DOCKETED

Docket Number:	16-BSTD-06
Project Title:	Updates to the 2019 Time Dependent Valuation of Energy
TN #:	212680
Document Title:	Electrification Analysis
Description:	Research and analysis on how all-electric buildings perform from a life-cycle economic basis relative to their mixed-fuel counterparts under the proposed 2019 TDV of energy.
Filer:	Adrian Ownby
Organization:	Energy and Environmental Economics, Inc.
Submitter Role:	Public
Submission Date:	8/8/2016 4:18:29 PM
Docketed Date:	8/8/2016

Electrification Analysis

July 2016

Energy+Environmental Economics

Electrification Analysis

July 2016

Submitted to Adrian Ownby

California Energy Commission

Contributors:

Brian Conlon, Victoria Clark, Snuller Price, Zachary Ming - E3

Energy and Environmental Economics, Inc.

101 Montgomery Street, Suite 1600

San Francisco, CA 94104

415.391.5100

www.ethree.com

Table of Contents

Table of Figures

Table of Tables

Electrification Analysis

Overview and Approach

In this analysis, we investigate how all-electric buildings will perform from a lifecycle economic basis relative to their mixed-fuel counterparts. Consistent with the other economic analysis of Title 24, we use the Time Dependent Valuation (TDV) metric as a measurement of overall cost-effectiveness. This task makes use of the new TDV values that were updated for the use in the 2019 Title 24 code cycle. There are several key questions to be addressed in this analysis.

First, we compare identical homes that use mixed-fuel to those that use all-electric to assess the difference in lifecycle cost with the standard TDV values. This analysis answers the question of whether we expect the buildings to cost more for the participants to operate over the life of the building. This is also the question that is asked in the Title 24 Alternative Calculation Method (ACM) for buildings that would like to be all-electric, but need to pass Title 24. For the purposes of the analysis, we use the prescriptive standard appliances in the mixed-fuel home. For the all-electric home, we replace the gas furnace with a heat pump for space heating and the natural gas water heater in the prescriptive home with a heat pump water heater. The other gas appliances (stove, oven, dryer) are replaced with conventional electric appliances. These appliances are not within the scope of Title 24, but assumptions about them are necessary to estimate the total electricity consumption of the home.

Second, we assess those factors that significantly affect the relationship between the TDV results of the mixed-fuel and all-electric homes in order to identify those conditions that would result in a lower expected lifecycle cost for an all-electric home than the mixed-fuel home. The fundamental factor is the difference between the electric and natural gas retail rate levels. We capture this by assessing the change in the estimated consumer bills as a function of the following key factors:

1. **Carbon price.** The carbon price is a key factor because the mixed-fuel and all-electric homes have different greenhouse gas emissions levels.
2. **Retail rate escalation rates.** The trajectory of retail electric and natural gas prices is an important driver of the lifecycle differences in cost. We model these as changes in electric resource planning decisions, including the amount of energy efficiency that is achieved.

Varying these underlying factors results in a changing set of TDVs that increase or decrease the TDV gap between mixed-fuel and all-electric homes. For a given set of retail rate escalation assumptions (Table 1), we vary the carbon prices across a reasonable range and identify the carbon price that makes the lifecycle TDV budget for an all-electric home equivalent to that of a mixed-fuel home. We also compare the lifecycle carbon footprint between the mixed-fuel and all-electric home with assumptions consistent with the underlying TDV framework.

Table 1. Electric Retail Rate Escalators Relative to Mid-IEPR Forecast, by Carbon Price								
Year	**Carbon Price ($/ton CO_2)**							
	10	**30**	**80**	**200**	**250**	**350**	**450**	**600**
2020	100%	101%	106%	117%	122%	132%	141%	155%
2021	100%	102%	106%	118%	122%	132%	141%	155%
2022	101%	102%	107%	118%	123%	132%	142%	156%
2023	101%	103%	108%	119%	123%	133%	142%	156%
2024	102%	104%	109%	120%	124%	133%	142%	156%
2025	103%	105%	110%	122%	127%	138%	148%	164%
2026	104%	106%	111%	123%	128%	139%	149%	164%
2027	105%	107%	112%	124%	129%	139%	150%	165%
2028	107%	109%	114%	126%	131%	141%	151%	166%
2029	109%	111%	115%	127%	132%	142%	151%	166%
2030	111%	113%	118%	129%	133%	143%	152%	166%
2030+	111%	113%	118%	129%	133%	143%	152%	166%

Third, we assess the difference in construction costs that would bring the total lifecycle costs of switching to all-electric homes from a mixed-fuel home to be equivalent. A comparison of total costs (including both construction costs and lifecycle operating costs) answers the question of whether all-electric would be lower cost overall. The difference in construction costs would include the higher costs of heat pump appliances that were modeled, and the reduced costs of an all-electric home through reduced natural gas plumbing, any costs of a new gas connection above the allowed interconnection costs, and the cost of required testing of natural gas for health and safety.

Energy simulation and TDV results for mixed-fuel and all-electric homes

With the support of Ken Nittler and Bruce Wilcox our team simulated three prototype residential homes (2,100 sqft, 2,700 sqft, and multifamily) in each of the 16 California climate zones in a mixed-fuel and all-electric configurations. In each case, the buildings are identical except for the natural gas and electric appliances. The all-electric homes use heat pump water heaters and heat pump space conditioning along with standard electric cooking, and clothes dryer. The most recent version of CBECC is used to do the simulation analysis which includes a new heat pump water heater simulation model. Detailed specifications of the home are provided in Appendix A.

Table 2 shows the energy consumption results of the building simulation and the total TDV values for 2,100 sqft mixed-fuel and all-electric prototypes in each climate zone.

Table 2. Total kWh, Therms, and lifecycle TDVs for three types of homes by climate zone (2,100 sqft)						
Climate Zone	Mixed-Fuel			All-Electric		
	kWh	Therms	TDV (kBtu)	kWh	Therms	TDV (kBtu)
CZ01	3,899	476	214,683	9,331	-	267,803
CZ02	3,870	385	193,396	8,151	-	226,202
CZ03	3,779	286	170,581	7,091	-	204,482
CZ04	3,829	314	177,414	7,403	-	209,343
CZ05	3,758	263	165,111	7,004	-	202,432
CZ06	3,792	224	158,278	6,440	-	183,699
CZ07	3,736	181	141,501	5,902	-	164,815
CZ08	3,926	188	157,353	6,169	-	178,929
CZ09	4,126	206	186,231	6,545	-	212,168
CZ10	4,232	213	191,288	6,768	-	218,969
CZ11	4,946	331	256,484	8,721	-	293,099
CZ12	4,054	348	220,403	7,854	-	253,419
CZ13	5,079	307	260,390	8,500	-	292,459
CZ14	4,925	328	244,109	8,827	-	277,188
CZ15	8,111	132	322,048	9,827	-	350,080
CZ16	4,034	604	247,492	11,270	-	346,698

The dominant driver of the relatively high energy performance of all-electric buildings is the performance of the latest heat pump technologies for space and water heating. Given the importance of this technology, the California building simulation engine, CBECC, has been updated with a more sophisticated simulation of heat pumps and heat pump water heaters in particular. Given the relatively high performance of heat pump electric appliances, and the increase in renewable energy goals to meet electricity demand (50% by 2030), the relative GHG emissions is significantly lower for the electric appliances.

One of the goals and key metrics for increased efficiency and self-generation measures in the Title 24 California building energy code is reducing greenhouse gas emissions (GHGs). Building electrification may be a path to meet this goal, so it is important to develop a method to estimate a building's lifecycle GHG emissions. Our approach focuses on the primary drivers behind emissions savings and makes use of the detailed analyses already in place to estimate emissions in the Time Dependent Valuation to make it accurate within the bounds of uncertainty. In the methodology, we recognize where simplifications are made explicitly.

In particular, the approach recognizes two key aspects of electricity emissions as the primary drivers of air emissions changes attributable to building electrification. First, there is a short-term impact that is based on the generation dispatch in each hour, day, and year that is measured by the marginal emissions rate using production simulation. Second, there is a long-term impact that captures the change in renewables development due to a change in efficiency.

+ **Generation dispatch**. The change in electricity demand due to Title 24 measures will change emissions at the marginal emissions rate. This rate varies by time based on the generators dispatched to meet load, and the associated emissions rates of those power plants that will change their production with a variation in load demand. The marginal emissions rate is simulated using PLEXOS by the CEC staff and the simulation includes interactions of California's grid with other states, varying time of electricity demand with seasons, weekdays and holidays. In addition, the load levels are calibrated to reflect temperatures around the state which are used in the building simulation so that the marginal emissions rates are consistent with the simulated effects of building measures.

- **Renewable development**. The impact of a load reduction program on new infrastructure development over time, and in particular the impact on new investment in renewable generation development since the renewable portfolio standard (RPS) program is based on a percentage of retail sales.

In order to get the correct economic value of the State's demand-side resources, detailed assumptions are already made about both generation dispatch and renewable development. Therefore, since the work has been completed to develop TDV, a reformulation of the same information can provide an estimate of air emissions that accounts for both of the primary drivers.

Therefore, our methodology is to estimate the GHG reductions in two steps. For the short term impact, we use the underlying simulated marginal emissions rate in each hour over the life of the building as the impact on emissions. Load reductions will reduce emissions at this marginal rate, and load increases will increase emissions at this rate. For the long term impact, we use the share of energy that is to be produced with renewable resources. For load reductions we reduce the amount of renewables that would be built at the RPS percentage, and for load increases, we increase the amount of renewables at the RPS percentage. With this approach, the formula for estimated GHG savings in buildings is the following;

Lifecycle GHGs = Sum (hr, year) [Load(hr,year) * 1-RPS Percentage (year)]

Table 3 compares the carbon emissions intensity of mixed-fuel and all-electric homes for each climate zone.

Table 3. Lifecycle CO2 emissions per square foot by fuel supply and home size

Climate Zone	Lifecycle CO_2 (tons)					
	Mixed-Fuel Total			All-Electric Total		
	2100 Sqft	2700 Sqft	6960 Sqft	2100 Sqft	2700 Sqft	6960 Sqft
CZ01	114	119	422	71	76	311
CZ02	97	109	398	62	70	299
CZ03	79	86	361	54	59	277
CZ04	85	96	373	56	64	286
CZ05	75	81	358	53	58	278
CZ06	70	81	353	52	59	285
CZ07	62	71	343	48	54	277
CZ08	65	76	359	50	58	294
CZ09	71	83	371	54	63	305
CZ10	73	87	377	56	66	313
CZ11	97	116	424	67	80	334
CZ12	92	108	402	60	70	307
CZ13	94	113	419	66	79	333
CZ14	100	119	438	73	86	356
CZ15	94	112	454	84	100	405
CZ16	139	161	522	89	103	405

Figure 1 and Figure 2 show the carbon emissions of space heating and water heating end-uses for 2,100 sqft homes in each climate zone. Similar relationships are found for the larger building prototypes.

Figure 1. Lifecycle CO_2 emissions from space heating in mixed-fuel (natural gas space heating) and all-electric homes (electric space heating), by CZ - 2,100 sqft

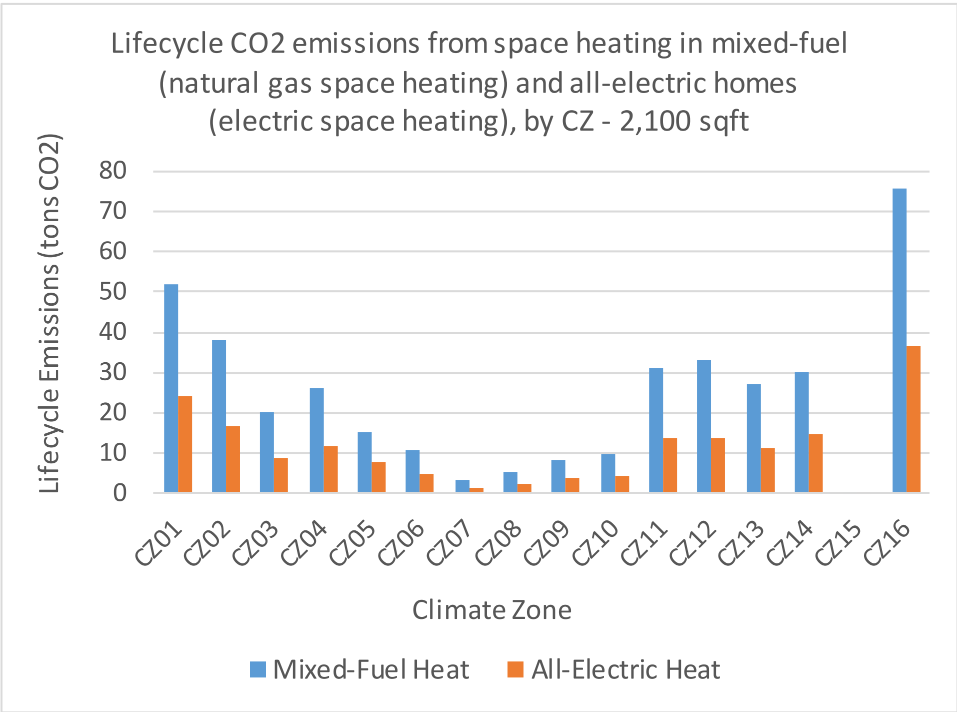
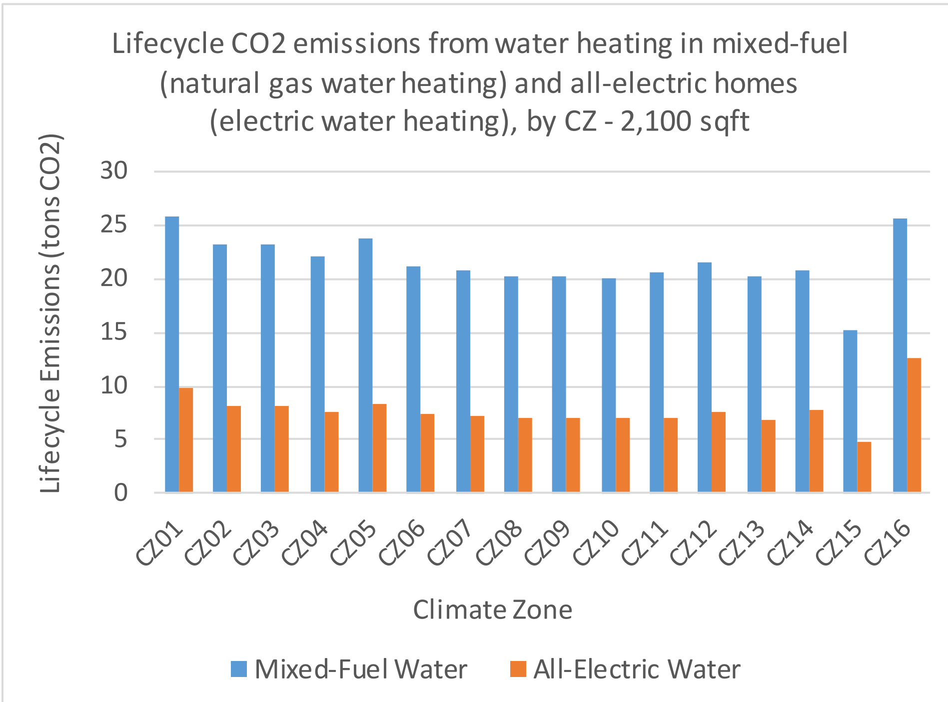


Figure 2. Lifecycle CO2 emissions from water heating in mixed-fuel (natural gas water heating) and all-electric homes (electric water heating), by CZ - 2,100 sqft



The cost of all-electric homes, measured using TDV consistent with California Building Energy Code, shows that despite the much higher efficiency of the heat pump appliances, the consumer cost to operate these appliances is somewhat higher for the all-electric end use. Figure 3 and Figure 4 show the comparative TDV performance of space heating and water heating end-uses for 2,100 sqft homes in each climate zone.

Figure 3. Lifecycle TDV for space heating in mixed-fuel (natural gas space heating) and all-electric homes (electric space heating), by CZ - 2,100 sqft

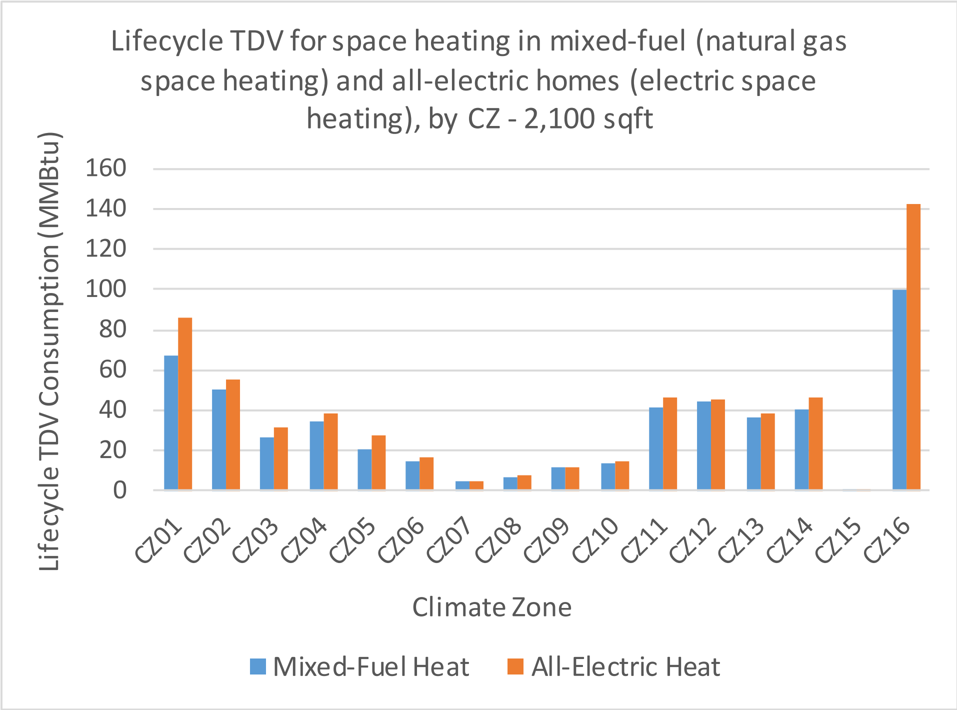
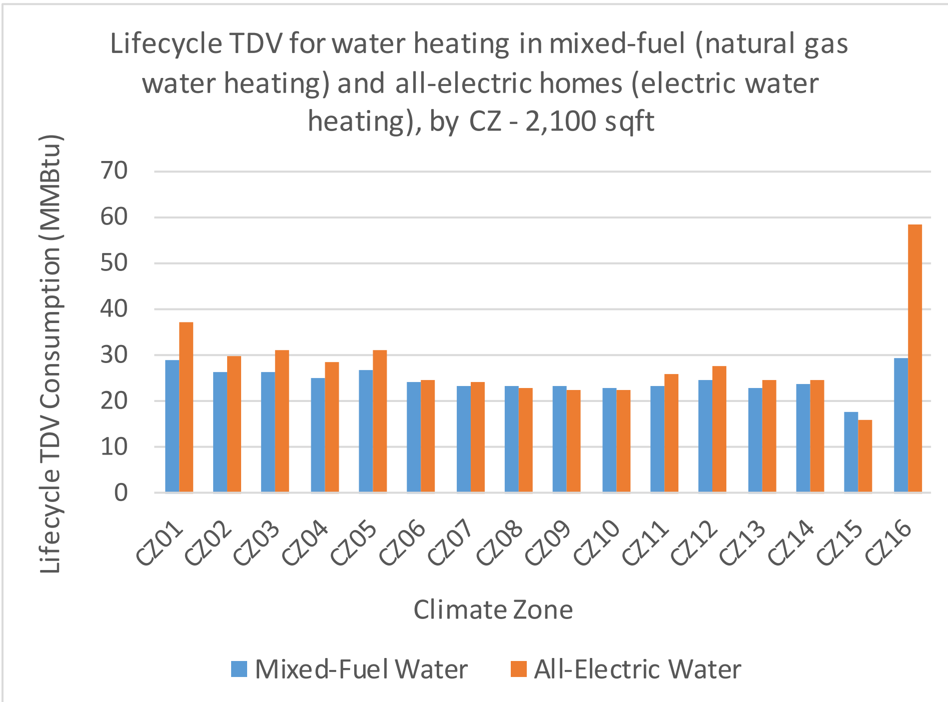


Figure 4. Lifecycle TDV for water heating in mixed-fuel (natural gas water heating) and all-electric homes (electric water heating), by CZ - 2,100 sqft



Analysis of the CO_2 Price and Sensitivity Analysis

Based on the building simulation and TDV analysis there is a gap between the expected utility bills of mixed-fuel and all-electric buildings, with all-electric buildings being higher, but a significantly lower level of GHG emissions. This is primarily driven by the relatively lower cost of natural gas as a fuel for some end-uses. However, the greater efficiencies of heat pump technology, which can have very high energy factors by gathering energy from the environment, counteract the higher costs of electricity.

As an example, Table 4 and Table 5 show characteristics on the consumption and carbon emissions of two homes of identical size (2,100 sqft) and located in climate zone 12, one mixed-fuel and the other all-electric. In this example, switching from mixed-fuel to all-electric would result in a TDV increase of 15% from 220,403 kBtu to 253,419 kBtu. In units of cost, this is a difference of $5,718 of higher costs over the life of the building and $24 per month on average. Lifecycle CO_2 emissions on the other hand will see a 35% decrease with such a switch, dropping from 92 to 60 tons. For this building, a carbon price of $245/ton would be necessary to result in an equivalent lifecycle building cost.

Table 4. Lifecycle energy consumption and CO_2 emissions in mixed-fuel – 2,100 sqft prototype home

Mixed-Fuel Home, CZ12 – 2,100sqft				
End Use	**kWh**	**Therms**	**Tons CO_2**	**kBtu**
Heat	156	182	33	44,054
Cool	187	-	2	33,996
HVAC Other	-	-	-	-
Water	-	123	22	24,612
Appliance	947	44	15	38,069
Other	2,764	-	21	79,671
Total	**4,054**	**348**	**92**	**220,403**

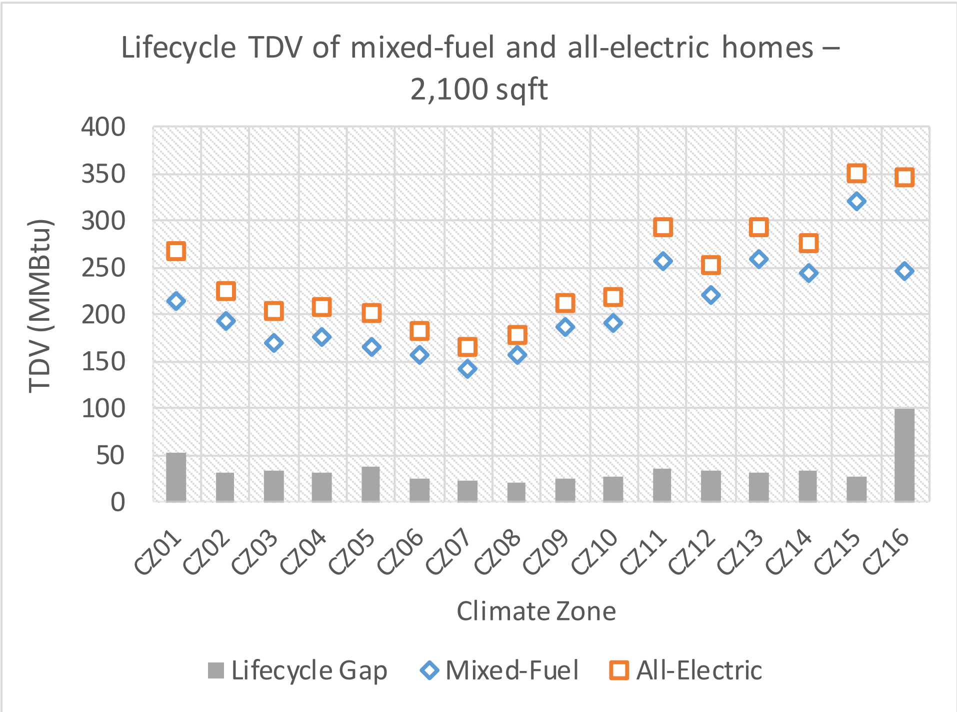
Table 5. Lifecycle energy consumption and CO_2 emissions in all-electric – 2,100 sqft prototype home

All-Electric Home, CZ12 – 2,100sqft				
End Use	**kWh**	**Therms**	**Tons CO_2**	**kBtu**
Heat	1,804	-	14	45,569
Cool	180	-	2	35,938
HVAC Other	85	-	1	2,145
Water	1,011	-	8	27,837
Appliance	2,011	-	15	62,259
Other	2,764	-	21	79,671
Total	**7,854**	**-**	**60**	**253,419**

The conditions of the above tables were consistent with the 2019 TDV Update's Base Case, which includes the CEC IEPR's carbon price forecast. Sensitivities testing the impact of carbon prices were run to find a carbon price, such that the all-electric home reached parity with mixed-fuel in terms of kBtu.

Figure 5 compares the lifecycle TDV value for 2,100 sqft for each climate zone for mixed-fuel and all-electric homes, in addition to the 'gap' between each prototype. This analysis is also completed for the 2,700 sqft prototype and the multi-family home with information in Appendix B.

Figure 5. Lifecycle TDV of mixed-fuel and all-electric homes – 2,100 sqft prototype



The gap between the mixed-fuel and the all-electric home is based, in part, on the assumption of the cost of CO_2 allowances. The TDV values assume the mid-IEPR case for CO_2 costs. As a sensitivity we vary the carbon price to calculate the carbon price that would result in the same lifecycle costs.

As there is a demonstrable reduction in a building's lifecycle carbon emissions associated with electrification, an increase in carbon price may close the lifecycle TDV gap between mixed-fuel and all-electric buildings. In order to find the carbon prices that would enable such parity, we generated a number of TDV sets with varying carbon prices. The current TDV model uses retail rate adders that were created by adjusting IEPR's rate forecast with the CPUC RPS Calculator to a scenario with the current 50% RPS target and doubling of energy efficiency targets. This same methodology was followed to produce retail rate adders under a range of carbon prices. Each carbon price (adjusted for inflation over the TDV model's 30 years) and corresponding retail rate adder were input into the TDV model to produce a set of 30-year residential electric and natural gas TDVs for each carbon price.

The building simulation energy consumption shapes for mixed-fuel and all-electric homes are multiplied by each set of TDVs and summed to get the energy consumption in TDV units by carbon price. The difference between the TDV consumption of equivalent mixed-fuel and all-electric buildings is plotted against the corresponding carbon price.

Figure 6 shows the reduction in the gap as a function of the carbon price for each climate zone. The intersection points are highlighted which identify the points where the expected lifecycle costs are equivalent between 2,100 sqft mixed-fuel and all-electric homes. These analyses are repeated for the 2,700 sqft and multi-family prototypes which show similar results. The breakeven CO_2 prices are shown as the x-intercept of each line in Figure 6 for the 2,100 sqft prototype and for all prototypes in Table 6.

Figure 6. Base Scenario net lifecycle TDV values of all-electric homes compared to mixed-fuel homes, by embedded carbon price and CZ - 2,100 sqft

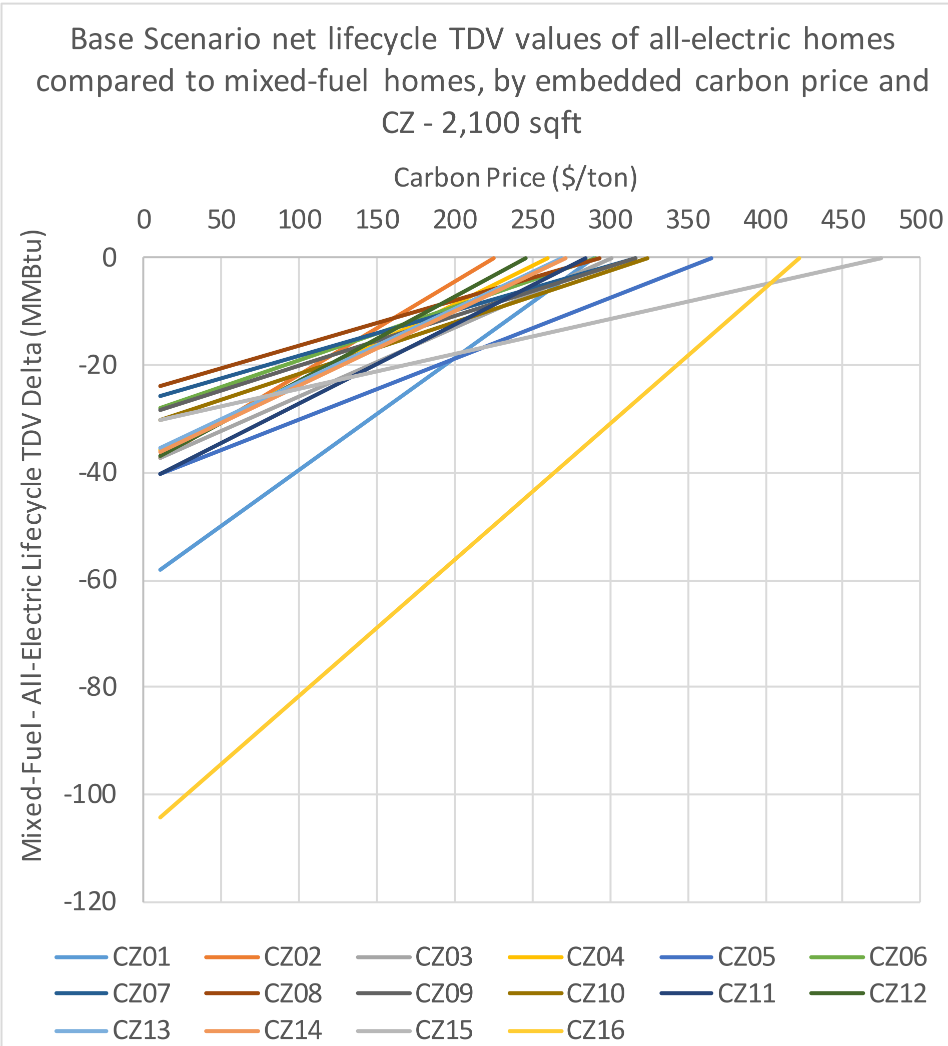
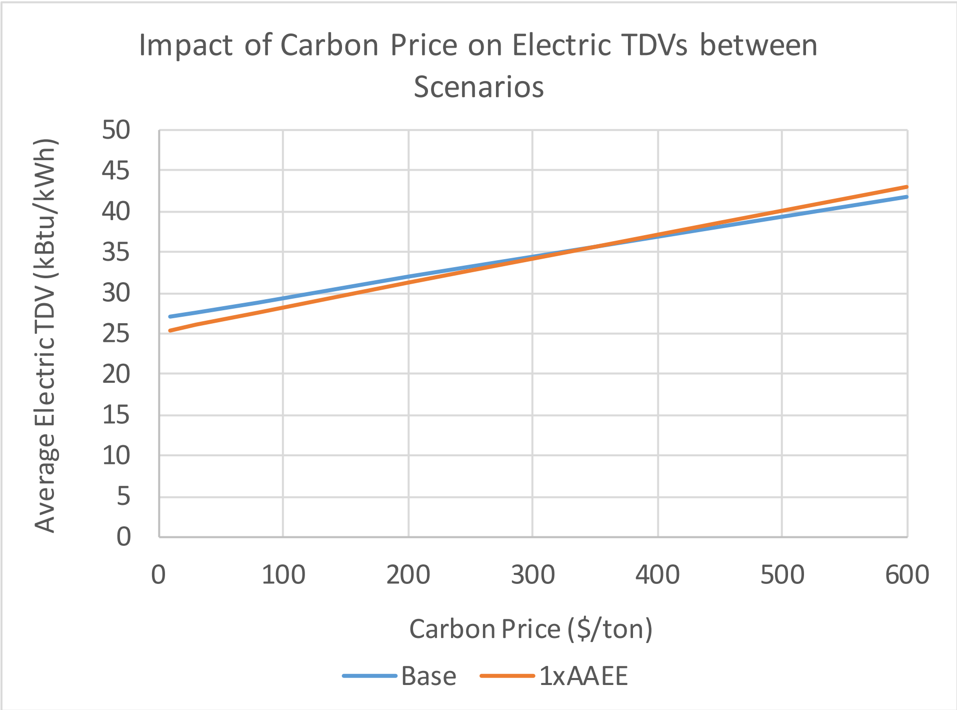


Table 6. Breakeven carbon price required for lifecycle TDV of all-electric to be equivalent to mixed-fuel, by building prototype and climate zone

Climate Zone	Carbon Price Required for Mixed-Fuel TDV to Exceed All-Electric TDV ($/ton)		
	2,100 Sqft	2,700 Sqft	6,960 Sqft
CZ01	$288.76	$275.54	$458.41
CZ02	$225.55	$201.54	$444.14
CZ03	$301.50	$279.46	$475.32
CZ04	$260.09	$267.41	$560.32
CZ05	$365.58	$334.09	$508.64
CZ06	$290.37	$241.63	$457.58
CZ07	$316.49	$286.20	$433.42
CZ08	$292.74	$238.98	$510.84
CZ09	$315.82	$254.69	$570.74
CZ10	$324.61	$273.19	$614.88
CZ11	$284.32	$249.11	$614.19
CZ12	$245.25	$218.96	$532.80
CZ13	$268.33	$250.21	$595.93
CZ14	$271.94	$250.68	$522.09
CZ15	$475.11	$435.29	$616.93
CZ16	$422.41	$424.08	$691.10

In order to test the significance of electric retail rates on the relationship between carbon price and the TDV electrification gap, we repeated these analyses by using retail rate adders corresponding to a 1xAAEE scenario. The 1xAAEE scenario serves as a proxy for lower electric retail rates, as the lower buildout of energy efficiency generally translates to lower rates. Reducing electricity rates in turn reduces electric TDVs, while natural gas TDVs remain constant, narrowing the lifecycle TDV gap between mixed-fuel and all-electric homes. However, at carbon prices above $350/ton CO_2, energy efficiency becomes more economical than the marginal gas generation, so for climate zones in which the base scenario breakeven carbon price exceeds $350/ton (CZ5, CZ15, CZ16), the 1xAAEE scenario breakeven carbon price is greater than that of the base scenario.

Figure 7. Impact of Carbon Price on Electric TDVs between Scenarios



While a sensitivity that decreases electric rates by a simple percentage relative to the base scenario would apply a more uniform change to all climate zones, the results of this sensitivity consistently show that lower electricity rates reduce the carbon price needed to close the lifecycle TDV gap between mixed-fuel and all-electric homes. Table 7 shows a comparison of breakeven carbon prices for the two scenarios for 2,100 sqft homes. Note that negative deltas (when prices in the base scenario exceed those in the 1xAAEE) occur when carbon prices are at a level at which 1xAAEE electric TDVs are greater than base scenario electric TDVs, as shown in Figure 7.

Table 7. Sensitivity Analysis of Breakeven Carbon Price for Electrification - 2,100 sqft

Climate Zone	Breakeven CO_2 Price		Delta
	Base Scenario	1xAAEE Scenario	
CZ01	$288.76	$280.09	$8.67
CZ02	$225.55	$208.67	$16.88
CZ03	$301.50	$294.60	$6.90
CZ04	$260.09	$247.64	$12.45
CZ05	$365.58	$368.37	-$2.79
CZ06	$290.37	$281.66	$8.71
CZ07	$316.49	$311.73	$4.76
CZ08	$292.74	$284.31	$8.43
CZ09	$315.82	$310.99	$4.83
CZ10	$324.61	$321.01	$3.59
CZ11	$284.32	$275.08	$9.24
CZ12	$245.25	$231.46	$13.79
CZ13	$268.33	$257.23	$11.10
CZ14	$271.94	$259.91	$12.03
CZ15	$475.11	$494.73	-$19.62
CZ16	$422.41	$434.24	-$11.83

Figure 8 shows the impact of carbon price on the lifecycle TDV gap between 2,100 sqft mixed-fuel and all-electric homes for the 1xAAEE scenario. Figure 6 shows the comparable figures for the base scenario. 1xAAEE breakeven carbon prices for all three building prototypes are summarized in Table 8.

Figure 8. 1xAAEE Scenario net lifecycle TDV values of all-electric homes compared to mixed-fuel homes, by embedded carbon price and CZ - 2,100 sqft

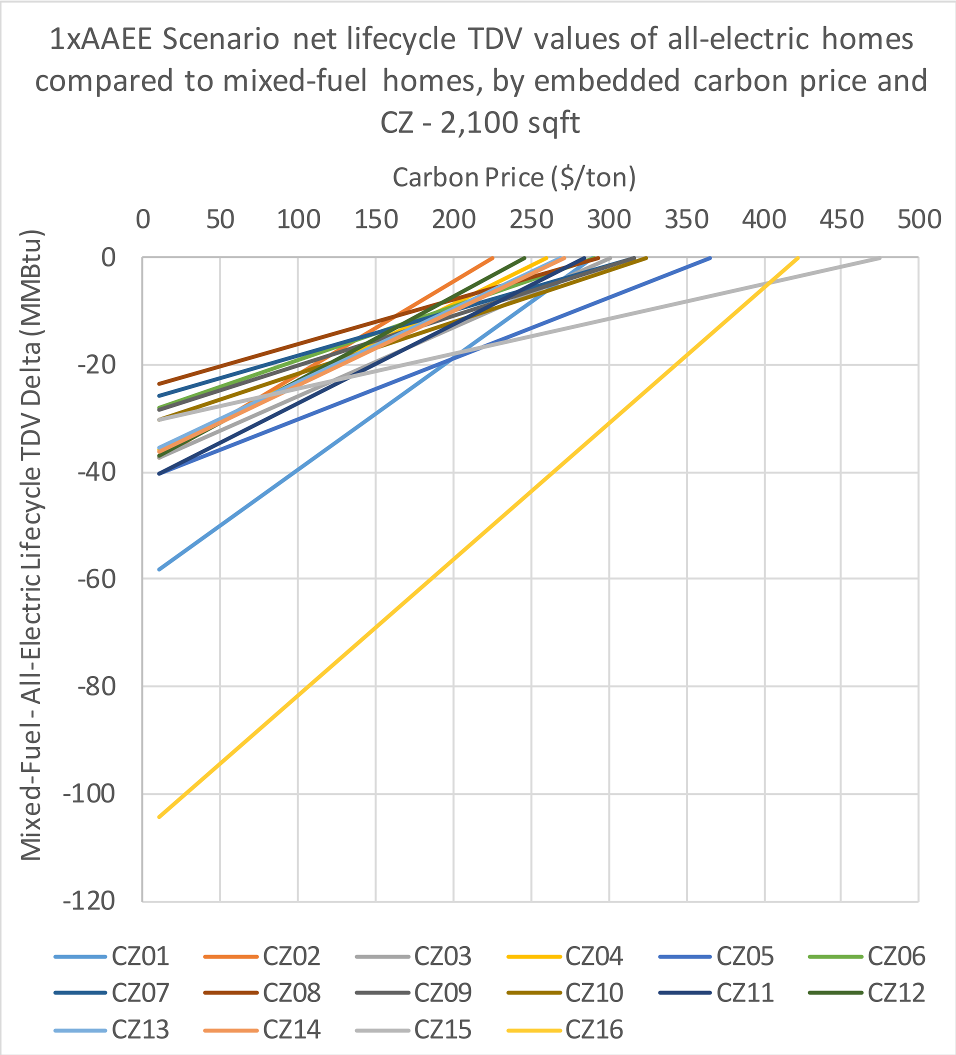


Table 8. 1xAAEE Sensitivity Breakeven carbon price required for lifecycle TDV of all-electric to be equivalent to mixed-fuel by building prototype and climate zone

Climate Zone	Carbon Price Required for Mixed-Fuel TDV to Exceed All-Electric TDV ($/ton)		
	2,100 Sqft	2,700 Sqft	6,960 Sqft
CZ01	$280.09	$264.93	$479.32
CZ02	$208.67	$181.79	$462.49
CZ03	$294.60	$269.62	$499.22
CZ04	$247.64	$256.17	$600.64
CZ05	$368.37	$331.73	$540.70
CZ06	$281.66	$226.16	$478.42
CZ07	$311.73	$277.31	$448.91
CZ08	$284.31	$223.01	$542.08
CZ09	$310.99	$241.47	$613.44
CZ10	$321.01	$262.42	$667.12
CZ11	$275.08	$235.44	$668.02
CZ12	$231.46	$202.19	$568.81
CZ13	$257.23	$237.25	$645.98
CZ14	$259.91	$236.01	$559.27
CZ15	$494.73	$448.14	$672.68
CZ16	$434.24	$435.80	$775.81

Total Lifecycle costs of All-Electric Homes

In addition to different operating costs, all-electric homes can be expected to have differences in construction costs. There are a number of factors that contribute to the differences in the construction cost depending on the situation. On the one hand, there are differences in the costs of the electric appliances. In particular, the cost of heat pump water heaters is greater than their natural gas equivalents. On the other hand, there are construction cost differences. All-electric homes may require a larger capacity panel and electricity service. All-electric will also reduce costs from avoiding the plumbing of natural gas lines both within the home, and in some cases in the street where natural gas service connection exceeds the allowable costs under utility interconnection Rule 15. Given the uncertainty, we calculate the break-even cost that would result in equivalent total lifecycle costs for mixed-fuel and all-electric.

The following analysis shows the total gap in total lifecycle cost between all-electric and mixed-fuel homes based on the 2,100 sqft prototype. The results for the 2,700 sqft and multifamily homes are provided in the appendix. In order to break even on a total lifecycle basis, all-electric would have to cost from $3,737 to $17,183 less to construct per home in order to break even.

Table 9 also shows the average monthly bill difference over the assumed 30-year life of the building. This cost ranges from $15 to $71 per month higher utility bill for the all-electric home.

Table 9. Lifecycle cost gap between all-electric and mixed-fuel homes – 2,100 sqft prototype			
Climate Zone	**Mixed-Fuel**	**All-Electric**	**Lifecycle Gap**
CZ01	$37,183	$46,383	$9,200
CZ02	$33,496	$39,178	$5,682
CZ03	$29,545	$35,416	$5,872
CZ04	$30,728	$36,258	$5,530
CZ05	$28,597	$35,061	$6,464
CZ06	$27,414	$31,817	$4,403
CZ07	$24,508	$28,546	$4,038
CZ08	$27,254	$30,990	$3,737
CZ09	$32,255	$36,747	$4,492
CZ10	$33,131	$37,925	$4,794
CZ11	$44,423	$50,765	$6,342
CZ12	$38,174	$43,892	$5,718
CZ13	$45,100	$50,654	$5,554
CZ14	$42,280	$48,009	$5,729
CZ15	$55,779	$60,634	$4,855
CZ16	$42,866	$60,048	$17,183

Appendix A. CBECC Documentation

The CBECC-Res Compliance Software was used to simulate building energy consumption for every hour in a year. This appendix details the specific assumptions that were used as inputs to CBECC-Res. Building simulation runs were completed by Enercomp, Inc. in CBECC-Res Compliance Software version 838r561.

For energy efficiency measures, we tried to set up measures to represent the 2019 prescriptive standards. To do this, we started with the 2016 prescriptive requirements and added the following measures:

- R19 below deck for a higher performance attic
- QII
- Windows with U-factor 0.29, SHGC 0.23 for cooling climates, SHGC 0.50 for mild climates
- Doors with U-factor 0.20

Our mixed-fuel home included the following technologies:

- Tankless instantaneous gas water heater with EF of 0.82 (standard from 2016)

+ Gas space heater meeting federal minimum standards (central furnace 0.78 AFUE, Central AC 14 SEER/11.7EER)
+ Gas stove and clothes dryer

Our all-electric home included the following technologies:

+ Electric heat pump water heater, Model AO Smith HPTU 50, (EF 3.6)
+ Electric heat pump space heater meeting federal minimum standards (central split heat pump 8.2 HSPF, Central AC 14 SEER/11.7EER)
+ Electric stove and clothes dryer

Appendix B. Results for 2700 and 6960 sqft Prototypes

Table 10 shows the energy consumption results of the building simulation and the total TDV values for 2,700 sqft mixed-fuel and all-electric prototypes in each climate zone.

Table 10. Total kWh, Therms, and lifecycle TDVs for mixed-fuel and all-electric homes by climate zone (2,700 sqft)

Climate Zone	Mixed-Fuel			All-Electric		
	kWh	Therms	TDV (kBtu)	kWh	Therms	TDV (kBtu)
CZ01	4,490	480	232,580	9,953	-	282,970
CZ02	4,516	424	227,245	9,150	-	258,594
CZ03	4,386	299	190,755	7,777	-	223,224
CZ04	4,492	350	216,172	8,399	-	252,553
CZ05	4,361	270	183,703	7,645	-	218,224
CZ06	4,445	251	185,522	7,326	-	208,304
CZ07	4,354	200	162,831	6,680	-	185,768
CZ08	4,666	213	188,993	7,119	-	207,944
CZ09	4,955	236	225,601	7,643	-	248,786
CZ10	5,115	245	233,458	7,940	-	259,629
CZ11	6,053	387	311,394	10,338	-	348,299
CZ12	4,874	399	268,406	9,107	-	301,127
CZ13	6,220	363	316,791	10,159	-	352,280
CZ14	6,042	380	298,565	10,442	-	333,733
CZ15	9,652	154	383,879	11,589	-	413,740
CZ16	4,789	694	292,589	12,931	-	407,657

Table 11 shows the energy consumption results of the building simulation and the total TDV values for 6,960 sqft mixed-fuel and all-electric prototypes in each climate zone.

Table 11. Total kWh, Therms, and lifecycle TDVs for mixed-fuel and all-electric homes by climate zone (2,700 sqft)

Climate	Mixed-Fuel			All-Electric		
Zone	kWh	Therms	TDV (kBtu)	kWh	Therms	TDV (kBtu)
CZ01	21,022	1,484	923,879	41,020	-	1,185,673
CZ02	21,495	1,321	955,517	39,301	-	1,178,813
CZ03	21,036	1,136	864,019	36,338	-	1,074,396
CZ04	21,530	1,178	924,179	37,493	-	1,184,288
CZ05	21,081	1,116	859,704	36,562	-	1,077,543
CZ06	21,549	1,003	856,271	35,132	-	1,032,776
CZ07	21,259	962	809,602	34,124	-	973,686
CZ08	22,855	956	903,430	35,813	-	1,091,723
CZ09	23,720	972	969,713	37,040	-	1,188,832
CZ10	24,337	976	984,005	37,916	-	1,221,989
CZ11	26,568	1,224	1,173,851	43,378	-	1,459,817
CZ12	23,303	1,253	1,076,680	40,107	-	1,329,195
CZ13	27,110	1,172	1,188,949	43,243	-	1,455,199
CZ14	26,293	1,224	1,119,574	43,564	-	1,353,938
CZ15	36,835	777	1,402,203	48,133	-	1,592,124
CZ16	22,232	1,929	1,071,523	50,938	-	1,539,838

Figure 9 and Figure 10 show the carbon emissions of space heating and water heating end-uses for 2,700 sqft homes in each climate zone.

Figure 9. Lifecycle CO2 emissions from space heating in mixed-fuel (natural gas space heating) and all-electric homes (electric space heating), by CZ - 2,700 sqft

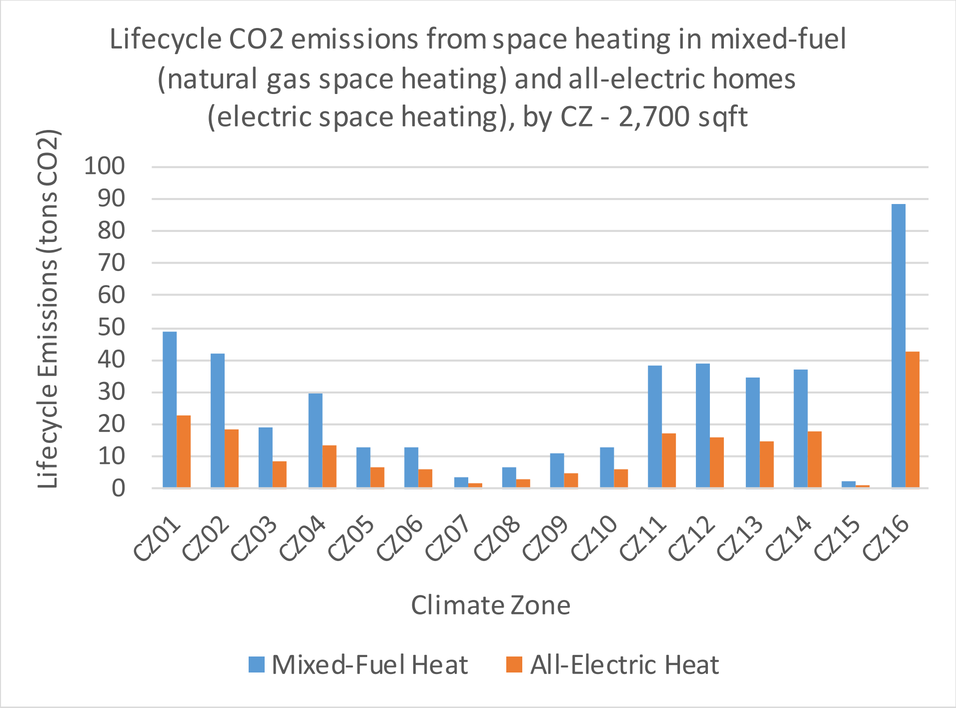


Figure 10. Lifecycle CO2 emissions from water heating in mixed-fuel (natural gas water heating) and all-electric homes (electric water heating), by CZ - 2,700 sqft

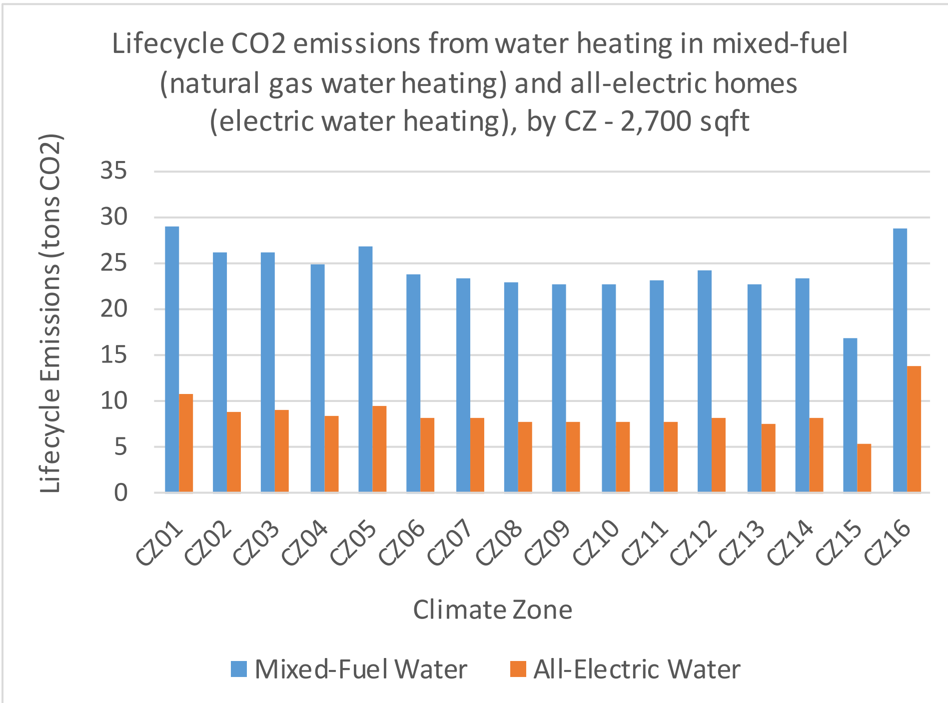


Figure 11 and Figure 12 show the carbon emissions of space heating and water heating end-uses for 6,960 sqft homes in each climate zone.

Figure 11. Lifecycle CO2 emissions from space heating in mixed-fuel (natural gas space heating) and all-electric homes (electric space heating), by CZ - 6,960 sqft

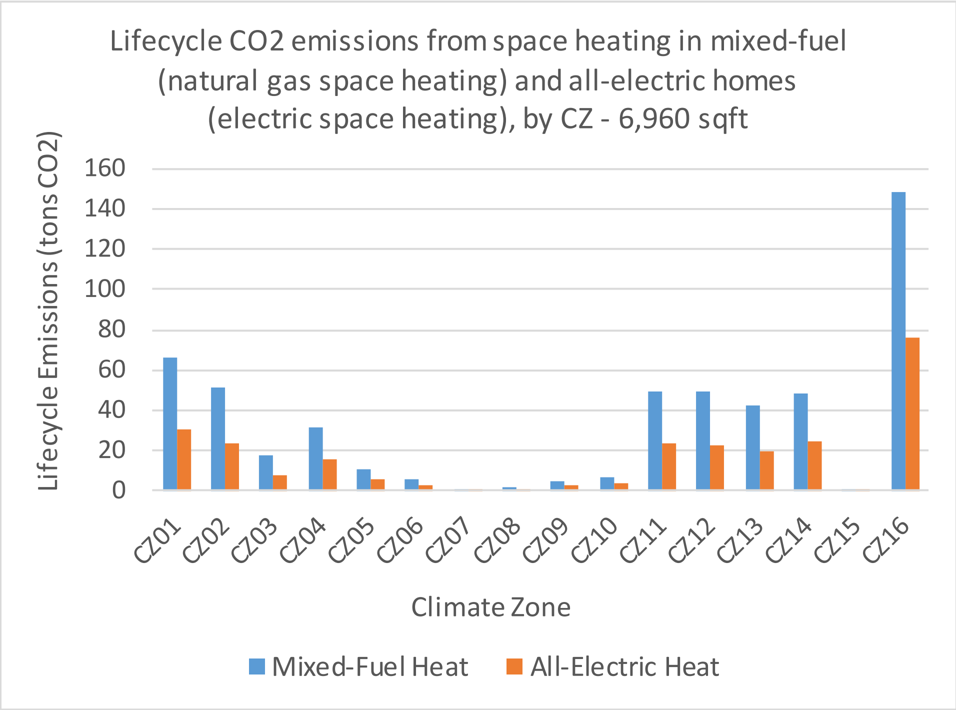


Figure 12. Lifecycle CO2 emissions from water heating in mixed-fuel (natural gas water heating) and all-electric homes (electric water heating), by CZ - 6,960 sqft

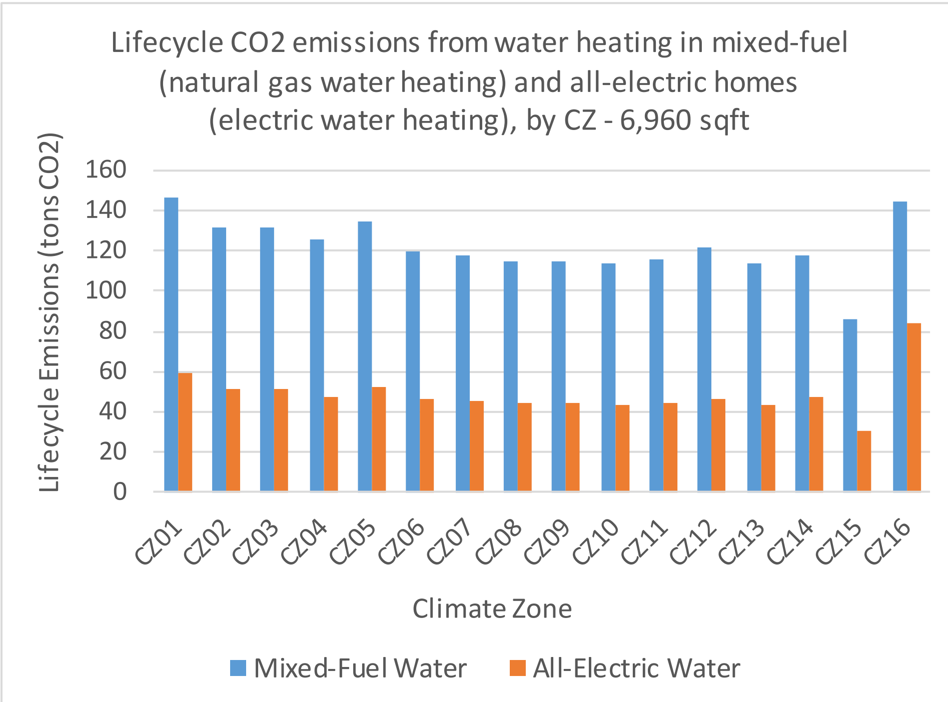


Figure 13 and Figure 14 show the comparative TDV performance of space heating and water heating end-uses for 2,700 sqft homes in each climate zone.

Figure 13. Lifecycle TDV for space heating in mixed-fuel (natural gas space heating) and all-electric homes (electric space heating), by CZ - 2,700 sqft

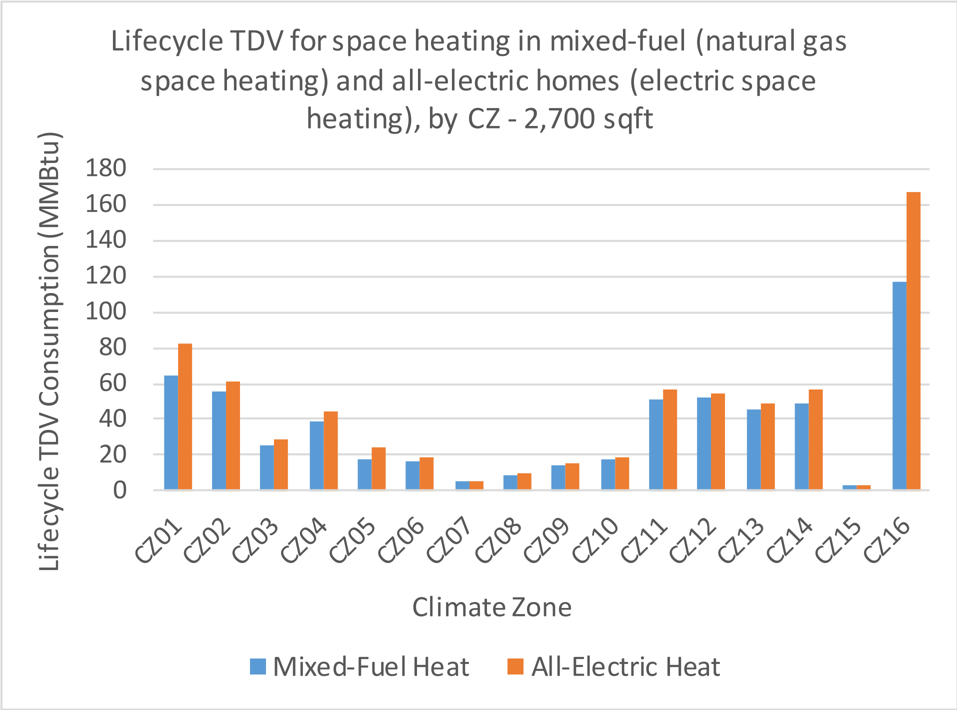


Figure 14. Lifecycle TDV for water heating in mixed-fuel (natural gas water heating) and all-electric homes (electric water heating), by CZ - 2,700 sqft

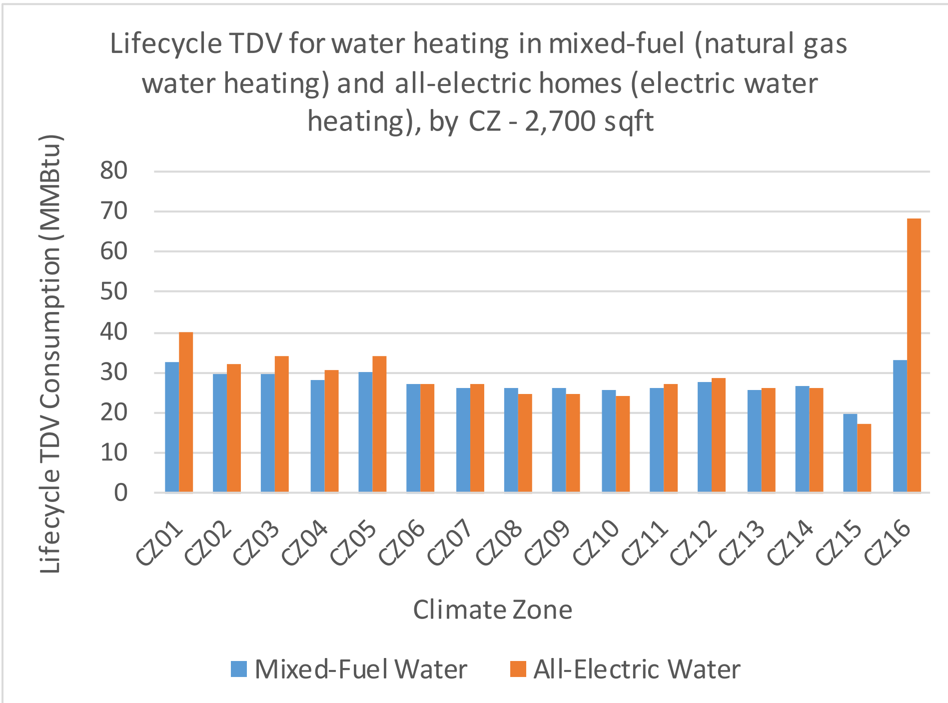


Figure 15 and Figure 16 show the comparative TDV performance of space heating and water heating end-uses for 2,700 sqft homes in each climate zone.

Figure 15. Lifecycle TDV for space heating in mixed-fuel (natural gas space heating) and all-electric homes (electric space heating), by CZ - 6,960 sqft

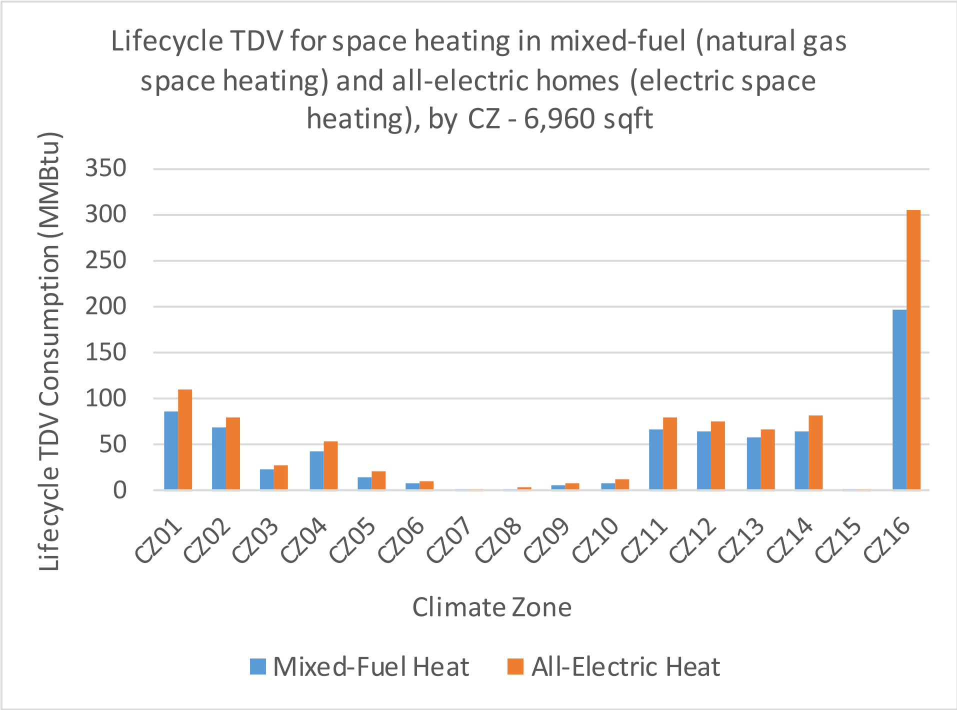


Figure 16. Lifecycle TDV for water heating in mixed-fuel (natural gas water heating) and all-electric homes (electric water heating), by CZ - 6,960 sqft

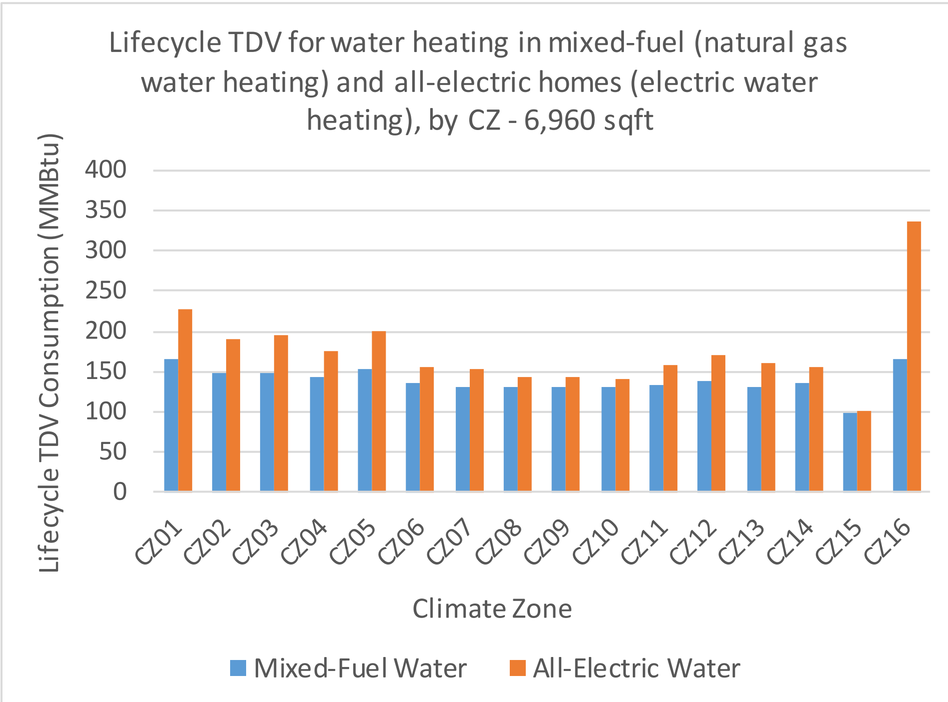


Figure 17 compares the lifecycle TDV value for 2,700 sqft for each climate zone for mixed-fuel and all-electric homes and the 'gap' between the two prototypes.

Figure 17. Lifecycle TDV of mixed-fuel and all-electric homes – 2,700 sqft

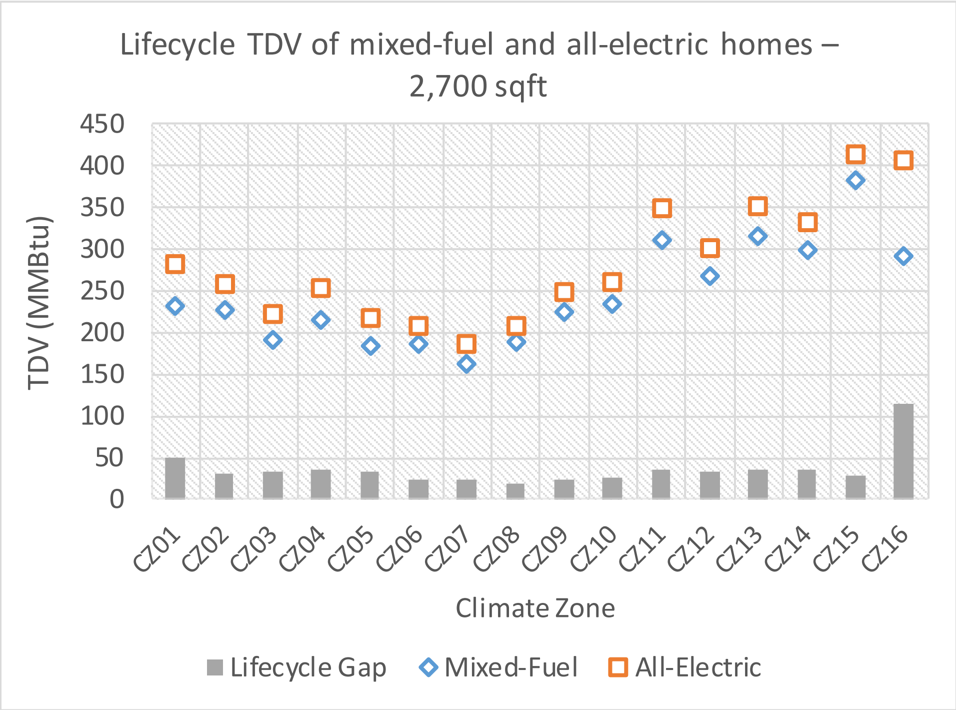


Figure 18 compares the lifecycle TDV value for 6,960 sqft for each climate zone for mixed-fuel and all-electric homes and the 'gap' between the two prototypes.

Figure 18. Lifecycle TDV of mixed-fuel and all-electric homes – 6,960 sqft

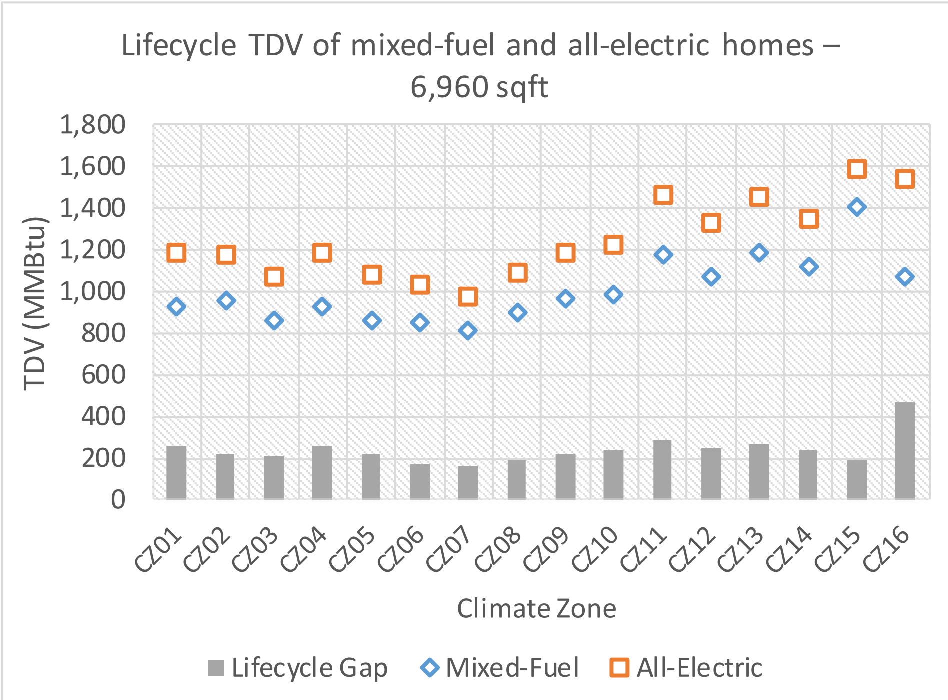


Figure 19 and Figure 20 show the reduction in the TDV gap between mixed-fuel and all-electric homes as a function of the carbon price for 2,700 sqft and 6,960 sqft buildings, respectively, for each climate zone.

Figure 19. Base Scenario net lifecycle TDV values of all-electric homes compared to mixed-fuel homes, by embedded carbon price and CZ - 2,700 sqft

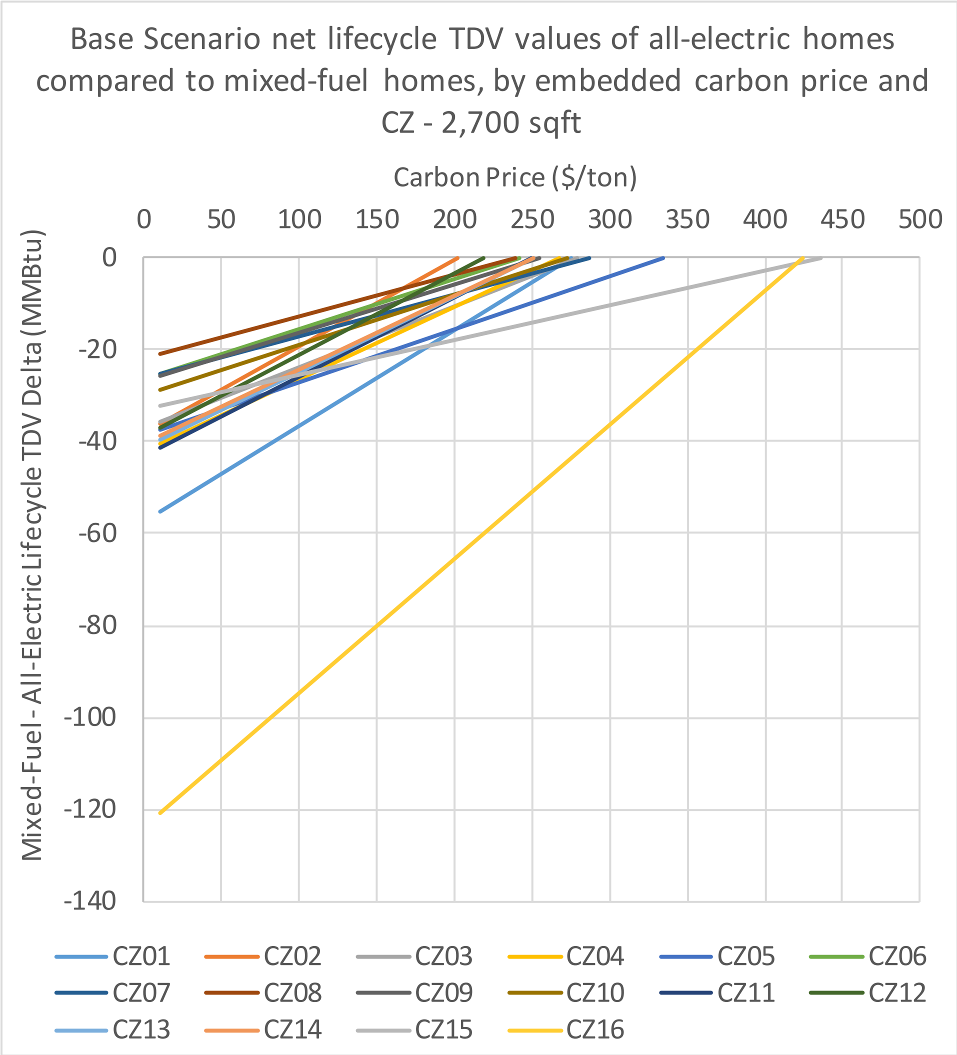


Figure 20. Base Scenario net lifecycle TDV values of all-electric homes compared to mixed-fuel homes, by embedded carbon price and CZ - 6,960 sqft

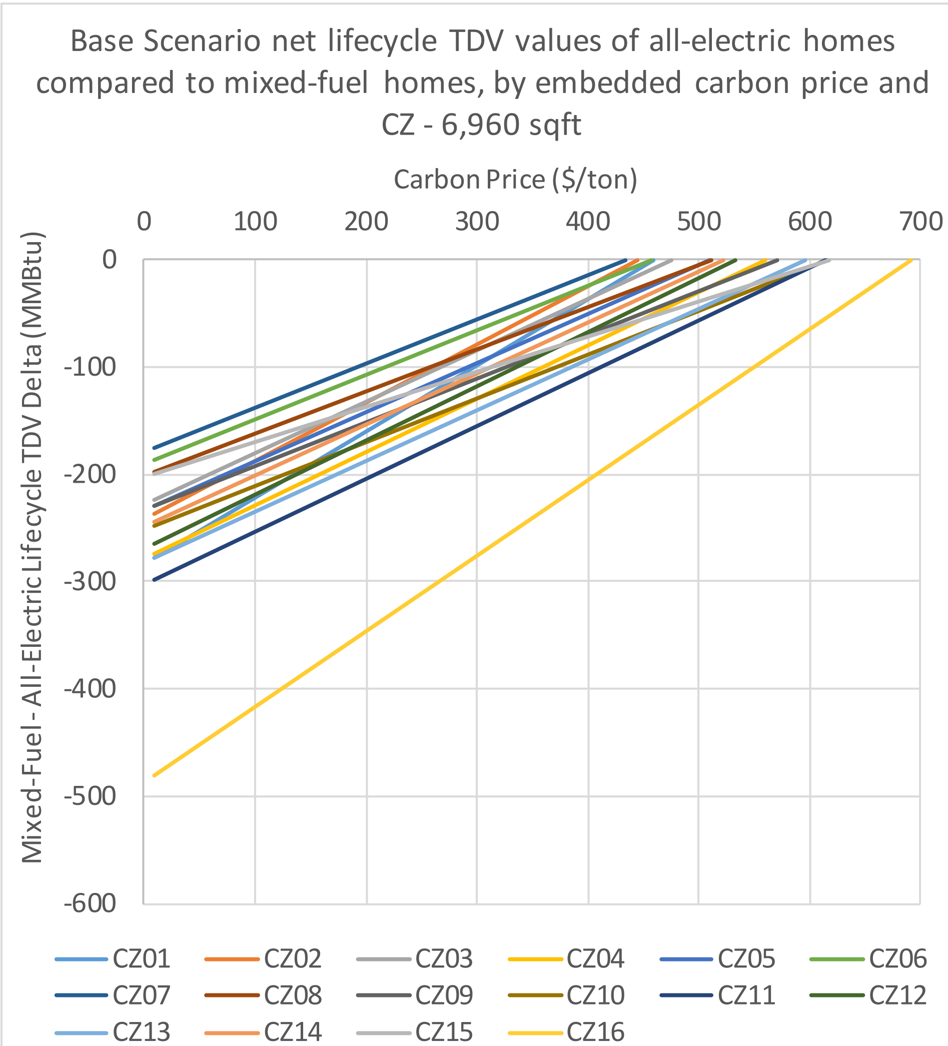


Table 12 shows the average monthly bill difference over the assumed 30-year life of a 2,700 sqft building.

Table 12. Lifecycle cost gap between all-electric and mixed-fuel homes – 2,700 sqft prototype			
Climate Zone	**Mixed-Fuel**	**All-Electric**	**Lifecycle Gap**
CZ01	$40,283	$49,010	$8,728
CZ02	$39,359	$44,789	$5,430
CZ03	$33,039	$38,662	$5,624
CZ04	$37,441	$43,742	$6,301
CZ05	$31,817	$37,796	$5,979
CZ06	$32,132	$36,078	$3,946
CZ07	$28,202	$32,175	$3,973
CZ08	$32,734	$36,016	$3,282
CZ09	$39,074	$43,090	$4,016
CZ10	$40,435	$44,968	$4,533
CZ11	$53,933	$60,325	$6,392
CZ12	$46,488	$52,155	$5,667
CZ13	$54,868	$61,015	$6,147
CZ14	$51,711	$57,802	$6,091
CZ15	$66,488	$71,660	$5,172
CZ16	$50,676	$70,606	$19,930

Table 13 shows the average monthly bill difference over the assumed 30-year life of a 6,960 sqft building.

Table 13. Lifecycle cost gap between all-electric and mixed-fuel homes – 6,960 sqft prototype			
Climate Zone	Mixed-Fuel	All-Electric	Lifecycle Gap
CZ01	$160,016	$205,359	$45,343
CZ02	$165,496	$204,170	$38,675
CZ03	$149,648	$186,085	$36,437
CZ04	$160,068	$205,119	$45,051
CZ05	$148,901	$186,630	$37,730
CZ06	$148,306	$178,877	$30,571
CZ07	$140,223	$168,642	$28,419
CZ08	$156,474	$189,086	$32,612
CZ09	$167,954	$205,906	$37,951
CZ10	$170,430	$211,649	$41,219
CZ11	$203,311	$252,840	$49,529
CZ12	$186,481	$230,217	$43,736
CZ13	$205,926	$252,040	$46,114
CZ14	$193,910	$234,502	$40,592
CZ15	$242,862	$275,756	$32,894
CZ16	$185,588	$266,700	$81,112