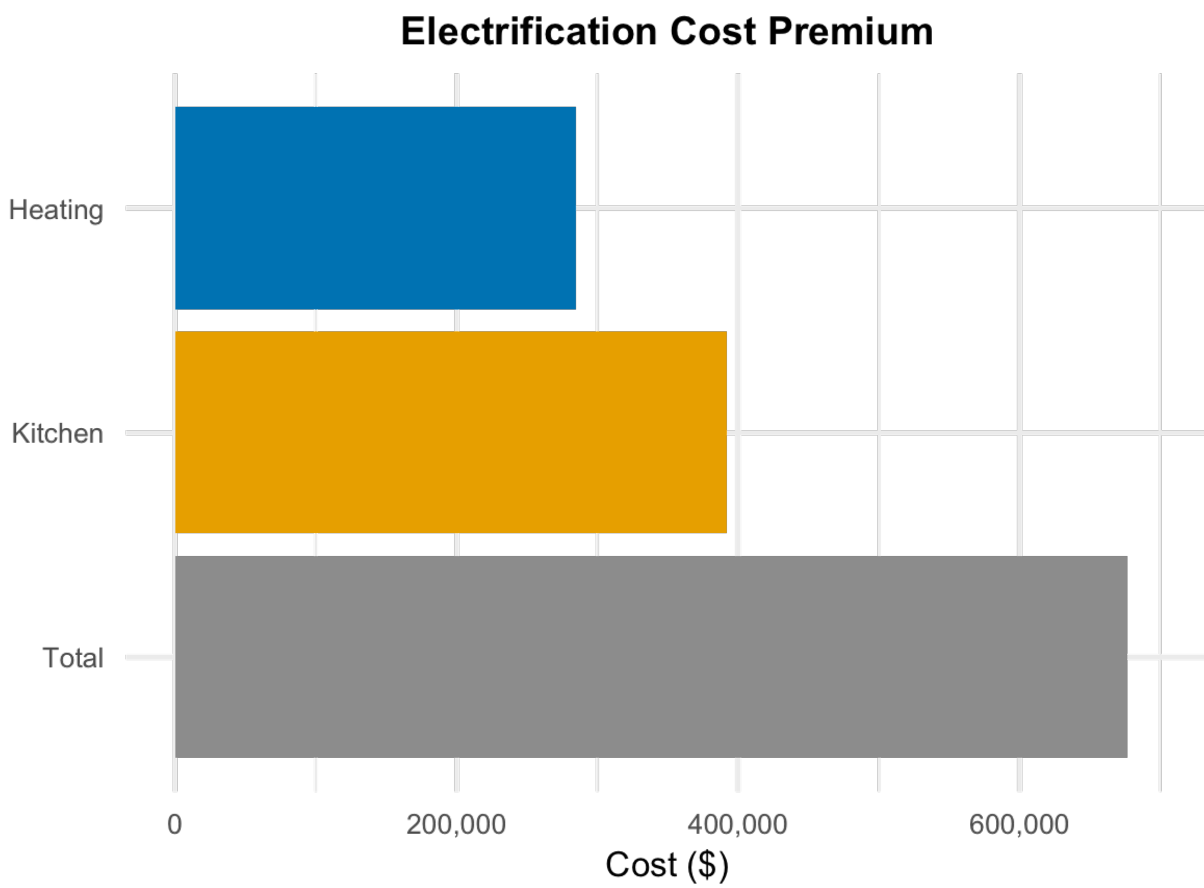

Figure 3. *Electrification premium for space and water heating, kitchen operations, and total building operations of De La Guerra.*

<u>**6.2 San Miguel Residence Hall**</u>

Applying the baseline conditions to San Miguel Residence Hall reveals it is more expensive to electrify space and water heating and laundry services, than to continue operating with natural gas appliances.

6.2.1 Space and Water Heating

The initial capital cost of a heat pump starts the electricity cost time series above that of natural gas, as shown in Figure 4. Though the heat pump performs more efficiently than the traditional boiler and there is a capital cost of replacing the aged boiler in 2030, these factors are not sufficient enough to overcome the relatively low natural gas cost and high heat pump capital cost. At the end of the simulated scenario electrified space and water heating costs $503,740 more than natural gas-fired space and water heating, as shown in Figure 5.

6.2.2 Laundry

Though electric laundry equipment performs more efficiently in aggregate than natural gas laundry equipment, the relatively low natural gas cost offsets these efficiency improvements. Laundry equipment capital costs are not considered here, leading to a much smaller cost difference between electrification and continued natural gas appliances. At the end of the simulated scenario, electrified laundry operations cost $12,937 more than natural gas-fired laundry operations, as shown in Figure 5.

6.2.3 Total

At the end of the simulated scenario the combined electrified space and water heating and laundry operations cost $516,677 more than combined natural gas-fired space and water heating and laundry operations, as shown in Figure 5.

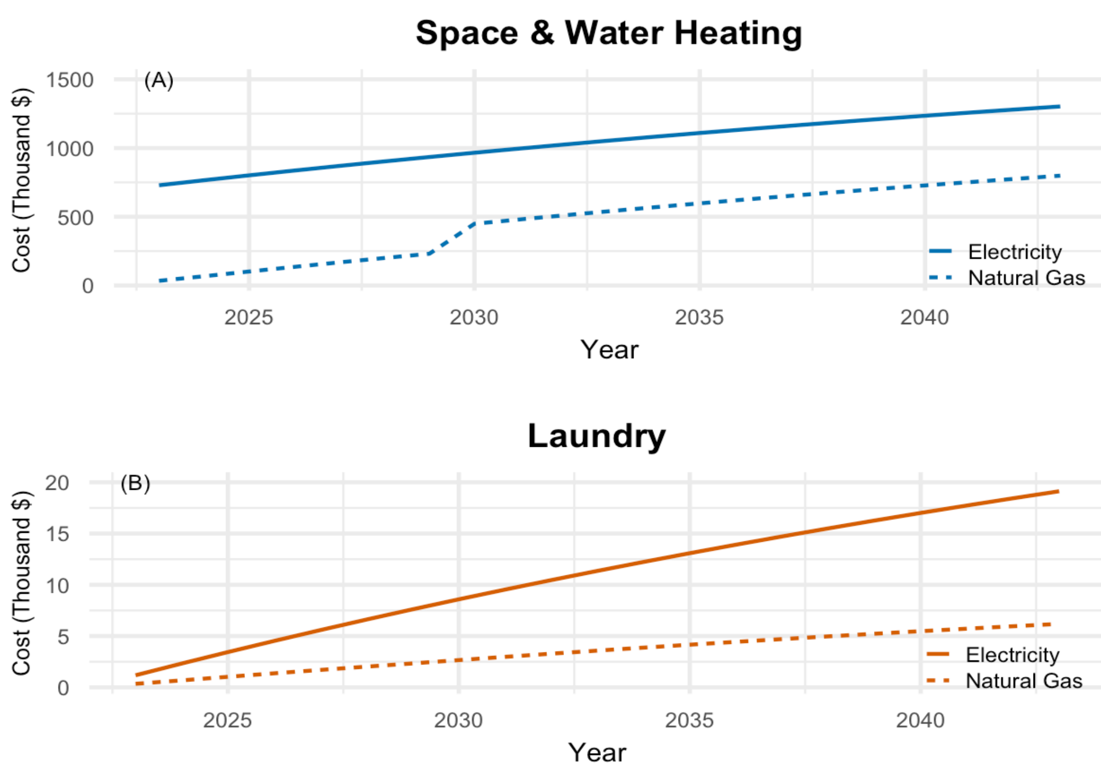

Figure 4. *Time series of net cost (discounted at 4% relative to 2023), including capital equipment purchases, operating San Miguel space and water heating (top) and laundry operations (bottom), with electricity (solid line) and natural gas (dashed line).*

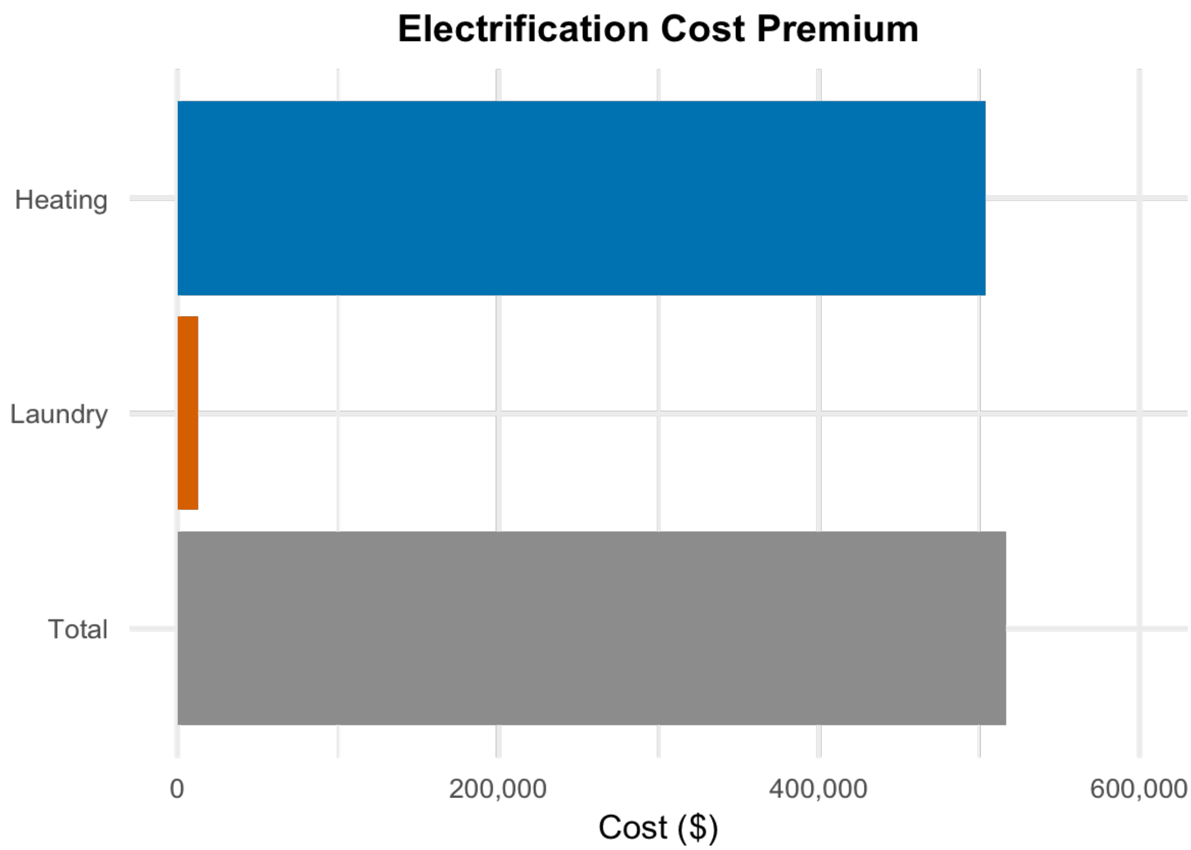

Figure 5. Premium of electrification for space and water heating laundry operations and total building operations of San Miguel.

6.3 West Campus FSH Apartments

Applying baseline conditions to West Campus Apartments reveals it is more expensive to electrify both space and water heating than to continue operating with natural gas appliances.

6.3.1 Space Heating

There is no central HVAC in the West Campus Apartments, which means that electrification of space heating requires a large quantity of residential scale mini split heat pumps. This leads to a significant initial capital cost that starts the electricity cost time series above that of natural gas, shown in Figure 6. Though the heat pumps perform more efficiently than the traditional wall furnaces, and there is a capital cost of replacing the aged wall furnaces in 2030, these factors are not sufficient to overcome the relatively low natural gas cost and high capital cost of heat pumps. At the end of the simulated scenario electrified space and water heating costs $1,457,468 more than natural gas-fired space and water heating, as shown in Figure 7.

6.3.2 Water Heating

The initial capital cost of electric water heaters starts the electricity cost time series above that of natural gas, reference Figure 6. Though the electric water heaters perform more efficiently than the traditional gas water heaters, this is not sufficient to overcome the relatively low natural gas cost and high electric boiler capital cost. At the end of the simulated scenario electrified water heating costs $43,790 more than natural gas-fired water heating, reference Figure 7.

6.3.3 Total

At the end of the simulated scenario the combined electrified space and water heating cost $1,501,258 more than combined natural gas-fired space and water heating and laundry operations, reference Figure 7.

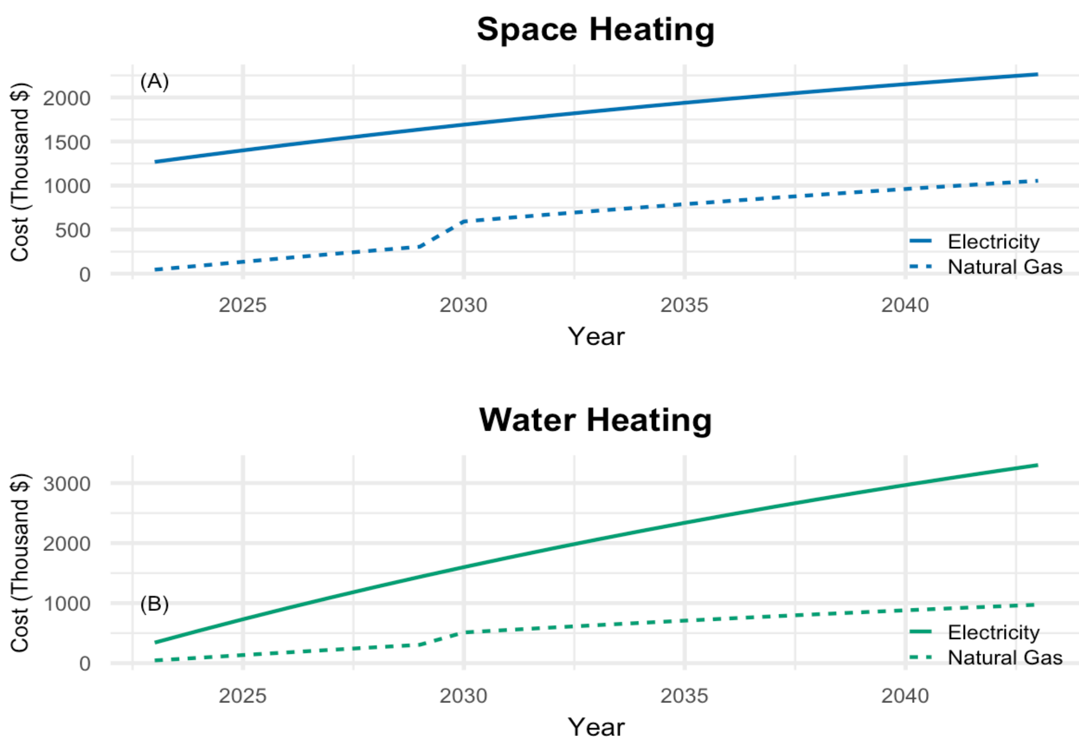

Figure 6. *Time series of net cost (discounted at 4% relative to 2023), including capital equipment purchases, operating West Campus space heating (top) and water heating (bottom), with electricity (solid line) and natural gas (dashed line).*

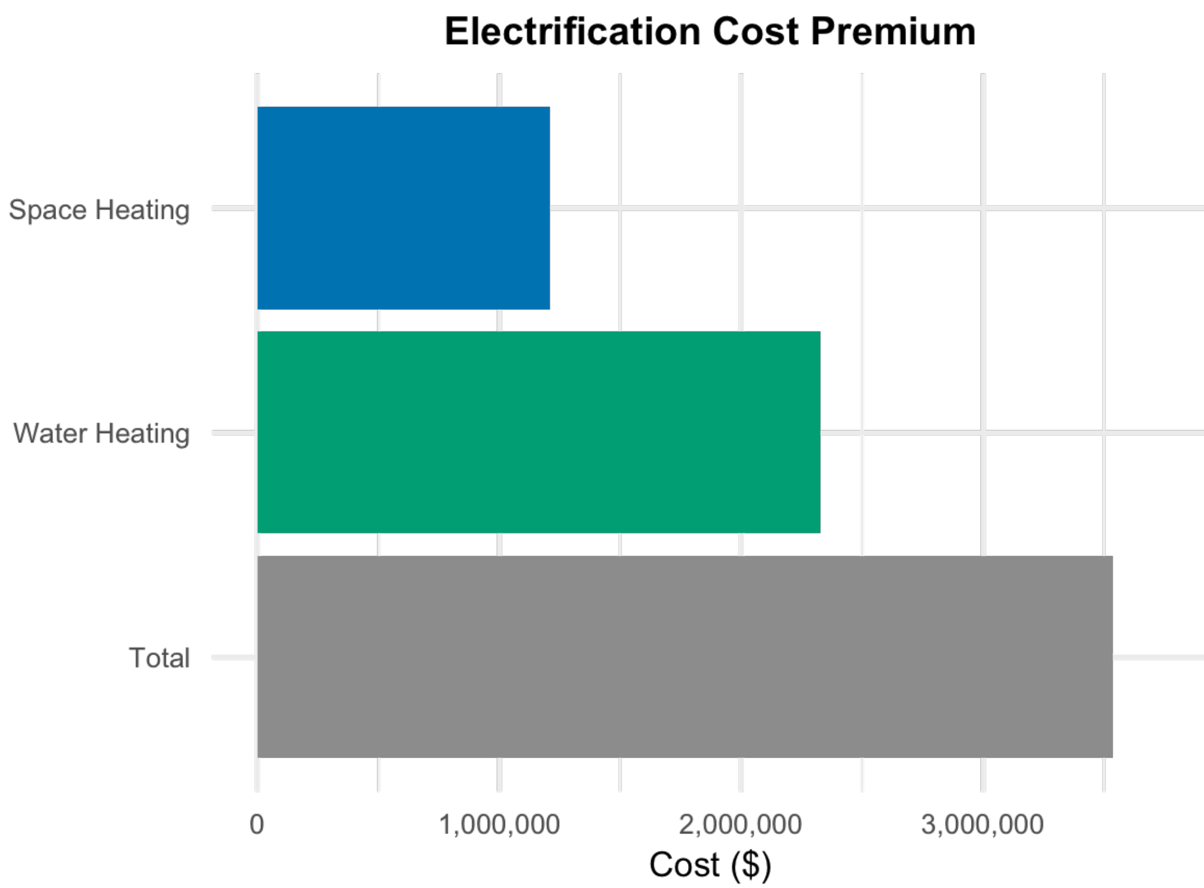

Figure 7. Premium of electrification for space heating, water heating, and total building operations of West Campus.

6.4 Sensitivity Results

The following figures compare the total electrification premium that results from high and low bounds for the parameters of Heat Pump Capital Cost, Carbon Offset Prices, Natural Gas Prices, and Electricity Prices. This analysis shows the sensitivity of results to changes in these parameters, comparing these costs to those found with our baseline parameters, shown in the above results section. The inputs and results from this sensitivity analysis can be found below in Table 3.

This analysis revealed that for all three analyzed buildings the most sensitive input parameter was the Heat Pump Capital Cost. This parameter is the largest influence over the total cost for each building. In San Miguel, applying the Low Heat Pump Capital Cost resulted in a lower heating and overall total cost for electrification, shown in Figure 9. Varying natural gas prices, electricity prices, and offset prices did not make electricity cheaper for any of the considered buildings, as shown in Figure 8, Figure 9, and Figure 10.

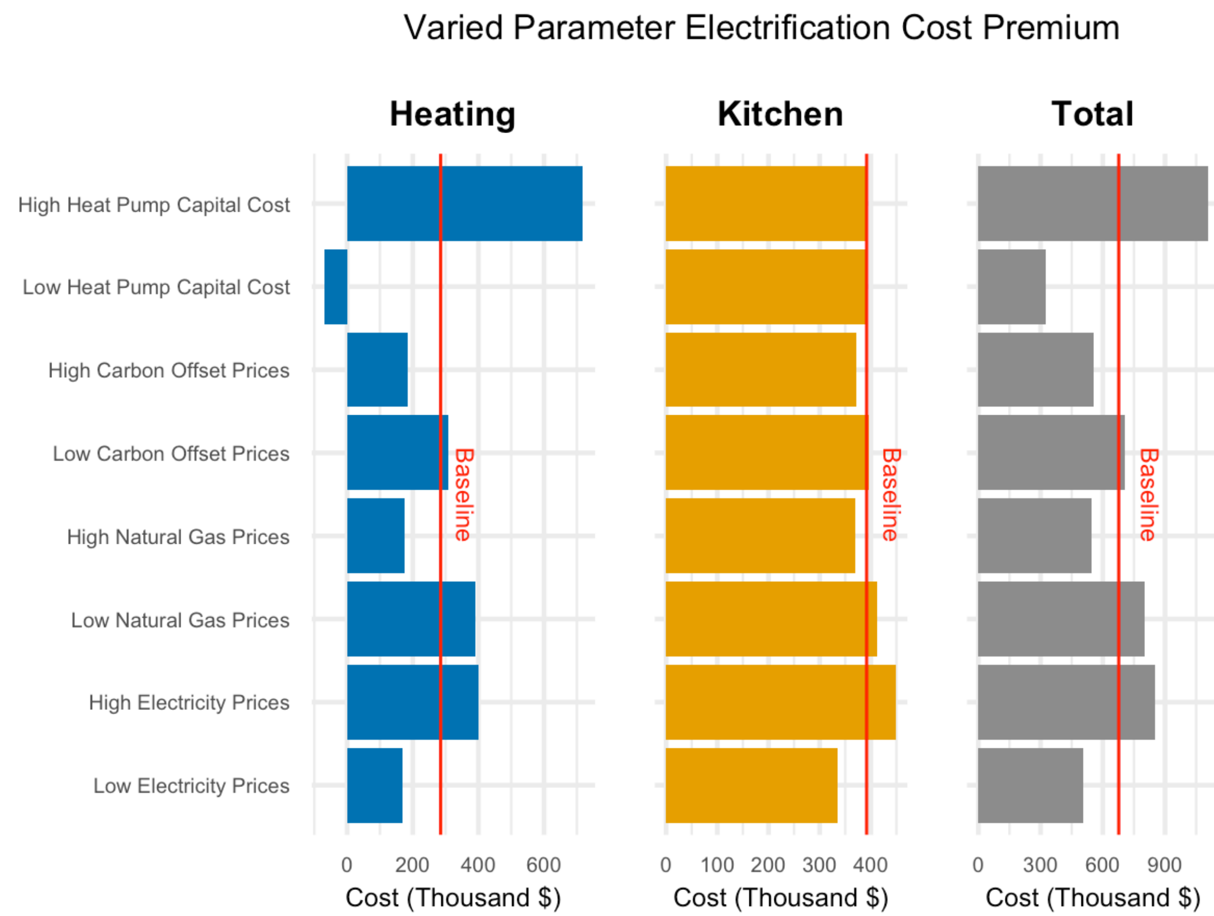

__Figure 8.__ Sensitivity analysis for De La Guerra Dining Commons. Bars show magnitude of electrification premium with associated high and low values for selected model inputs.

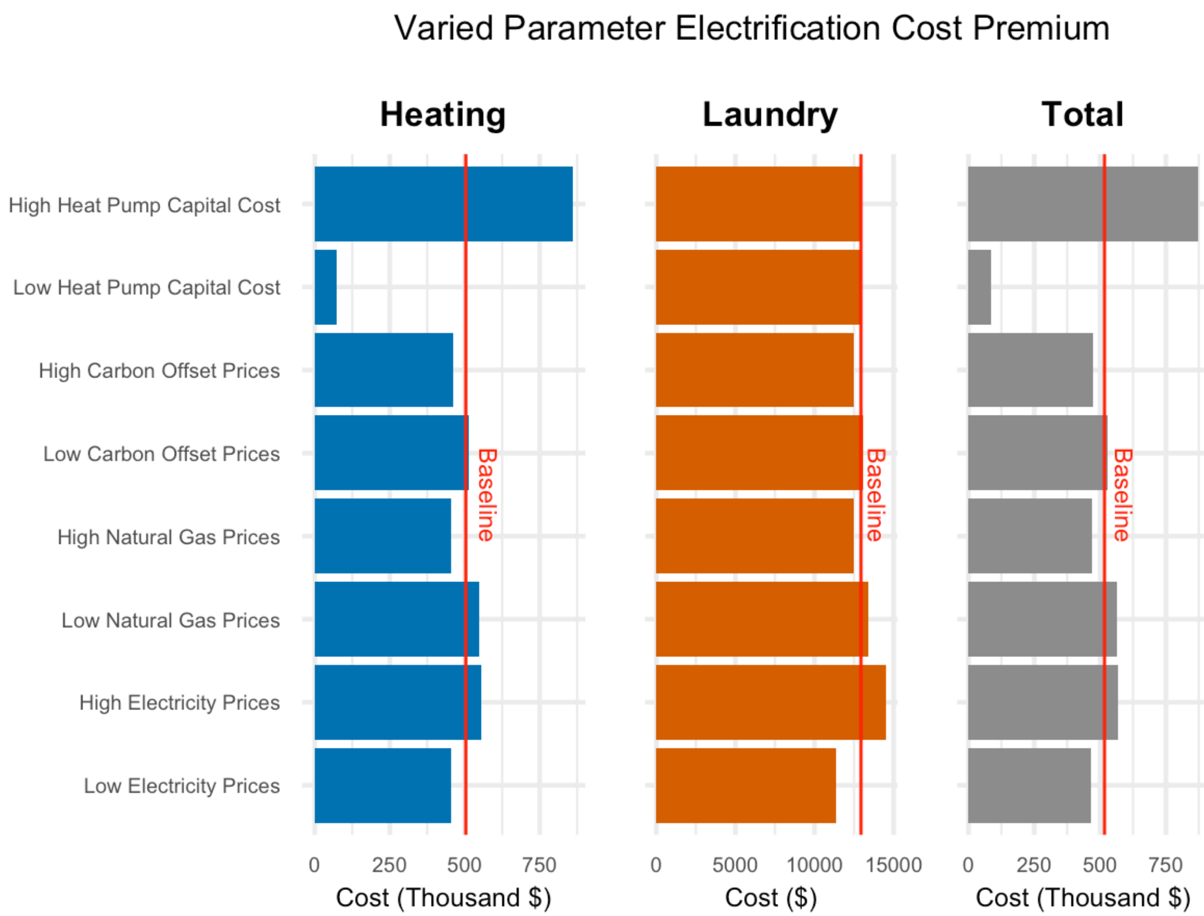

Figure 9. *Sensitivity analysis for San Miguel Residence Hall. Bars show magnitude of electrification premium with associated high and low values for selected model inputs.*

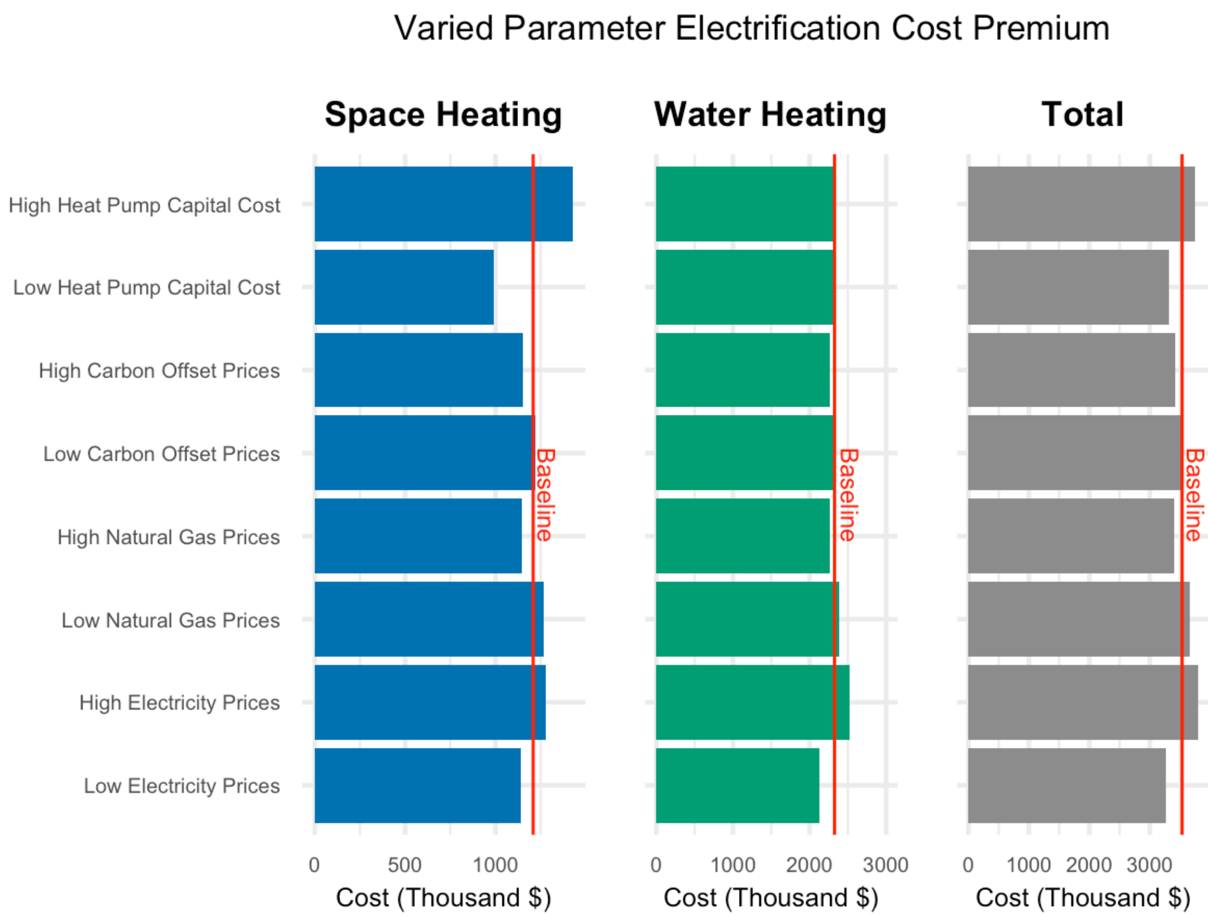

Figure 10. *Sensitivity analysis for West Campus FSH. Bars show magnitude of electrification premium with associated high and low values for selected model inputs.*

Table 3 demonstrates the theoretical changes in parameters necessary for the NPV of our baseline scenarios to be equal. The first two groups of rows display monetary costs, while the latter two groups display percent changes to energy and fuel prices every year, according to each type of parameter inputted into the model. The sensitivity value is either the monetary value or percent change necessary to achieve scenario parity. In the case of “$0” values, this theoretical calculation yielded a negative value as necessary to achieve scenario parity.

***Table 3**. Sensitivity analysis parameters and results. Model took high and low values for heat pump capital costs, carbon offset price, electricity prices, and natural gas prices for each building. Threshold value corresponds to the value that would result in the NPV of our baseline scenarios to be equal, and the amount of change necessary for this is captured by percent change.*

Building	Sensitivity Value Input Range			Threshold Analysis	
	Low	Base	High	Threshold Value	Percent Change
Heat Pump Capital Cost					
San Miguel	$302,500	$798,600	$1,210,000	$166,808	-79%
De La Guerra	$302,500	$711,480	$1,210,000	$0	NA
West Campus	$1,133,798	$1,385,752	$1,637,708	$0	NA
Carbon Offset Price					
San Miguel	$17	$24	$50	$336	1,331%
De La Guerra	$17	$24	$50	$173	638%
West Campus	$17	$24	$50	$842	3,482%
Electricity Rate					
San Miguel	1.2%	2.18%	3.05%	-1,699%	-78,178%
De La Guerra	1.2%	2.18%	3.05%	-120%	-5,622%
West Campus	0.89%	1.66%	2.37%	-1,323%	-79,659%
Natural Gas Rate					
San Miguel	2.3%	3.18%	4.03%	352%	10,987%
De La Guerra	2.3%	3.18%	4.03%	247%	7,682%
West Campus	2.3%	3.18%	4.03%	543%	16,976%

Table 3 reiterates the original results; the capital cost of heat pumps must be reduced in order to achieve an electrification scenario that has an equal or lower NPV of that resulting from natural gas operations. In the case of San Miguel, this percent change is large in magnitude, but smaller than each of the other parameter categories' findings. Carbon offset prices and electricity prices must see drastic swings in prices that could be considered unachievable within our model's time frame. Natural gas prices follow a similar trend; however, these percent swings are much smaller than the previous two parameter categories. This magnitude difference makes natural gas prices an important parameter of consideration when considering the volatility of energy and fuel markets throughout time.

6.5 Summary

Table 4 contains the total cost of electrification and total cost of the continued use of natural gas appliances from 2023 - 2045 in net present value. Electrification is more expensive in all baseline cases. As discussed above, varying heat pump capital cost for San Miguel causes space and water heating costs and total building costs to become cheaper than BAU. No other variation of parameters resulted in a switch from gas to electricity being the cheaper option. The capital cost of electric appliances is consistently the biggest contributing factor, driving the lower cost of natural gas pathways compared to electricity.

Table 4. *Total costs to electrify and operate campus buildings, and to continue operations using natural gas appliances based on simulated models.*

Building	Electrification Total	BAU Total
San Miguel	$1,321,526	$804,848
De La Guerra	$2,956,507	$2,279,735
West Campus	$5,562,965	$2,027,571

7. Discussion and Conclusions

Below are the discussed limitations of this report's analysis. Additional features of the electrification analysis that were considered relevant to this project but out of feasible scope for inclusion in the model are expanded on below.

7.1 Limitations

This model employs many assumptions in order to reduce scope to a reasonable level and fulfill the objectives of the project. These assumptions streamline the analysis, but limit the applicability of the results and their interpretations. A significant assumption throughout is that the function of appliances would be maintained on a 1:1 basis when electrified, meaning no change in quality or functionality of a service provided by an electric appliance compared to a natural gas appliance. This simplifies the analysis considerably, but fails to address the differences between gas and electric appliances. Electrification of buildings will necessitate operational changes, which are not fully understood and could not be accurately modeled, nonetheless, it is worth noting that this simplification leads to inaccuracy. A second notable assumption is that electric equipment replacement was only considered to take place in the year 2023. This simplified the model, and allowed for the direct comparison of the two scenarios. In reality, electrification of these campus buildings will take longer to implement. Electric equipment can be purchased in future years, possibly taking advantage of reduced costs of capital equipment or utility rate changes. Due to the relatively high influence of capital costs, the expected decrease in electric appliance costs in coming years will have a major impact on the overall electrification premium. UCSB should thus use this report's results as a reference when considering electrification. UCSB should also understand that the necessary and unavoidable changes in service when using electrical equipment for some services, and the potential for lower capital costs in the future as technology develops are not considered and may influence the true cost of electrification of these campus buildings.

7.1.1 Electrical Infrastructure

This project considers the electrification of three buildings, but excludes the electrical infrastructure that connects these buildings to UCSB's campus. The electrification of campus buildings would create a higher demand for electricity that UCSB's electrical infrastructure would have to meet. While we acknowledge that electrical infrastructure upgrades will be necessary for the success of this building electrification, quantifying the capital cost of this falls out of this project's scope. The analysis required to include the infrastructure upgrades to support electrified buildings will require calculating the added load of all the equipment being electrified, addressing the new demand load of UCSB's two main transformers as new buildings come online, as well as greater infrastructure to support this as briefly demonstrated by UCSB's 2008 electrification infrastructure upgrades summarized below in 7.2.1. As advised by UCSB Design, Facilities, & Safety Services staff, the complexity and magnitude of analysis required to accurately estimate the infrastructure upgrades necessitates a larger study, and falls outside the scope and expertise of this project. The interpretation of this report should not ignore the backdrop of campus electrical infrastructure, and the costs needed to adapt to support large scale electrification.

7.1.2 San Miguel Laundry Services

The laundry services housed in San Miguel Residence Hall are owned and operated by a third-party servicer, Speed Queen. Speed Queen has operational control of the laundry machines, and is responsible for their maintenance and associated costs. The capital cost of electrifying this service includes the purchasing and installation of electric washers and dryers, and this project assumes that these capital costs will be taken on by Speed Queen, as recommended by HDAE. These technologies are readily available, and are assumed to be provided by Speed Queen for the purpose of this project. This assumption presents a large limitation to the results of this analysis, as capital costs were found to be an influential factor in the total cost of electrification.

The results of the sensitivity analysis show that the electrification of San Miguel Residence Hall could be cost effective when using a low value for heat pump capital costs. The absence of a laundry capital cost included in this model means there is a larger influence of the heat pump capital cost on the total cost of electrification. This limits the applicability of this finding, as it is possible that the capital costs of laundry equipment may not be shouldered entirely by the third party, or that UCSB would want to own and operate laundry services, and would therefore incur the total capital and installation costs of the laundry machines. It is also important to note that we believe if UCSB asks Speed Queen to switch to electric washers and dryers in 2023, the cost may be high, but not incrementally more than the costs of natural gas laundry machines going through end-of-life.

7.1.3 Boiler and Heat Pump Capacity

The results of this project show that heat pump capital costs are a large factor in the total cost of electrification. The interpretation of this result, however, is limited by the uncertainty in the price and size of heat pumps necessary to complete the building electrification. Common design practice when employing natural gas boilers is to oversize their capacity relative to the demand they will fulfill, due to the relatively insignificant expense of increasing the size of a boiler. Since the cost to increase the capacity of a boiler is low, buildings will default to installing a boiler that is oversized, and will have excess capacity after meeting maximum demand. This project chose to size heat pump replacements with the same capacity as the boilers they replace in the electrification scenario. However, since these boilers are likely oversized, the costs of heat pumps considered in this project are likely higher than necessary to fulfill the space and water heating demands in the buildings considered.

7.1.4 Caveats about Use of Biomethane

This project considers one scenario of continued use of natural gas with emissions mitigated through the purchase of offsets and biomethane. Biomethane is a renewable natural gas that is produced from decayed organic matter through the process of anaerobic digestion (Commission). Biomethane is an appealing element to decarbonization because it can be used wherever natural gas is used without the need to change the equipment or infrastructure. The use of biomethane for campus's natural gas appliances helps to support California's climate goals because of its low greenhouse gas emissions and significant reduction of nitrogen oxides. As of 2023, the UC system plans to continue contracting activities that produce biomethane certificates, but acknowledges that this substitution is a stepping stone to carbon neutrality rather than a long-term solution. Similar to natural gas, biomethane is composed entirely of methane (CH_4) and thus has the potential to leak emissions from gas infrastructure. Biomethane leakage is a huge source of concern from a climate perspective, as methane has 80 times the global warming potential of CO_2. Research has shown that nationwide fugitive methane emissions from gas distribution pipelines are approximately five times greater than the U.S. EPA inventory has reported (Weller et al., 2020) and the use of biomethane would only exacerbate these existing leakage challenges. Leaks in the natural gas infrastructure and appliances of DLG, San Miguel, West Campus are uncertain, thus posing a limitation on our analysis and making our net zero carbon assumption for biomethane uncertain.

Biomethane is not changing the energy grid in actuality which presents another caveat to its use, but does provide additional motivation for UCSB to electrify. According to the Biden Administration's U.S. Methane Emissions Reduction Action Plan, building electrification provides one potential strategy to avoid methane emissions (*U.S. Methane Emissions Reduction Action Plan*, 2021). Concurrently, the Department of Energy recently launched its Initiative for Better Energy, Emissions, and Equity, a national research initiative with the focus of deploying clean, efficient heating and cooling systems in commercial and residential buildings and new appliance standards for electric induction stoves and heat pump technologies. While biomethane is a feasible, temporary solution, its procurement is only a drop-in strategy, and these policies show momentum towards electrification in lieu of these partial solutions.

7.2 Discussion

7.2.1 Cost of Electrification and Potential Funding Opportunities

Electrification of carbon intensive infrastructure will always require capital investment. Increasing the electrical load of transmission lines, improving wiring within a building, as well as upgrading structures including substations and transformers, is a substantial undertaking and requires cooperation between power companies, local governments, and the groups looking to electrify their facilities.

In 2008, UCSB completed a $22 million electrical infrastructure upgrade running 135,000 circuit feet of electrical cables, 90,000 feet of new conduit, 75,000 feet of fiber optic cables, and two new main 66 kilovolt substation transformers (*UCSB Completes $22 Million Electrical Infrastructure Upgrade*, 2008). These substations are the campus's current two main transformers and required the assistance of Southern California Edison to reliably provide a steady stream of electricity. UCSB's past work in upgrading electrical infrastructure helps demonstrate the transformative changes to campus infrastructure required to integrate more electrical capacity. Electrical infrastructure upgrades are required when demand for electricity is dramatically increased through the proposed decarbonization efforts.

Quantification of these costs requires a thorough engineering study and expert recommendations, and would also impact other buildings on campus besides the three of interest in this project. With increased demands for housing on campus, there may be opportunity to utilize the construction of these buildings and their additional electrical demands to increase electrical capacity of the campus as a whole. Upgrading transmission lines and installing substations could not only support the new housing, but also other electrification efforts so the cost per unit of electricity supplied may be lowered overall.

Capital costs that were used in this model are likely to change in the future, and decarbonizing technologies such as heat pumps and electric kitchen equipment should decrease in price per unit as their market share increases. While incentives for residential decarbonization are already available at local, state, and federal levels, there are less opportunities on a commercial scale. Under the Biden Administration and the passage of the Inflation Reduction Act, new funding may be available for commercial buildings such as those considered in this model. Tax credit 179D outlines that savings may be available if certain energy efficiency requirements are met, up to $1.88 per square foot. Energy savings necessary to receive this credit can be achieved through changes to building operations such as the installation of heat pumps or substitution of natural gas appliances (Rep. Yarmuth, 2022). Furthermore, because the Inflation Reduction Act pushes for energy efficiency and decarbonization, industry investment in technology should continue to bring down capital costs.

7.2.2 Resiliency and Battery Storage

Resilience is the ability of a system to remain uninterrupted despite changes in external forces; integrating resilience into design is a pillar of climate adaptation, and is a necessary aspect of decarbonization efforts. Resiliency of campus electrical infrastructure is important to ensure that operations are not interrupted in the event of an energy supply disturbance. Currently, De La Guerra Dining Commons has backup diesel generators that are run for a short time monthly for routine testing. These backup generators start up in the event that energy supply to campus is interrupted and can run for several days at reduced output. When transitioning to an all-electric building, other systems that create resiliency should be considered in place of the diesel backup generators. An option for an all-electric system is installed battery storage for each building. Battery storage would allow for continued service if external electricity is interrupted, while additionally allowing the system to recharge when electricity prices are lower, and discharge when electricity is in peak demand on the grid, offsetting peak demand pricing premiums for the University. When designing for resilience, battery storage is an option that would allow UCSB's campus buildings to adapt to changing conditions.

7.2.3 Changes to Kitchen Function

In order to electrify a building, all services provided by natural gas appliances will need to be instead met by electric appliances. This project considers all appliance swaps that would be required, including each kitchen appliance in De La Guerra Dining Commons. For the sake of simplicity, this project has assumed that there would be no changes in service or capability with the electrification of appliances. This assumption, although crucial for the objectives of this project, does not represent the reality of electrifying a commercial kitchen. Electrification in the commercial kitchen sector has barriers that stem from a lack of widely conducted studies, varied availability of direct replacements, and necessary kitchen staff engagement.

At this time there are no available commercial kitchen electrification case studies for reference. This project's methodology for selecting kitchen appliances thus references industry expertise, and a conceptual assumption that these appliances would be drop-in replacements. When considering kitchen electrification, this project researched a philosophy proposed by the Food Service Technology Center (FISHNICK), a team of engineers, technicians, and culinary experts who advise the commercial foodservice industry on how to become more sustainable in purchasing decisions. FISHNICK developed a “Kitchen Of the Future”, which transitions the traditional food cookline to a more energy efficient, compact layout (Young, 2019). The reality of an efficient electrified commercial kitchen requires a redesign to promote and maximize the functionality of electrical appliances, which this project does not account for in its model.

When transitioning to an electric kitchen there will be changes to service due to the difference in cooking technique between natural gas appliances and their electrical counterparts; in some cases, there are no electrical counterparts due to the specific reliance on natural gas for a cooking technique. This circumstance is found in DLG, as the service provided by the char broiler may no longer be possible due to the lack of an electric version of the appliance. This means that with a fully electrified kitchen in DLG, there will be no charbroiled burgers as there are found now, a small caveat to this project’s assumption of no changes in service. This is one example of necessary adaptations to service that will need to be accepted in order to transition to an electric kitchen, while still meeting the day-to-day demands of providing food to students on campus. Adapting to small changes in service is necessary when electrifying a commercial kitchen, but broadly services will remain intact.

Beyond this, other behavioral changes will be imperative for the transition. Chefs and kitchen staff may be hesitant to shift from natural gas to electric cooking, fueled partly by the concern of sacrificing food quality, and partly by expected resistance to change. However, induction cooking appliances are known to cook more quickly and precisely than gas-fired cooking, and may help to cut down on overall cook times, improving efficiency for output of food (*Electrifying Commercial Kitchens Across Sectors | Better Buildings Initiative*, n.d.). Adapting to electrical cooking techniques is an anticipated barrier to the adoption of electrification, but proven performance of these appliances is expected to help garner support of kitchen staff.

7.2.4 Social Cost of Carbon

The goal of electrification is to eliminate carbon emissions for the purpose of mitigating climate change damages. Emissions released by on campus activities contribute to this global problem, and thus contribute to the damages felt by climate change across the globe. The Social Cost of Carbon (SCC) quantifies these impacts of climate change and allows decision makers to acknowledge the true cost of carbon emissions released. To integrate the SCC into this analysis, the EPA's established SCC would be a reputable and standardized value for UCSB to consider.

For the purposes of this project, the SCC is not considered because the emissions created in the natural gas scenario are considered net zero. The natural gas pathway is modeled to include the purchase of carbon offsets to mitigate emissions from continued operations. This use of carbon offsets means, theoretically, that the emissions created in this scenario are not contributing to climate damages because there are offset measures taken of the same magnitude. Since these emissions are being offset, this project does not account for climate damages through an SCC or other means. Carbon offset pricing was provided by UCSB, though prices of carbon offsets vary dramatically, as does the reputability of offsets. Future analysis could be performed by assessing the quality of carbon offsets selected for UCSB, particularly given concerns about additionality of offsets, and utilizing different prices for carbon offset options with varying prices.

7.3 Future Work

The work done in completion of this project sheds light on important aspects of building electrification that should be addressed in order to best prepare for the decarbonization of campus buildings. A severe limitation to this project was data availability including accessibility of natural gas use metering data. Installing sub meters to individual boilers and the pipes that supply natural gas into the kitchen would provide a granularity in readings that allows for more precise parsing of natural gas use between the boilers, kitchen, and CNG filling station. Maximizing electrical efficiencies in buildings will help with the overall shift to electricity. Improving the electrical efficiencies throughout buildings will minimize overall future energy demand, and reduce the amount of supply that must be met by a new electrified system. This project recommends maximizing these efficiencies wherever possible. Lastly, this project recommends continually monitoring the decline in costs for decarbonization technology such as heat pumps and electric kitchen appliances. As these technologies become more prevalent, their price per unit should decline as production of these products increases.

Appendix

Table 5. *Current and future recommended technologies used in De La Guerra Dining Commons.*

De La Guerra Dining Commons					
Appliance	**Model**	**Natural Gas / Electric**	**Efficiency**	**Capital Costs**	**Citation**
Boiler	De La Guerra Parker Boiler Model 105-70	Natural Gas	0.7976	439113	Link to Efficiency Capital cost estimates were provided by Clients
	Unspecified	Heat Pump	3.5	588000	Efficiency estimate provided by External Advisor Link to Capital Cost Estimates
Rotating Rack Oven	Baxter OV210G2	Natural Gas	0.48	43797	Link to Efficiency Link to Capital Cost Estimates
	Doyon SRO2E Electric Double Rotating Rack Bakery Convection Oven	Electric	0.65	46595	Link to Efficiency Link to Capital Cost Estimates
2 Burner Cooktop	2 Burner Cooktop (US Range Co, Montague Company) Model C24-9	Natural Gas	0.4	27600	Link to Efficiency Link to Capital Cost Estimates
	Vollrath 912HIDC Cayenne Heavy Duty Double Induction Hot Plate with Digital Controls	Electric	0.84	14544	Link to Efficiency Link to Capital Cost Estimates
4 Burner Cooktop	4 Burner Cooktop (US Range Co, Montague Company) Model 24-5	Natural Gas	0.4	8000	See 2-Burner Cooktop Efficiency Link to Capital Cost Estimates
	Vollrath Cayenne HD 208 to 240 Heavy Duty Four Hub	Electric	0.84	23600	See 2-Burner Cooktop Efficiency Link to Capital Cost Estimates

	Induction Range				
	Charbroiler Grill Montague Corporation UFLC-36R	Natural Gas	0.48	7759	Link to Efficiency Link to Capital Cost Estimates
Charbroiler Grill	Star Max 5136CF_208/60/1 36" Stainless Steel Electric Charbroiler	Electric	N/A	5674	Efficiency Rating is lacking Link to Capital Cost Estimates
	H55 and H55-2 High Efficiency Gas Fryers - Domestic and Import	Natural Gas	0.54	32248	Link to Efficiency Link to Capital Cost Estimates
Fryer	Imperial Range IFS-50-E 50 lb Electric Fryer	Electric	0.8	34616	Link to Efficiency Link to Capital Cost Estimates
	Heavy Duty 12-36" Countertop Griddle	Natural Gas	0.4	25044	Link to Efficiency Link to Capital Cost Estimates
Grill	Garland E24-36G 36" Heavy Duty Electric Countertop Griddle	Electric	N/A	17022	Efficiency rating is lacking Link to Capital Cost Estimates
	Double Deck Gas Pizza Oven Montague Corporation 25-P2	Natural Gas	0.49	29414	Link to Efficiency Link to Capital Cost Estimates
Pizza Oven	Bakers Pride EP-2-8-5736 74" Double Deck Electric Pizza Oven	Electric	0.65	40564	Link to Efficiency Link to Capital Cost Estimates
	Vectaire Double Deck, Full Size Gas Convection Oven	Natural Gas	0.49	29134	See Pizza Oven Efficiency Link to Capital Cost Estimates
Convection Oven	Vulcan VC55ED - 240/3 Double Deck Full Size Electric Convection Oven	Electric	0.65	11840	See Pizza Oven Efficiency Link to Capital Cost Estimates

	Tilting Braising Pan	Natural Gas	0.5	53130	Link to Efficiency Link to Capital Cost Estimates
Tilt Skillet	Groen BPM-40EC Stainless Steel 40-Gallon Tilting Electric Braising Pan	Electric	0.8	40062	Link to Efficiency Link to Capital Cost Estimates

Table 6. Current and future recommended technologies used in San Miguel Residence Hall.

San Miguel Residence Hall					
Appliance	**Model**	**Natural Gas / Electric**	**Efficiency**	**Capital Costs**	**Citation**
	Natural Gas	Speed Queen Provided	3.48	0	Link to Efficiency
Dryers	Electric	Speed Queen Provided	3.93	0	Link to Efficiency
	Natural Gas	Parker Water Wall Series 204L-G2304RL	0.82	249690	Link to Efficiency Capital Cost Estimate provided by Client
Boiler	Electric	No specified brand - heat pump	3.5	433000	Efficiency estimate provided by External Advisor See report for Capital Cost Estimation Description

Table 7. Current and future recommended technologies used in West Campus FSH Apartment Complex.

West Campus FSH Apartment Complex					
Appliance	**Model**	**Natural Gas / Electric**	**Efficiency**	**Capital Costs**	**Citation**
	Natural Gas	Speed Queen Provided	3.48	0	Link to Efficiency
Dryers	Electric	Speed Queen Provided	3.93	0	Link to Efficiency

	Natural Gas	Williams AC2030T	0.82	328750	Link to Efficiency and Capital Costs
Wall Furnaces	Electric	Non-specified mini-split ductless heat pump	3.5	1145250	Efficiency Provided by External Advisors Capital Costs were estimated based on several mini-split ductless heat pumps available on market at time of project completion
	Natural Gas	RayPak High Delta Water Heater	0.85	220500	Link to Efficiency Link to Capital Cost Estimate
Boiler	Electric	Rheem Commercial Heavy-Duty 120 Gal. 240-Volt 18 kW 3 Phase Electric Surface Thermostat Tank Water Heater	1	131187	Link to Efficiency Link to Capital Cost Estimate

References

2020-2021 Annual Sustainability Report to the Chancellor. (2021). UC Santa Barbara Sustainability. https://sustainability.ucsb.edu/sites/default/files/images/2022-02/Annual%20Sustainability%20Report%20to%20the%20Chancellor%20(20_21)%20(3)%20(1).pdf

Building Decarbonization | California Air Resources Board. (n.d.). Retrieved February 4, 2023, from https://ww2.arb.ca.gov/our-work/programs/building-decarbonization

Commission, C. E. (current-date). *Energy Efficiency in Existing Buildings*. California Energy Commission; California Energy Commission. https://www.energy.ca.gov/programs-and-topics/programs/energy-efficiency-existing-buildings

De La Guerra Dining Commons | UCSB Dining. (n.d.). Retrieved February 18, 2023, from https://dining.ucsb.edu/dining-commons/de-la-guerra-dining-commons

Defying expectations, CO2 emissions from global fossil fuel combustion are set to grow in 2022 by only a fraction of last year's big increase—News. (n.d.). IEA. Retrieved January 22, 2023, from https://www.iea.org/news/defying-expectations-co2-emissions-from-global-fossil-fuel-combustion-are-set-to-grow-in-2022-by-only-a-fraction-of-last-year-s-big-increase

Electrifying Commercial Kitchens Across Sectors | Better Buildings Initiative. (n.d.). Retrieved February 23, 2023, from https://betterbuildingssolutioncenter.energy.gov/beat-blog/electrifying-commercial-kitchens-across-sectors

Energy | UCOP. (n.d.). Retrieved May 24, 2022, from https://www.ucop.edu/sustainability/policy-areas/clean-energy/index.html

Energy Information Administration (EIA)- About the Commercial Buildings Energy Consumption Survey (CBECS). (n.d.). Retrieved March 17, 2023, from https://www.eia.gov/consumption/commercial/data/2018/bc/html/b6.php

Existing Buildings | California Air Resources Board. (n.d.). Retrieved February 4, 2023, from https://ww2.arb.ca.gov/our-work/programs/building-decarbonization/existing-buildings

Frequently Asked Questions (FAQs)—U.S. Energy Information Administration (EIA). (n.d.). Retrieved February 4, 2023, from https://www.eia.gov/tools/faqs/faq.php

Heat Pump Water Heaters. (n.d.). Energy.Gov. Retrieved February 4, 2023, from https://www.energy.gov/energysaver/heat-pump-water-heaters

Hicks, A. (2022). 2022 State SIP Strategy. *California Air Resources Board*.

Industrial Heat Pumps for Steam and Fuel Savings. (2003). U.S. Department of Energy Energy Efficiency and Renewable Energy.

https://www.nrel.gov/docs/fy03osti/33971.pdf

Kirk, C. (2022, July 6). *Best Practices Among UC Campuses for Decarbonization—UC Davis* [Personal communication].

Mahone, A., Li, C., Subin, Z., Sontag, M., Mantegna, G., Karolides, A., German, A., & Morris, P. (2019, April). *Residential Building Electrification in California: Consumer economics, greenhouse gases and grid impacts*. https://www.ethree.com/wp-content/uploads/2019/07/CA_Res_Building_Electrification_Final_Presentation.pdf

Newsom, G. (n.d.). *Characterization of Fugitive Methane Emissions from Commercial Buildings in California*.

Occupational Employment and Wages in Santa Barbara-Santa Maria-Goleta, May 2013: Western Information Office : U.S. Bureau of Labor Statistics. (n.d.). Retrieved February 4, 2023, from https://www.bls.gov/regions/west/news-release/2014/occupationalemploymentandwages_santabarbara_20140603.htm

President Napolitano proposes tuition freeze, new systemwide initiatives. (2013, November 13). University of California. https://www.universityofcalifornia.edu/press-room/president-napolitano-proposes-tuition-freeze-new-systemwide-initiatives

Rep. Yarmuth, J. A. [D-K.-3. (2022, August 16). *H.R.5376 - 117th Congress (2021-2022): Inflation Reduction Act of 2022* (08/16/2022) [Legislation]. http://www.congress.gov/

Robinson, C. (n.d.). *2019 California Energy Efficiency Action Plan*.

San Miguel | Campus Housing. (n.d.). Retrieved February 18, 2023, from https://www.housing.ucsb.edu/housing-options/options-filter/san-miguel

Stoll, K. (2022, June 28). *Best Practices Among UC Campuses for Decarbonization—UC Berkeley* [Personal communication].

Strategies for Replacing Natural Gas to Help Decarbonize the University of California. (n.d.). National Center for Ecological Analysis and Synthesis. Retrieved February 6, 2023, from https://www.nceas.ucsb.edu/tomkat-natural-gas-replacement-strategies

Summary for Policymakers (pp. 3–33). (2022). IPCC. https://www.ipcc.ch/report/ar6/wg2/downloads/report/IPCC_AR6_WGII_SummaryForPolicymakers.pdf

The Capital Stock Turnover Problem for 100% Clean Energy Targets. (n.d.). Retrieved March 17, 2023, from https://www.greentechmedia.com/articles/read/the-capital-stock-turnover-problem-for-100-clean-energy-targets

UCSB Completes $22 Million Electrical Infrastructure Upgrade. (2008, November 10).

The UCSB Current. https://www.news.ucsb.edu/2008/012502/ucsb-completes-22-million-electrical-infrastructure-upgrade

US EPA, O. (2015, August 10). *Greenhouse Gases Equivalencies Calculator—Calculations and References* [Data and Tools]. https://www.epa.gov/energy/greenhouse-gases-equivalencies-calculator-calculations-and-references

U.S. Methane Emissions Reduction Action Plan: Critical and Commonsense Steps To Cut Pollution And Consumer Costs, While Boosting Good-Paying Jobs And American Competitiveness. (2021). The White House Office of Domestic Climate Policy. https://www.whitehouse.gov/wp-content/uploads/2021/11/US-Methane-Emissions-Reduction-Action-Plan-1.pdf

Weller, Z. D., Hamburg, S. P., & von Fischer, J. C. (2020). A National Estimate of Methane Leakage from Pipeline Mains in Natural Gas Local Distribution Systems. *Environmental Science & Technology*, *54*(14), 8958–8967. https://doi.org/10.1021/acs.est.0c00437

West Campus Family | Campus Housing. (n.d.). Retrieved February 19, 2023, from https://www.housing.ucsb.edu/housing-options/options-filter/west-campus-family

Yang, H. T., Auston, D., Fisher, M., Covarrubias, N., Snavely, J., Behlman, J., Haines, C., Sarkar, A., Nocciolo, M., McTague, B., Macy, T., Riley, A., Suh, S., Switzer, J., Rousseau, M., Tiffney, B., Sager, J., Lovegreen, M., Maynard, K., & Getty, A. (2016). *UC Santa Barbara Climate Action Plan 2016*. 43.

Young, R. (2019, October 11). *Using Energy Efficiency To Decarbonize Kitchens*. https://gettingtozeroforum.org/wp-content/uploads/sites/2/2019/10/RichardYoungFrontierEnergyNBIGTZwithEEKitchens10112019.pdf