

Time-of-Use Electricity Pricing: Implications of Hawai'i's Pilot Program

Research Questions

Which households or customer groups are likely to come out ahead, and who may see bill increases due to the pilot program?

What consumption characteristics are common among customers who win, and those who lose?

How can customers benefit from time-of-use pricing?

Related Literature

The Long-Run Efficiency of Real-Time Electricity Pricing

- Borenstein (2005)

Time-of-Use Rates and Real-Time Prices

- Hogan (2014)

Real-Time Pricing and the Cost of Clean Power

- Imelda, Fripp, & Roberts (2023)

Knowledge Is (Less) Power: Experimental Evidence from Residential Energy Use

- Jessoe & Rapson (2014)

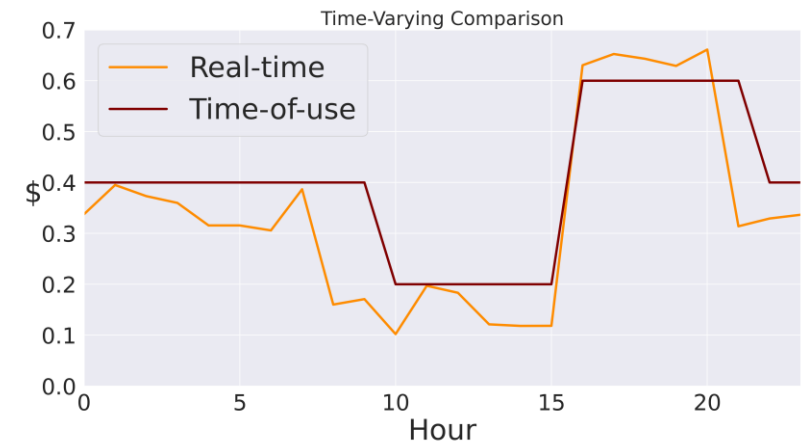
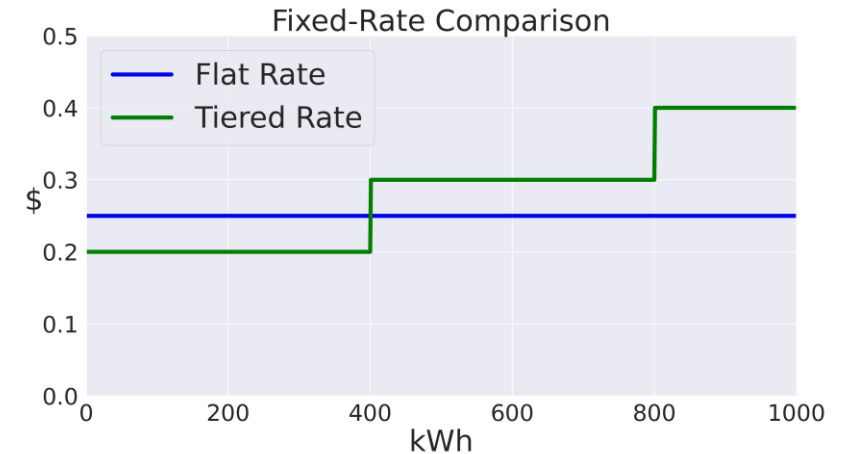
Energy Pricing

Fixed-rate

- Flat rate
 - The price per kWh is constant regardless of amount consumed or time of consumption.
- Tiered rate
 - Prices remain constant over time but fluctuate based on usage levels.

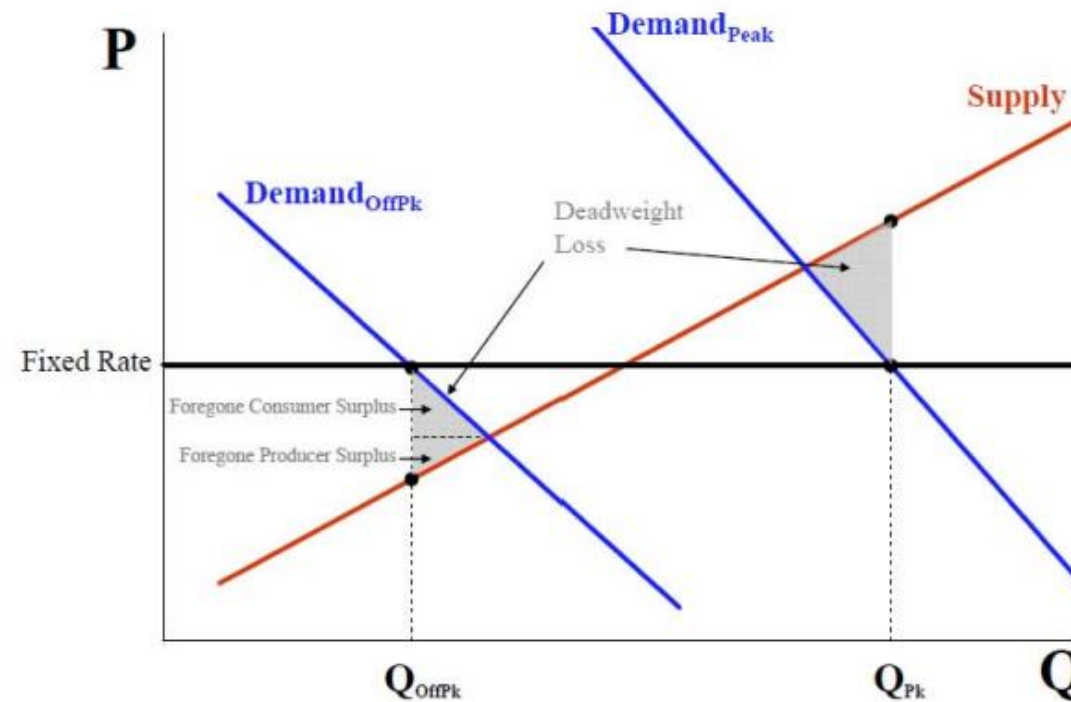
Time-varying pricing

- Real-time pricing (RTP)
 - The prices customers face mirrors the underlying wholesale electricity market or cost of production.
- Time-of-use pricing (TOU)
 - A simple implementation of time-varying pricing in which prices move at set times to set values throughout the day.



Variable Pricing

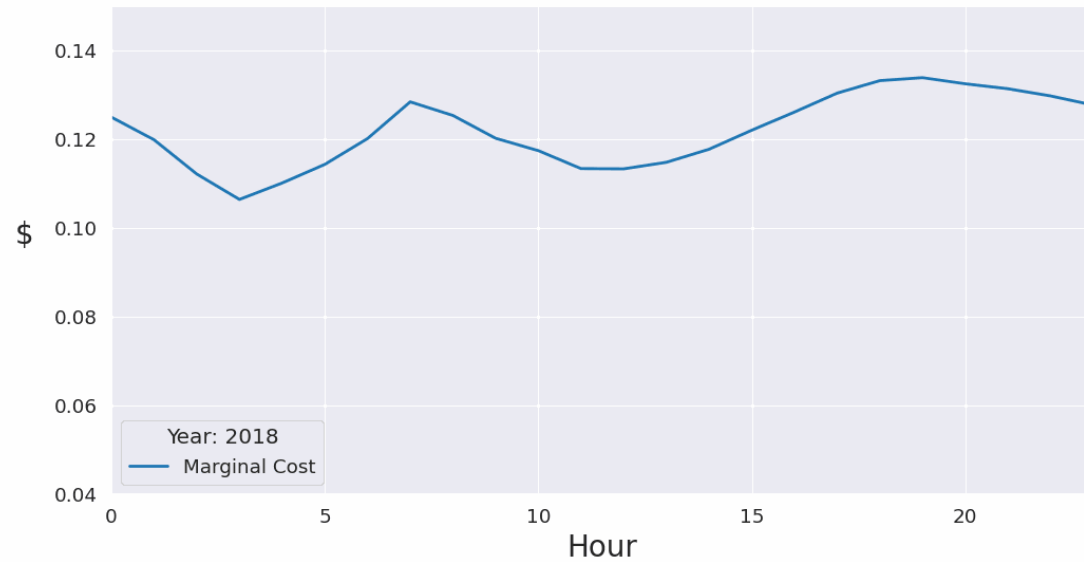
Economic Inefficiencies Caused by Fixed Retail Rates



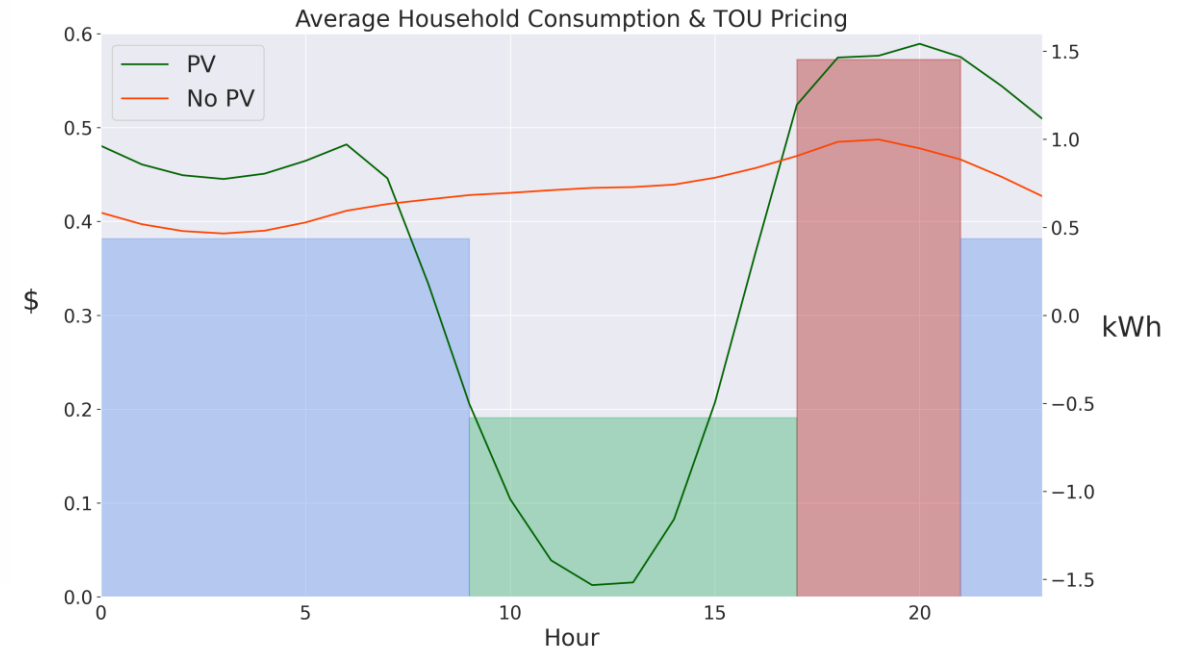
Source: Figure 2 in (Newell & Faruqi, 2009)

Variable Pricing

Efficient Pricing

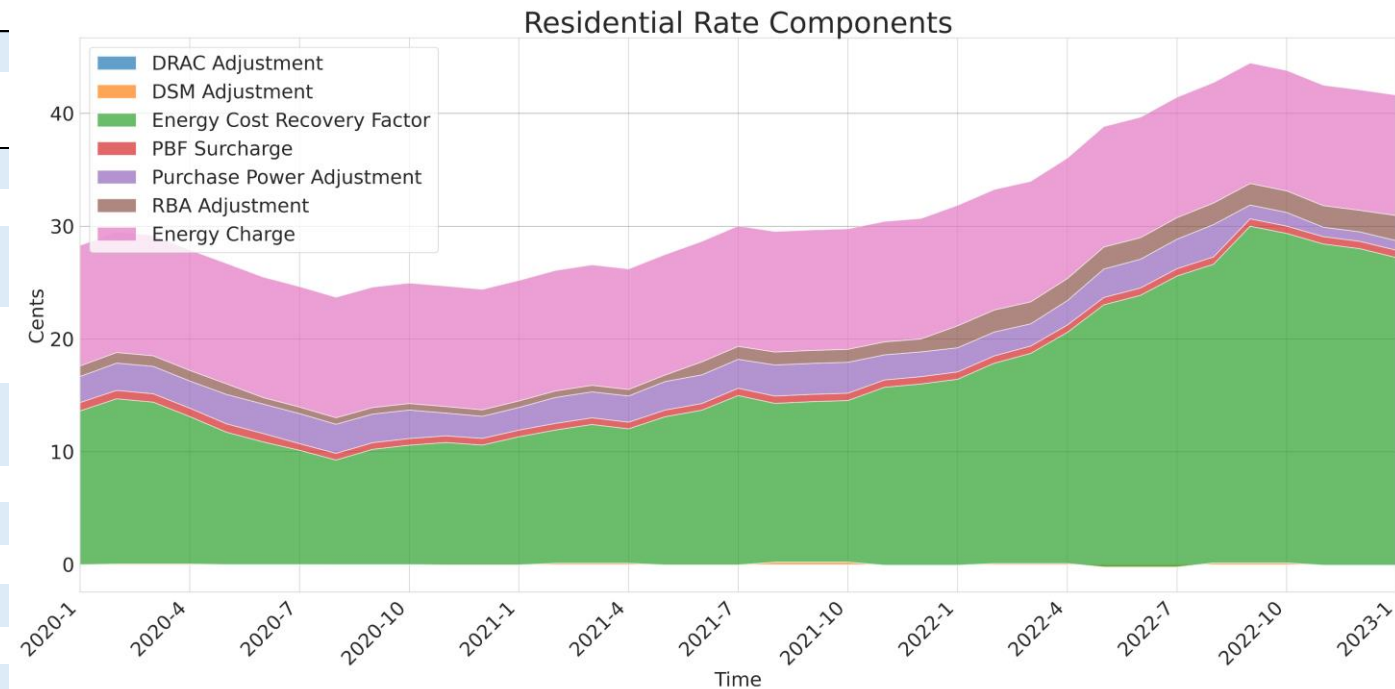


Demand Shifting: Win-Win



HECO Effective Rates

| | R Residential | G Small Commercial | J Medium Commercial |
|---|------------------|--------------------------|---------------------------|
| Fixed Costs (\$/month) | | | |
| Customer Charge | 11.5 | 35.00 | 66.00 |
| Green Infrastructure Fee | 1.23 | 1.33 | 26.06 |
| Variable Costs (\$/kWh) | | | |
| DRAC Adjustment | -0.00008 | -0.00038 | -0.00038 |
| DSM Adjustment | 0.00092 | 0.00002 | 0.00002 |
| Energy Cost Recovery Factors | 0.24781 | 0.24781 | 0.24781 |
| Public Benefits Fund Surcharge | 0.00649 | 0.00408 | 0.00408 |
| Purchase Power Adjustment | 0.01370 | 0.01745 | 0.01537 |
| RBA Rate Adjustment | 0.02224 | 0.02224 | 0.02224 |
| First 350 kWh | 0.10681 | - | - |
| Next 850 kWh | 0.11835 | - | - |
| Over 1,200 kWh | 0.13712 | - | - |
| All kWh | - | 0.09601 | 0.05318 |
| Demand Charge (all billing kWh per month) | - | - | 13.00 |



Solar PV & Battery Bonus

| Program | Export Credit | Program Capacity | Program Availability |
|----------------------------------|---------------|------------------|----------------------|
| Customer Self Supply (CSS) | 0 | - | Open |
| Smart Export (SE) | 14.97* | 35 MW | Open |
| Customer Grid-Supply (CGS) | 15.07 | 51.31 MW | Closed |
| Customer Grid-Supply Plus (CGS+) | 10.08 | 95 MW | Open |
| Net Energy Metering (NEM) | ~40** | - | Closed |
| Net Energy Metering Plus (NEM+) | ~40** | - | Open*** |

* SE customers do not receive any export credit between 9 a.m. and 4 p.m.

** NEM and NEM+ customers receive the current effective rate for all exports to the grid.

*** NEM+ is only available to households grandfathered under the original NEM program.

Battery Bonus Program

- Initial incentive: \$850 per kW of installed capacity
 - A 15 kWh battery can commit 5kW to the grid over the two-hour discharge period making the one-time payment $\$850 \times 5 \text{ kW} = \$4,250$.
- Customers not in the NEM program receive a monthly credit for the first three years at the retail rate for electricity during the two-hour discharge period.
- Customers receive a \$5 per KW monthly peak capacity payment for the 10-year duration of the program.

Shift & Save

Program Details

- The 1-year pilot takes effect 10/1/23.
- Customers will receive a bill protection credit for the first six months.
- Selected customers are automatically enrolled with the ability to opt-out at any time.

Sampling

- Stratified by island and selected randomly within the AMI population.
- 15,000 residential customers
 - Oversampling of Solar PV households (40% of total sample)
- 1,700 commercial customers

| | R | G | J |
|--------------------------------|-------------|------------------|-------------------|
| | Residential | Small Commercial | Medium Commercial |
| Fixed Costs (\$/month) | | | |
| Customer Charge \$/month | 5.65 | 8.64 | 49.00 |
| Grid Access Charge \$/month | 8.60 | 19.45 | 3.67 |
| Variable Costs (\$/kWh) | | | |
| Off-Peak (9am - 5pm) | 0.1908 | 0.2332 | 0.2143 |
| Mid-Peak (9pm - 9am) | 0.3816 | 0.4663 | 0.4286 |
| On-Peak (5pm - 9pm) | 0.5724 | 0.6995 | 0.6429 |

HECO AMI Data

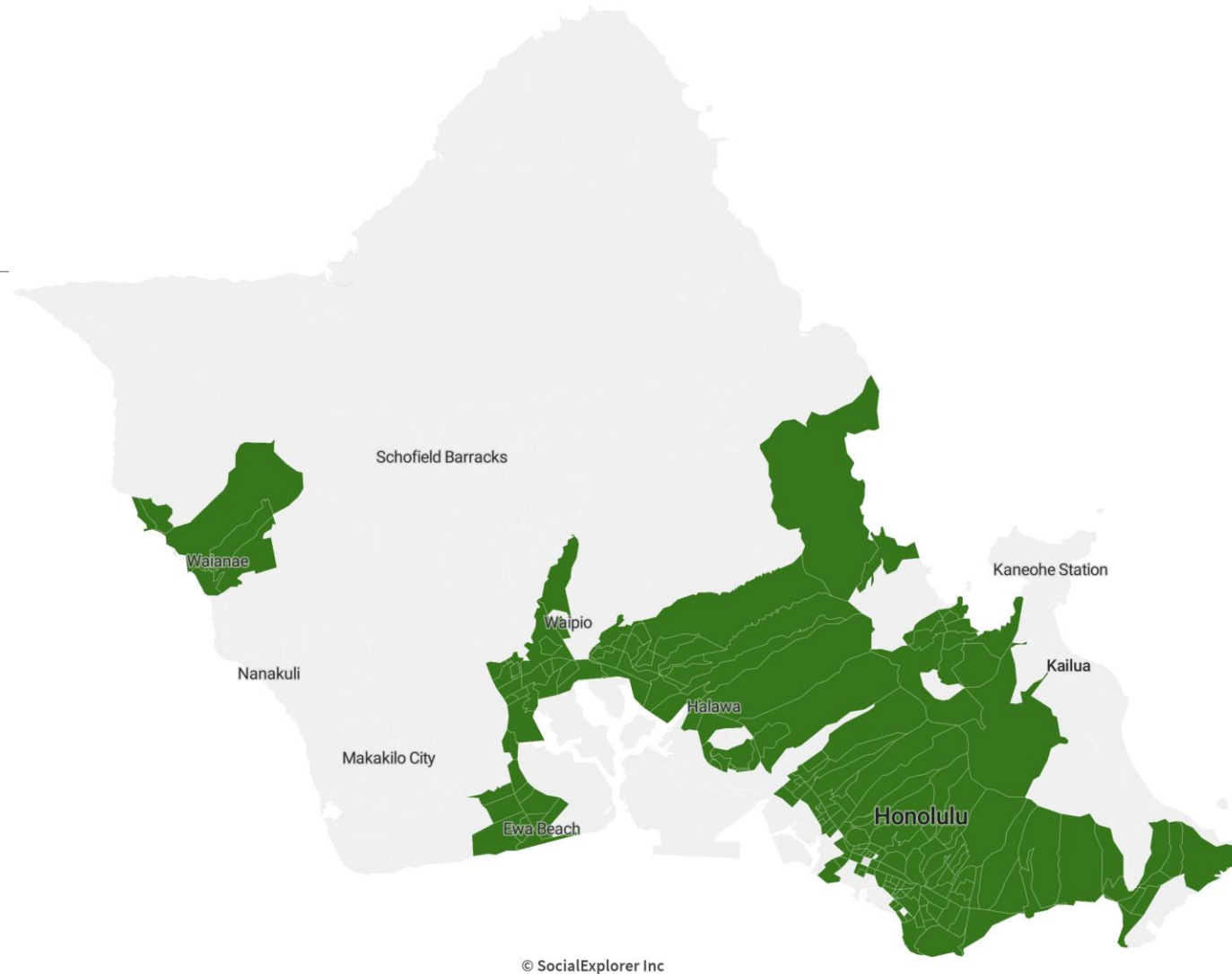
Features

- 15 Minute Meter Measurements
 - kWh imported & exported
- Solar PV Status
- Solar PV Program
- Observation Location (Census Tract)

Summary (March 2023)

- Unique Households: 105k
- Solar PV Households: 23%
- Unique Census Tracts: 188

AMI Data are provided by Hawaiian Electric Company



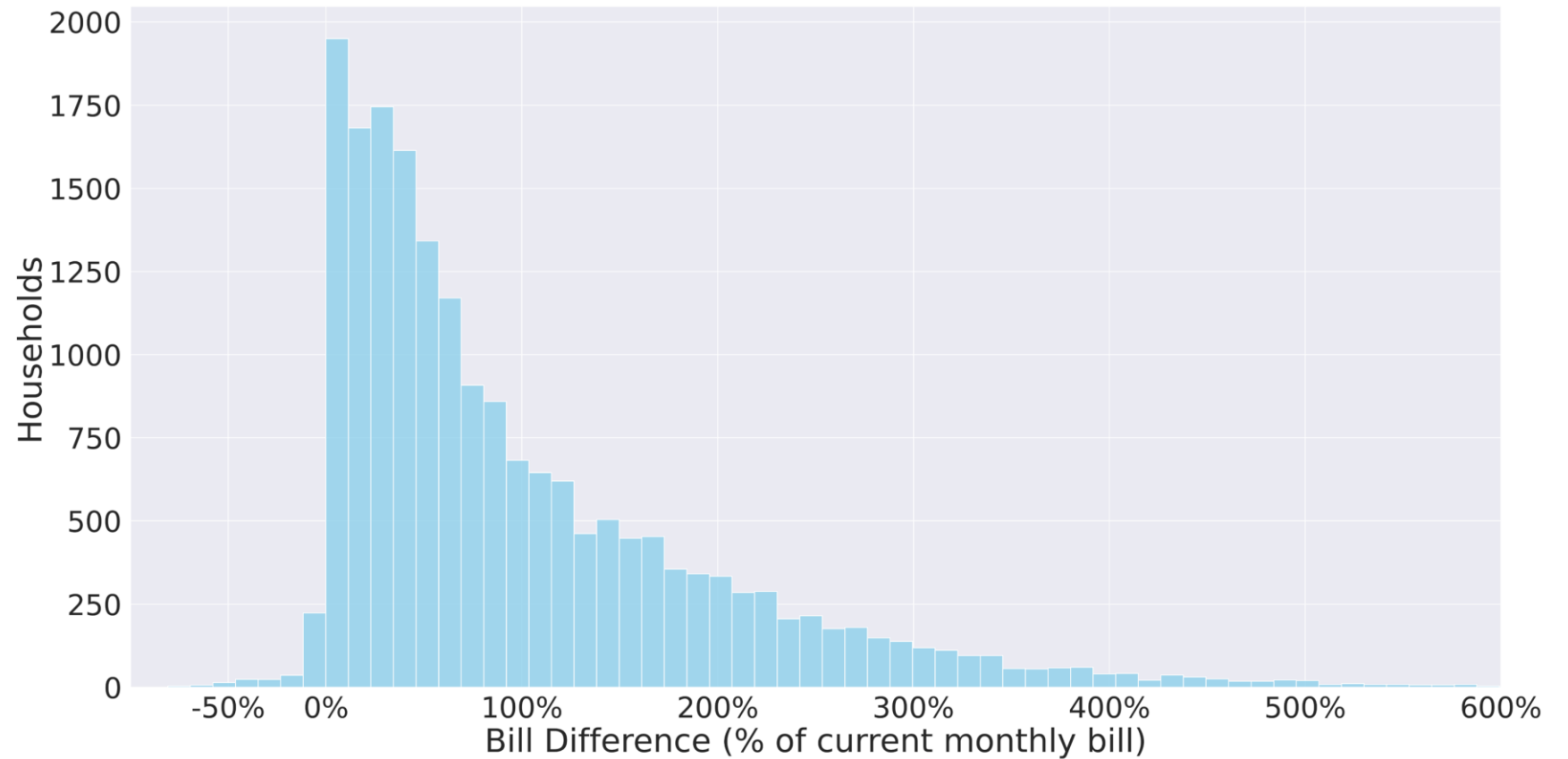
Residential (R) Mean Billing Impacts

NEM (Current)

- ~43¢

NEM (TOU)

- 19.08¢ (9am – 5pm)



Further Analysis: Hourly Consumption Summary Data

Features

- Hourly Summary Statistics of Imported & Exported kWh
 - Minimum, Mean, Maximum, & Standard Deviation

Non-PV Households

- Losers ($\Delta > 0$)*: 42,505
- Big Losers ($\Delta > 10\%$): 1,284
- Winners ($\beta > 0$)**: 37,701
- Big Winners ($\beta > 10\%$): 751

PV Households

- Losers ($\Delta > 0$): 21,917
- Big Losers ($\Delta > 100\%$): 7,175
- Winners ($\beta > 0$): 838
- Big Winners ($\beta > 25\%$): 82

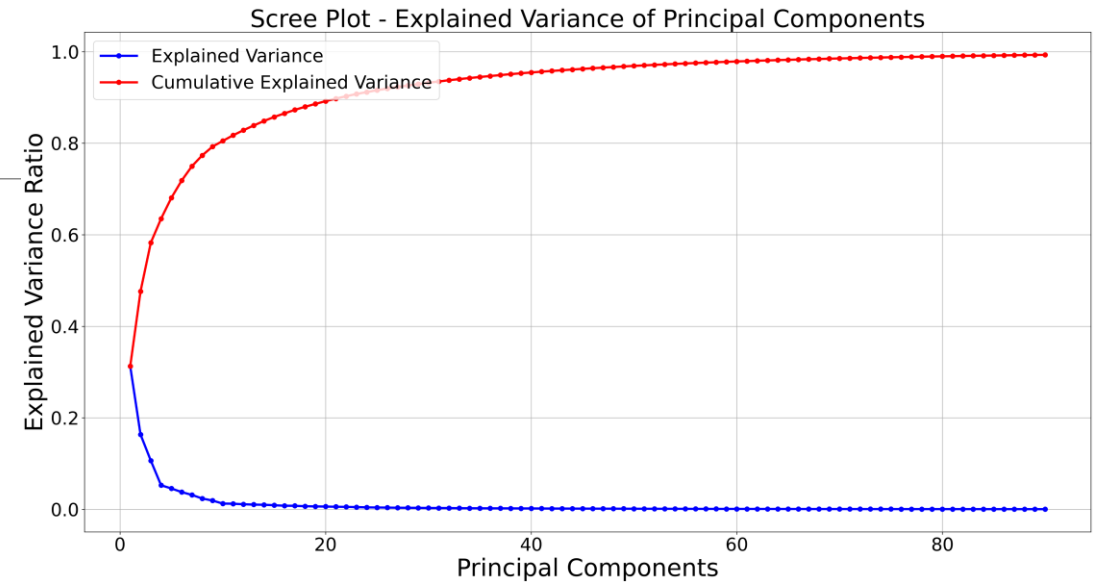
* Δ represents the mean increase in monthly bill.

** β represents the mean decrease in monthly bill.

Further Analysis: Methods

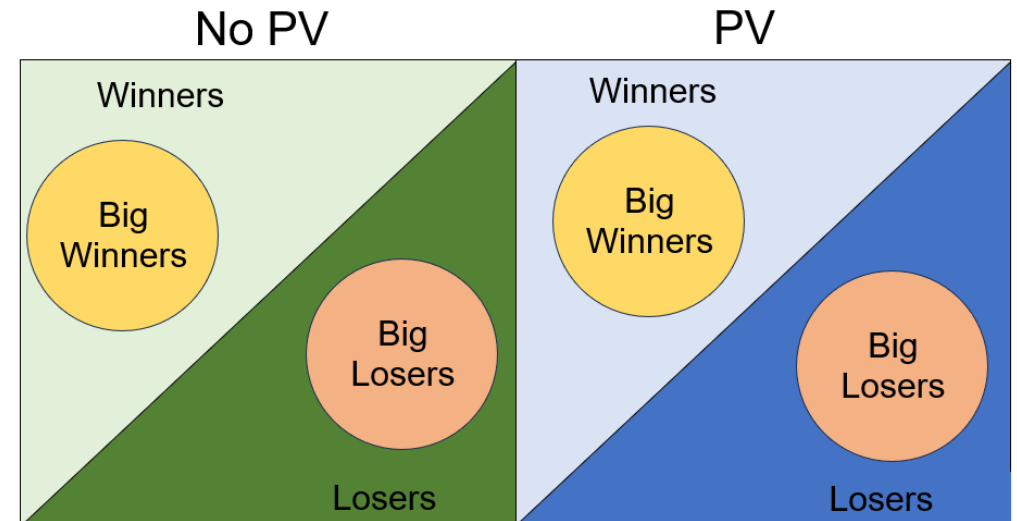
Principal Component Analysis (PCA)

- PV Households
 - 90 principal components
- Non-PV Households
 - 40 principal components



K-Means

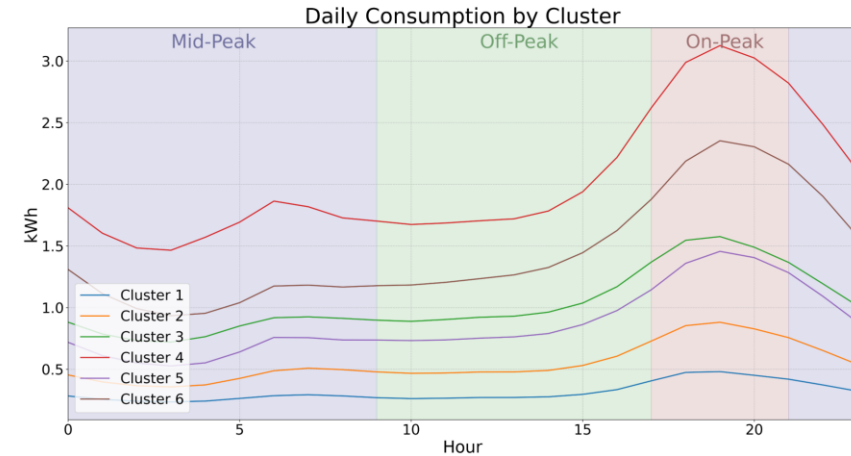
- Households are clustered within each subgroup:
 - Non-PV Losers & Non-PV Big Losers
 - Non-PV Winners & Non-PV Big Winners
 - PV Losers & PV Big Losers
 - PV Winners & PV Big Winners



Residential (R) Non-PV Losers

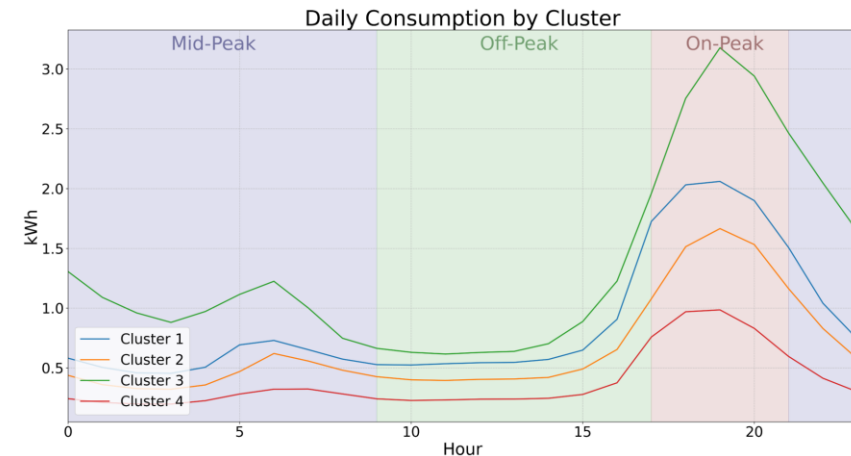
Losers

| Cluster | Population | Mean Household Bill Increase (\$) | | Mean Household Bill Increase (%) | |
|---------|------------|-----------------------------------|-------|----------------------------------|-------|
| | | Mean | Max | Mean | Max |
| 1 | 12645 | 3.40 | 37.20 | 3.10 | 24.59 |
| 2 | 13762 | 6.36 | 52.48 | 3.70 | 23.10 |
| 3 | 4684 | 8.29 | 76.21 | 2.80 | 21.20 |
| 4 | 1102 | 12.63 | 96.55 | 2.20 | 15.60 |
| 5 | 7213 | 9.47 | 64.09 | 3.60 | 24.40 |
| 6 | 3099 | 12.58 | 95.36 | 3.00 | 20.00 |



Big
Losers

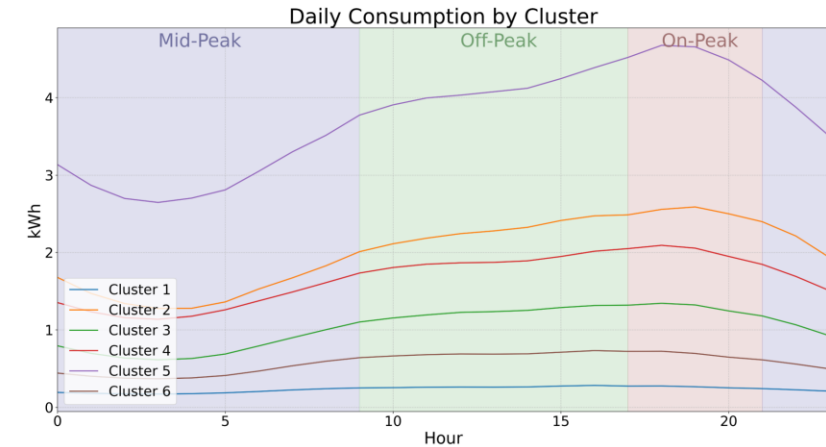
| Cluster | Population | Mean Household Bill Increase (\$) | | Mean Household Bill Increase (%) | |
|---------|------------|-----------------------------------|-------|----------------------------------|-------|
| | | Mean | Max | Mean | Max |
| 1 | 187 | 33.52 | 76.21 | 12.20 | 21.17 |
| 2 | 388 | 25.85 | 61.85 | 12.30 | 24.44 |
| 3 | 79 | 50.07 | 96.55 | 12.09 | 19.98 |
| 4 | 630 | 16.19 | 40.89 | 12.55 | 24.59 |



Residential (R) Non-PV Winners

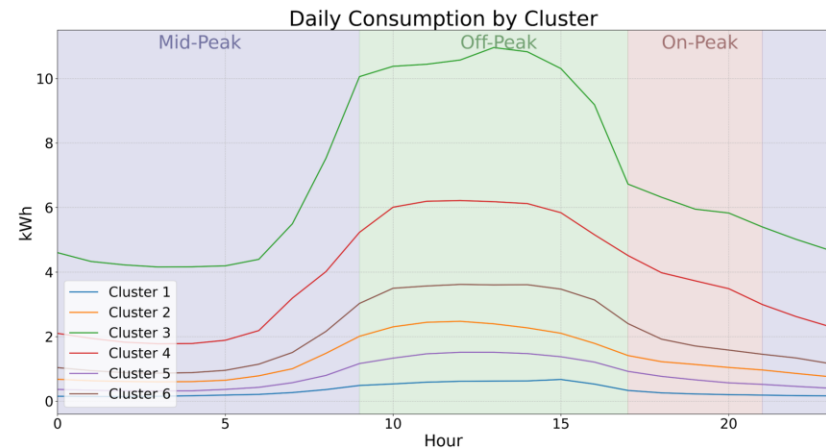
Winners

| Cluster | Population | Mean Household Bill Decrease (\$) | | Mean Household Bill Decrease (%) | |
|---------|------------|-----------------------------------|--------|----------------------------------|-------|
| | | Mean | Max | Mean | Max |
| 1 | 12938 | 2.19 | 39.81 | 2.62 | 27.12 |
| 2 | 1810 | 23.13 | 257.09 | 3.21 | 29.77 |
| 3 | 7256 | 10.12 | 119.32 | 2.77 | 28.18 |
| 4 | 2567 | 17.08 | 118.42 | 3.00 | 20.22 |
| 5 | 493 | 56.13 | 433.68 | 4.25 | 22.49 |
| 6 | 12637 | 5.59 | 76.32 | 2.71 | 25.48 |



Big
Winners

| Cluster | Population | Mean Household Bill Decrease (\$) | | Mean Household Bill Decrease (%) | |
|---------|------------|-----------------------------------|--------|----------------------------------|-------|
| | | Mean | Max | Mean | Max |
| 1 | 299 | 15.42 | 62.79 | 13.21 | 27.11 |
| 2 | 103 | 55.13 | 115.99 | 12.80 | 20.22 |
| 3 | 5 | 313.56 | 433.68 | 13.97 | 18.29 |
| 4 | 24 | 156.59 | 293.84 | 12.58 | 22.49 |
| 5 | 250 | 34.05 | 119.32 | 12.74 | 28.17 |
| 6 | 70 | 93.29 | 257.08 | 13.50 | 29.77 |



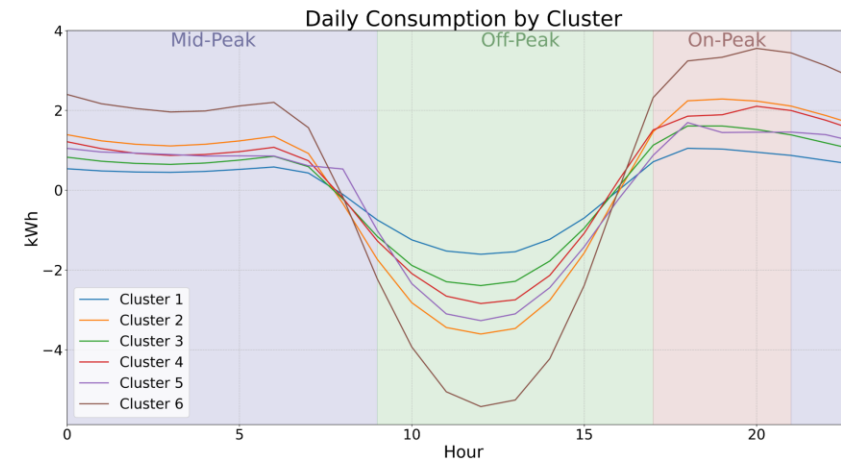
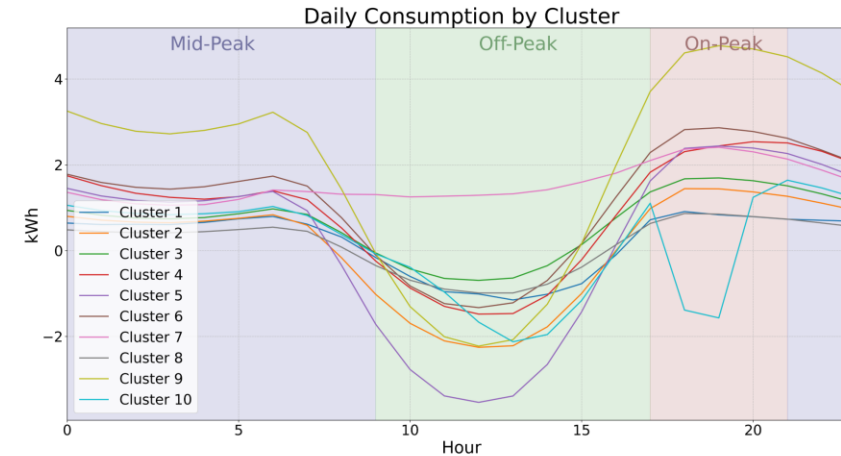
Residential (R) PV Losers

Losers

| Cluster | Population | Mean Household Bill Increase (\$) | | Mean Household Bill Increase (%) | |
|---------|------------|-----------------------------------|--------|----------------------------------|---------|
| | | Mean | Max | Mean | Max |
| 1 | 32 | 17.56 | 82.40 | 20.06 | 329.61 |
| 2 | 5407 | 69.89 | 162.13 | 145.69 | 587.99 |
| 3 | 3927 | 53.36 | 133.47 | 37.44 | 375.71 |
| 4 | 935 | 83.69 | 243.00 | 62.72 | 678.87 |
| 5 | 2242 | 121.29 | 325.57 | 192.70 | 1302.30 |
| 6 | 2042 | 95.52 | 200.33 | 34.95 | 273.65 |
| 7 | 202 | 12.54 | 62.27 | 2.87 | 14.30 |
| 8 | 6287 | 37.01 | 115.25 | 74.82 | 342.76 |
| 9 | 506 | 145.92 | 389.74 | 39.11 | 619.47 |
| 10 | 337 | 28.96 | 124.05 | 52.79 | 455.20 |

Big
Losers

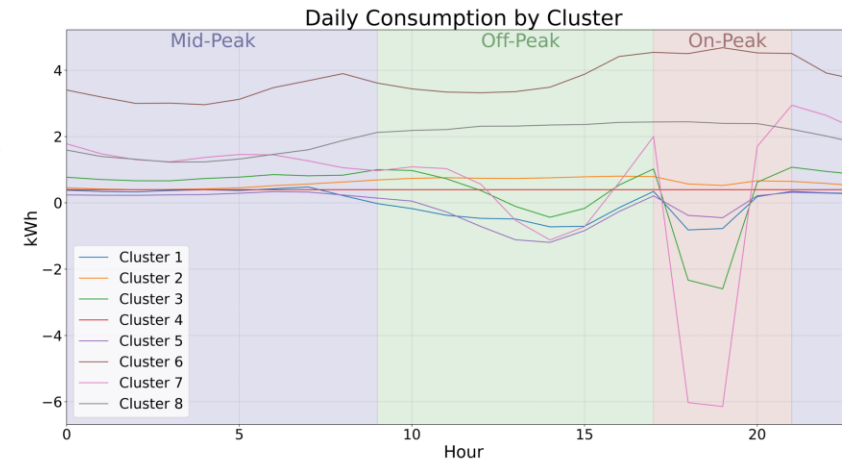
| Cluster | Population | Mean Household Bill Increase (\$) | | Mean Household Bill Increase (%) | |
|---------|------------|-----------------------------------|--------|----------------------------------|---------|
| | | Mean | Max | Mean | Max |
| 1 | 2646 | 57.49 | 118.27 | 166.86 | 395.30 |
| 2 | 1229 | 130.44 | 230.42 | 263.55 | 773.42 |
| 3 | 2662 | 86.74 | 162.13 | 208.44 | 587.99 |
| 4 | 459 | 110.67 | 243.03 | 216.65 | 678.87 |
| 5 | 3 | 86.36 | 109.82 | 217.43 | 329.61 |
| 6 | 176 | 204.89 | 389.74 | 299.22 | 1302.30 |



Residential (R) PV Winners

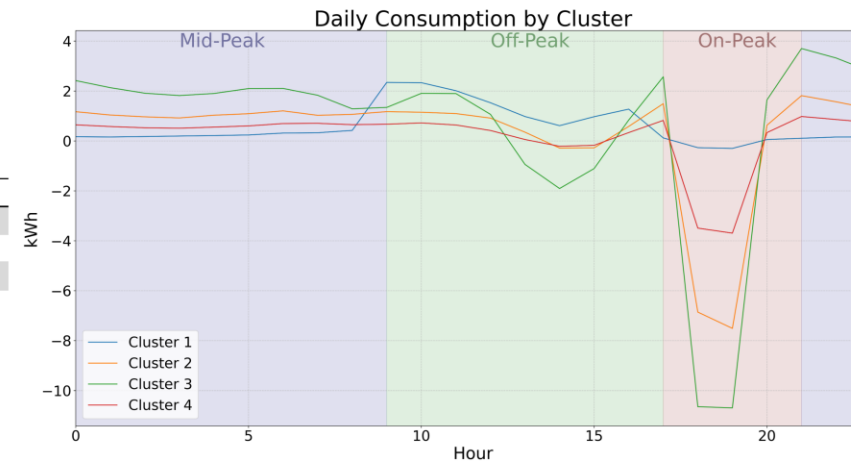
Winners

| Cluster | Population | Mean Household Bill Decrease (\$) | | Mean Household Bill Decrease (%) | |
|---------|------------|-----------------------------------|--------|----------------------------------|-------|
| | | Mean | Max | Mean | Max |
| 1 | 18 | 6.56 | 20.93 | 7.37 | 24.31 |
| 2 | 296 | 8.31 | 57.77 | 5.09 | 56.16 |
| 3 | 140 | 29.02 | 143.64 | 19.67 | 80.85 |
| 4 | 2 | 1.91 | 1.91 | 1.27 | 1.27 |
| 5 | 192 | 4.67 | 56.19 | 6.12 | 68.24 |
| 6 | 26 | 36.10 | 92.94 | 2.73 | 7.61 |
| 7 | 27 | 40.86 | 150.00 | 23.80 | 77.95 |
| 8 | 137 | 25.75 | 140.68 | 3.76 | 32.13 |

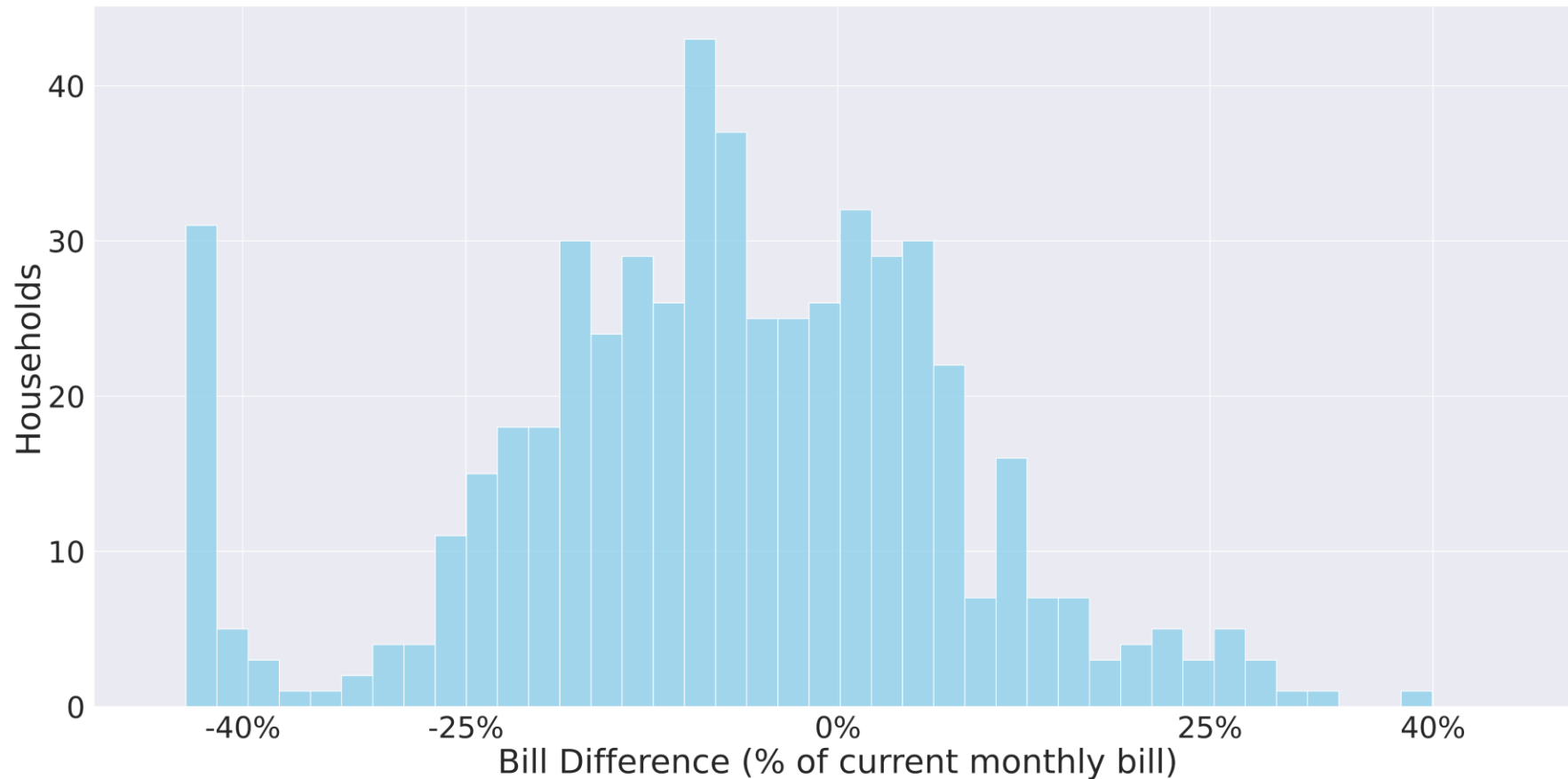


Big
Winners

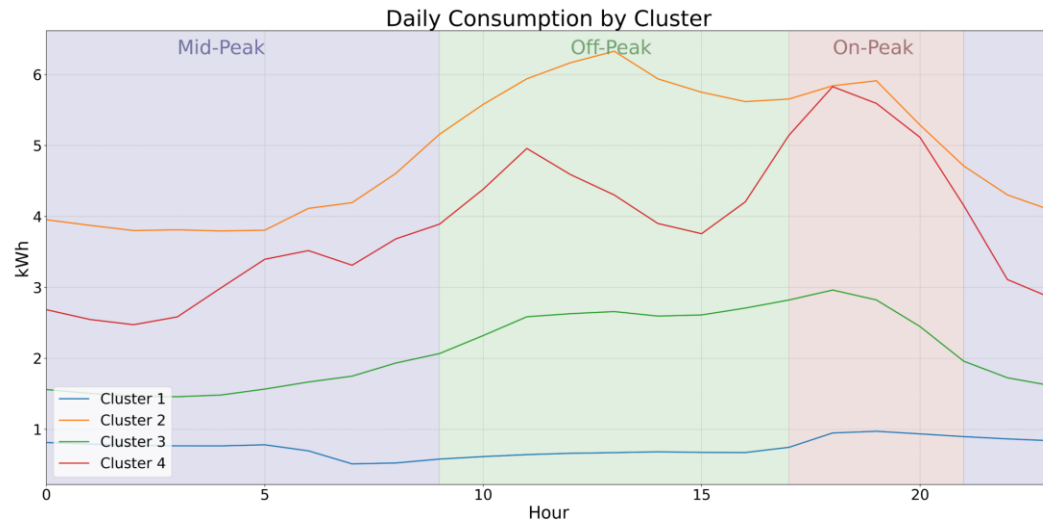
| Cluster | Population | Mean Household Bill Decrease (\$) | | Mean Household Bill Decrease (%) | |
|---------|------------|-----------------------------------|--------|----------------------------------|-------|
| | | Mean | Max | Mean | Max |
| 1 | 11 | 77.43 | 135.63 | 33.20 | 46.86 |
| 2 | 32 | 56.51 | 143.64 | 43.66 | 80.85 |
| 3 | 6 | 106.40 | 150.00 | 54.28 | 77.95 |
| 4 | 33 | 33.09 | 78.52 | 40.44 | 68.24 |



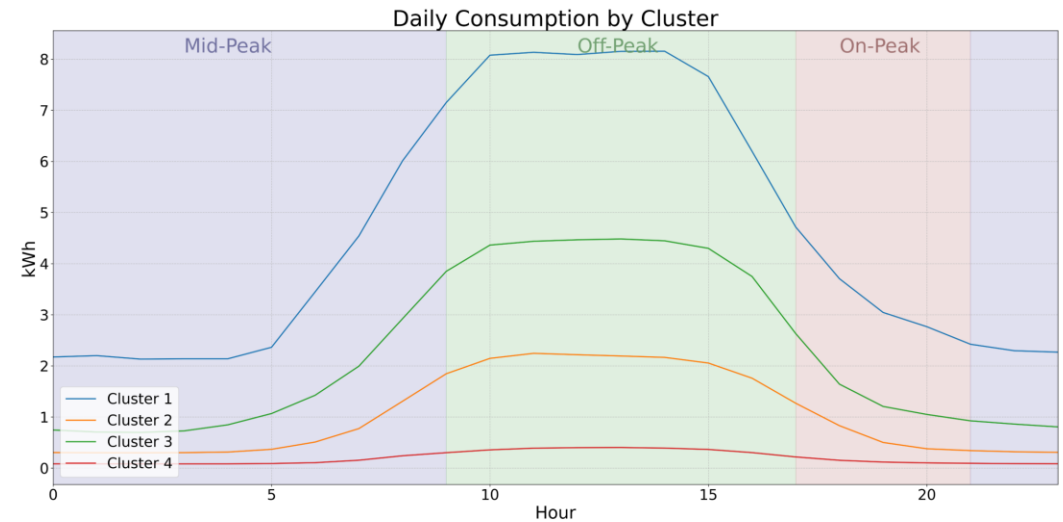
Small Commercial (G) Mean Billing Impacts



Small Commercial (G) Losers & Winners



| Cluster | Population | Mean Household Bill Increase (\$) | | Mean Household Bill Increase (%) | |
|---------|------------|-----------------------------------|--------|----------------------------------|-------|
| | | Mean | Max | Mean | Max |
| 1 | 99 | 25.45 | 184.62 | 8.76 | 31.34 |
| 2 | 27 | 121.82 | 349.69 | 8.36 | 31.66 |
| 3 | 40 | 54.22 | 229.01 | 7.97 | 29.13 |
| 4 | 14 | 137.61 | 721.34 | 10.42 | 39.95 |



| Cluster | Population | Mean Household Bill Decrease (\$) | | Mean Household Bill Decrease (%) | |
|---------|------------|-----------------------------------|--------|----------------------------------|-------|
| | | Mean | Max | Mean | Max |
| 1 | 14 | 64.32 | 148.99 | 4.37 | 9.70 |
| 2 | 102 | 41.17 | 145.26 | 11.68 | 26.92 |
| 3 | 27 | 67.09 | 187.32 | 9.23 | 21.79 |
| 4 | 231 | 14.95 | 64.42 | 19.04 | 43.82 |

How to win:

Consumption Shifting (20% On-Peak)

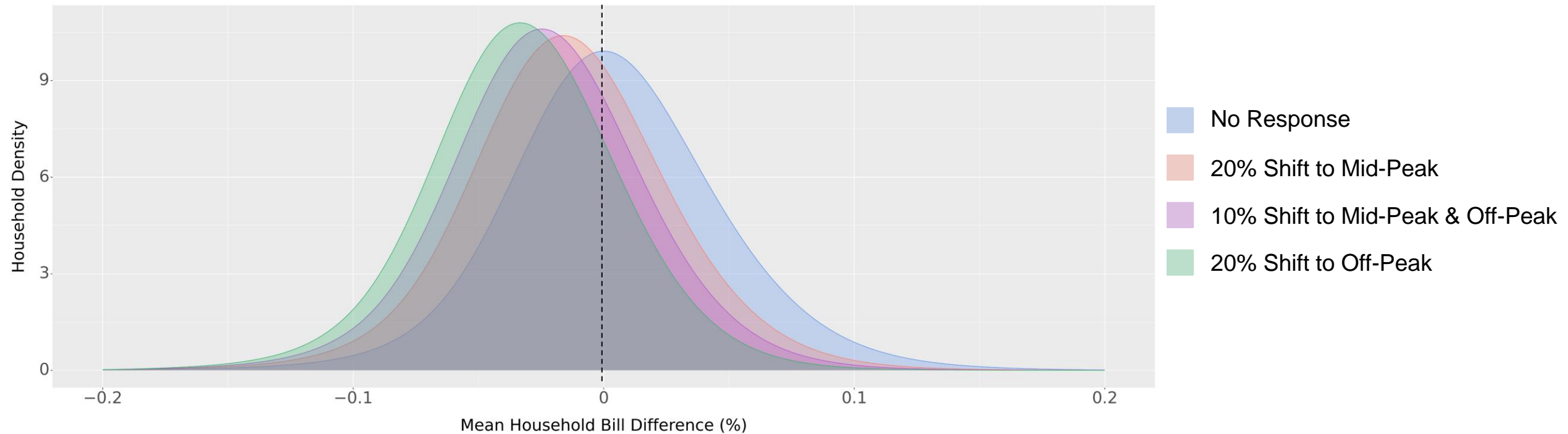
On average, households would need to shift 26 kWh each month equating to roughly 5% of total monthly consumption.

- 8 laundry cycles (washer & dryer)
- 15 dishwasher cycles
- ~1 hour a day of window AC use

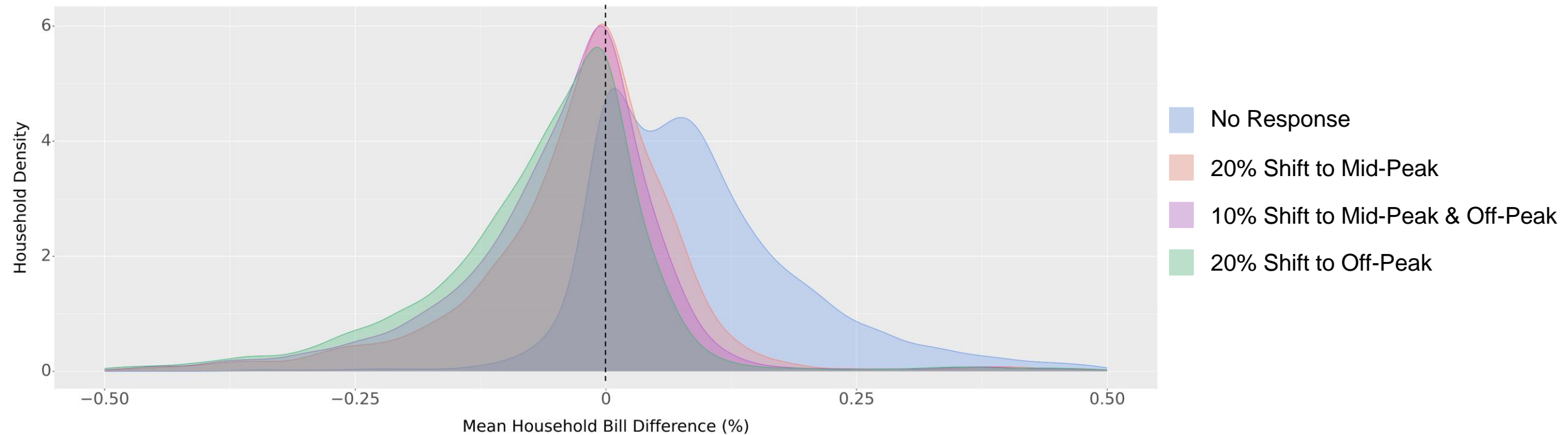
Home automation and appliance controllers

- The typical monthly consumption for water heaters is approximately 100 kWh, and with the aid of modern appliance controllers, this entire usage can be effectively rescheduled.

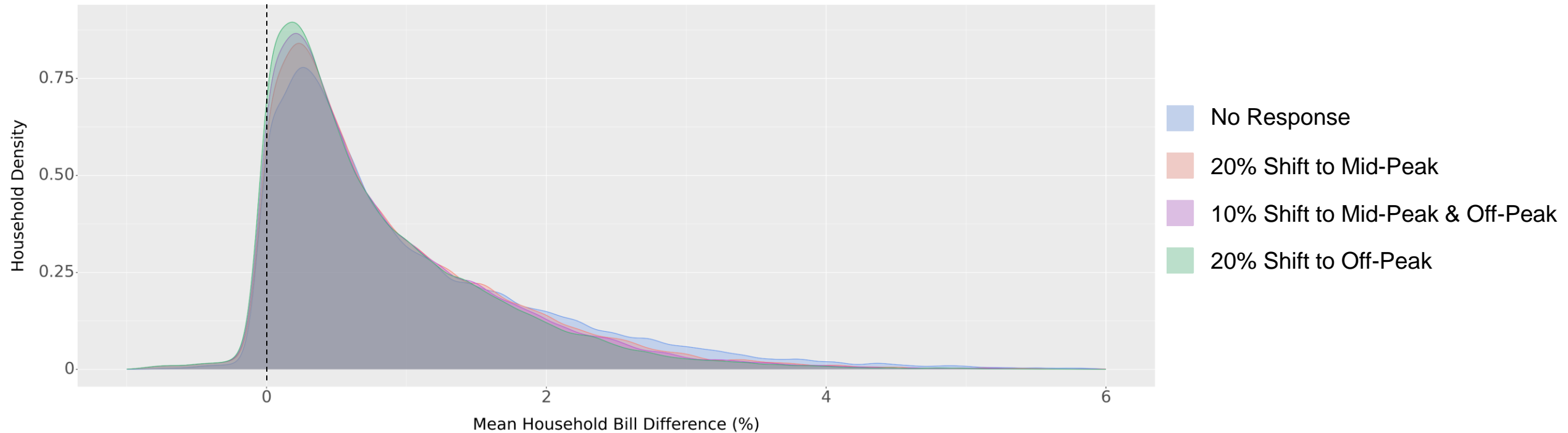
How to Win: Consumption Shifting (No PV)



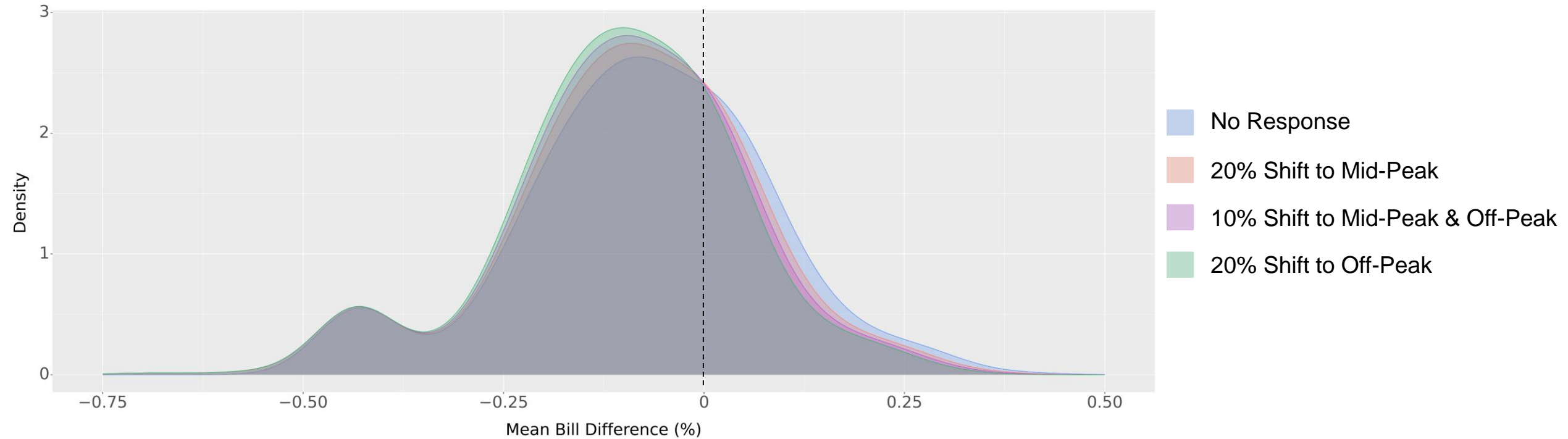
How to Win: Consumption Shifting (Other PV)



How to Win: Consumption Shifting (NEM)



How to Win: Consumption Shifting (Small Commercial)



How to win: Battery Bonus Program

Tesla Powerwall

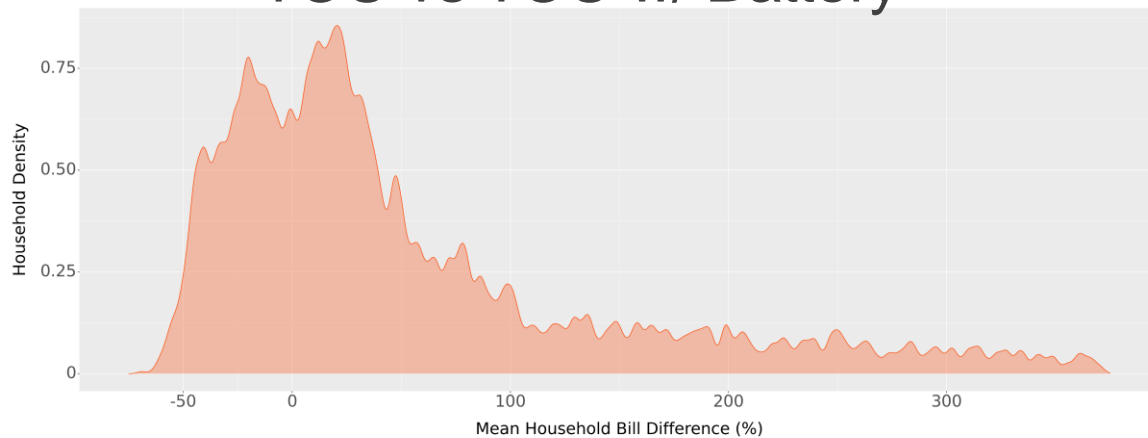
- 13.5 kWh capacity
- \$15,000 estimated cost of unit & installation
 - \$11,175 post one-time incentive
- ~ \$3 daily fixed cost
 - Total cost split across the 10-year life span (warranty) of the unit

Battery Bonus Incentives

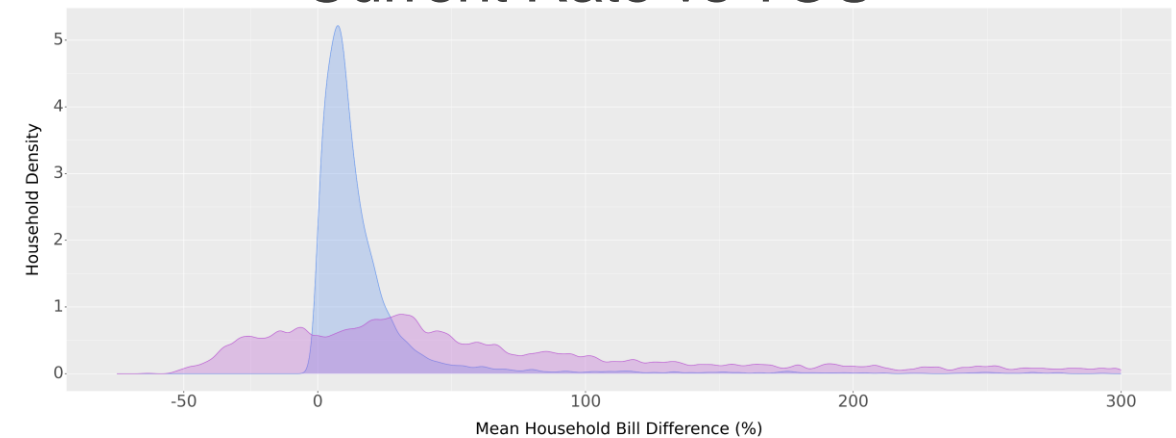
- \$3,825 one-time incentive
- Monthly bill credit
 - NEM customers always receive the respective retail rate
 - Non-NEM customers receive the respective retail rate for the first 3 years then receive the export credit of their respective PV program.
 - We visualize the impact during the first 3 years.
- \$5 per KW monthly peak capacity payment for the 10-year program duration.
 - Our current calculations omit this bill credit as it is unclear what this value currently is.

How to win: Battery Bonus (Other PV Losers)

TOU vs TOU w/ Battery



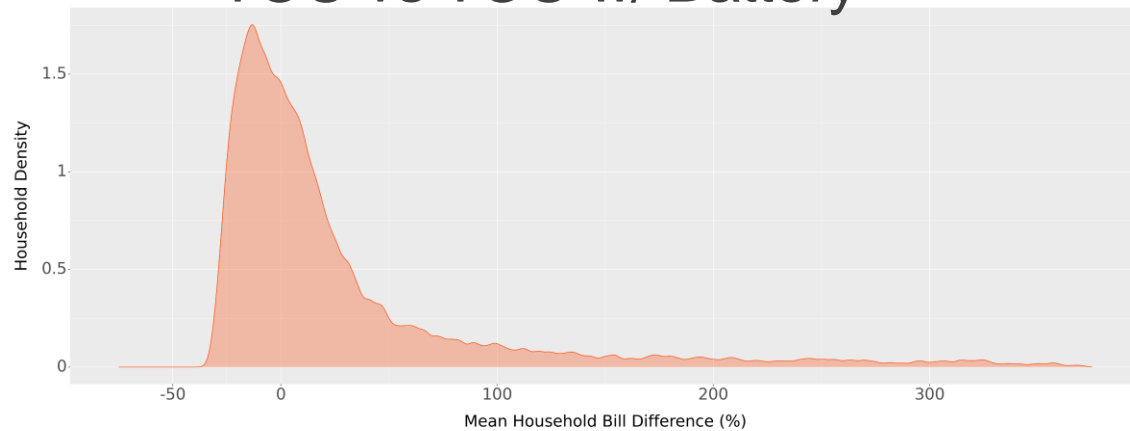
Current Rate vs TOU



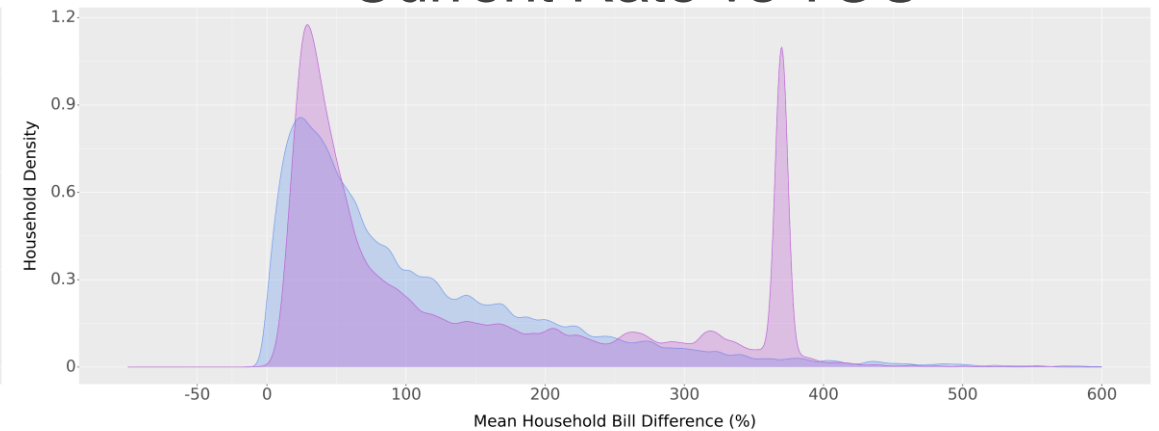
- Current Rate vs TOU
- Current Rate vs TOU w/ Battery

How to win: Battery Bonus (NEM Losers)

TOU vs TOU w/ Battery



Current Rate vs TOU



- Current Rate vs TOU
- Current Rate vs TOU w/ Battery

Conclusion

Winners & Losers

- No Response
 - 53% of non-PV and 96% of PV households will see an increase in their monthly bill
- Consumption Shifting
 - 16% of non-PV and 82% of PV households will see an increase in their monthly bill
- Battery Bonus
 - 18% of CGS, CGS+, SE, & CSS customers transition from losing to winning under TOU
 - 0.0002% of NEM customers transition from losing to winning under TOU

Shift & Save Sample

- Why sample so many PV households?
 - Is it ethical to nudge these households into a program that isn't in their best interest?