CALIFORNIA ENERGY COMMISSION

Energy Research and Development Division

APPENDICES A, B and C: Using Big Data to Holistically Assess Benefits from Building Energy System Transition Pathways in Disadvantaged Communities

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APPENDIX A: Introduction and Project Approach

A.1. Study Area Demographic Data

Table A-1: Demographic Data for Avocado Heights and the City of El Monte

2010 demographic information from www.census.gov/quickfacts

Fact	Fact Note	Avocado Heights CDP, California	City of El Monte, California
Population, Census, April 1, 2010		15,411	113,475
Persons under 5 years, percent		6.50%	6.10%
Persons under 18 years, percent		21.70%	24.40%
Persons 65 years and over, percent		13.50%	12.40%
Female persons, percent		49.80%	50.40%
White alone, percent	(a)	46.00%	50.80%
Black or African American alone, percent	(a)	0.10%	0.50%
American Indian and Alaska Native alone, percent	(a)	0.40%	0.50%
Asian alone, percent	(a)	11.10%	28.80%
Native Hawaiian and Other Pacific Islander alone, percent	(a)	0.00%	0.30%
Two or More Races, percent		2.30%	1.40%
Hispanic or Latino, percent	(b)	82.00%	65.70%
White alone, not Hispanic or Latino, percent		6.40%	4.20%
Veterans, 2012-2016		487	1,778
Foreign born persons, percent, 2012-2016		35.00%	49.20%
Owner-occupied housing unit rate, 2012-2016		76.40%	39.30%
Median value of owner-occupied housing units, 2012-2016		$403,600	$374,900
Households, 2012-2016		3,893	30,114
Persons per household, 2012-2016		4.13	3.8
Language other than English spoken at home, percent of persons age 5 years+, 2012-2016		72.60%	84.20%
In civilian labor force, total, percent of population age 16 years+, 2012-2016		61.70%	58.30%
In civilian labor force, female, percent of population age 16 years+, 2012-2016		54.20%	49.70%
Total health care and social assistance receipts/revenue, 2012 ($1,000)	(c)	15,959	215,439
Mean travel time to work (minutes), workers age 16 years+, 2012-2016		30.2	31.3
Median household income (in 2016 dollars), 2012-2016		$71,799	$40,654
Persons in poverty, percent		11.80%	23.80%
Population per square mile, 2010		5,695.10	11,867.30
Land area in square miles, 2010		2.71	9.56
FIPS Code		"0603344"	"0622230"

NOTE: FIPS Code values are enclosed in quotes to ensure leading zeros remain intact.

(a) - Includes persons reporting only one race

(b) - Hispanics may be of any race, so also are included in applicable race categories

(c) - Economic Census - Puerto Rico data are not comparable to U.S. Economic Census data

Source: UCLA

A.2. Project Schedule

Table A-2: Project Schedule Showing Major Tasks

Task	2018		2019				2020				2021			
	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Community Outreach and Survey														
Air Quality Monitoring and Questionnaires														
Air Quality Data Analysis and Interpretation														
Building Scale Energy Modeling														
Review of Historic Transitions Data and Forecasting														
Community Scale Energy Modeling and Holistic Assessment														
Develop Final Project Report														
TAC Meeting #1														
TAC Meeting #2														
TAC Meeting #3														
Communication back to participants and community														

Source: UCLA

APPENDIX B: Methods

B.1. Survey

Figure B-1: Survey

Healthy Home Study Survey

All information will be used solely to inform our outreach and will be kept completely confidential. Unless you indicate you would like more information on the final page of this survey, you will not be contacted for any reason.

Zip Code:__________ Average monthly electric bill $___________ Gas bill $___________ Water bill $__________

1. **Number of people in household: Adults ______ Children (under 18) ______**

2. **Do you rent or own the property?** Rent Own

3. **What type of building do you live in?**
   - □ Single Family Home
   - □ Townhouse or Condominium
   - □ Multi-Unit Dwelling (2-4 units)
   - □ Apartment Building (5 or more units)
   - □ Mobile Home
   - □ Other (Please specify) ____

4. **What type of heating and cooling do you use in your home? (Check all that apply)**
   - □ Central heating
   - □ Central air
   - □ Wall heaters:
     □Gas □Electric □I don't know
   - □ Space heaters:
     □Gas □Electric □I don't know
   - □ Wall/window mounted air conditioners
   - □ Standalone fans
   - □ Ceiling fans
   - □ Other (Please specify) ____

5. **Do you currently use any energy saving practices? (Check all that apply)**
   - □ Turn off lights in unoccupied rooms
   - □ Use energy efficient bulbs
   - □ Wash clothes in cold water only
   - □ Purchase efficient refrigerator, clothes dryer, water heater, stove or other appliance
   - □ Unplug TV / computer / electronics or use smart power strips
   - □ Weatherize doors or windows
   - □ Insulate water heater
   - □ Upgrade wall / ceiling / attic insulation
   - □ Set thermostat to 68 for heating and 78 for cooling when home
   - □ Solar panels
   - □ Other (Please specify) ____
   - □ I do not use any energy saving practices

6. **Does anyone in your household drive a plug in hybrid or electric battery vehicle?** Yes No

7. **Do you have an electric charging station at home? If so, what type?**
   □Level 1 □Level 2 □I do not have a charging station at home

8. **Is anyone in your household planning to purchase a hybrid or electric vehicle within the next 2 years?**
   Yes No
   Please describe why: ____

9. Is anyone in your household planning to purchase rooftop solar panels within the next 2 years?
Yes No
Please describe why: ____________________

10. Is anyone in your household planning to replace any natural gas appliance with an electric appliance within the next 2 years? If yes, check the appropriate appliances below. (Check all that apply)
□ Water heater □ Space heater □ Stove □Dryer
Please describe why: ____________________

11. I would be interested in receiving more information about how I can (Check all that apply):
□ Receive financial support for gas and/or electric bills
□ Lower my electric / gas / water bill
□ Receive free efficiency upgrades
□ Find out if I qualify for free rooftop solar panels
□ Access appliance rebates
□ Replace my gas-powered lawn mower
□ Receive rebates for the purchase of new or used hybrid / electric vehicles
□ Receive financing / loan information to purchase electric vehicles, solar panels, or perform more extensive energy efficiency retrofits for my home

12. UCLA is conducting a study to test the air quality within several homes in Los Angeles county. This requires select homeowners to host two small air quality monitors in their homes (family room) and one outside the home for two weeks. Would you be interested in learning more and possibly participating in this study? Yes No

13. If yes, when would you be available to participate in the study? Winter 2019 Summer 2019 Both

14. Do you have reliable wifi in your home? Yes No

15. Does anyone in your household smoke? (Smoking refers to the inhalation of smoke products of any kind via cigarettes, cigars, vaping, etc.) Yes No

16. If you answered yes to #12 please provide your contact information.

Name:____________________ **Phone:**____________________

Address:____________________

Email: ____________________

What is your preferred language? ____________________

17. What is the best way for you to learn more about available utility bill savings, clean energy, and clean vehicle incentive programs? (Check all that apply)
□ Workshops or one-to-one consultation available
□ At home consultations with outreach staff from a local community-based organization
□ At home consultations with SoCal Edison, SoCal Gas, or local service representative
□ Online information
□ Printed materials
□ Other (Please specify) ____________________

18. Would you be interested in receiving more information about future Active San Gabriel Valley events and activities? Yes No

Source: Active San Gabriel Valley

Air Quality Monitoring Methodology

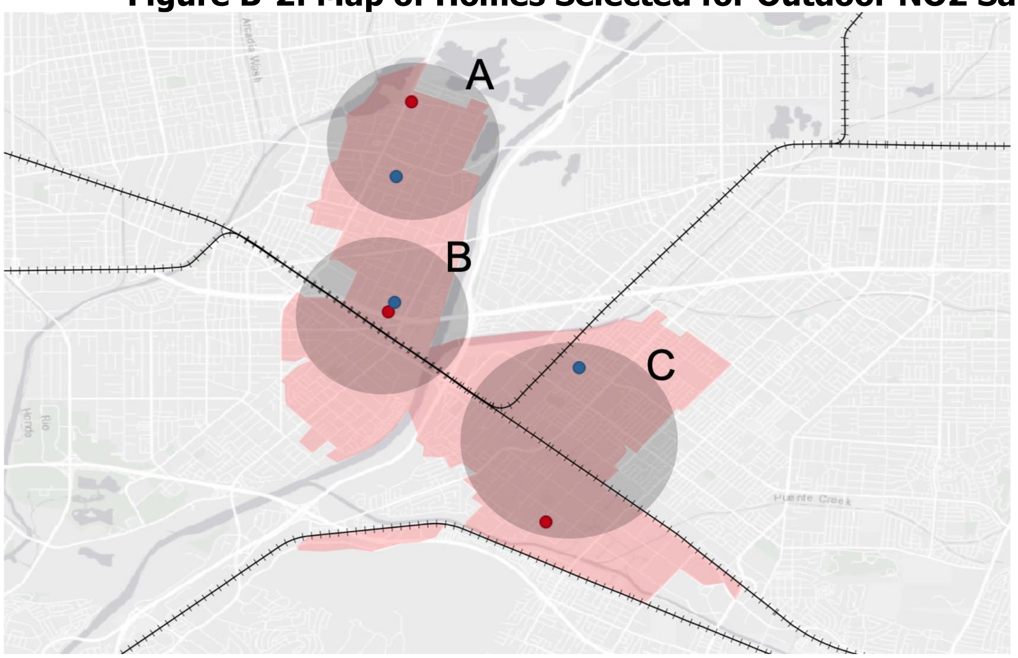
B.2.1 Human Subjects Research – University Review

After submitting an Internal Review Board (IRB) application to the UCLA Office of the Human Research Protection Program and speaking directly with IRB staff, the team received an official determination that this study is not categorized as "human subjects research". The indoor air quality questionnaires do not include questions about health, medical, or income information, nor is such data collected through other means for individual residents. Nevertheless, various IRB recommended best practice tools were used in the study, including informed consent forms and data privacy forms (provided in the attachments) which will be signed prior to any work being done in the home, as well as the use of procedures for data privacy and anonymization.

B.2.2 Controls for Outdoor Sources and Weather

To understand the impact from outdoor NO_2, a small subset of homes was selected for outdoor NO_2 analysis. Three primary outdoor environments were identified to understand the effects of local sources on ambient air and residential penetration factors specific to the focus area (Figure B-2). One home was selected for outdoor NO_2 sampling to represent each of the following environmental categories: (A) local removed from any identifiable competing sources; (B) near major roadways; and (C) near industrial emissions. These three distinct environments provided information about the impact of local NO_2 sources and the penetration factors on adjacent homes.

Figure B-2: Map of Homes Selected for Outdoor NO2 Sampling



Homes shown in blue circles (winter) and red circles (summer) were selected to represent areas (A) removed from any identifiable competing sources; (B) near major roadways; and (C) near industrial emissions.

Due to the lack of available meteorological data in the target area, the team also used three Ambient Weather WS-1002- WiFi Smart Weather Stations in the target sampling area during February through August 2019.

B.2.3 QA/QC, Data Management, and Privacy

Air quality data was acquired following the technical guidelines provided by sampler manufacturers. Field metadata was recorded in field notebooks and Chain of Custody (CoC) forms, scanned and transcribed (as needed) and input to Excel spreadsheets for analysis.

Passive NO2 samplers included trip blanks, field blanks, and replicate samples to ensure quality assurance and quality control (QA/QC) compliance. Ogawa passive samples were analyzed by RTI Laboratories, a State of California-certified laboratory. Laboratory deliverables were validated to assess method compliance, calibration frequency and acceptability, QC frequency and acceptability, and data usability when failures are identified.

Speciated data from the ambient PM monitors will be available for public viewing and download through the manufacture's online clearinghouse (if participant has wifi). Data from the indoor PM monitors was set to private and the data was only accessible to project team members, unless the homeowner opted to voluntarily to display these data on the web as part of the PurpleAir map. All PM data was downloaded from USB drives at the end of the project collection period and stored on the project's UCLA Box shared account, which is only accessible to the project team.

Questionnaires were collected at the end of each sampling day, and digitized into Excel by project personnel. The original hardcopy questionnaires were stored at UCLA offices, which have restricted access, and digitized copies will be saved to the project's UCLA Box shared account.

B.3. Energy System Modeling Method Overview

B.3.1 Residential DER Adoption Scenarios and Pathways

Table B-1: Household Scale Prototype Building Model Scenarios – Residential DER Adoption

Scenario Name	***Summary Parameter Description***
Baseline Scenario	Household without solar PV or behind the meter energy storage systems
Solar Only	Household with solar PV maximized for available suitable rooftop area
Storage Only	Household with battery storage system sized for peak electricity load
Solar + Storage	Household with solar PV maximized for rooftop size and a battery storage system sized for peak PV production and peak electricity load

Source: The Energy Coalition

Table B-2: Community Scale Energy System Pathways – Residential DER Adoption

Pathway Name	***Summary Description***	***Narrative Description***
Baseline Growth	Current growth rates in solar and storage continue as projected.	California fails to meet its legislated goals. Growth in DER adoption only occurs in accordance with recent historical trends.
Solar Only Dominated Growth	Future acceleration in the rate of adoption of rooftop solar systems relative to the current baseline. Behind the meter storage system adoption rates consistent with baseline.	Continued rooftop solar system cost reductions, incentive programs, and escalating total household energy costs motivate larger numbers of residential homeowners to adopt new rooftop solar systems. Projected cost reductions in lithium-ion batteries do not materialize as forecast due to rapid growth in competing demand for electric vehicles battery packs or other factors.
Storage Only Dominated Growth	Future acceleration in the rate of adoption of behind the meter storage systems relative to the current baseline. Rooftop solar system adoption rates consistent with baseline.	Global lithium-ion storage output increases significantly to satisfy demand from the growing market for electric vehicles. Increased economies of scale are realized, and system costs decline rapidly. Exacerbation of "duck-curve" peak load ramps lead to increasingly aggressive time-of-use rate structures. Stand-alone storage system ROI's improve largely due to peak shaving capability.

Solar + Storage Dominated Growth	Future acceleration in the rate of adoption of rooftop solar PV system is coupled with the requirement of behind the meter energy storage systems.	In order to deal with power quality issues (voltage & frequency regulation, reactive power supply, etc.) stemming from the grid interconnection of increasing volumes distributed renewable generation assets utilities require that new systems be coupled with behind-the-meter storage to receive interconnection approval. The operation of these systems is optimized to maximize the return on investment for individual homeowners.

Source: UCLA

B.3.2 Residential EV Adoption Scenarios and Pathways

Table B-3: Household Scale Prototype Building Model Scenarios – Residential EV Adoption

Model Name	***Summary Parameter Description***
Baseline	Household with fossil fuel based internal combustion engine vehicles
EV Households	Household with one battery electric vehicle that is charged at hourly rate consistent with the average L1 residential EV load profile from the NREL EVI-pro dataset.

Source: The Energy Coalition

Table B-4: Community Scale Energy System Pathways – Residential EV Adoption

Scenario Name	***Summary Description***	***Narrative Description***
Baseline Growth	Current growth rates in EV and PHEV adoption continue as projected.	California fails to meet its designated goals. EV adoption continues at rates corresponding with recent historical trends.
EV Dominated Growth	Future acceleration in the rate of adoption of EVs relative to the current baseline. PHEV adoption rates continue at levels consistent with the baseline.	Simultaneous cost reductions and performance improvements in lithium-ion battery technologies continue to materialize. Subsequent generations of EV offerings become more competitive with ICE alternatives both in terms of up-front cost as well as in range and driving performance. Questions of EV charger availability are resolved through large scale deployment of public and private charging infrastructure. Consumer tastes begin to favor EVs over PHEVs due to their lower lifetime O+M costs, stemming from the reduced complexity and higher reliability of their drivetrain components. Vehicle manufactures respond by adjusting production outputs and the range of available vehicle models accordingly.

Source: UCLA

B.4. Building Scale Prototypes and Modelling

B.4.1 Data Sources

Table B-5: BEopt Model Data Sources

BEopt Input	**Data Source**				
	Participant Questionnaire and Monitoring Data	UCLA Energy Atlas	IOU Supplied Data	Assessor's Parcel Data	Building Code Vintage Tables
Building Type - *Apartment, Condo, Duplex, Single or Multi-Story House*	X	X		X	
Home Orientation - *Direction front door faces*	X				
Wall Properties - *Thermal properties of walls*	X				X
Roof/Ceiling Properties - *Thermal properties of roofs and attics*	X				X
Foundation and Floor Properties - *Type of slab and flooring*	X				
Window and Door Properties - *Type, area and thermal properties of windows and doors*	X				X
Airflow - *Air leakage rate*	X				X
Energy Systems for Space Conditioning - *Type and efficiency of space conditioning systems*	X				X
Schedules for Space Conditioning - *Hours of operation based on day*	X				
Water Heating Systems and Schedule - *Type, efficiency and hours of operation based on day*	X				X
Lighting Systems and Schedule - *Type, efficiency and hours of operation based on day*	X				X

Appliance and Fixture Systems and Schedules - *Type, efficiency and hours of operation based on day*	X				X
Additional Plug Load Systems and Schedules - *Type, efficiency and hours of operation based on day*	X				X
Power Generation Systems - *PV, solar water heating, battery storage or gas generators*	X				
Electricity Consumption Data		X (Aggregated)	X (SCE monthly system average)		
Natural Gas Consumption Data		X (Aggregated)	X (Survey Area Zip codes hourly average)		
Indoor Air Temperature and Relative Humidity	Purple Air Monitors				

Source: The Energy Coalition

B.4.2 BEopt Occupancy Adjustments

Table B-6: BEopt Occupancy Adjustments

Building Type	Avg Number of Bedrooms (among study participant homes)	Avg Number of Occupants (among study participant homes)	BEopt Calculated Number of Occupants	Actual Occupancy as a % of BEopt default
Single Family Home	2.95	4.45	2.60	174%
Townhouse/Condo	2.33	2.33	2.25	103%
Multi-Unit (2-4)	1.40	4.20	1.70	244%
Apartment (5 or more units)	1.82	4.64	1.94	245%
Mobile Home	2.50	7.00	2.35	292%

Source: The Energy Coalition

B.4.3 HVAC Equipment Descriptions

Table B-7: HVAC Equipment Descriptions

Equipment	Description
Central Forced Air	A general type of heating or cooling system that moves air through ducts throughout the home.
Wall Furnace	An appliance permanently attached to a wall that combusts natural gas and radiates heat directly into the living space
Central Furnace	A piece of equipment that combusts natural gas and distributes warm air through ducts throughout the home. (A specific type of central forced air)
Space Heater	A plug-in electric portable heater that radiates heat
Window Air Conditioning Unit	A device that is affixed to a window opening that cools outside air and distributes into the room
Central Air Conditioning Unit	A piece of equipment which is powered by electricity and distributes cool air through ducts throughout the home (A specific type of central forced air)
Fans	Either ceiling mounted or portable devices that circulate air in a room

Source: The Energy Coalition

B.4.4 Single Family Building Prototype Model Details

Table B-8: Single Family Prototype Names and Defining Features

Prototype Number	Heating System	Cooling System
Single Family Prototype 1	Wall Furnace Only	Window Unit AC
Single Family Prototype 2	Central Furnace Only	Central AC
Single Family Prototype 3	Central Furnace Only	No AC
Single Family Prototype 4	Wall Furnace + Space Heater	Window Unit AC
Single Family Prototype 5	Central Furnace + Space Heater	Central AC

Source: The Energy Coalition

Table B-9: Fixed Model Inputs for All Single-Family Building Prototypes

	Single Family

Weather File	El Monte 2019 AMY[1]
Baseline Tariff	SCE Region 9
Analysis Period[2]	1 year
Building/Unit Area (sq ft)	1,254 sq ft
Vintage	1961
Number of Bedrooms	3
Number of Occupants	4
Air Conditioning Energy Type	Electricity
Heating Energy Type	Gas
Water Heating	Gas
Cooking Range	Gas ignition equipment

Source: The Energy Coalition

[1] CALMAC weather files: http://www.calmac.org/weather.asp

[2] To compare the prototypes to one year of community-average energy consumption, the models were set to analyze one year of data.

Table B-10: Variable Model Inputs for Single-Family Building Prototypes

Input Name	Options Modeled in the BEopt Prototype
Heating Set Point	64, 68, 70, 70F constant 70, 71F w/ 65F setback
Cooling Set Point	72, 73, 75, 76F w/ 95F setback 72F with only 2 hr use in afternoon
MEL[3] Multiplier*	1.0, 1.5, 1.7 factor to increase the national average[4] watts per square foot of miscellaneous electric load
Hot Water Loads*	1.0, 1.2, 1.5, 1.7 factor of national average[5]
Ceiling Insulation R Value	Uninsulated Vented, R-7, R-13
Clothes Dryer Usage*	Gas Standard Use, Gas Premium Efficiency w 1.2 usage factor, Gas Standard 1.7 usage factor
Duct Leakage/Insulation	30* Leakage Uninsulated 30* Leakage R-4 Insulation Vents in living space (wall furnace)
Window U Value	Single Pane Metal Clear, Double Pane, Non-Metal
Heating Equipment Efficiency	Central Furnace AFUE: 68, 72, 78 Space Heater Option 1500W, 0%, 30% or 100% of the living area heated Wall Furnace AFUE 60 Space Heater Option 1500W, 0%, 30% or 100% use
Cooling Equipment Efficiency	Central AC SEER 8, 10, 13 Window Units EER 8.5, 9.8, 10.7

Source: The Energy Coalition

[3] Miscellaneous Electric Load - Plug loads such as TVs, small appliances, phones, etc. Space heaters were modeled by adjusting inputs related to heating equipment to account for the seasonal and temperature dependence on the use of the space heater.

[4]BEopt multipliers are based on national averages, whereas this study has actual occupancy data and therefore factors were adjusted accordingly. It is worth noting that the team saw no homes with occupancy less than the national average and did not model an occupancy factor of less than 1.0.

B.4.5 Multi-Family Building Prototype Model Details

Table B-11: Multifamily Prototype Names and Defining Features

Prototype Number	Heating System	Cooling System
Multifamily Prototype 1	Wall Furnace Only	Window Unit AC
Multifamily Prototype 2	Space Heater Only	Window Unit AC
Multifamily Prototype 3	Wall Furnace and Space Heater	Window Unit AC

Source: The Energy Coalition

Table B-12: Fixed Model Inputs for All Multi-Family Building Prototypes

	Multifamily
Weather File	El Monte 2019 AMY
Baseline Tariff	SCE Region 9
Analysis Period	1 year
Building/Unit Area (sq ft)	700 sq ft
Vintage	1960
Number of Bedrooms	2
Number of Occupants	5
Air Conditioning Energy Type	Electricity
Heating Energy Type	Gas
Water Heating	Gas
Cooking Range	Gas ignition equipment

Source: The Energy Coalition

Table B-13: Variable Model Inputs for Multi-Family Building Prototypes

Input Name	Options Modeled in the BEopt Prototype
Heating Set Point	64, 68, 70, 70F constant 70, 71F w/ 65F setback
Cooling Set Point	72, 73, 75, 76F w/ 95F setback 72F with only 2 hr use in afternoon
MEL Multiplier*	0.75, 1, 1.25, 1.5 factor of national average
Hot Water Loads*	0.75, 1, 1.25, 1.5 factor of national average
Ceiling Insulation R Value	Uninsulated 2x4, R-7 2x4, R-13 2x4
Clothes Dryer Usage*	None, Gas Standard Use, Gas Premium Efficiency
Air Leakage	20 ACH50[6] (Poor), 14 ACH50 (Typical), 10 ACH50 (Efficient)
Window U Value	Clear, Single Pane, Metal Clear, Single Pane, Non-Metal
Heating Equipment Efficiency	Wall Furnace with AFUE 60 Space Heater with 1500W and usage of 0%, 30% or 100%
Cooling Equipment Efficiency	Window Units with EER 8.5, 9.8, 10.7 and 30% and 100% area conditioning

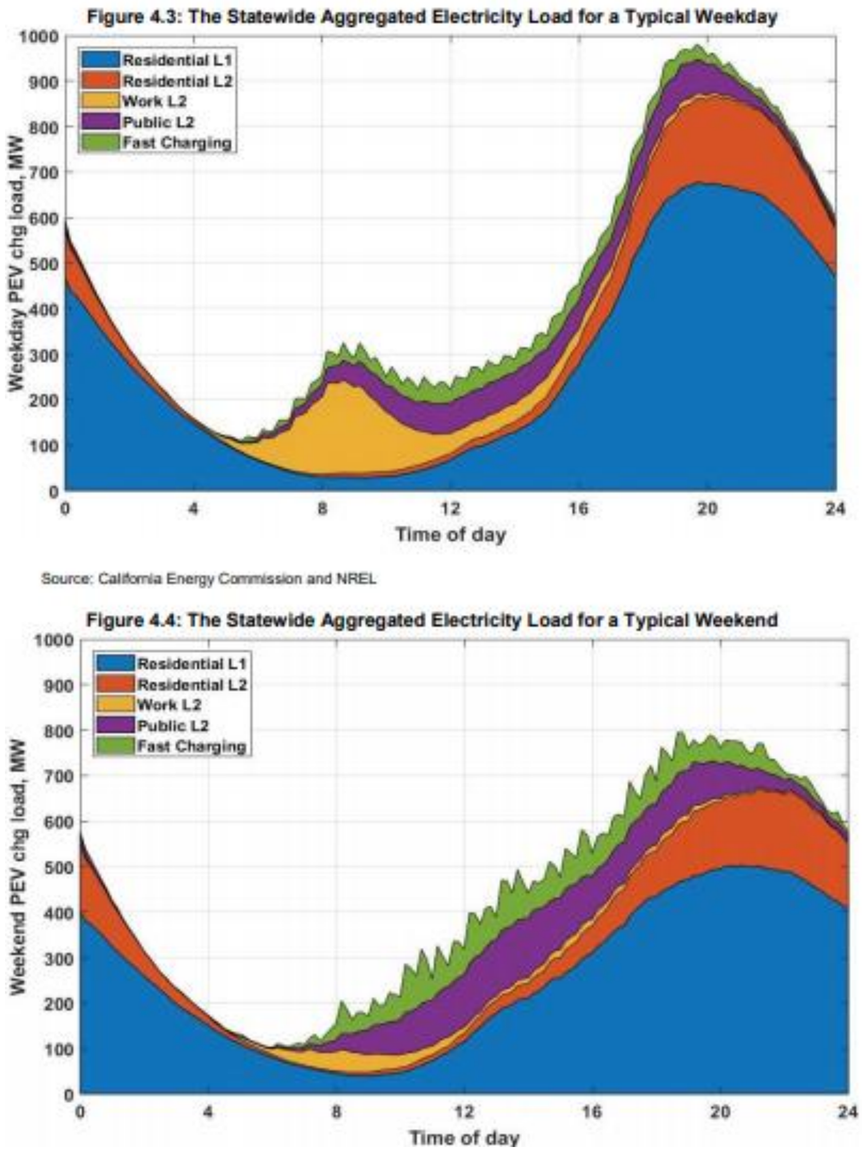
*** BEopt scales these inputs as a function of number of bedrooms, therefore an occupancy correction factor was applied to this input.**

Source: The Energy Coalition

[6] ACH50 is used to evaluate the amount of air leakage in a building at a set condition. ACH50 represents the air changes per hour at a pressure of 50 Pascals.

B.4.6 EV Charging Load Profile

Figure B-3: California Aggregated EV Electricity Load for Residential, Commercial, and Public Charging for a Typical Weekday (top) and Weekend (bottom)



Source: California Energy Commission Report - California Plug-in Electric Vehicle Infrastructure Projections: 2017-2025.

B.4.7 Solar PV and Battery Storage Capacities for Prototype Models and Retrofit Scenarios

Table B-14: REopt Sized Solar PV and Battery Storage Capacities for Each Residential Prototype Model and Retrofit Scenario

Building Configuration	PV + BESS	PV only	BESS only
Single Family Prototype 1			
Baseline	3 kW (PV) 2 kW - 4 kWh (BESS)	3 kW	2 kW - 5 kWh
Minor IAQ Focused	3 kW (PV) 1 kW - 3 kWh (BESS)	3 kW	2 kW - 5 kWh
Moderate IAQ Focused	3 kW (PV) 2 kW - 4 kWh (BESS)	3 kW	2 kW - 5 kWh
Full Home Electrification	3 kW (PV) 5 kW - 9 kWh (BESS)	3 kW	5 kW - 10 kWh
Single Family Prototype 1 with EV Charging			
Baseline	3 kW (PV) 2 kW - 4 kWh (BESS)	3 kW	2 kW - 5 kWh
Minor IAQ Focused	3 kW (PV) 1 kW - 3 kWh (BESS)	3 kW	2 kW - 4 kWh
Moderate IAQ Focused	3 kW (PV) 1 kW - 3 kWh (BESS)	3 kW	2 kW - 4 kWh
Full Home Electrification	3 kW (PV) 5 kW - 9 kWh (BESS)	3 kW	5 kW - 10 kWh
Single Family Prototype 2			
Baseline	3 kW (PV) 1 kW - 2 kWh (BESS)	3 kW	1 kW - 2 kWh
Minor IAQ Focused	3 kW (PV) 1 kW - 1 kWh (BESS)	3 kW	1 kW - 2 kWh
Moderate IAQ Focused	3 kW (PV) 1 kW - 1 kWh (BESS)	3 kW	1 kW - 1 kWh
Full Home Electrification	3 kW (PV) 4 kW - 8 kWh (BESS)	3 kW	4 kW - 9 kWh

Single Family Prototype 2 with EV Charging			
Baseline	3 kW (PV) 2 kW - 4 kWh (BESS)	3 kW	1 kW - 3 kWh
Minor IAQ Focused	3 kW (PV) 1 kW - 3 kWh (BESS)	3 kW	1 kW - 2 kWh
Moderate IAQ Focused	3 kW (PV) 1 kW - 2 kWh (BESS)	3 kW	1 kW - 1 kWh
Full Home Electrification	3 kW (PV) 4 kW - 8 kWh (BESS)	3 kW	4 kW - 9 kWh
Single Family Prototype 3			
Baseline	3 kW (PV) 1 kW - 1 kWh (BESS)	3 kW	1 kW - 1 kWh
Minor IAQ Focused	3 kW (PV) 1 kW - 1 kWh (BESS)	3 kW	1 kW - 1 kWh
Moderate IAQ Focused	3 kW (PV) 1 kW - 1 kWh (BESS)	3 kW	1 kW - 1 kWh
Full Home Electrification	3 kW (PV) 4 kW - 8 kWh (BESS)	3 kW	4 kW - 8 kWh
Single Family Prototype 3 with EV Charging			
Baseline	3 kW (PV) 1 kW - 1 kWh (BESS)	3 kW	1 kW - 1 kWh
Minor IAQ Focused	3 kW (PV) 1 kW - 1 kWh (BESS)	3 kW	1 kW - 1 kWh
Moderate IAQ Focused	3 kW (PV) 1 kW - 2 kWh (BESS)	3 kW	1 kW - 2 kWh
Full Home Electrification	3 kW (PV) 4 kW - 9 kWh (BESS)	3 kW	4 kW - 9 kWh
Single Family Prototype 4			
Baseline	3 kW (PV) 4 kW - 9 kWh (BESS)	3 kW	4 kW - 7 kWh
Minor IAQ Focused	3 kW (PV) 3 kW - 7 kWh (BESS)	3 kW	3 kW - 6 kWh
Moderate IAQ Focused	3 kW (PV) 2 kW - 5 kWh (BESS)	3 kW	2 kW - 6 kWh
Full Home Electrification	3 kW (PV)	3 kW	5 kW - 11 kWh

	4 kW - 9 kWh (BESS)		
Single Family Prototype 4 with EV Charging			
Baseline	3 kW (PV) 4 kW - 9 kWh (BESS)	3 kW	4 kW - 10 kWh
Minor IAQ Focused	3 kW (PV) 3 kW - 7 kWh (BESS)	3 kW	4 kW - 9 kWh
Moderate IAQ Focused	3 kW (PV) 2 kW - 3 kWh (BESS)	3 kW	2 kW - 5 kWh
Full Home Electrification	3 kW (PV) 4 kW - 9 kWh (BESS)	3 kW	4 kW - 10 kWh
Single Family Prototype 5			
Baseline	3 kW (PV) 5 kW - 13 kWh (BESS)	3 kW	6 kW - 15 kWh
Minor IAQ Focused	3 kW (PV) 4 kW - 10 kWh (BESS)	3 kW	4 kW - 11 kWh
Moderate IAQ Focused	3 kW (PV) 2 kW - 6 kWh (BESS)	3 kW	2 kW - 6 kWh
Full Home Electrification	3 kW (PV) 5 kW - 11 kWh (BESS)	3 kW	5 kW - 12 kWh
Single Family Prototype 5 with EV Charging			
Baseline	3 kW (PV) 7 kW - 17 kWh (BESS)	3 kW	6 kW - 15 kWh
Minor IAQ Focused	3 kW (PV) 6 kW - 14 kWh (BESS)	3 kW	5 kW - 13 kWh
Moderate IAQ Focused	3 kW (PV) 2 kW - 5 kWh (BESS)	3 kW	3 kW - 7 kWh
Full Home Electrification	3 kW (PV) 5 kW - 12 kWh (BESS)	3 kW	5 kW - 13 kWh
Multi Family Prototype 1			
Baseline	1 kW (PV) 1 kW - 3 kWh (BESS)	1 kW	1 kW - 3 kWh
Minor IAQ Focused	1 kW (PV) 1 kW - 3 kWh (BESS)	1 kW	1 kW - 3 kWh
Moderate IAQ Focused	1 kW (PV) 1 kW - 2 kWh (BESS)	1 kW	1 kW - 3 kWh

Full Home Electrification	2 kW (PV) 5 kW - 8 kWh (BESS)	1 kW	5 kW - 8 kWh
Multi Family Prototype 1 with EV Charging			
Baseline	1 kW (PV) 1 kW - 3 kWh (BESS)	1 kW	1 kW - 3 kWh
Minor IAQ Focused	1 kW (PV) 1 kW - 2 kWh (BESS)	1 kW	1 kW - 3 kWh
Moderate IAQ Focused	1 kW (PV) 1 kW - 1 kWh (BESS)	1 kW	1 kW - 2 kWh
Full Home Electrification	1 kW (PV) 1 kW - 1 kWh (BESS)	1 kW	1 kW - 2 kWh
Multi Family Prototype 2			
Baseline	1 kW (PV) 1 kW - 3 kWh (BESS)	1 kW	1 kW - 4 kWh
Minor IAQ Focused	1 kW (PV) 1 kW - 3 kWh (BESS)	1 kW	1 kW - 3 kWh
Moderate IAQ Focused	1 kW (PV) 1 kW - 2 kWh (BESS)	1 kW	1 kW - 3 kWh
Full Home Electrification	2 kW (PV) 5 kW - 8 kWh (BESS)	1 kW	5 kW - 9 kWh
Multi Family Prototype 2 with EV Charging			
Baseline	1 kW (PV) 1 kW - 2 kWh (BESS)	1 kW	1 kW - 3 kWh
Minor IAQ Focused	1 kW (PV) 1 kW - 1 kWh (BESS)	1 kW	1 kW - 2 kWh
Moderate IAQ Focused	1 kW (PV) 1 kW - 1 kWh (BESS)	1 kW	1 kW - 2 kWh
Full Home Electrification	3 kW (PV) 5 kW - 8 kWh (BESS)	1 kW	5 kW - 8 kWh
Multi Family Prototype 3			
Baseline	2 kW (PV) 2 kW - 5 kWh (BESS)	1 kW	2 kW - 4 kWh
Minor IAQ Focused	1 kW (PV) 1 kW - 2 kWh (BESS)	1 kW	1 kW - 3 kWh
Moderate IAQ Focused	1 kW (PV)	1 kW	1 kW - 3 kWh

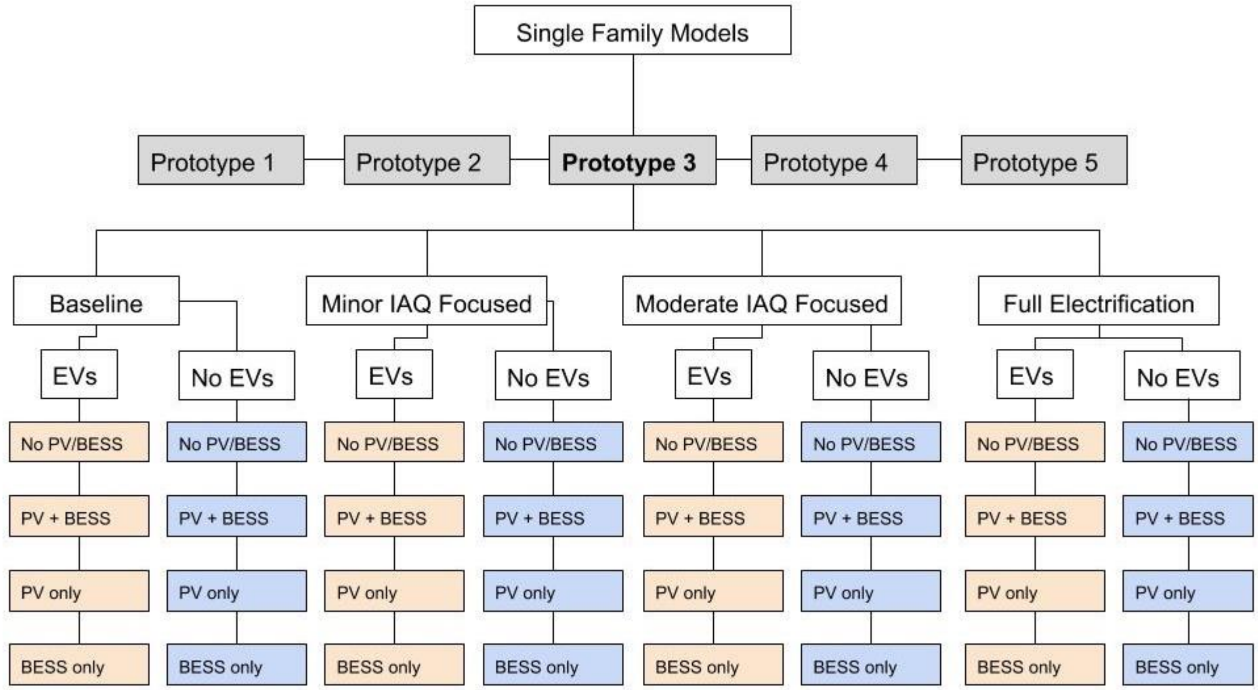
	1 kW - 3 kWh (BESS)		
Full Home Electrification	2 kW (PV) 4 kW - 7 kWh (BESS)	1 kW	5 kW - 8 kWh
Multi Family Prototype 3 with EV Charging			
Baseline	2 kW (PV) 2 kW - 4 kWh (BESS)	1 kW	2 kW - 5 kWh
Minor IAQ Focused	1 kW (PV) 1 kW - 2 kWh (BESS)	1 kW	1 kW - 3 kWh
Moderate IAQ Focused	1 kW (PV) 1 kW - 1 kWh (BESS)	1 kW	1 kW - 2 kWh
Full Home Electrification	3 kW (PV) 5 kW - 9 kWh (BESS)	1 kW	4 kW - 8 kWh

Source: The Energy Coalition

The solar PV and battery storage system sizing followed the expected trend of recommending smaller systems for the minor and moderate IAQ retrofit scenarios and larger systems for the full home electrification scenario. Although the full home electrification has a number of energy efficiency retrofits, the fuel switch adds significant load to the building, making battery storage more valuable. This is made clear on the sizing for the battery-storage-only scenario. Interestingly, the solar PV sizing for single family homes was not affected by the building load and solely affected by the available rooftop area. Given that the homes in the project study area are relatively small, the available rooftop area for solar was not enough to reach the break point for size over cost savings. For the multifamily solar PV sizing, the solar PV was only sized based on the electricity load. Since the multifamily homes were assumed to be ineligible for net energy metering, the maximum size for solar was limited without battery storage. Therefore, the solar-PV-only size was 1 kW across all of the multifamily prototypes and retrofit scenarios.

B.4.8 Summary of Building Prototypes and Scenarios

Figure B-3: Scenarios Modeled for Single-family Prototype 3



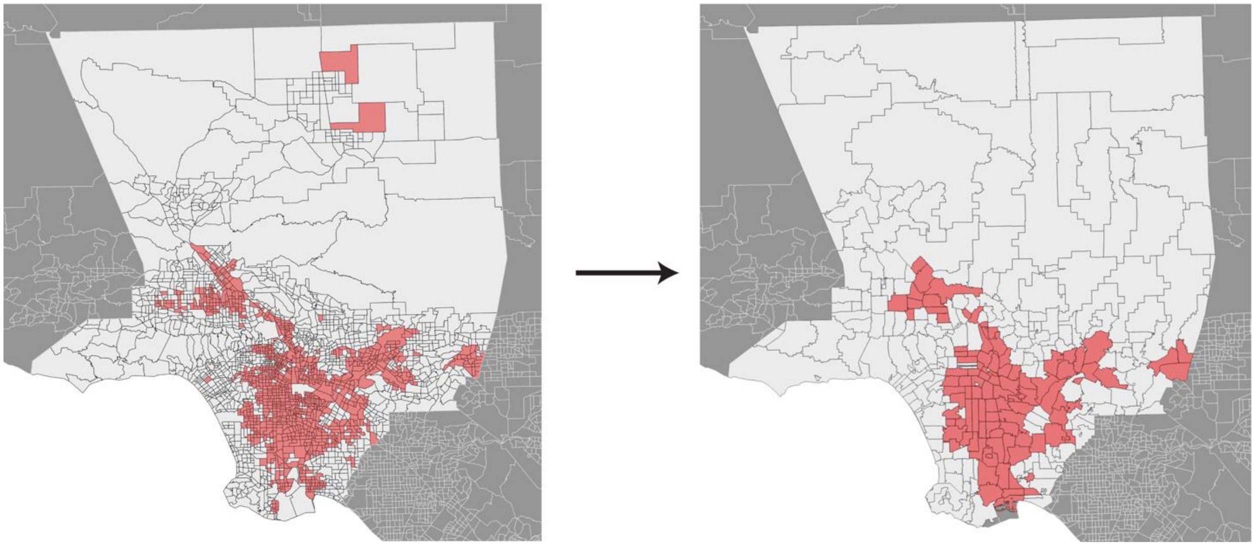
The same set of scenarios were run for all prototypes for both single-family and multi-family.

Source: The Energy Coalition

B.5. Baseline Growth Forecasts

B.5.1 Comparison of CalEnviroScreen Tracts and Zip Code Scale Aggregation

Figure B-5: Map Comparison of Census Tracts and Zip Code Scale Aggregation



Map comparison of disadvantaged census tracts (red on left, CES 3.0 score of 75 percent or higher) and aggregation to the zip code geographic boundaries (red on right) per the methodology described.

Source: UCLA

Table B-14: Comparison of Los Angeles County Disadvantaged Community Census Tract and Majority Disadvantaged Community

	DAC Census Tracts	Majority DAC Zipcodes
Percentage of Total Features	44.4%	31.2%
Percentage of Total Land Area	17.0%	11.1%
Percentage of Total Population	45.1%	45.7%

Source: UCLA

B.5.2 Historic Empirical Data Sources for Transformation Pathways

Table B-16: Historic Empirical Data Sources for Transformation Pathways

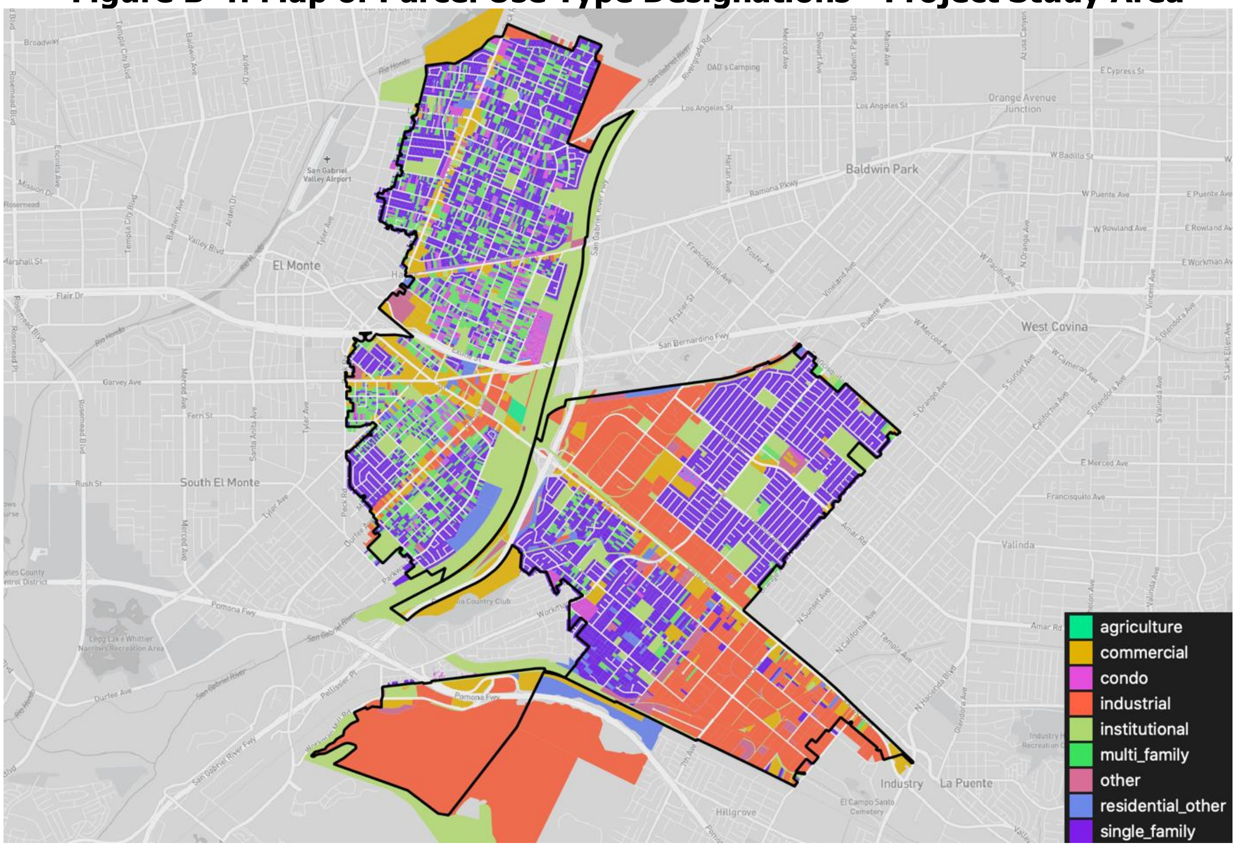
Pathway	Data Source	Spatial / Temporal Scale	Period of Record
Light-Duty Plug-In Hybrid & Battery Electric Vehicle Adoption	The National Renewable Energy Laboratory (NREL) centralized time series database of new vehicle registration data, compiled from state level department of motor vehicle records and disaggregated by vehicle fuel type category	Zip code / annual	1996-2018
Residential Distributed Energy Resource Adoption	The California Solar Initiative (CSI) data repository -- residential scale systems (<25kW)	Zip code / annual	1998-2018
Residential Energy Efficiency Performance Improvement	The UCLA Energy Atlas electricity and natural gas consumption data for SCE territory	Account level / monthly	2006-2016
Residential Appliance Electrification	Survey data collected as part of this project	Study community	2019

Source: UCLA

B.6. Community Scale Simulations

B.6.1 Study Area Parcel Use Types

Figure B-4: Map of Parcel Use Type Designations - Project Study Area



Source: UCLA

Table B-17: Parcel Counts and Square Footage Totals for Single Family and Multi-family in the Study Area

Parcel Use Type	Parcel Counts	Total Square Footage	Mean Square Footage / Parcel
Single-Family	10,649	14,376,560	1,350
Multi-Family	1,731	6,821,470	3,940

Source: UCLA

B.7. Holistic Assessment of Residential Appliance Electrification

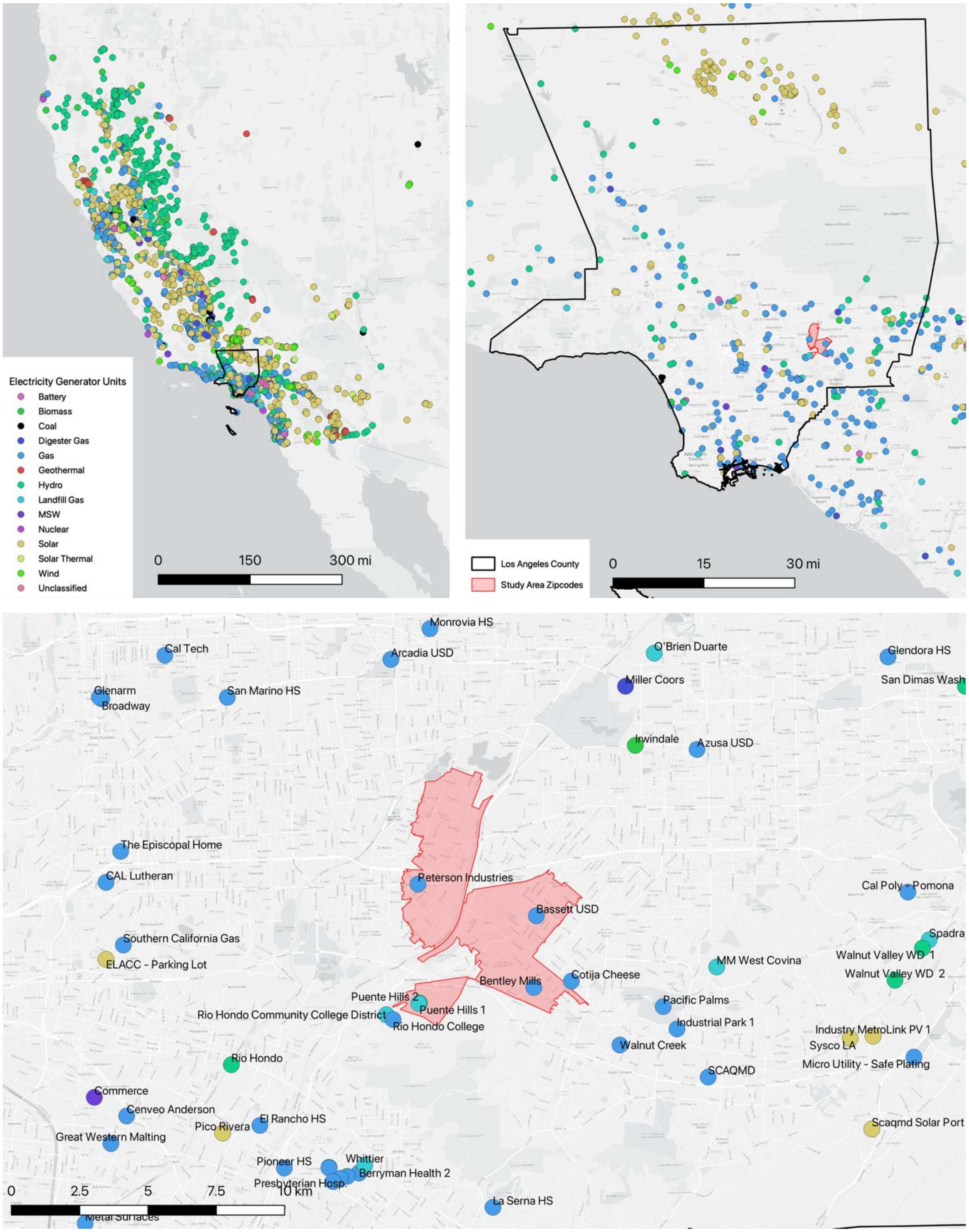
B.7.1 California's Electricity Generator Unit (EGU) Fleet

Residents of the project's designated study area receive gas service through Southern California Gas (SCG) and electricity service through Southern California Edison (SCE) – both investor-owned utilities (IOUs). The operations of the fleet of electricity generator units (EGU) responsible for serving SCE's loads are administered by the California Independent System Operator (California ISO). California ISO is a not-for-profit organization with three main responsibilities: (1) administering the wholesale market for power, (2) managing power transfers through the high-voltage transmission network, and (3) coordinating large scale infrastructure planning activities among the various utilities and energy service providers operating within its territory.

The majority of the EGUs serving California's loads are physically located within the state itself. However, there are significant exceptions, with a number of the largest and most polluting EGUs still being located out of state. The map in the top-left portion Figure B- 7 provides a regional view of the locations of the EGUs in this fleet. Within this map, individual facilities are colored by their primary fuel type – ranging from fossil based thermal sources such as coal and natural gas to zero-emissions renewable sources such as solar, wind and geo-thermal.

Plotted in the top-right portion of the figure is an inset map view of the EGUs located within Los Angeles County (LAC). As this map illustrates, the LAC region hosts a mix of generators of different types, with significant fossil generation capacity – principally natural gas – located in the coastal areas. There is also a growing installed base of renewable capacity, particularly in the northern high desert communities – comprised principally of solar PV and wind. Also plotted in the lower portion of the figure is an inset map view of the EGUs located within ~15km of the two zipcodes (red) [91746 & 91732] which define the project's study area. All of the subsequent modeling results for both local and ambient emissions have been assessed relative to forecasts of future energy demands from the residential sector within this geographic area.

Figure B-7: Locations of Electricity Generator Units Serving California Loads



Throughout the Southwestern United States (top-left), in the Los Angeles County region (top right), and locally, with detailed plant labels, near the two zipcodes which define the project.

Source: UCLA

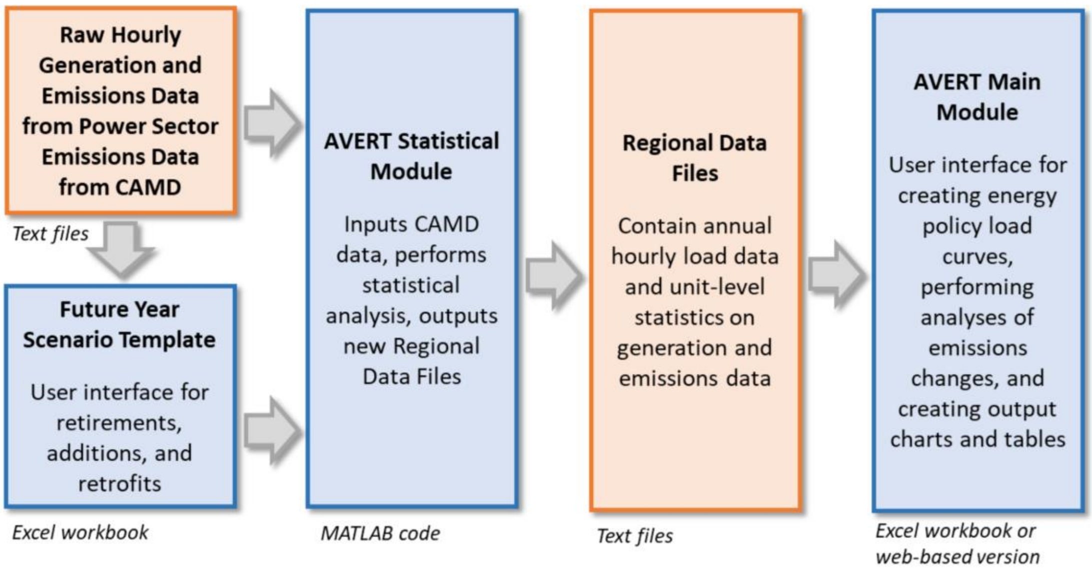
The individual EGUs plotted in the bottom, study area focus map, have been labeled with their facility names to give some sense of their respective purposes. Looking at the detailed generator unit capacity data associated with these EGUs indicate that the majority of are smaller scale natural gas turbines which are either contributing to the California ISO grid or being operated as on-site generator support for different commercial/industrial activities.

There are five EGUs located within the boundaries of the project study area. The largest two EGUs are located within the Puente Hills landfill gas generator station, with a total of 52 MW of nameplate capacity. The other three EGUs within the study site are small natural gas turbines with a total combined nameplate capacity of less than 1MW. Located just outside the project study area – approximately 2.5 km to the Southeast – is the Walnut Creek generating station. With a combined nameplate capacity of 500 MW, it is the single largest fossil generator facility within view. This facility is comprised of five EGUs and is designated as a "peaker plant," being designed to operate infrequently, primarily during hours of peak electricity demand.

B.7.2 AVERT Model Framework Discussion

Model parameterization begins in Figure B-8 with a USEPA database of historical EGU operational performance and emissions data, known as CAMD. The CAMD database was developed as part of the agency's Clean Air Market's Initiative. Data from CAMD is used to generate a set of regional data files (RDFs) that provide a statistical representation of individual operations for collections of EGUs located within a pre-defined set of regional geographies. For past historical years, these regional datafiles are pre-computed by the Avoided Emissions and Generation Tool (AVERT) development team and are made available for download on the project's website. For future years, new RDFs can be optionally generated by running a separate statistical module. The option gives users fine grained control over any desired changes in the composition and operational characteristics of individual EGUs contained within the CAMD database.

Figure B-5: The Modeling Approach Used by the U.S. EPA's Avoided Emissions and Generation Tool

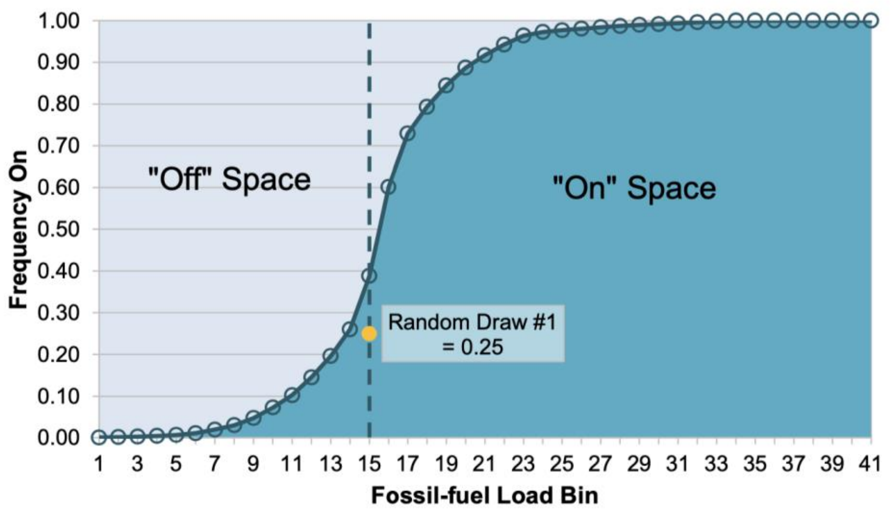


Source: AVERT User Manual

AVERT's main module is implemented as a Microsoft Excel spreadsheet model with a graphical user interface for specifying input parameters and key computational routines executed as macros elements. Alternatively, AVERT's statistical module is implemented as a packaged MATLAB executable. This executable requires a specific version of the MATLAB runtime compiler be installed on the host machine in order to run. Once installed, it provides a graphical interface which facilitates the creation of new RDFs for future years.

AVERT uses historical EGU data to develop a parametric description of plant level operational decisions. This parametric description takes the form of a probability density function that describes the likelihood that an EGU will either be turned "On" or "Off" when faced with the decision to supply a marginal unit of electricity demand. This function is based on a discretized representation of the current aggregate demand experienced across the entire fossil generator fleet, represented in the form of a set of "Fossil-fuel Load Bins" – as illustrated in the graphic contained in Figure B-6. Using a set of probability distributions computed for all of the generator units within a specific geographic region, marginal grid emissions associated with different aggregate load changes can then be derived using a Monte-Carlo sampling procedure.

Figure B-6: Conceptual Illustration of the Parametric Description of Individual EGU Operations



Individual EGU operations used by the AVERT modeling framework to estimate grid power emissions associated with marginal units of consumption.

Source: AVERT User Manual

Different fossil EGUs exhibit different characteristic operational patterns. These patterns reflect the fuel source, generation technology, and management practices in use at each facility. Generally, fossil EGUs can be thought of as fitting into three different prototypical categories. These include:

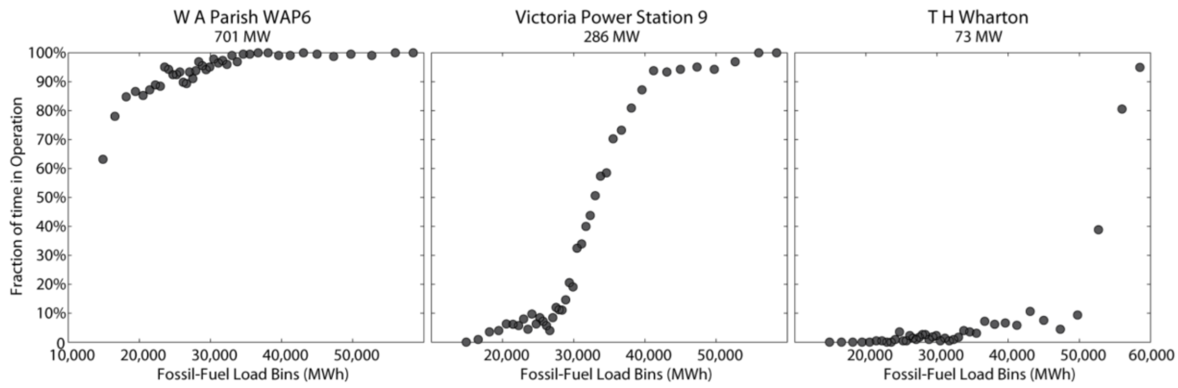
(1) *Baseload Plants* – generator units which can be operated at very low cost and thus tend to be run, almost continually, rarely ever being turned off except for scheduled maintenance activities.

(2) *Standard Plants* – generator units which can be operated at an intermediate cost and thus, vary their output on a seasonal basis depending upon the wholesale price of power – something which is determined by anticipated future aggregate power demands.

(3) *Peaker Plants* – generator units which are among the most expensive to operate and thus, tend only to be activated during periods of peak power demand when the combined output of baseload and standard generator units is insufficient.

Figure B-10 provides a graphical illustration of the operational characteristics of three different EGUs selected which illustrate the behaviors of the aforementioned generator prototypes.

Figure B-7: Graphical Illustration of the Three Prototypical Fossil EGU Categories



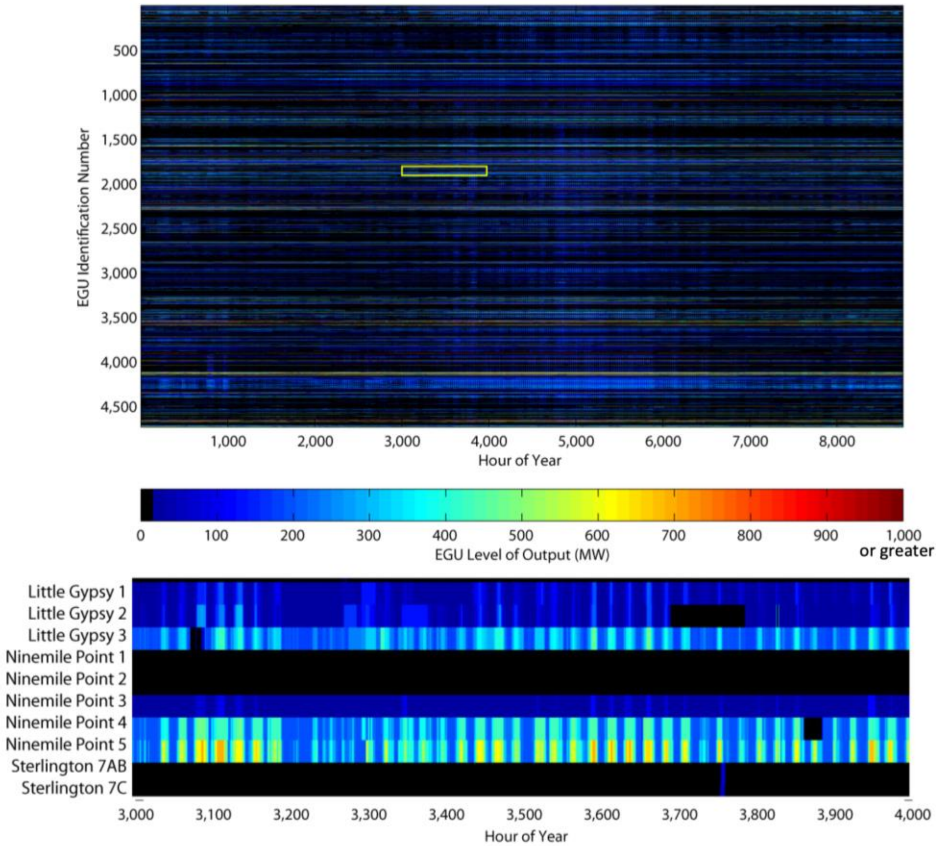
Baseload Standard Peaker

Prototypes are based on the frequency of time spent in operation relative to overall output levels for the entire fossil generator fleet.

Source: AVERT User Manual

As mentioned previously, the parametric descriptions of each individual EGU – which are encoded as probability density functions within AVERT's RDFs – are based upon a statistical analysis of historical plant level operations data. This plant level data is collected as part of the USEPA's Clean Air Markets program and is updated on an annual basis. Figure B-8, reproduced here from the AVERT user manual, provides a graphical depiction of the data in the CAMD database. The plot in the upper portion of the figure gives an overview of the hourly output in MW for each of the roughly 4,700 EGUs in the CAMD database. Black areas depict periods where the EGUs were offline. The prototype output patterns discussed in the previous section can be readily identified here, as well. For a more detailed discussion of the AVERT modeling framework's approach and underlying data sources we direct the reader to the latest version of AVERT's user manual which is available for download from the USEPA's website.

Figure B-8: Overview Plot of Hourly Power Output Levels for the EGUs in the CAMD Database



A detailed inset plot of several months of hourly operations for 10 randomly selected generators are plotted at the bottom of the figure.

Source: AVERT User Manual

B.7.3 Electricity Generator Unit Retirement Schedules

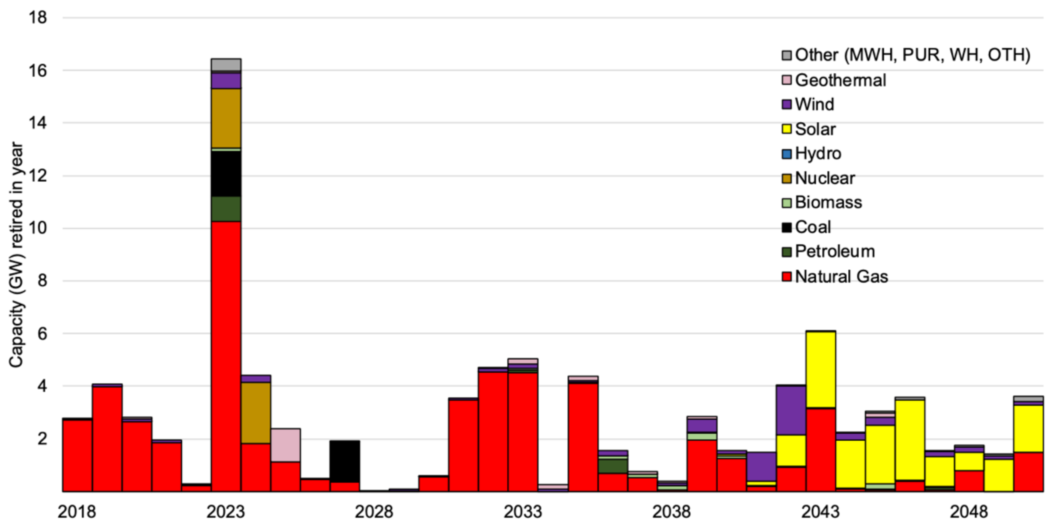
Future changes in the emissions of CO_2 and other criteria air pollutants associated with the consumption of grid electrical power will depend significantly upon the changing composition of the fossil generator fleet. While California's RPS provides interim targets for the fraction of total electrical power which must come from zero-carbon sources, it does not provide explicit guidance as to which specific fossil generator units must be retired or retrofitted in order to achieve these interim goals. Individual EGU retirement decisions are influenced by a number of factors including, but not limited to, their location, age, fuel source, capacity, heat rate, ramp rate, operational costs, and, increasingly, emissions intensities.

Developing a detailed schedule of future EGU retirements is a complex undertaking, one which requires through research into existing plans for facility retirements, policies that may influence future retirements based upon the presence of certain technologies (such as the phasing-out of "once through cooling" plants, for example), as well as identifying operational characteristics and/or thresholds that could make individual EGUs more or less favorable for continued operation. While such a detailed assessment is beyond the scope of this project, fortunately, one was recently completed by Grubert et al. with detailed data for plant level retirement forecasts being published as part of the study's supplemental information (Grubert et al. 2020).

Figure B-9, which has been reproduced here from the Grubert el al. study, plots the timing and characteristics of future fossil EGU retirements which have been determined according to their research and modeling assumptions. As illustrated, the path to achieving zero-emission grid power is not expected to follow a uniform trajectory. Rather, there is significant variation from year to year in terms of the number and type of EGUs expected to be retired.

As the figure shows, 2023 marks a critical juncture in the evolution of California's fossil EGU fleet. This year is anticipated to experience the single largest reductions in exiting generator capacity, not only limited to fossil EGUs, across the entire remaining time horizon governed by the RPS. A major portion of this reduction in capacity will stem from the phasing out of once-through-cooling plants located in the state's coastal communities. Another significant portion will come from the planned retirement of remaining nuclear generator capacity as well as a major coal fired generation station.

Figure B-9: Projected Timing of Future Grid Electricity Generator Unit Retirements by Primary Fuel Type 2018 – 2050

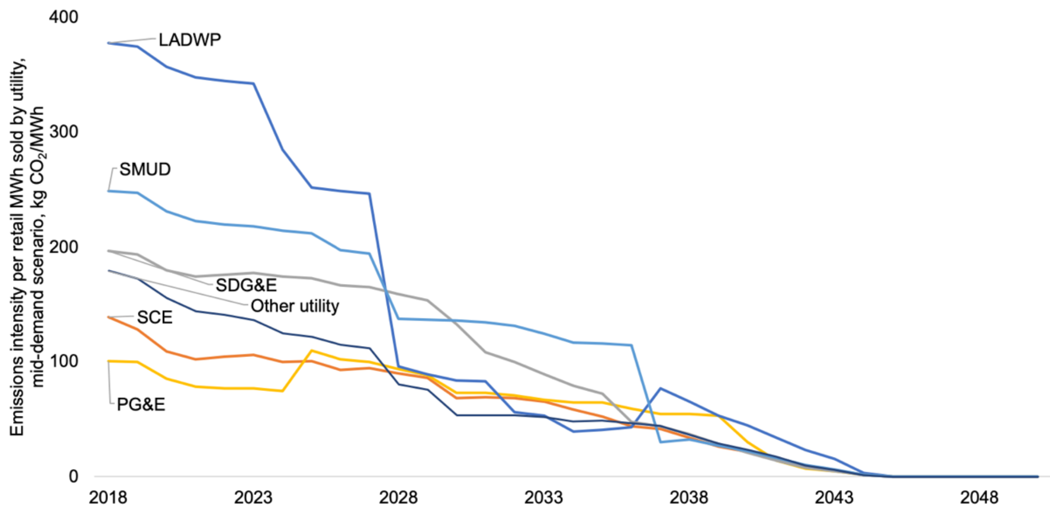


Source: Grubert et al. 2020.

B.7.4 Future Grid Emissions Intensities Assuming RPS Compliance

Once a schedule of anticipated future fossil EGU retirements has been developed, it then becomes possible to accurately model future grid electricity emissions intensities at the individual utility level. This is an analysis which was done in the Grubert et al. 2020 study and the results of which are graphically illustrated in Figure B-10. As this figure shows, the rate of declines in emissions intensities are not equal across the state's different major utilities. Indeed, some utilities are expected to experience temporary increases in the emissions intensity of the supplied power, as some large-scale renewable generator assets reach the end of their effective service lifetimes and must be either decommissioned, retrofit, or replaced. It remains to be seen, however, how the emerging role of Community Choice Aggregations (CCA's) might affect these rates of progress. It is anticipated that CCA's will soon come to serve the majority of the loads within California and thus their renewable energy procurement strategies and progress will become a matter of significant interest and relevance going forward.

Figure B-10: Projected Future Changes in Major California Electric Utilities' Emissions Intensities 2018-2050



Emission intensities are measured in kg CO2 / retail MWh sold, over the time period spanning from 2018 – 2050

Source: Grubert et al. 2020

Generally, however, the work done by Grubert el al. in anticipating future fossil EGU retirement dates provides an extremely plausible set of assumptions upon which to base our future year ambient emissions analyses. Consequently, the specific EGU level retirement dates published in their study have been propagated into the model runs developed for this study using the AVERT framework.

Due to the number of pathways being considered, the time required to manually parameterize and run the AVERT statistical module required to generate each future year RDF, and the need to manually evaluate each unique pathway-year combination with a new AVERT main module run, the following, restricted number of years were directly simulated for each pathway [2020, 2025, 2030, 2035, 2040, 2045]. The output of these model runs was a truncated time series of hourly emissions changes from grid fossil EGU operations for each of the six forecast years. Annual results reported for interstitial years – specifically those years that were not explicitly simulated using AVERT – have been generated by applying a 3rd order polynomial fit to the annualized total data produced from each forecast year and interpolating.

Prior to inputting the hourly load profiles for each pathway scenario into the AVERT main module an adjustment was made to account for Transmission and Distribution (T&D) losses. According to the most recently available reporting, California's average systemwide T&D loss rate is 6.26 percent. (Mutialu and Zafar 2017) This loss rate was used to develop a coefficient of adjustment (c = 1.0626) which was multiplied by the hourly loads for each pathway to account for grid losses when determining the true marginal demand for electricity experience by fossil EGUs.

B.7.5 Residential Appliance Emissions Factors for CO_2 and NO_x

Residential Gas Appliance CO_2 Emissions Factors

Rates of CO_2 emissions generated by the combustion of gas in residential appliances can be obtained from published literature sources provided by both the USEPA and the California Air Resources Board (CARB). The CARB values reflect those used for the development of GHG emissions inventories for the state's residential energy sector [CITE USEPA, CARB]. For the purpose of this study a range of upper and lower bounds of the mass of CO_2 emissions per unit of gas consumed were derived from the values referenced in these two sources.

Residential Gas Appliance NO_x Emissions Factors

Estimating rates of emissions for additional air pollutant species, that are produced as co-products during the combustion of gas in residential appliances, requires detailed measurements be performed over a large number of individual devices under both laboratory and real-world operating conditions. The most comprehensive investigation conducted on this topic has been performed by researchers at the Lawrence Berkeley National Laboratory (Singer et al. 2009) Statistical analyses of the primary measurement data reported in this study have appeared in subsequent analyses, most recently in a UCLA Fielding School of Public Health report, funded by the Sierra Club, entitled: "Effects of Residential Gas Appliances on Indoor and Outdoor Air Quality and Public Health in California." (Zhu et al. 2020). This Fielding School report, and the Berkeley Labs measurement studies upon which its data is derived, provides a sound basis for the estimation of the range of NO_x emissions factors [mass / energy] associated with different categories of residential gas appliances.

Table , reproduced here from the Fielding School report, depicts ranges of emissions factors (EF) and emissions rates (ER) for three different gas combustion co-product air pollutant species: CO, NO_2, and NO_x and four different types of major residential gas appliances. The values which are of primary interest to this analysis are the reported mean EFs (ng/J) for NO_x in the column second to right within the table.

For the purposes of the local avoided emissions calculations which will be reported on in this study the four major residential gas appliance types referenced in the table were grouped into two major categories: "Air & Water Heating" and "Cooking & Other." This grouping is intended to reflect major differences in the venting locations of these appliances (outdoors vs. indoors, respectively). The individual EF values reported in each of these two categories will be used to define an upper and lower bound on the assumed EF range within each.

Table 3 Mean Emissions Factors (EF) and Emissions Rates (ER) for Each Appliance Type

Appliance Type	CO (mean)		NO_2 (mean)		NO_x (mean)	
	EF (ng/J)	ER (µg/h)	EF (ng/J)	ER (µg/h)	EF (ng/J)	ER (µg/h)
Gas Stove	52	670,000	10	130,000	38	440,000
Gas Oven[ii]	92	1,700,000	8.3	150,000	36	640,000
Gas Water Heater[iii]	18	3,200,000	3.4	490,000	25	2,300,000
Gas Heater	16	1,300,000	5.3	320,000	37	1,600,000

Note: Values correspond to total emission factors and rates when the appliance is turned on, regardless of whether an appliance is vented outdoors (meaning not all these emissions travel indoors).

ii. Separate EFs were calculated for stoves and ovens, but throughout this report we combined the two for most analyses (using a sum of emission rates), due to the nature of existing data (e.g. the RASS and CARB State Implementation Plan data). More specifics available upon request.

iii. This analysis incorporates both tankless and storage water heaters, which do have significantly different emissions for CO; tankless water heaters have higher emissions of CO. We did not control for these differences in our analysis. These higher emissions also occur for formaldehyde, which we did not quantitatively assess in this report.[44]

EF and ER considered in the UCLA Field School of Public Health Report on "Effects of Residential Gas Appliances on Indoor and Outdoor Air Quality and Public Health in California"

Source: Zhu et al. 2020

B.7.6 COBRA Screening Tool

Introduction to the USEPA's CO-Benefits Risk Assessment (COBRA) Screening Tool

The USEPA's CO-Benefits Risk Assessment (COBRA) model is a screening tool which can be used to estimate the human health impacts associated with changes in county level PM-2.5m emissions. The tool is comprised of three core modules which have been described generally below as well as illustrated graphically in the process diagram in Figure B-11.

(1) A streamlined fate-transport module which is used to determine how the primary emissions in one county may ultimately result in a change in the effective ambient concentration of the pollutant in other adjacent counties. This module is based upon a simplified model of regional atmospheric dynamics.

(2) A human-health impact module which translates ambient air pollutant concentrations into estimates of human health incidents (mortality, hospitalizations, lost work). This module is based upon regional population densities as well as epidemiological studies of the exposure-response relationships for various human health outcomes.

(3) A monetization module which converts the number of human health incidents experienced in a given time frame into a dollar value of increased/decreased public health costs.

Figure B-11: General Overview of the COBRA Screening Tool's Workflow and Computational Operations

Source: COBRA User Manual

The USEPA technically considers the COBRA model to be a streamlined "screening tool." This designation means that while its health-impact estimates should be considered as sufficiently robust for use in policy evaluation exercises the methodologies used are not detailed enough to be considered appropriate for more rigorous applications such as in environmental litigation. One significant benefit of this more streamlined approach is that COBRA does not require advanced expertise in air quality modeling, health effects assessment, or economic valuation to be used. Among the use-cases for which the tool was explicitly designed includes use by energy planning agencies looking to estimate and promote the air quality, health, and associated economic co-benefits of their energy efficiency or renewable energy policies.

Built into COBRA are emissions inventories, a simplified air quality model, health impact equations, and economic valuations ready for use, based on assumptions that EPA currently uses as reasonable best estimates. According to the COBRA user manual:

"Analyses can be performed at the state or county level and across the 14 major emissions categories. The model contains detailed emissions estimates for the years 2016, 2023, and 2028. These baseline emissions estimates account for federal and state regulations as of May 2018. The projected EGU emissions comply with the Cross-State Air Pollution Rule Update (CSAPR Update) finalized December 27, 2016, the Mercury and Air Toxics Rule (MATS), and the Standards of Performance for Greenhouse Gas Emissions from New, Modified, and Reconstructed Stationary Sources."

Outcomes can be modeled nationwide or for smaller geographic areas. Results include changes in ambient PM-2.5m concentrations, and changes in the number of cases of a variety of health endpoints that have been associated with PM-2.5m. These health endpoints include:

- Adult and infant mortality
- Non-fatal heart attacks
- Respiratory-related and cardiovascular-related hospitalizations
- Acute bronchitis
- Upper and lower respiratory symptoms

- Asthma-related emergency room visits and asthma exacerbations
- Minor restricted activity days (specifically days on which activity is reduced, but not severely restricted) & workdays lost due to illness

The health effects output results generated by the model includes low and high estimates for the changes in the number of cases and the corresponding economic values for adult mortality and non-fatal heart attacks. The low and high estimates are derived using two sets of assumptions about the sensitivity of adult mortality and non-fatal heart attacks to changes in ambient PM-2.5m levels. Specifically, the high estimates are based on studies that estimated a larger effect of changes in ambient PM-2.5m levels on the incidence of these health effects. The low and high estimates for each of these values are derived as follows:

- ***Adult Mortality*** - In the health effects table, the low range estimates of adult deaths avoided and their economic value, respectively, are based on (Krewski et al. 2009). The high range estimates of adult deaths avoided and their economic value, respectively, are based on (Lepeule et al. 2012). More details on these two studies are available in Appendix C of the COBRA user manual.
- ***Nonfatal Heart Attacks*** – In the health effects table, the low range estimates of non-fatal heart attack cases avoided (Nonfatal Heart Attacks) and their economic value ($ Nonfatal Heart Attacks) are based on (Peters et al. 2001). The high range estimates are based on a combination of the following four studies: (Sullivan et al. 2005; Pope et al. 2006; Zanobetti et al. 2009; and Zanobetti & Schwartz 2006). More details on the studies are available in Appendix C of the COBRA user manual.

All health effects are monetized in the results of the model. The statistical value for the loss of human life used by the model ranges from $9.7 million - $10 million per mortality event. The monetized value of future increases/decreases in mortality events and other health effect categories are discounted based upon the designated baseline reference year and a user defined choice of discount rates (either 3 percent or 7 percent). The application of a discount rate is a mechanism which is commonly used to express future economic values in present terms. Larger discount rates express a bias towards benefits which accrue in the near-term relative to those which are more delayed in time. All results reported in this analysis are based upon the use of a 3 percent discount rate. Consistent with USEPA guidance, a series of test model runs were performed in which both discount rate options were applied to the same set of user-defined emissions changes. The results of these tests indicated that the choice of discount rate did not significantly affect the results in terms of the relative scale of the local air quality benefits as compared to the ambient air quality impacts.

Atmospheric Dispersion Modeling in COBRA

COBRA estimates particulate matter levels using the Phase II Source-Receptor (S-R) Matrix. The S-R Matrix consists of fixed transfer coefficients that reflect the relationship between annual average PM-2.5m concentration values at a single receptor in each county (a hypothetical monitor located at the county centroid) and the contribution by PM-2.5m species to this concentration from each emission source (E.H. Pechan & Associates Inc., 1994). COBRA's S-R matrix approach is based upon the Climatological Regional Dispersion Model (CRDM).

Relative to more sophisticated and resource-intensive three-dimensional modeling approaches, the CRDM does not fully account for all the complex chemical interactions that take place in the atmosphere in the secondary formation of PM-2.5m. Instead, it relies on more simplistic species dispersion–transport mechanisms supplemented with chemical conversion at the receptor location. This limitation is one of the main reasons why COBRA is designated as a screening tool as opposed to a full-fledged air pollutant fate-transport modeling framework. However, given the scope and aim of this analysis, its approach promises a reasonable level of accuracy and sophistication. For more detailed documentation of COBRA's modeling approach, input data sources, and key assumptions, the reader is referred to the model's documentation which is available for download from the USEPA's project website.

APPENDIX C:
Results

C.1 Community Survey Results

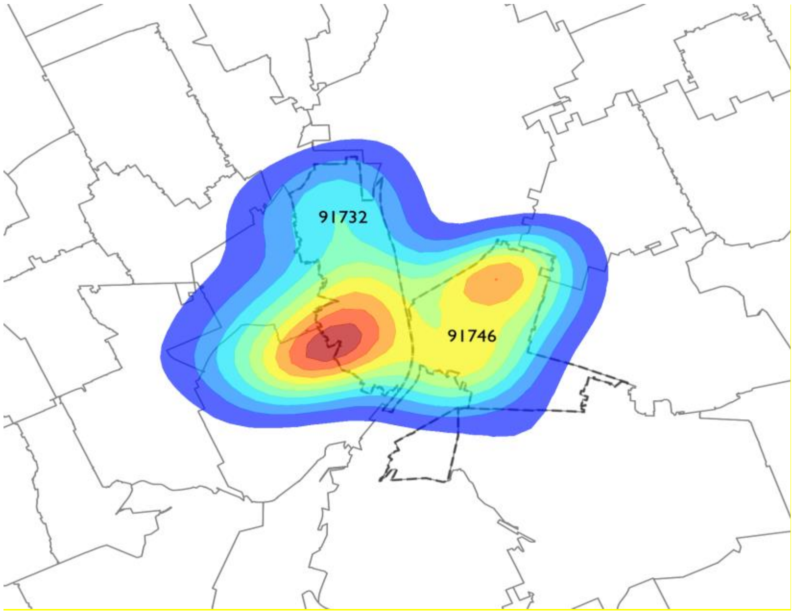
The following is a summary of the results from the community survey (n=449) for the key questions that related to the building modeling and forecasting analysis. Comparisons to the community-wide (both zip codes) averages are provided for renter/owner and for building type.

- *Breakdown of renter / owner*
  - Community-wide average: 47% Renter, 53% Owner.
  - Project survey sample group: 73.5% Renter, 26.5% Owner
- *Building type breakdown*
  - Community-wide average: 83% Single Family, 16% Multi-Family (+1% Other).
  - Project survey sample: 56% Single Family, 44% Multi-Family.
- *Heating and cooling breakdown*
  - Central Heating: 24.7%
  - Central Air: 20.4%
  - Wall Heater: 37.0%
  - Space Heater: 28.0%
  - Wall / Window Mounted AC: 42.6%
  - Standalone Fans: 24.5%
  - Ceiling Mounted Fans: 24.3%
- *Solar Panels*
  - 3% (14 people) had rooftop solar.
  - 5% (21 people) were planning to purchase solar panels in the next 2 years.
- *Electric Vehicles*
  - 12% (52 people) drove a hybrid or electric vehicle.
  - <5% (20 people) had Level 1 charging at home
  - <2% (8 people) had Level 2 charging at home
  - 14% (62 people) said they were planning to buy a hybrid or electric vehicle within the next 2 years
- *Appliance Electrification*

- 28% (128 people) were planning some sort of appliance electrification purchase in the next two years. Of those respondents, the percent who indicated one of the following specific appliances (multiple choices were allowed, so total is >100%):
  - Water heater: 23%
  - Space heater: 20%
  - Stove: 48%
  - Dryer: 31%
- *Utility Bills* [Note: averages calculated based on all non-zero responses]
  - Average Electricity Bill: $92
  - Average Gas Bill: $48
  - Average Water Bill: $70
- *Average number of people in household*
  - Adults: 2.9
  - Children: 2.3
- *Zip code*
  - 134 surveys captured from zip code 91732
  - 69 surveys captured from zip code 91746

Figure plots the density of survey respondents for whom address information was recorded in the dataset (200 out of the 449 total). The most responses were obtained in the red areas, and the fewest in the blue areas.

Figure C-1: Density Map of Survey Respondents



Reflects information from respondents with available addresses.

Source: UCLA

C.2. Air Quality Monitoring Results

C.2.1 General Household Attributes

Key features of the participants' household attributes, collected by Questionnaire #1, are summarized in Table C-1 which also includes a comparison to the 2019 American Housing Survey (AHS), a national housing survey in the US, sponsored by the Department of Housing and Urban Development (HUD) and conducted by the U.S. Census Bureau.

Homes sizes were calculated using the County Assessor's database and/or via other online databases. In multiple cases, the exact square footage of a home was not found in either assessor or alternative databases, or the information in the questionnaire did not match the data available; in both cases, the home was omitted from the analysis.

Table C-1: Descriptive Statistics of Participant Household Attributes

	Current Study		AHS Survey (2019)	
	Total Number	**% Total Respondents**	**% CA (State-wide)**	**% LA-Long Beach Metro Area**
SFH (attached and detached)	47	73.4	65.0	56.6
Non-SFH	17	26.6	34.9	43.4
Owner Occupied	27	49.1	54.8	47.6
Renter Occupied	28	50.9	45.2	52.4

	Mean	Range	Mean	
Year Home Built*	1957	1903 - 2010	1974	1966
Home Size (sq ft)	1,259	480 - 2,376	1,602	1,589
Square foot per person	384	71 – 2,111	742	721
Square foot per person (Renter-Occupied only)	269	71 - 708	582	579
Square foot per person (Owner-Occupied only)	553	139 – 2,111	863	860

*Home size was determined from the assessor's parcel database and/or online databases and provided as median for current study and AHS Survey

Data was collected from the household questionnaires unless otherwise noted.

Source: UCLA

C.2.2 Appliance Fuel Sources, Ventilation, and Cooling

Information about appliance fuel sources for several of the most common residential appliances that could be powered by natural gas, collected through Questionnaire #1, is summarized in Table .

Table C-2: Percent of Household Appliances With Gas or Electric Fuel Sources and Comparison to AHS Estimate for California

	Electric Total (%)	**Gas Total** Total (%)	**Gas - Standing Pilot** Total (%)	**Gas - Ignition Pilot** Total (%)	**AHS Survey (CA estimate) Gas Total (%)**
Winter (n = 34)					
Dryer	5 (14.7)	24 (70.6)	9 (26.5)	12 (35.3)	53.0
Water heater	2 (5.9)	31 (91.2)	23 (67.7)	3 (8.8)	83.4
Wall furnace	0 (0)	10 (29.4)	7 (20.6)	2 (5.9)	NA
Stove top	2 (5.9)	32 (94.1)	6 (17.7)	26 (76.5)	69.8*
Oven	4 (11.8)	29 (85.3)	7 (20.6)	22 (64.7)	69.8*
Summer (n = 42)					
Dryer	3 (7.4)	30 (71.4)	16 (38.1)	7 (16.7)	53.0
Water heater	0 (0)	40 (95.2)	23 (54.8)	4 (9.5)	83.4
Wall furnace	0 (0)	13 (31.0)	7 (16.7)	0 (0)	NA
Stove top	2 (4.8)	39 (92.9)	11 (26.2)	15 (35.7)	69.8*
Oven	2 (4.8)	39 (92.9)	13 (31.0)	13 (31.0)	69.8*

Questions regarding ignition and standing pilot lights on gas appliances elicited multiple "don't know" responses, which were not included on this table.

*** The AHS survey does not provide data for fuel sources of individual kitchen appliances; the number provided is the percent of households that cook with piped gas fuel.**

Source: UCLA

The number of homes with different types of central forced air systems is shown in Table .

Table C-3: Homes with Central Forced Air, Gas-Powered CFA, and CFA With Air Conditioning

	Winter		Summer		AHS Survey (CA estimate) %
	Total Number	Percent of Total Respondents	Total Number	Percent of Total Respondents	
Central Forced Air (CFA) Unit in Home	17	50.0	9	21.43	71.1
Gas CFA Unit in Home	12	70.6	6	66.7	NA
CFA Unit with AC	13	38.2	8	19.0	78.9

Source: UCLA

The number of homes with different types of non-central cooling and purifying systems is shown in C-4.

Table C-4. Statistics of non-CFA Cooling and Purifying Appliances Within the Monitored Homes

	Number of Homes with Appliance	Percent of Homes with Appliance
Winter (n = 34)		
Air Purifier	2	5.9%
Wall/Window AC	18	52.9%
Ceiling or Standing Fan	30	88.2%
Summer (n = 42)		
Air Purifier	1	2.4%
Wall/Window AC	32	76.2%

Ceiling or Standing Fan	33	78.6%

Source: UCLA

C.2.3 Participant Cooking and Ventilation Behaviors

Table C-5 Tables C-6 and Table C-7 provide a summary of data collected around cooking behaviors, (aggregated by weekdays and weekends), use of kitchen exhaust systems, and general ventilation behaviors.

Questions about general kitchen ventilation behaviors were included in both the second and third questionnaires. For simplicity, only responses from the final questionnaire are shown here. Percentages were calculated by dividing the total number of responses in the frequency category by the sum of the responses from each of the four frequency categories; blanks and non-applicable responses were not included in the dominator.

Table C-5: Statistics for the Average Number of Times Each Kitchen Appliance Was Used per Sampling Timeframe

	Winter Mean (Min – Max)/ Mean %		**Summer** Mean (Min – Max)/ Mean %		**Total**
	Weekday	**Weekend**	**Weekday**	**Weekend**	
Microwave	5.4 (0 - 20)/1.1	1.7 (0 - 8)/0.9	3.1 (0 - 20)/0.6	1.0 (0 - 8)/0.5	5.4 (0 – 28)
Stovetop	7.3 (0 - 16)/1.5	1.8 (0 - 6)/0.9	6.9 (0 - 15)/1.4	2.2 (0 - 6)/1.1	9.1 (0 – 21)
Oven	0.7 (0 - 7)/0.1	0.2 (0 - 2)/0.1	0.4 (0 -10)/0.1	0.1 (0 – 4)0.1	0.7 (0 – 14)
Stovetop & Oven	8.0 (0 - 17)/1.6	2.0 (0 - 6)/1.0	7.3 (0 - 20)/1.5	2.3 (0 - 8)/1.2	9.8 (0 - 28)

Source: UCLA

Table C-6: Statistics of Kitchen Exhaust Systems

	Winter		**Summer**	
	Total Number	**Percent of Total Respondents**	**Total Number**	**Percent of Total Respondents**
Kitchen Exhaust Information				
Exhaust fan in the ceiling or wall	1	3.4	4	10.3
Microwave & exhaust fan combination above the stove top	2	6.9	5	12.8

Range hood above the stove top	26	89.7	29	74.4
Other Type of Exhaust	0	0	1	2.6
Exhaust vents to the outdoors	24	80.0	32	82.1

Source: UCLA

Table C-7: Total Values for Frequency of Each Ventilation Related Behaviors for Winter and Summer Samples

	Never	Rarely	Usually	Always
Kitchen exhaust vent usage while cooking				
Winter	10 (35.7)	8 (28.6)	4 (14.3)	6 (21.1)
Summer	8 (21.1)	7 (18.4)	6 (15.8)	17 (44.7)
Open kitchen windows while cooking				
Winter	19 (63.3)	3 (10.0)	5 (16.7)	3 (10.0)
Summer	7 (18.4)	2 (5.3)	10 (26.3)	19 (50.0)
Open kitchen door(s) to the exterior while cooking				
Winter	17 (54.8)	2 (6.5)	6 (19.4)	6 (19.4)
Summer	9 (25.7)	3 (8.6)	7 (20.0)	16 (45.7)
Open kitchen door(s) to the interior while cooking				
Winter	13 (61.9)	2 (9.5)	4 (19.0)	2 (9.5)
Summer	2 (25.0)	0 (0)	3 (37.5)	3 (37.5)
Open other windows or doors while cooking				
Winter	16 (55.2)	6 (20.7)	4 (13.8)	3 (10.3)
Summer	6 (24.0)	2 (8.0)	8 (232.0)	9 (36.0)

Source: UCLA

C.2.4 Indoor/Outdoor PM2.5 Ratios for Resampled Homes

Table shows a representative subset of I/O results - for just resampled homes, and just for PM2.5 concentrations.

Table C-8: Mean Particle Concentrations and I/O Ratios Between Outdoor and Indoor Concentrations for Resampled Homes

		Winter			Summer		
#	**House Type**	**Indoor $PM_{2.5}$** (mean)	**Outdoor $PM_{2.5}$** (mean)	**Mean $PM_{2.5}$ I/O**	**Indoor $PM_{2.5}$** (mean)	**Outdoor $PM_{2.5}$** (mean)	**Mean $PM_{2.5}$ I/O**
1	Townhouse/ Condominium	6.5	13.7	1.1	4.5	16.3	0.3
2	SFH (detached)	24.9	13.6	5.3	18.7	19.8	1.1
3	SFH (detached)	13.7	7.8	3.2	15.0	15.9	1.0
4	SFH (detached)	2.5	11.1	0.6	3.0	17.5	0.2
5	SFH (detached)	17.2	13.9	2.3	16.2	17.4	1.0
6	SFH (detached)	17.2	13.2	1.2	24.5	23.3	1.1
7	SFH (detached)	11.2	12.5	2.1	12.5	17.8	0.8
8	SFH (detached)	27.2	13.0	5.3	14.1	18.7	0.8
9	SFH (detached)	4.3	10.9	0.9	6.1	18.2	0.4
10	SFH (detached)	45.4	12.6	10.0	36.4	17.2	2.7
11	Apt (5+ units)	31.5	11.9	7.6	29.7	16.9	2.0
12	Apt (5+ units)	25.4	12.4	2.4	12.8	15.1	0.9

Source: UCLA

C.2.5 NO_2 Indoor/Outdoor Ratios

Table C-9 shows indoor/outdoor ratios for sample pairs at homes located within the following three zones:

- Area A - removed from identifiable competing sources
- Area B - near major roadways
- Area C - near industrial emissions

Table C-19: Concentrations of Paired Indoor/outdoor NO2 Values (ppb)

	Winter	Summer
Area A		
Indoor/Outdoor (I/O)	38.8 / 16.6	30.1/9.1
I/O Ratio	2.3	3.3
Area B		
Indoor/Outdoor (I/O)	22.5 / 18.3	27.1/13.4
I/O Ratio	1.2	2.0
Area C		
Indoor/Outdoor (I/O)	22.8 / 19.3	13.1/11.7
I/O Ratio	1.2	1.1

For the homes removed from identifiable competing sources (A), near major roadways (B), and near industrial emissions (C).

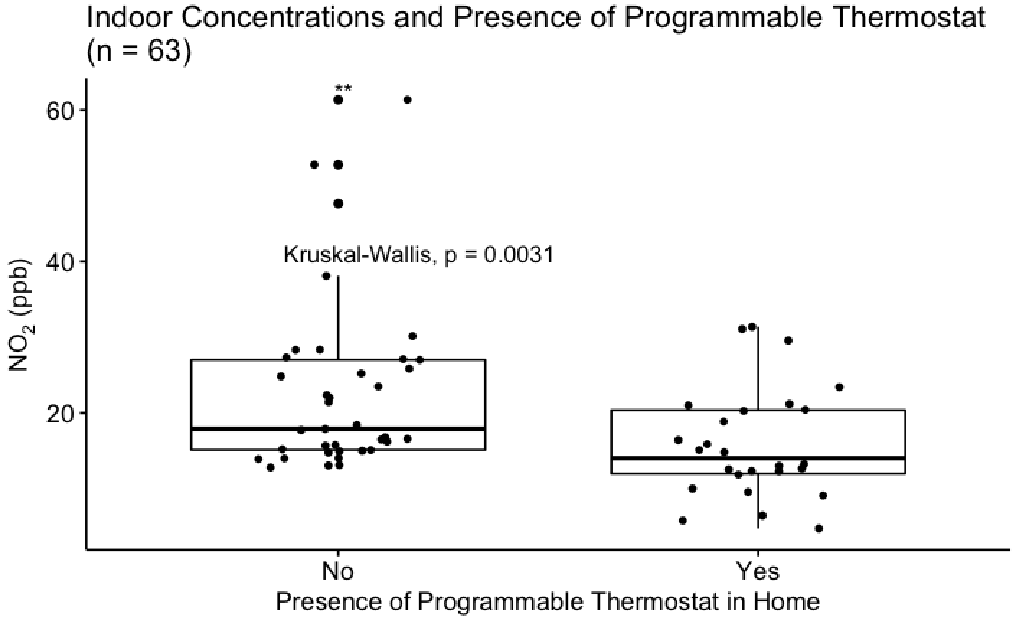
Source: UCLA

C.2.6 Relationships with Heating and Cooling Appliances

Programmable Thermostats

Figure 2 shows the relationships between the presence of a programmable thermostat and the measured concentrations of NO_2 and particulate matter.

Figure C-2: Box Plots for Programmable Thermostats

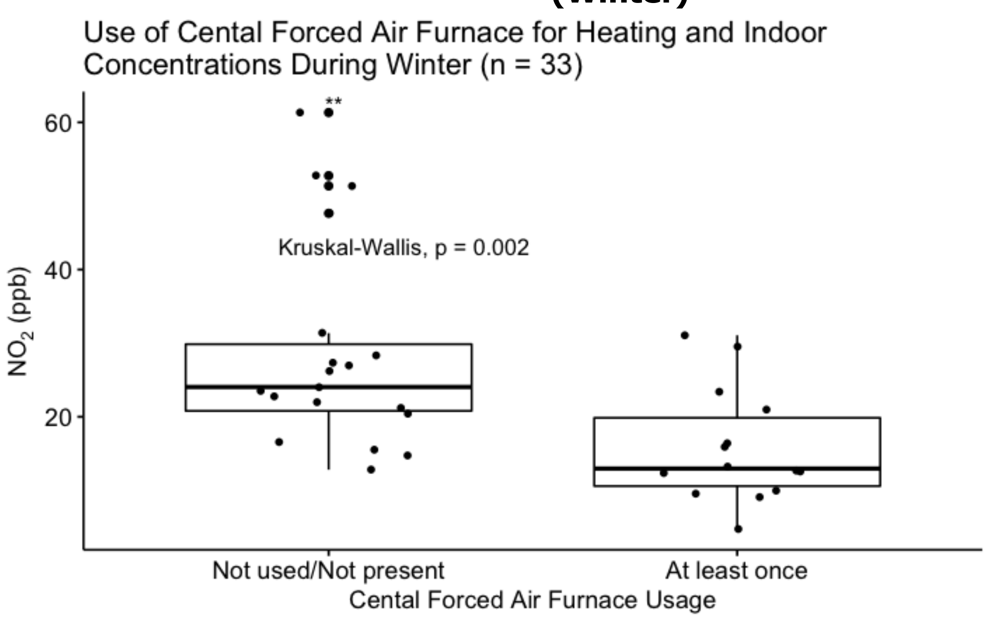


Measured air quality variable is on the y-axis and presence of a programmable thermostat (1 = "yes", 2 = "no") is on the x-axis.

Source: UCLA

Figure C-3 shows the relationships between daily use of central forced air furnaces over the winter sampling timeframe and the measured concentrations of NO_2.

Figure C-3: Box Plots for Daily Central Forced Air Furnace Use for Week 1 (Winter)

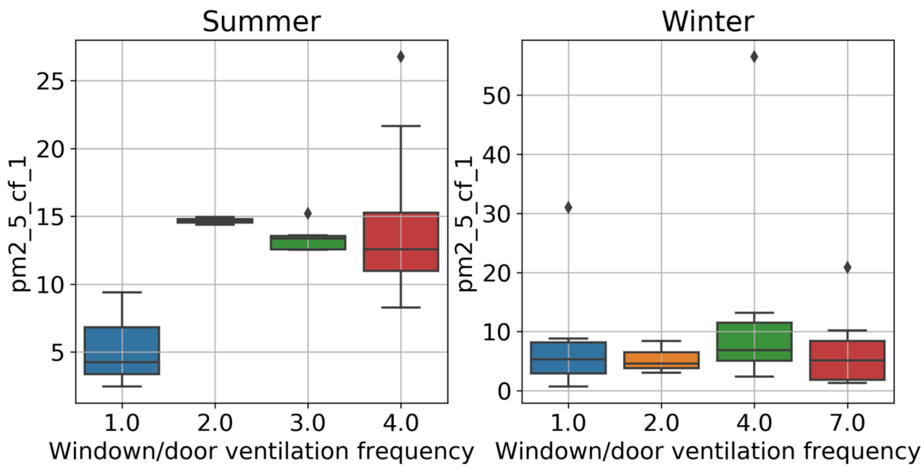


Passive NO_2 concentrations are on the y-axis and the daily usage on the x-axis.

C.2.7 Relationships with General Home Ventilation

Figure C-4 shows the relationships between window and door ventilation practices, and the measured concentrations of PM2.5.

Figure C-4: Box Plots for Frequency of Window and Door Ventilation With Particulate Concentrations



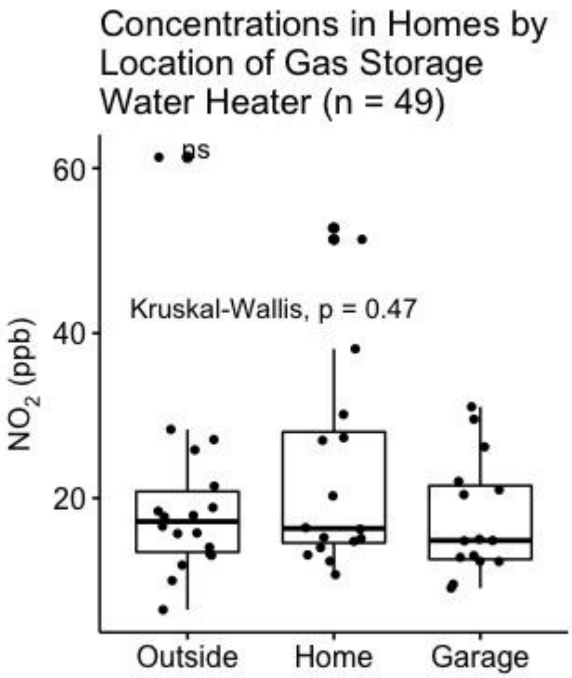
Particle values are on the y-axis and frequency of window and door ventilation practices (1 = "never", 2 = "rarely", 3 = "usually", 4 = "always").

Source: UCLA

C.2.8 Relationships with Non-Cooking Gas Appliances

Figure C-5 shows the relationships between the location of storage water heaters, and the measured concentrations of NO2.

Figure C-5: NO2 Concentrations Between Homes With Storage Water Heaters



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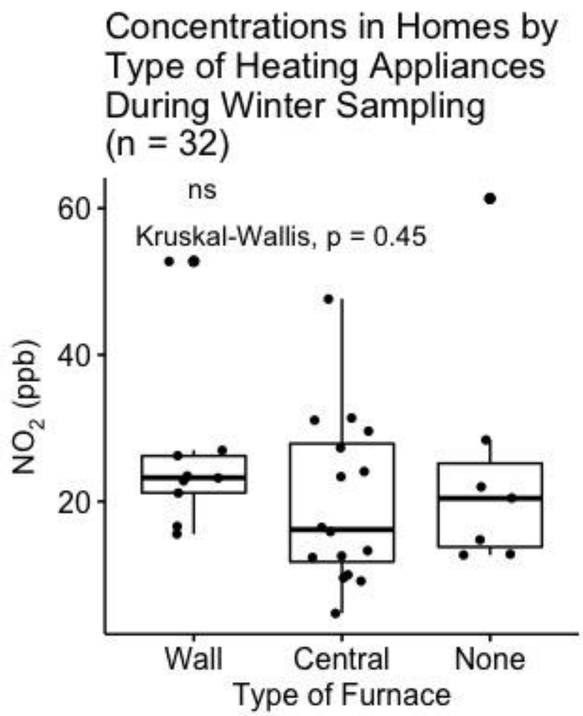


Water heaters located outside the home, within the main living area of the home, or in the garage (left); NO2 concentrations between homes that self-reported the presence of wall furnaces, central forced air furnaces, or neither (right).

Source: UCLA

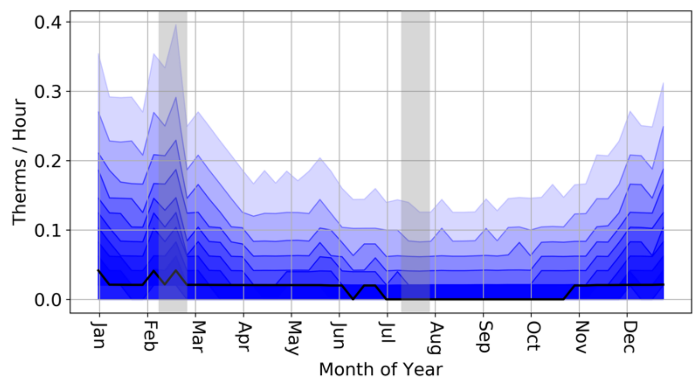
C.3. Hourly Natural Gas Consumption Analysis Results

C.3.1 Variation in Average Hourly Gas Use Rates for Monitoring Program Participants

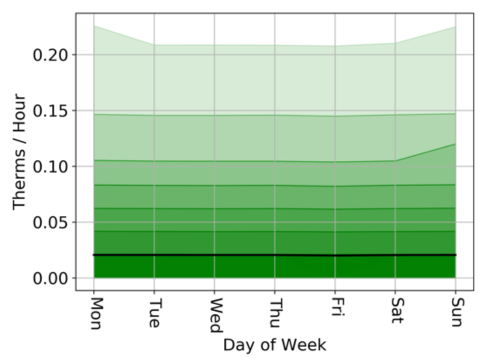
Figure C-6 depicts fan plots of monthly, daily, and hourly variations in average hourly natural gas use rates for just the subset of household accounts within the project study area that participated in the monitoring program.

Figure C-6: Fan Plots Illustrating Monthly and Hourly Variations in Natural Gas Use

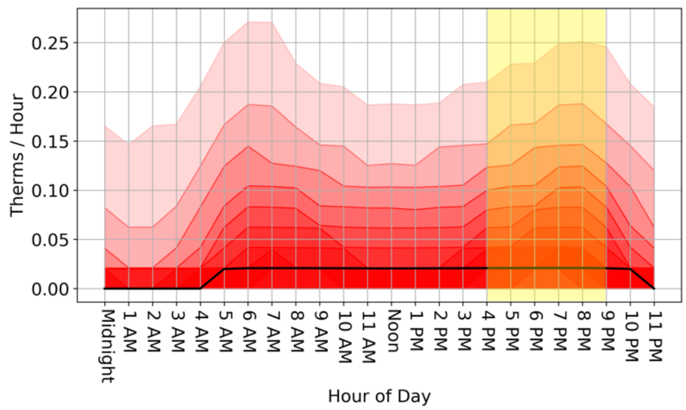
A.



B.



C.



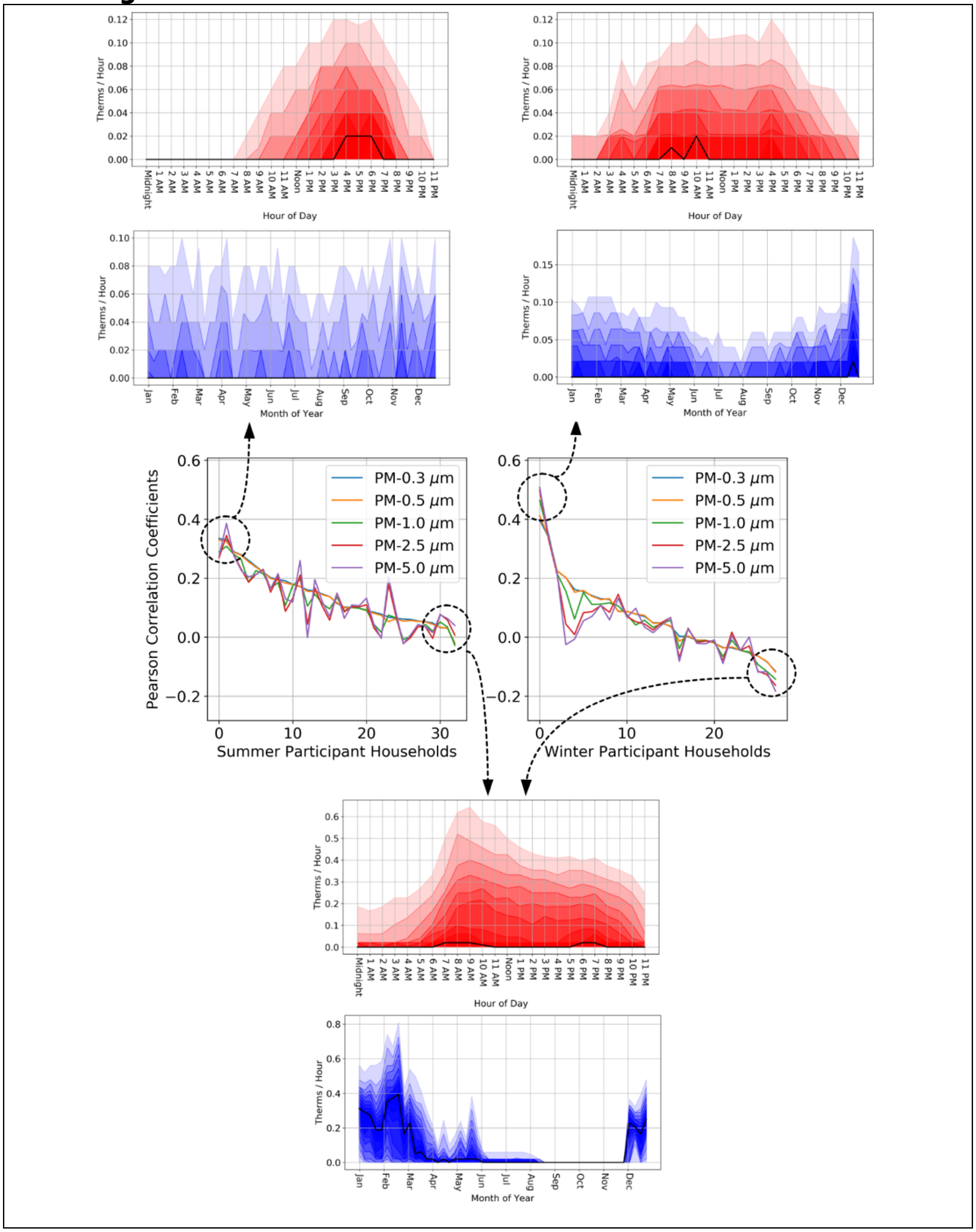
Fan plots illustrating monthly (A., top – blue), daily (B., middle – green), and hourly (C., bottom – red) variations in average hourly natural-gas use for all service accounts associated with households that participated in the indoor air quality monitoring program (63 households) for the data period spanning 8-15-2018 through 8-15-2019. In plot A, the timing of the two air quality monitoring periods, summer and winter, are highlighted in the gray shaded areas. In plot C, the timing of common "on-peak" electricity rate tariff time-of-use periods are similarly highlighted in the yellow shaded area.

Source: UCLA

C.3.2 Natural Gas Use Correlations With Indoor Air Quality

The pair of line plots shown in part B of Figure C-7 plot the Pearson Correlation Coefficient (PCC) values computed between each household's hourly natural gas usage time series and the matching hourly time series for the five different PM size fractions sampled as part of the indoor AQM program between the summer and winter cohorts. Among the summer cohort the strongest positive PCC value observed for any single household was 0.33 - between hourly therm use and PM-0.3 μm counts. Fan plots depicting the hourly and monthly average gas use rates for these, most strongly correlated, individual households are plotted jointly in part A. The weakest individual household correlations observed among this cohort were approximately zero. Among the winter cohort the strongest positive PCC value observed for any single household was 0.51 – between hourly therm use and PM-5.0 μm counts. The weakest individual household correlation observed among this cohort was -0.18 – between hourly therm use and PM-5.0 μm counts. Fan plots depicting the hourly and monthly average gas use rates for this, most weakly correlated individual household are plotted jointly in part B. of the figure.

Figure C-7: Line Plots of Pearson Correlation Coefficients



Plots computed for each household's hourly gas use and hourly PM counts for various size fractions (B. – middle), between the summer (left) and winter (right) air quality monitoring cohorts. Paired fan plots are shown illustrating the hourly and monthly gas use variations associated with the individual households with the strongest (A. - top) and the weakest correlations (C. - bottom) between hourly gas use and sampled PM counts.

Source: UCLA

Comparing the fan-plots in parts A and B of Figure 21**Error! Reference source not found.** reveal important structural differences between the timing of gas use among households with strong versus weak correlations to indoor air quality. In part A, it can be seen that for the strongly correlated household, hourly gas use (red) is concentrated in the late evening hours, around dinner time. Likewise, in the corresponding monthly gas use plot (blue) for this household, it can be seen that there is almost no variation in the rates of gas use across the months of the year. These two pieces of information suggest that end-use activities within the strongly correlated household are primarily related to cooking and not more seasonally dependent end-uses, such as space and water heating.

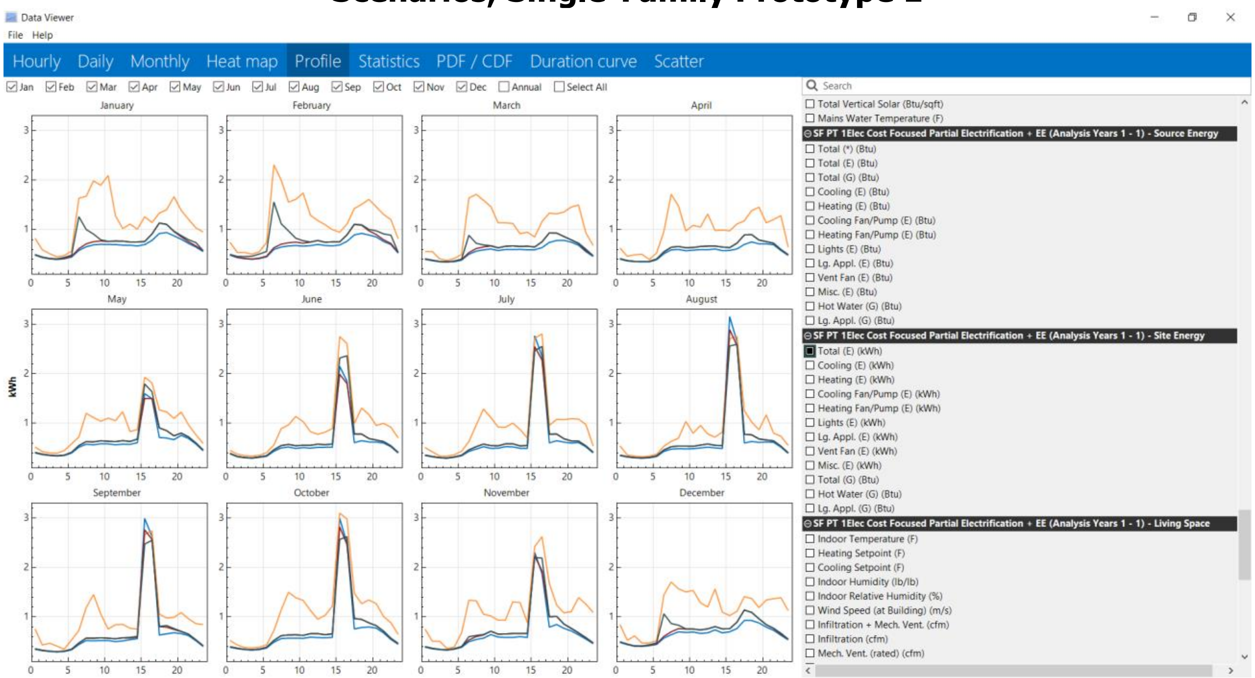
Alternatively, looking at the pair of fan-plots in part B, precisely the opposite trends can be seen. Hourly gas use rates track overall levels of activity and occupancy expected throughout the average day within a residential home. Furthermore, month to month variations in the rates of gas use are significant. Winter gas use rates are several multiples of those in the summer months, with gas use even declining to zero for a period, indicating that the pilot lights of gas heating device may have been extinguished to conserve energy. Taken together, this information indicates that for households in which PM counts were most weakly correlated with gas use, the dominant end-use activities likely consisted of seasonally variable heating loads, such as for space and water heating – and not indoor natural gas fueled cooking.

C.4. Building Prototype and Scenario Modeling

C.4.1 Example Building Model Output – Single Family Prototype 1

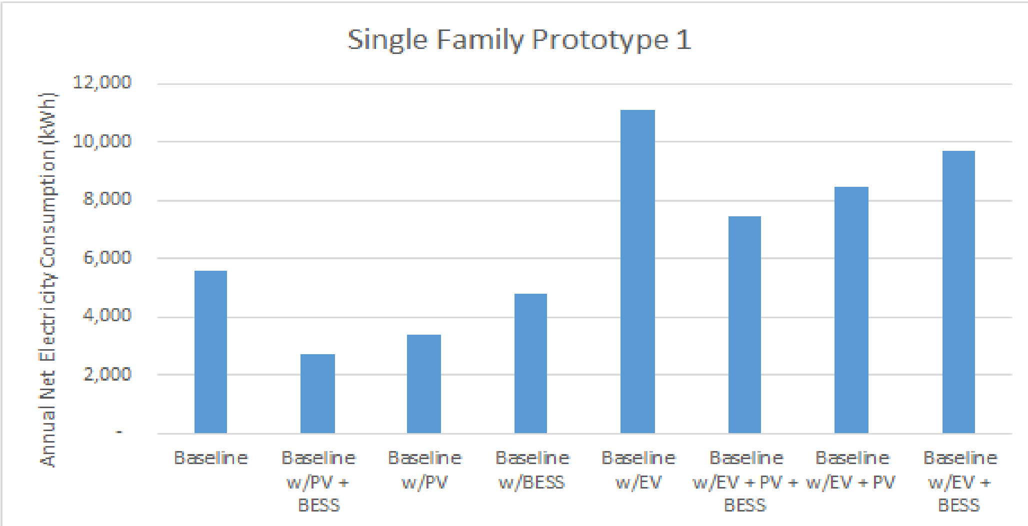
Example results for the Single Family Prototype 1 model (wall furnace for heating and a window AC unit for cooling) are shown in Figure C-8, Figure C-9 and Figure C-10.

Figure C-8: BEopt Hourly Load Profiles by Month for Various Electrification Scenarios, Single-Family Prototype 1



Source: The Energy Coalition

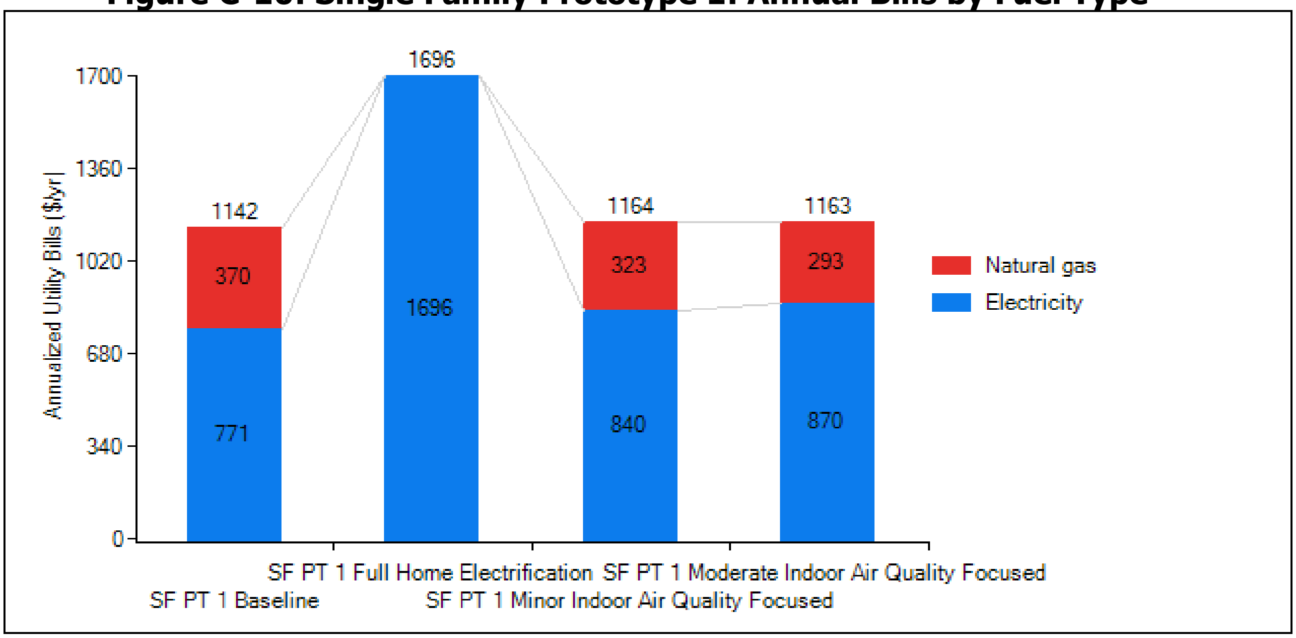
Figure C-9: Annual Net Electricity Consumption for Single Family Prototype 1



Baseline configuration with various EV and DER scenarios.

Source: The Energy Coalition

Figure C-10: Single Family Prototype 1: Annual Bills by Fuel Type



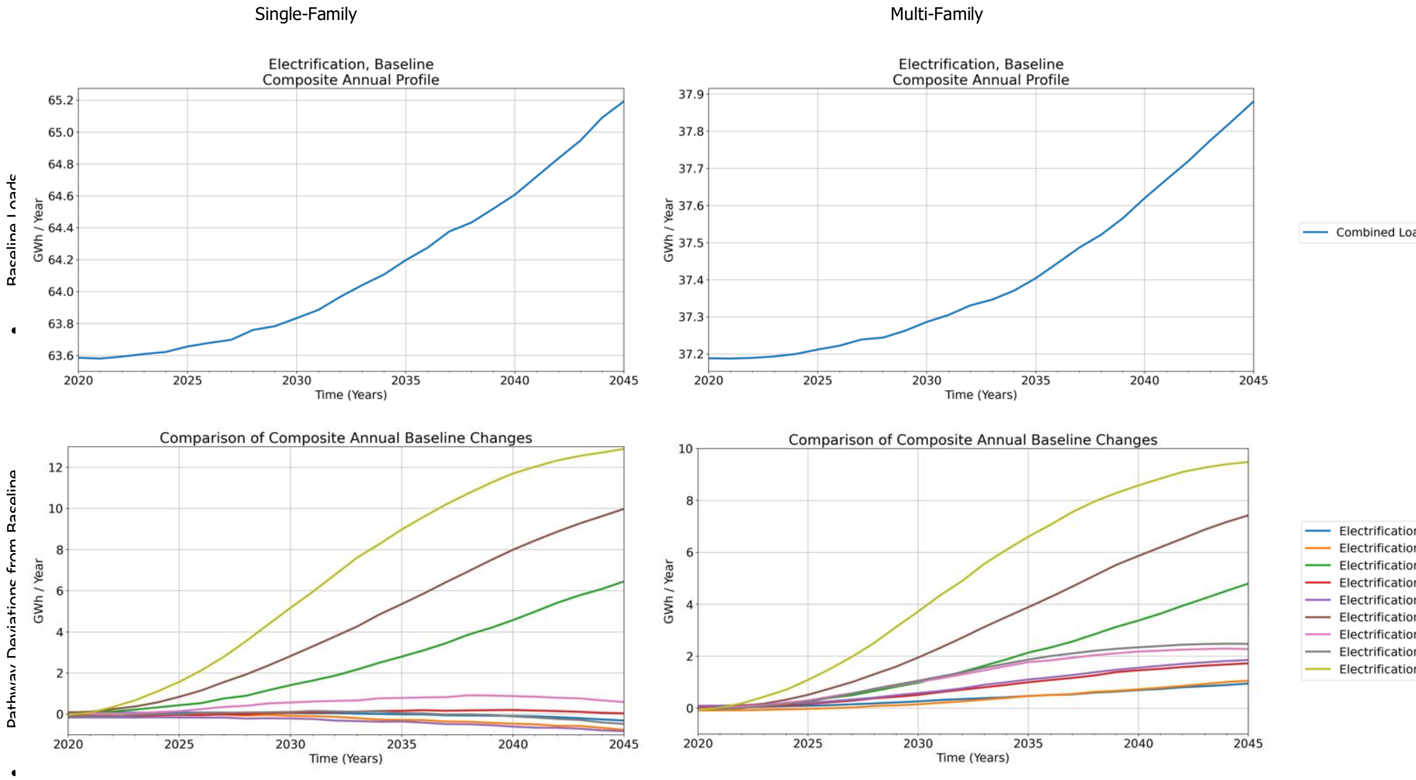
Source: The Energy Coalition

C.5. Community-Scale Simulations

C.5.1 Annual Load Growth for Appliance Electrification Pathways

Figure C-11 plots total annual load growth for the SF and MF baseline pathways (top row) and the expected future changes in annual total loads associated with each pathway alternative (bottom row).

Figure C-11: Comparisons of Each Building Electrification Pathway Simulations' Total Annual Loads and Annual Total Change



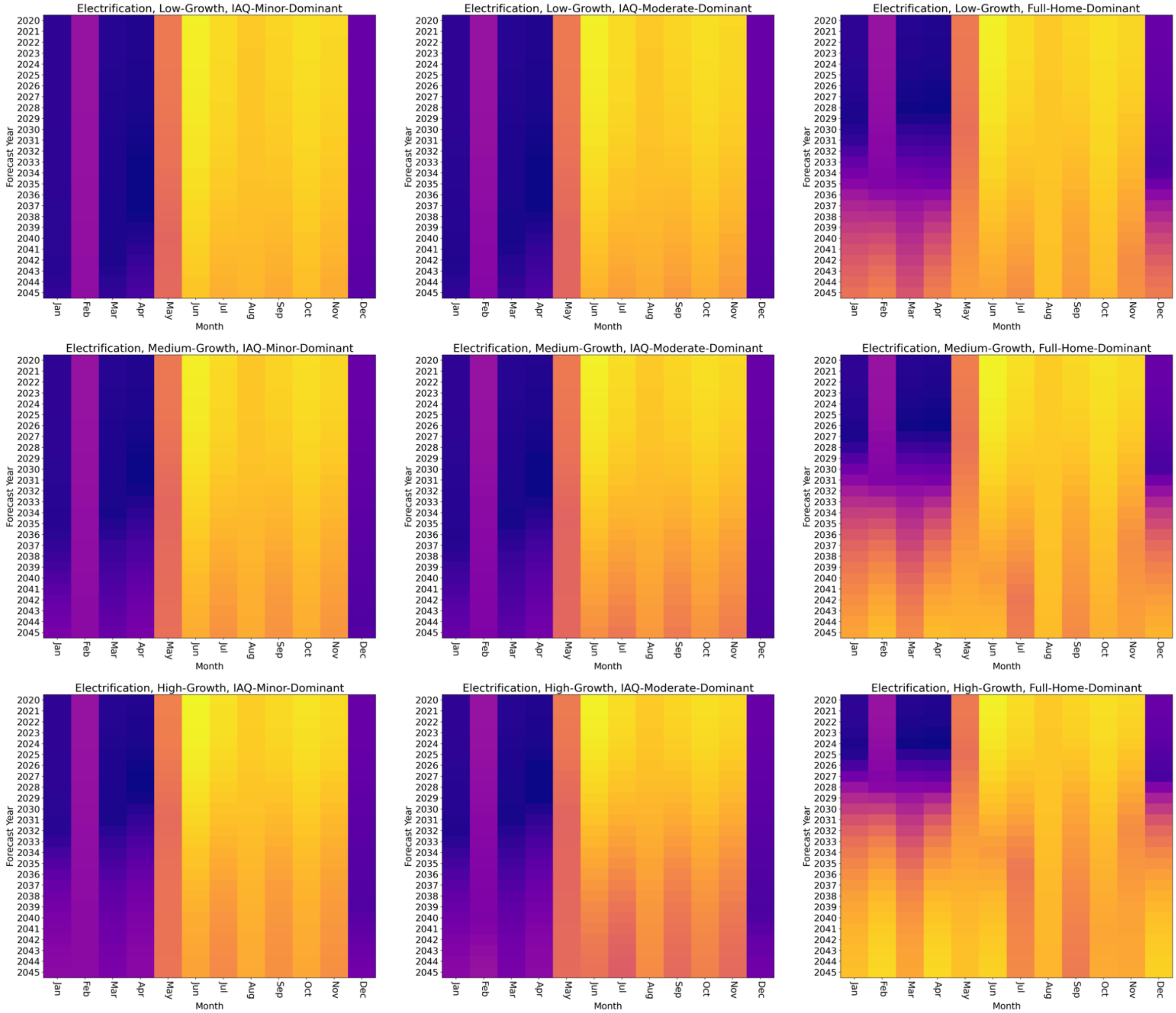
From the baseline composite load profile for the community's single-family housing stock (left column) and multi-family housing stock (right column).

Source: UCLA

C.5.2 Monthly Load Factors for Appliance Electrification Pathways

Figure C-12 depicts the monthly load factor for each year of the simulation period between the nine electrification pathway alternatives for SF buildings.

Figure C-12: Comparison of Single-family Building Electrification Pathway Composite Load Factors



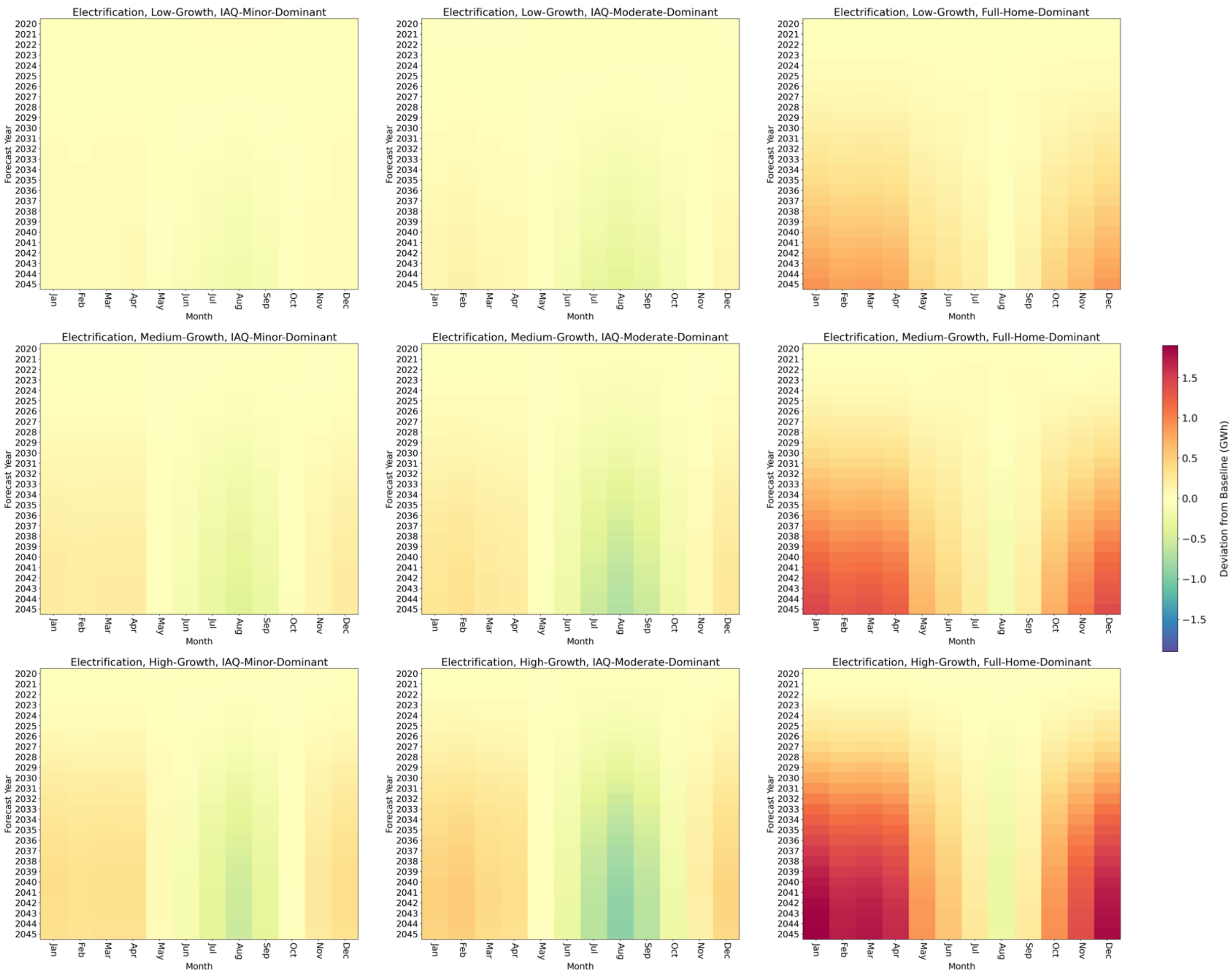
Comparison load factors (unitless) by month for each year of the simulation period.

Source: UCLA

C.5.3 Monthly Total Loads for Appliance Electrification Pathways – Changes from Baseline for Single Family Homes

Figure C-13 illustrates the changes in total monthly loads relative to the baselines for single family buildings, showing the net increases (red) and decreases (blue) in the monthly demand.

Figure C-13: Monthly Comparison of Single-family Building Electrification Pathway Changes



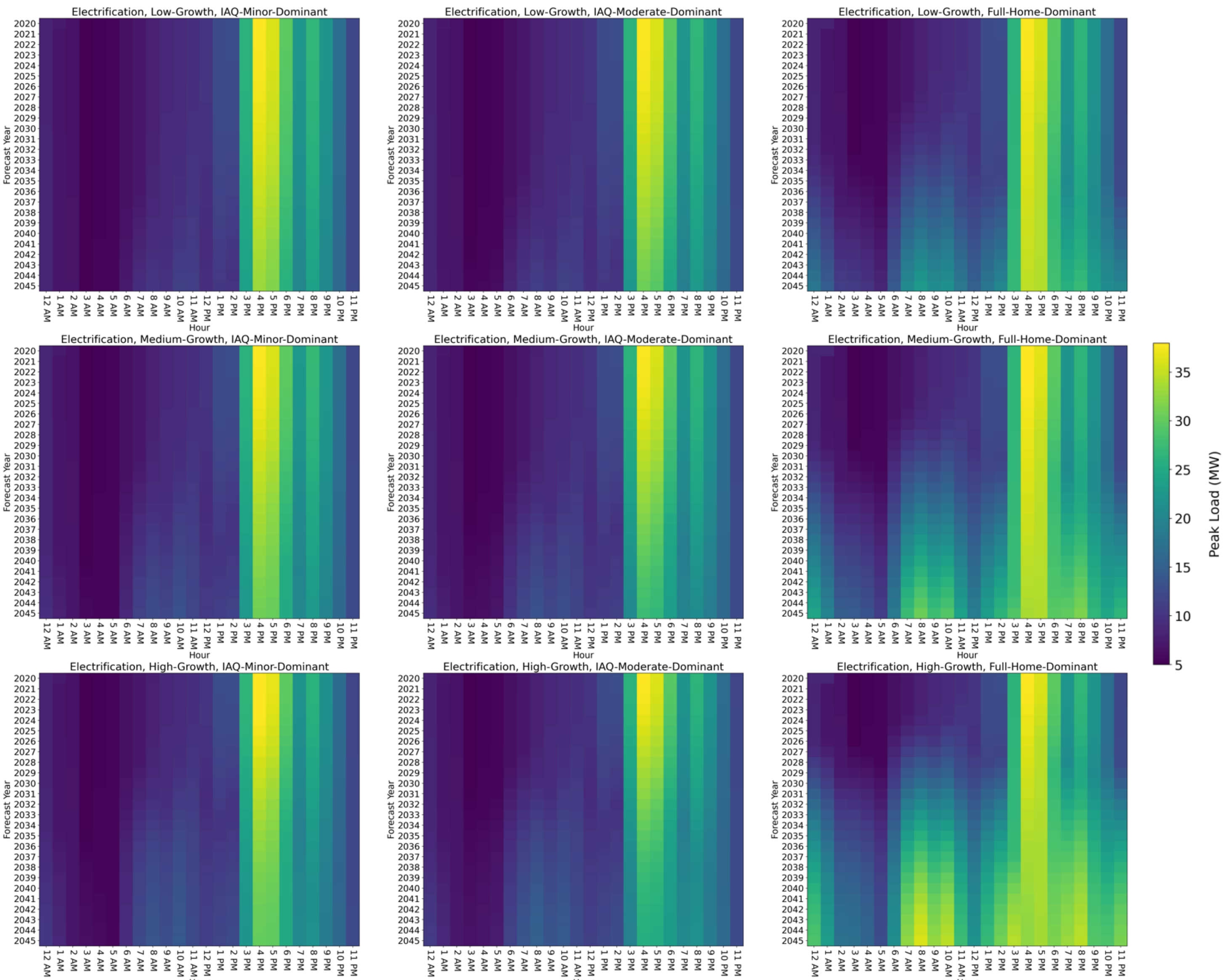
Changes in total load from the baseline (GWh) by month for each year of the simulation period.

Source: UCLA

C.5.4 Hourly Peak Loads for Appliance Electrification Pathways for Single Family Homes

Figure C-14 plots hourly changes in average peak loads across the 25-year simulation period for single family buildings.

Figure C-14: Hourly Comparison of Single-family Building Electrification Pathway Composite Peak Loads



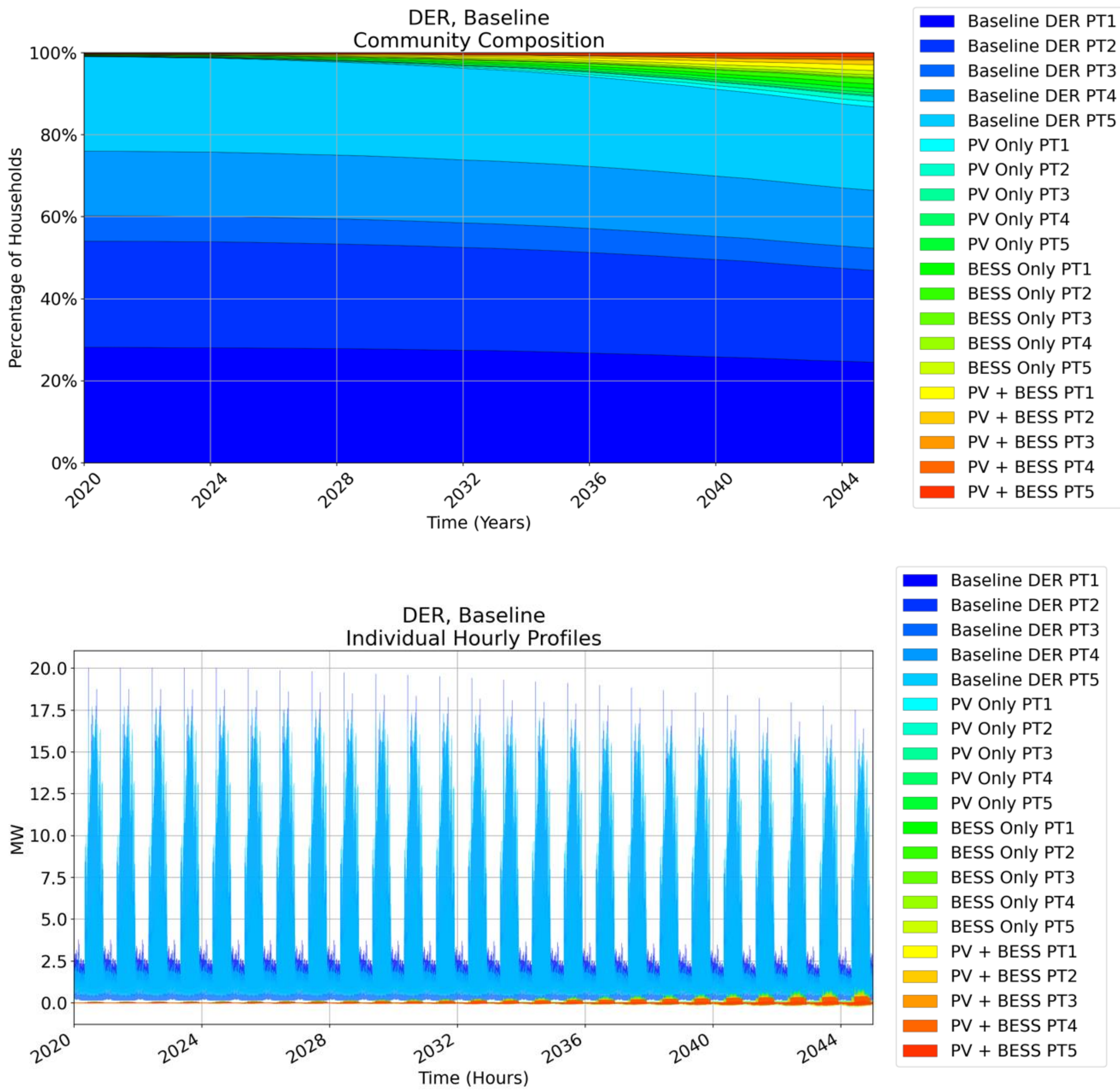
Peak loads (MW) by hour of the day for each year of the simulation period.

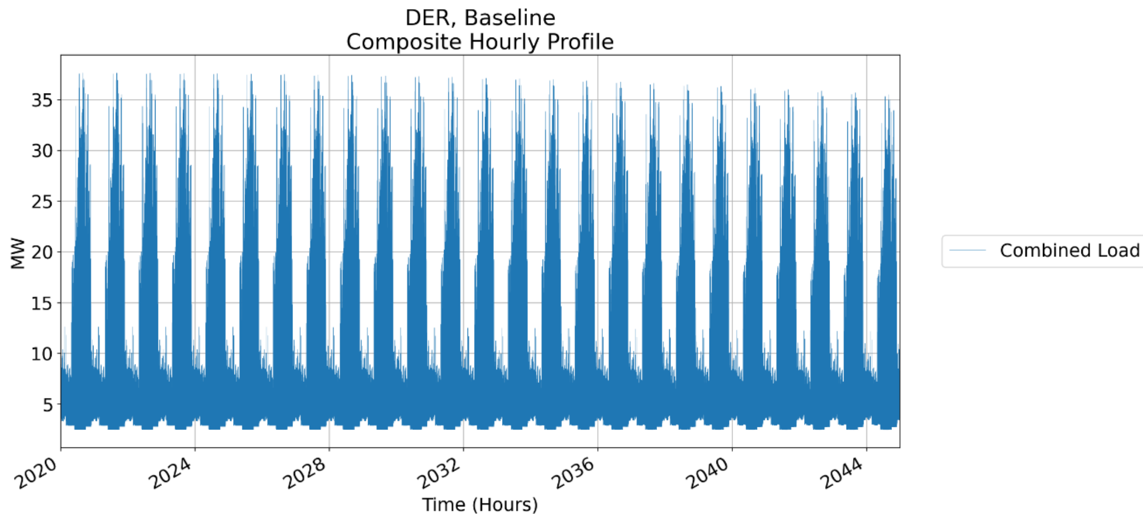
Source: UCLA

C.5.5 Baseline Community Composition for Single Family – Distributed Energy Resources

Figure C-15 illustrates the evolution of the baseline composition of the community's building stock with respect to the different DER prototype building models for single family buildings, and how this evolution is reflected in the contribution of each prototype model category to the community's composite hourly load profile.

Figure C-15: Baseline Single-family Baseline DER Pathway





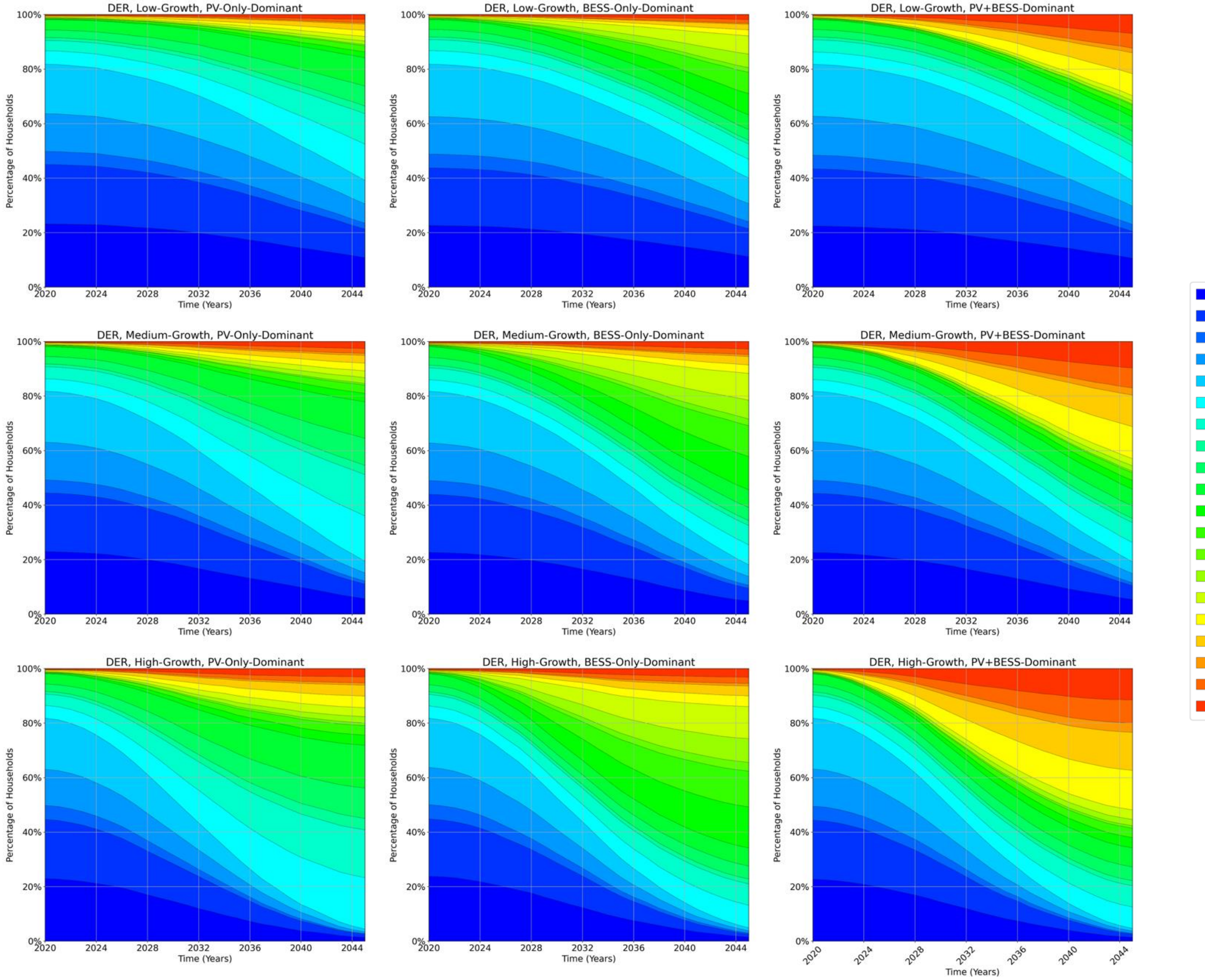
Community composition (top), individual prototype model load contributions (middle) and composite hourly load profile (bottom)

Source: UCLA

C.5.6 Single Family Building Stock Under DER Pathways

Figure C-16 plots the changing composition of the single-family housing stocks over the 25-year simulation period.

Figure C-16: Comparison of Single-family Building Stock Compositions Under Nine DER Simulation Pathways

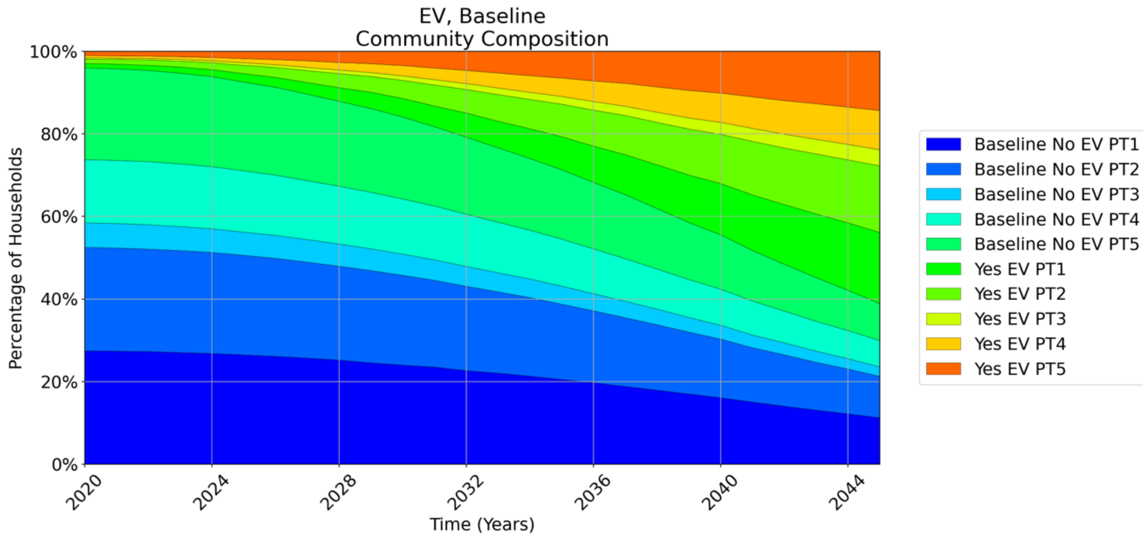


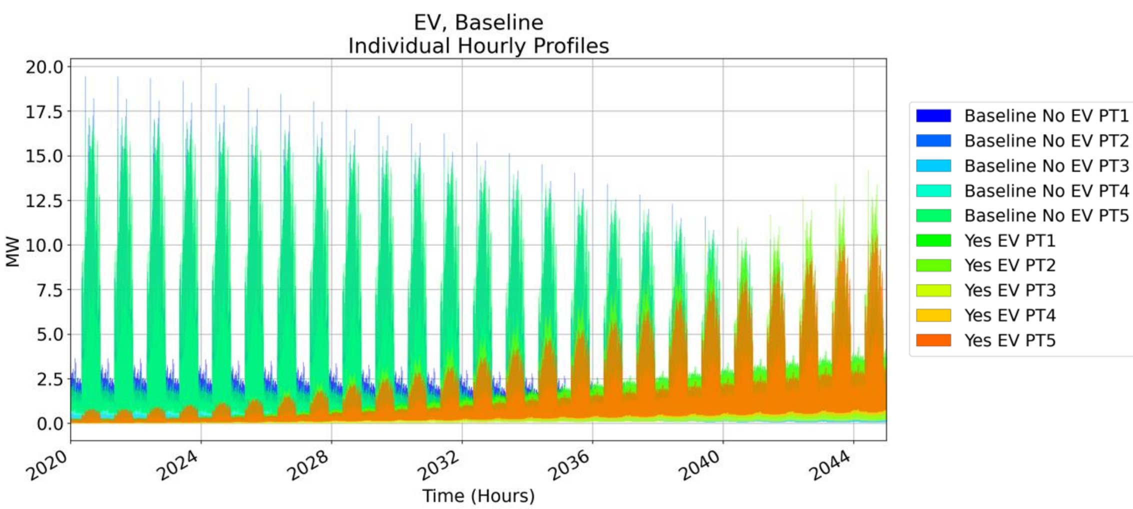
Source: UCLA

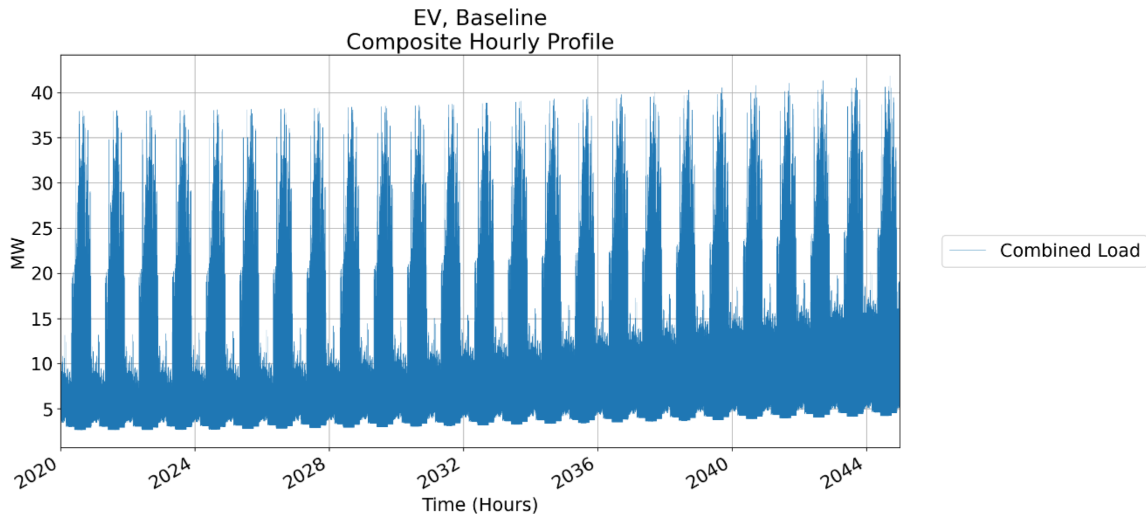
C.5.7 EV Scenarios – Baseline Composition and Load Profiles

Figure C-17 plots changes in the community composition, individual prototype model load contributions, and community wide composite hourly loads for single-family buildings for baseline EV adoption over the simulation period.

Figure C-17: Hourly Comparison Single-family Baseline Electric Vehicle Adoption Pathway





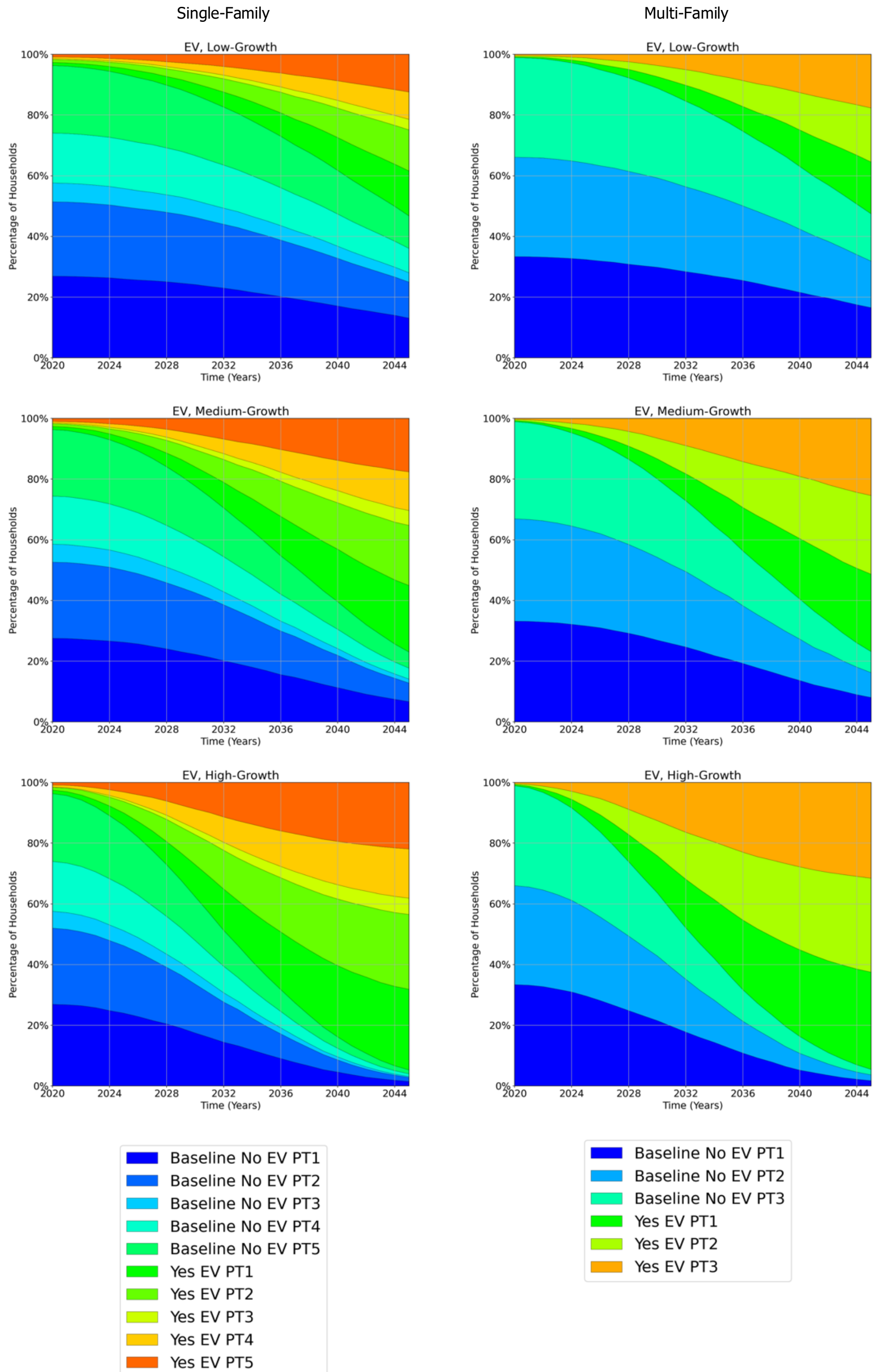


Community composition (top), individual prototype model load contributions (middle) and composite hourly load profile (bottom).

Source: UCLA

C.5.8 Single Family Building Stock under Electric Vehicle Adoption Pathways

Figure C-18: Comparison of Single-family and Multi-family Community Compositions Under Three Electric Vehicle Adoption Simulation Pathways



Comparison of single-family (left column) and multi-family (right column) community compositions under three electric vehicle adoption simulation pathways.

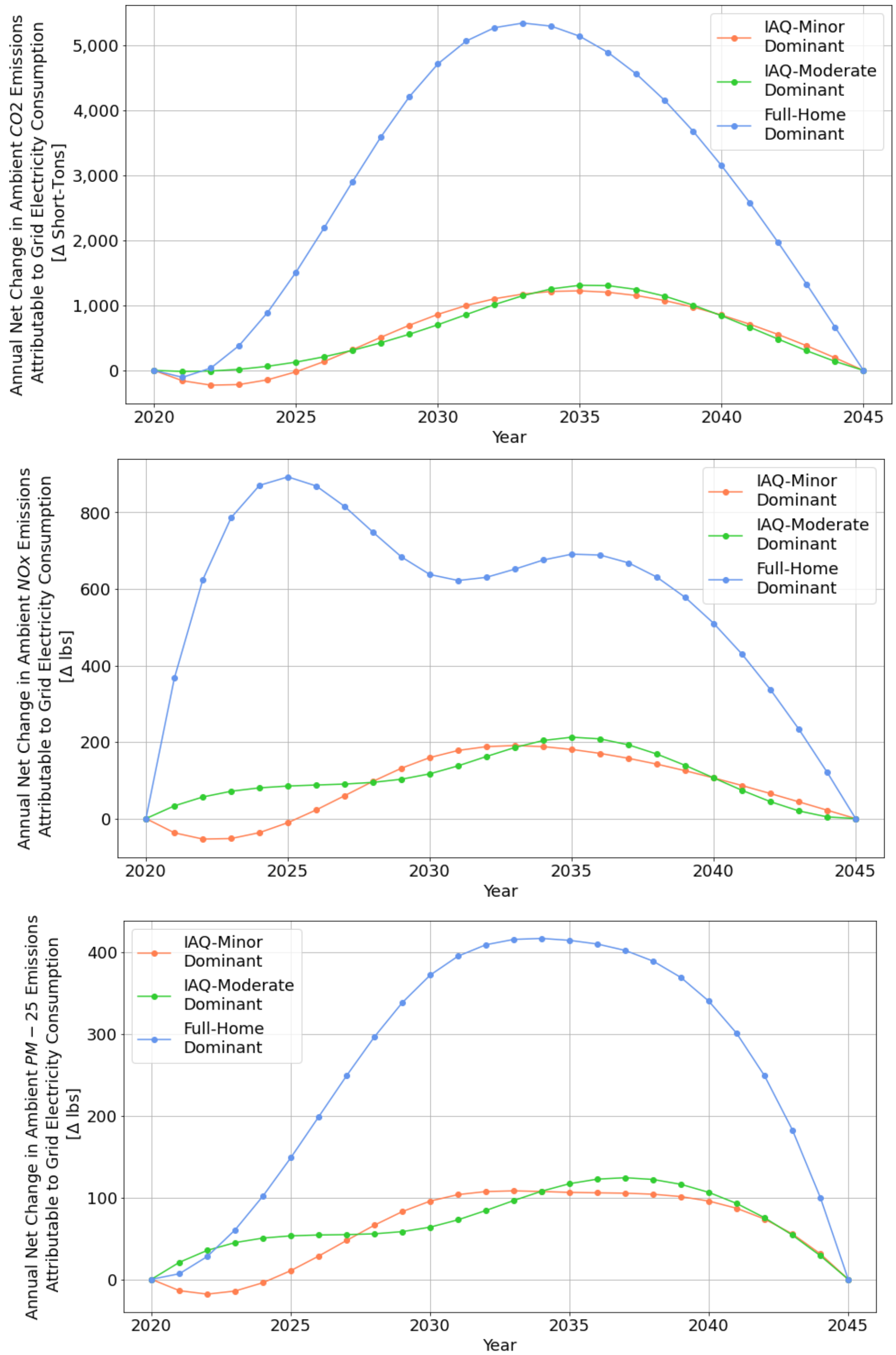
Source: UCLA

Holistic Assessment of Residential Appliance Electrification

C.6.1 Annual and Monthly Breakdown of Ambient Emission Increases from Fossil EGUs Due to High Growth Rate Appliance Electrification

Figure C-19 contains plots of the annual changes in total ambient emissions of CO_2, NO_x, and PM-2.5m calculated using the AVERT framework.

Figure C-19: Annual Net Change in Ambient CO2 Emissions

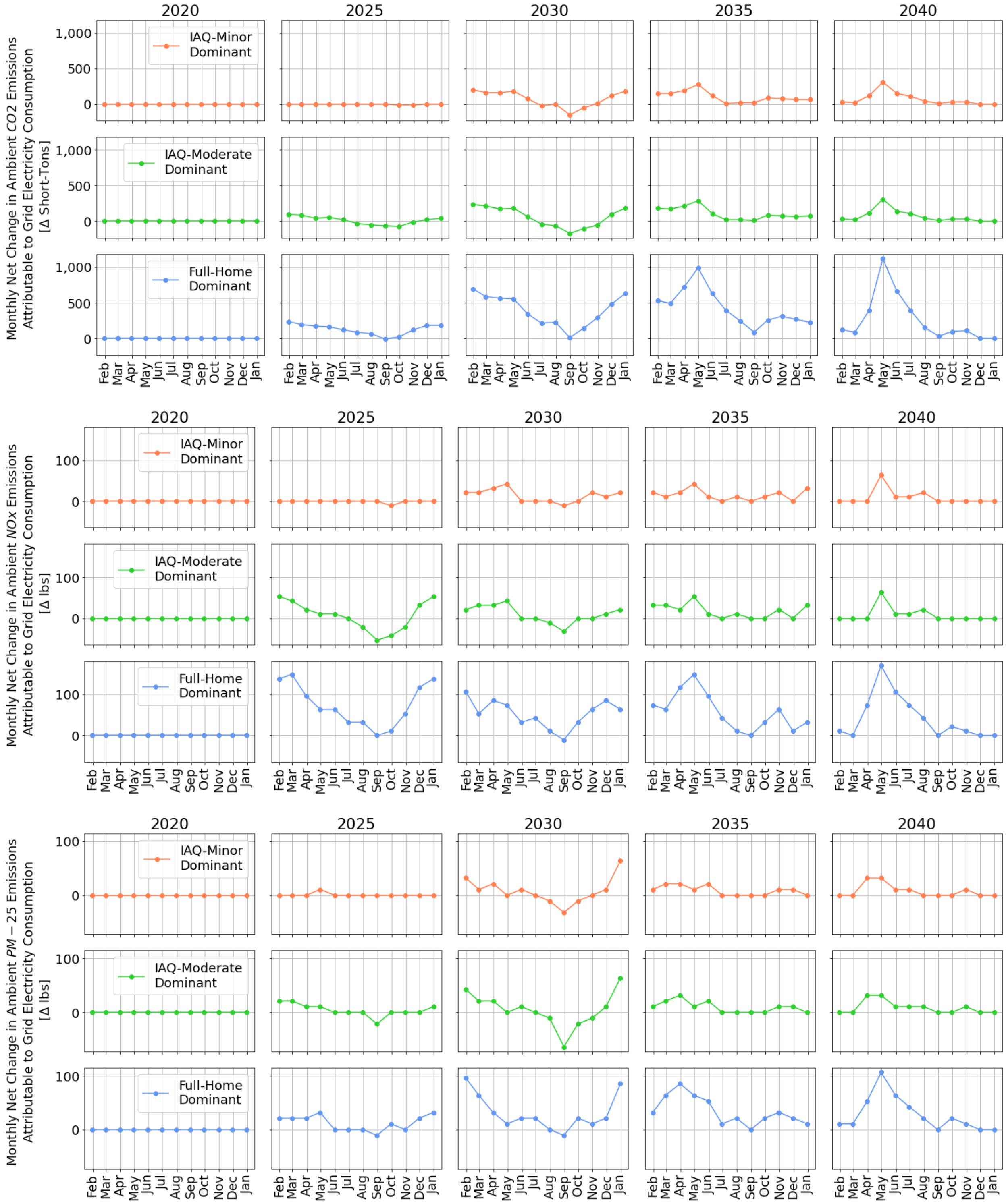


[Δ short-tons] (top), NOx [Δ lbs] (middle), and PM-2.5 emissions [Δ lbs] (bottom) attributable to increased grid electricity consumption – computed for each high-growth transformation pathway relative to the baseline pathway from 2020-2045.

Source: UCLA

C-20 provides a series of monthly snapshots for the five future years for which ambient emissions changes from EGU operations were directly simulated using the AVERT framework. Once again, within this figure, the top-most plots correspond to net CO_2 emissions, the middle plots to net NO_x emissions, and the bottom plot to net PM-2.5m emissions. Additionally, the same mapping of data series colors to pathways as was used previously, has also been retained here. These monthly net-emissions data once again illustrate a number of important interactions between anticipated future changes in the characteristics of the community's load profile relative to the emissions intensities of the dominant fossil EGUs in continued operation within each time period.

Figure C-20: Monthly Net Change in Ambient CO2 Emissions



[Δ short-tons] (top), NOx emissions [Δ lbs] (middle), and PM-2.5 emissions [Δ lbs] (bottom) attributable to increased grid electricity consumption – computed relative to the baseline for each high-growth transformation pathway and for each of five simulated future years.

Source: UCLA

If the focus is again on the FH electrification dominant pathway results (blue) it can be seen that despite the fact that this pathway is associated with the largest year-over-year load growth during the winter months – for heating end-uses – it exhibits different monthly patterns in net-emissions increases over time. In 2030 for example, peak net emissions associated with this pathway occur in the winter months of January and February, as might naturally be expected from the introduction of new heating related electricity loads. However, in 2040, when a significantly larger proportion of the community's homes are expected to be fully electrified, peak net emissions can be seen to have shifted towards the spring months, occurring between April and June.

This shift in the monthly timing of peak net emissions in the later years can be explained by changes in the dominant characteristics of the remaining active fossil EGUs by this period. Spring months tend to be associated with the highest rates of renewable generator output relative to overall demand. This creates a situation where the ramping requirements for fossil EGUs during these spring months become most extreme thus, creating a set of operational requirements which are most well suited to the characteristics of rapid ramping peaker type fossil EGUs. By 2040, the majority of the net-emissions impacts associated with the Full-Home dominant electrification pathway, therefore, can be attributed to the continued operation of these types of peaker plants, particularly during Spring months, to address rapidly changing conditions in net-loads created by variable renewable outputs. This change portends the likely significant future challenges that will be encountered from 2040-2045, in terms of achieving continued RPS compliance, when these last peaker fossil EGUs which provide essential firm generation capacity during these periods, must be removed and replaced.

C.6.2 Categorical Breakdown of Ambient Air Quality Impacts from Increased Grid Emissions

Table C-20 provides a breakdown of the monetized human health impacts (positive dollar values & their associated event counts) computed for each of twelve different categories relative to each of the three high growth rate transformation pathways evaluated.

Table C-20: Cumulative Net Change in Estimated Human Health Impacts [$]

Human Health Impact Category	***IAQ-Minor-Dominant***		***IAQ-Moderate-Dominant***		***Full-Home-Dominant***	
	Dollars	*Events*	*Dollars*	*Events*	*Dollars*	*Events*
Mortality (low - high range estimates)	$418,400 - $946,147	<1	$376,824 – $851,969	<1	$1,442,297 – $3,260,885	<1
Infant Mortality	$2,221	<1	$1,957	<1	$7,429	<1
Nonfatal Heart Attacks (low - high range estimates)	$474 – $4,406	<1	$432 – $4,017	<1	$1,623 – $15,083	<1
Hospital Admits, All Respiratory	$363	<1	$328	<1	$1,214	<1
Hospital Admits, Cardiovascular (except heart attacks)	$430	<1	$389	<1	$1,442	<1
Acute Bronchitis	$39	<1	$35	<1	$135	<1
Upper Respiratory Symptoms	$49	1	$44	1	$169	4
Lower Respiratory Symptoms	$22	1	$20	1	$75	3
Emergency Room Visits, Asthma	$10	<1	$9	<1	$33	<1
Minor Restricted Activity Days	$2,930	33	$2,616	29	$9,971	112
Work Loss Days	$1,127	6	$1,005	5	$3,830	19
Asthma Exacerbation	$88	1	$78	1	$298	4
Total Health Impacts (low - high range estimates)	**$426,154 – $957,832**		**$383,736 – $862,466**		**$1,468,516 – $3,300,563**	

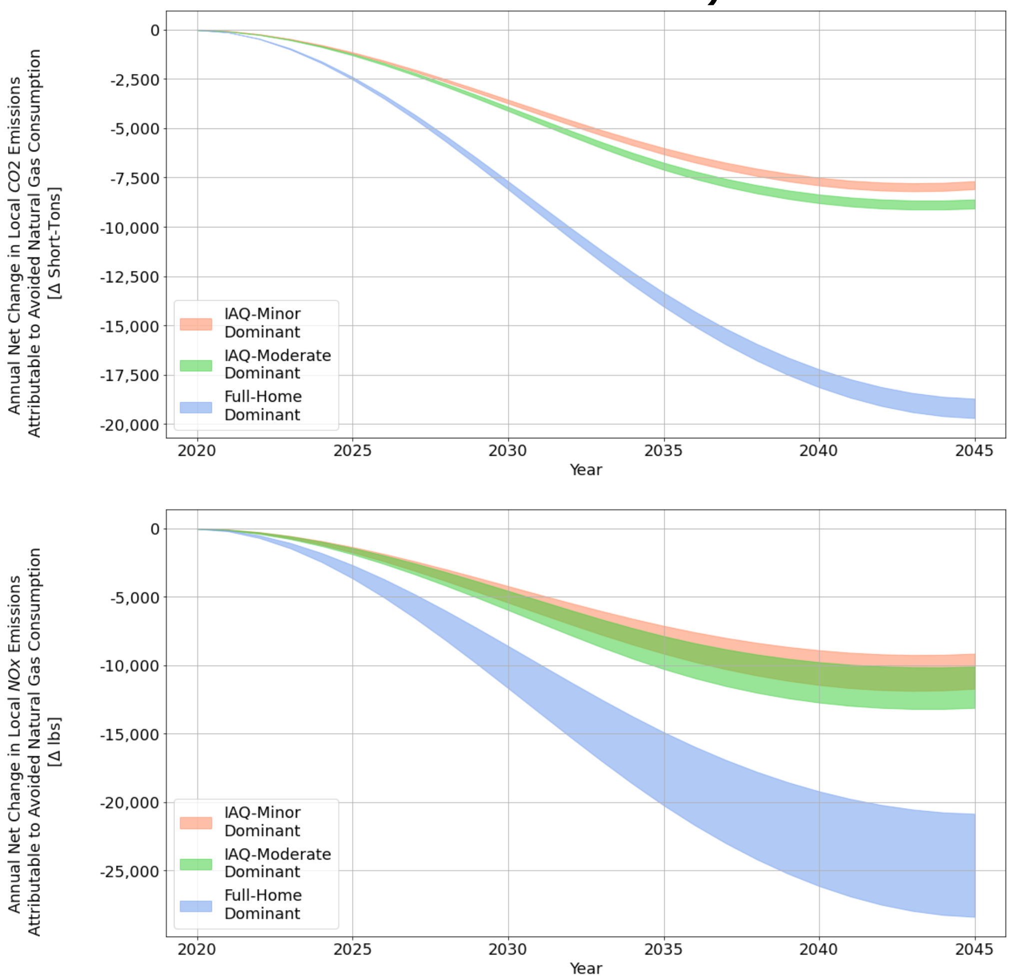
By impact category attributable to increased ambient emissions from grid electricity consumption – computed for each high-growth transformation pathway relative to the baseline pathway over the full forecast time horizon (2020-2045).

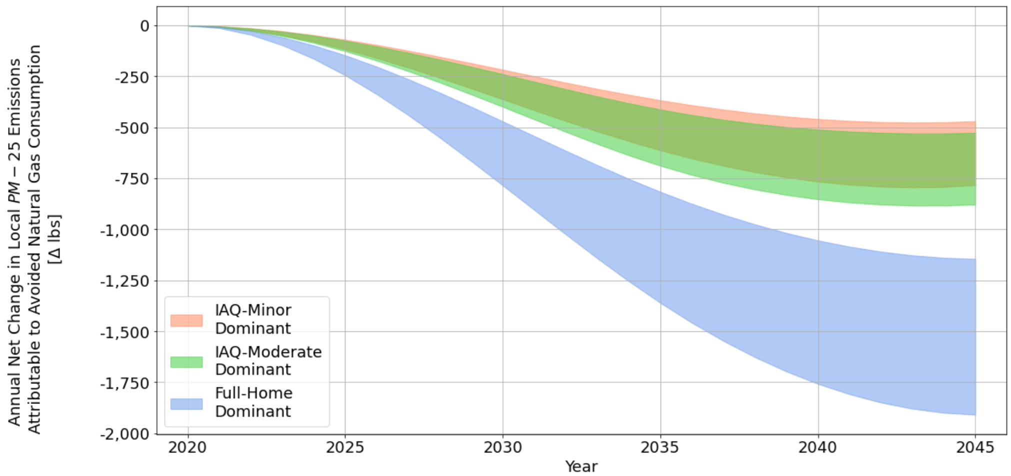
Source: UCLA

C.6.3 Annual and Monthly Breakdown of Local Emission Decreases from High Growth Rate Appliance Electrification

Figure C-21 contains a series of plots which illustrate the net annual reductions in local emissions associated with the avoided residential gas use calculated for each electrification pathway.

Figure C-21: Annual Net Change in Local CO2, NOx and PM-2.5 Emissions (2020-2045)





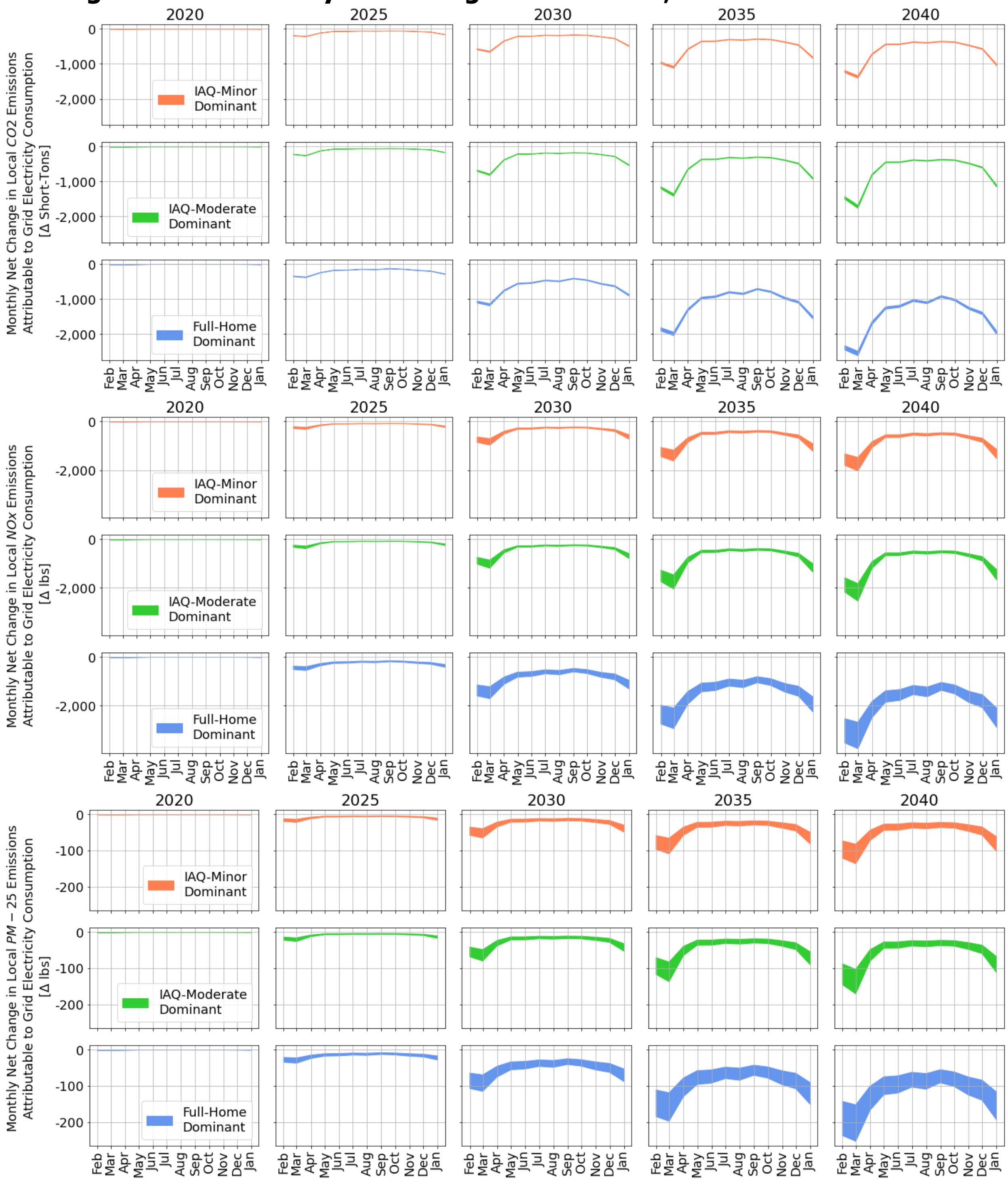
Annual net change in local CO2 emissions [Δ short-tons] (top), NOx [Δ lbs] (middle), and PM-2.5 emissions [Δ lbs] (bottom) attributable to avoided residential gas consumption – computed for each high-growth transformation pathway relative to the baseline pathway from 2020-2045.

Source: UCLA

Figure C-22 provides a monthly view of the calculated net emissions reductions associated with the avoided local gas use attributable to each pathway. These results are shown at five-year intervals, for the same set of years that were previously used in the monthly depiction of the ambient emissions increases calculated using AVERT. The trends which are visible in this case, however, are much more straightforward as no meaningful change in the future emissions intensities associated with residential gas consumption are assumed.

Overall, the seasonal variations in monthly avoided emissions generally respect the seasonal patterns of use for the dominant types of natural gas appliances that were assumed to be electrified within each pathway. For example, there is relatively little change from month-to-month in the magnitude of the emissions reductions associated with the IAQ-Minor dominant pathway (red) as the majority of the households electrified under this pathway on were assumed to have had their gas cooking appliances replaced. Conversely, for the FH dominant pathway (blue) there is a much stronger seasonal pattern of variation in avoided emissions, as the majority of total household gas use occurs during winter months for space and water heating.

Figure C-22: Monthly Net Change in Local CO2, Nox and PM-2.5 Emissions



Monthly net change in local CO2 emissions [Δ short-tons] (top), NOx emissions [Δ lbs] (middle), and PM-2.5 emissions [Δ lbs] (bottom) attributable to avoided residential gas consumption – computed relative to the baseline for each high-growth transformation pathway and for each of five simulated future years.

Source: UCLA

C.6.4 Categorical Breakdown of Local Air Quality Benefits from High Growth Rate Appliance Electrification

Table C-21 provides the exact same breakdown of estimated changes in human health impacts as was depicted previously within the ambient context. Table C-21: Cumulative Net Change in Estimated Human Health Benefits [$]

Human Health Impact Category	*IAQ-Minor-Dominant*		*IAQ-Moderate-Dominant*		*Full-Home-Dominant*	
	Dollars	*Events*	*Dollars*	*Events*	*Dollars*	*Events*
Mortality ***(low - high range estimates)***	$-4,715,602 – $-10,657,274	<1	$-5,238,457 – $-11,838,904	<1	$-10,667,292 – $-24,107,934	1 – 2
Infant Mortality	$-23,546	<1	$-26,152	<1	-53,230	<1
Nonfatal Heart Attacks ***(low - high range estimates)***	$-2,923 – $-27,165	<1	$-3,248 – $-30,177	<1	$-6,613 – $-61,449	<1
Hospital Admits, All Respiratory	$-3,880	<1	$-4,310	<1	$-8,778	<1
Hospital Admits, Cardiovascular ***(except heart attacks)***	$-4,384	<1	$-4,870	<1	$-9,916	<1
Acute Bronchitis	$-449	1	$-498	1	$-1,015	2
Upper Respiratory Symptoms	$-564	13	$-626	14	$-1,275	30
Lower Respiratory Symptoms	$-250	9	$-278	10	$-565	21
Emergency Room Visits, Asthma	$-83	<1	-92	<1	$-187	<1
Minor Restricted Activity Days	$-34,352	387	-38,156	430	$-77,677	876
Work Loss Days	$-13,161	66	-14,618	73	$-29,758	149
Asthma Exacerbation	$-999	13	-1,109	15	$-2,259	30
Total Health Impacts ***(low - high range estimates)***	**$-4,800,193 – -$10,766,107**		**$-5,332,416 – $-11,959,792**		**$-10,858,566 – $-24,354,044**	

By benefit category attributable to decreased local air emissions from avoided gas consumption – computed for each high-growth transformation pathway relative to the baseline pathway over the full forecast time horizon (2020-2045).

Source: UCLA