SUSTAINABILITY CHOICES: IDENTIFY OPTIONAL TECHNOLOGY USING THE PECAN STREET SMART GRID DATABASE

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Abstract

Effective measures for tackling climate change and the depletion of nature resources such as oil and natural gas are required, particularly in the residential sector. Varying in different countries, energy consumption of the residential sector accounts for 16–50% of that consumed by all sectors, and averages approximately 30% worldwide (Lukas G. Swan, 2009). This significant consumption level warrants leads researchers to have increasing interests in the real impact brought by renewable energy technologies and electricity pricing programs on electricity usage. A number of researches are conducted around this topic but most of them are not using real-time data to support their analysis. This report investigated the impact of solar, electric vehicles and demand response/time-of-use pricing programs on household electricity consumption using data collected by Pecan Street smart grid, which is one of the world’s largest energy database, from three different perspectives: 1) electricity savings 2) cost savings for utility 3) water savings for utility. Findings from this study suggest that all of the three approaches can lead to considerable savings for utility companies, and for consumers as well. The result of this report can be used as a strong and objective support in promoting renewable energy technologies and time-of-use pricing program.

1. Introduction

The fluctuant fossil fuel prices, increasing environmental and health-impact concerns, worried about climate change, and shrinking energy reserves are having significant effects on energy usage practice. With the pressure from increasing energy demand and climate change (Robert K. Dixon, 2010), instead of simply focusing on the usage of renewable energy resources, government, companies and non-profit organizations start to devote more time and energy on energy saving technologies, including smart grid (Zhuangli Hu, 2014).

A smart grid enables consumers to control their electricity usage by shifting demand over time, from peak demand periods to off-peak periods. At peak times, the power is more expensive than off-peak periods. It encourages consumers to change their electricity consumption behavior and therefore reach the goal of energy saving. Users will be notified of peak demand period of the next day one day ahead in this sample. Not only the energy savings are realized but the capacity requirement of generation, transmission and distribution is also reduced in this load shifting process. Therefore, energy and capacity savings are often considered as a significant potential benefit to developing the smart grid (Arif S. Malik, 2013). Time-of-use
pricing trials have shown significant peak reductions, and critical-peak pricing help reduce peak and critical demand as well, according to papers published in recently years (Ahmad Faruqui S. S., 2011) (Ahmad Faruqui S. S., 2010). However, most papers only study the load shifting effect brought by demand response program using smart grid, few consider the impact of other technologies such as rooftop solar PV or electric vehicles on household energy consumption in the same time.

Both solar energy and electric vehicles (EVs) play important roles in energy conservation nowadays. Researchers study the emission reduction (Alnaser, 2015), energy production and economic viability (Abdul Ghafoor, 2015) of solar PV system at household level. Also, Research works are being conducted to assess the impact of adoption of EV on grid energy demand and the resultant GHG emissions (Jae D. Kim, 2014) (Li Zhang, 2011). But compared to the large number of studies focusing on these topics, a relatively smaller number of studies consider the water savings brought by EV.

In this paper, I evaluates the water savings, and the cost savings achieved through the deployments of rooftop PV, electric vehicles, and demand response deployed by Pecan Street, Inc. in the Mueller neighborhood of Austin, Texas. Nearly 200 homes at Mueller community have secondary (second energy meter) and tertiary (meters inside the homes) meters to report electrical data in one minute and one second intervals. These monitors record circuit-level (disaggregated) and whole-home electricity use data. Muller community has more electric cars per capita than any other residential communities in America. Over 200 homes have rooftop solar panels. In this paper, the data gathered by the Pecan Street Project is used. The Pecan Street Database is the largest source of disaggregated customer energy data available to university researchers and industry-leading companies. I study the water savings, and the cost savings using data of rooftop PV, electric vehicles, and demand response (including critical peak price and wind enhancement program) using data gathered by Pecan Street smart meters (more information about the data I use can be find in Section 2). Data provided by Austin Energy, the Electric Reliability Council of Texas (ERCOT), EIA and Argonne National Laboratory is used to calculate the factors (See Appendix A, B and C for details). I develop models to calculate the energy savings, cost savings and water savings led by deploying three different kinds of technology, using the same database, in order to have a comprehensive analysis of the benefit brought by the combination of smart grid and new technologies, and identify the positive impact they have on environment and sustainable development.\(^1\)

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\(^1\) Numbers in this paragraph are cited from Pecan Street website: www.pecanstreet.org
This paper is organized as following: in the next section, detailed description of data used in this analysis is provided; in Section 3, I discuss the theoretical approaches in modeling to calculate the saving with the details of my approaches; Section 4 presents the result of my analysis and calculation; a concise summary and discussion is provided in Section 5; in Section 6, I provide a second methodology – regression analysis - to examine the results from earlier sections, and some household characteristics are included in the regression. This paper is part of Environmental Defense Fund (EDF)’s report “Emissions, Cost & Water Reductions from Three Clean Technologies: Rooftop Solar Photovoltaics, Electric Vehicles, & Demand Response (tentative title)” that will be released in the second half of 2015 or in early 2016. The report is authored by Marita Mirzatuny, Peter Sopher (both from EDF) and me. The parts I authored are included in the main body of this paper. As some co-authored parts are essential or necessary supplement for reaching the final conclusion, they are included in Appendix E based on Duke University’s policy that no co-authored work shall be presented in the main body of a solo Master’s Project paper.
2. Data Description

2.1 Solar

Table 1, below, summarizes sample sizes, as well as other pertinent metrics, such as average array size, azimuth, and tilt, for all solar homes and disaggregated for the direction a home’s panel(s) face.\(^2\)

<table>
<thead>
<tr>
<th>Table 1 - Solar Panel Features, by Orientation for Mueller Homes with Complete Data Sets</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong># of Homes</strong>&lt;br&gt;(% of All Solar Homes)</td>
</tr>
<tr>
<td>------------------------------------------</td>
</tr>
<tr>
<td>110 (100%)</td>
</tr>
<tr>
<td><strong># of Observations</strong>&lt;br&gt;(% of All Solar Observations)</td>
</tr>
<tr>
<td><strong>Average PV Array Size</strong>&lt;br&gt;(KW)</td>
</tr>
<tr>
<td><strong>Average Azimuth</strong></td>
</tr>
<tr>
<td><strong>Average Tilt</strong>&lt;br&gt;(Degrees)</td>
</tr>
</tbody>
</table>

In this analysis, I examined 110 unique data IDs from homes with solar panels in Austin Texas’ Mueller neighborhood during Austin Energy’s fiscal year 2013 (FY 2013).\(^3\) I analyzed the fuel costs and water impact associated with electricity generation by the PV panel. Data are measured at hourly intervals; and, each of the 110 homes has a complete dataset, which means that there are data for every hour of the year.

The number of homes for which a sample is statistically significant is 23. For this reason, the samples for “All Solar Homes,” “South Facing PV,” and “South & West Facing PV” are

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\(^2\) Some homes have multiple PV arrays that face different directions. “South & East Facing PV” refers to homes with multiple arrays, at least one of which faces south and at least one of which faces east. “South and West Facing PV” and “West & East Facing PV” are similar, substituting the appropriate directions.

\(^3\) This time span (October 1, 2012 – September 30, 2013) is used because that is the most recent period for which Austin Energy has published relevant grid electricity statistics. See Appendix A.
statistically significant. Samples for “South & East Facing PV” and “West & East Facing PV” are so small that I do not analyze them. Results for “West Facing PV,” while noteworthy, are not statistically significant either.

2.2 EV

In this section, the fuel costs, and water impact associated with the sum of household electricity and gasoline consumption from cars when the vehicle is an electric vehicle (EV) versus a traditional all-gas passenger vehicle are analyzed. Table 2, below, summarizes sample sizes, as well as other pertinent metrics – such as the percentage of these homes that have PV and hourly average household power usage, grid electricity consumption, and car electricity consumption – for all homes with EVs and disaggregated for vehicle type (Chevy Volt and Nissan Leaf).

<table>
<thead>
<tr>
<th></th>
<th>All EVs</th>
<th>Chevy Volt</th>
<th>Nissan Leaf</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Homes without Charger at Work</td>
<td>25 Homes</td>
<td>20 Homes</td>
<td>5 Homes</td>
</tr>
<tr>
<td>% of Homes with EVs</td>
<td>100%</td>
<td>80.00%</td>
<td>20.00%</td>
</tr>
<tr>
<td>Number of Observations</td>
<td>218,877</td>
<td>175,092</td>
<td>43,785</td>
</tr>
<tr>
<td>% of These Observations with PV</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>Hourly Average Electricity Usage (KWh)</td>
<td>1.329 KWh</td>
<td>1.321 KWh</td>
<td>1.362 KWh</td>
</tr>
<tr>
<td>Hourly Average Grid Electricity Consumption (KWh)</td>
<td>0.489 KWh</td>
<td>0.509 KWh</td>
<td>0.413 KWh</td>
</tr>
<tr>
<td>Hourly Average Car Electricity Consumption (KWh)</td>
<td>0.267 KWh</td>
<td>0.262 KWh</td>
<td>0.285 KWh</td>
</tr>
</tbody>
</table>

I examine 25 unique data IDs from homes with EVs in Austin Texas’ Mueller neighborhood during Austin Energy’s fiscal year 2013 (FY2013) in this part of the report. 4 Data are measured at hourly intervals; and, each of the 25 homes has a complete dataset, meaning there are data for every hour of the year. The number of homes for which a sample is statistically significant is 23. For this reason, the sample for “All EVs” is statistically significant. Homes with chargers at work are excluded from this sample, because the charging done at work doesn’t have a significant impact on household electricity usage and may lead to bias in the analysis.

4 Here I use this time span (October 1, 2012 – September 30, 2013) because that is the most recent period for which Austin Energy has published relevant grid electricity statistics. See Appendix A and Appendix B.
2.3 Demand Response Program (DR) and Time of Use Pricing Program (TOU)

This paper also analyzes the impact of demand response (DR) event and time of use (TOU) pricing program on residential load behavior, and the corresponding utility cost and water usage change in that 24 hour period (the day that the event happened). The residential load data derive from Pecan Street’s electricity pricing trial, a residential demand response (DR) and time of use (TOU) pricing program. This project is part of a larger project for the Center for the Commercialization of Electric Technologies (CCET) called “Technology Solutions for Wind Integration in ERCOT.” While CCET gathered data for other locations as well, this paper focuses on homes in Austin Texas’ Mueller neighborhood. More information about these programs can be found in Appendix D.

The CCET DR and TOU program includes two main components – a critical peak period (CPP) price component and a wind enhancement component – and this paper assesses the impacts of each.

- **The CPP component**: The CPP component of the CCET program comprises a high price during hours when the ERCOT electric system is likely to be most stressed (4pm-7pm), coupled with a discount on Austin Energy’s standard rate during other hours (see Appendix D for more details on rates designed for the CCET program). During the 2013 and 2014 summers Pecan Street called 27 CPP events. CPP event days were called by Frontier Associates (a partner organization of the Pecan Street) based on ERCOT day-ahead system-wide load and temperature forecasts. Participants of CCET program were notified that there would be a CPP event on the day prior. For this part of the analyses, the 24-hour period analyzed spans 6am on the CPP day until 6am the following day, in order to account for load that may have shifted past midnight due to the CPP event. A monetary incentive is used to entice participants to reduce energy consumption during critical peak time. Details about the incentive can be found in Appendix D.

- **The wind enhancement component**: The wind enhancement component features a low price during hours of the day when wind energy production tends to be highest (10pm-6am), coupled with a surcharge on Austin Energy’s standard rate during other hours. The wind enhancement rate was effective for pertinent CCET participants, members of the “Pricing Trial Group,” during November and December of 2013 and March, April, and May of 2014. A monetary incentive is used to entice participants to shift their energy load to “wind enhancement times”. Details about the incentive can be found in Appendix D.
The CCET program splits participants into two groups: the “Control Group” and the “Pricing Trial Group.” Homes part of the “Control Group” were unaware of the CCET program and not notified of CPP and wind enhancement events. Members of the “Pricing Trial Group” were notified of both wind enhancement events and CPP events.

Table 3 summarizes sample sizes, as well as other pertinent metrics – such as PV generation, grid electricity consumption, total usage, household size, house construction year, number of levels, number of bedrooms, and number of residents – for the average home in the “Control Group” and in the “Pricing Trial Group.”

<table>
<thead>
<tr>
<th>Table 3- Features of CCET Groups in Austin Texas’ Mueller Neighborhood</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CCET Control Group</strong></td>
</tr>
<tr>
<td><strong>Number of Homes in the Mueller Neighborhood</strong></td>
</tr>
<tr>
<td><strong>Number of Observations (Hours Observed)</strong></td>
</tr>
<tr>
<td><strong>Homes with PV</strong></td>
</tr>
<tr>
<td><strong>% of Observations with PV</strong></td>
</tr>
<tr>
<td><strong>Grid Electricity Consumption - Hourly Summer Average (KWh/h)</strong></td>
</tr>
<tr>
<td><strong>Power Usage - Hourly Summer Average (KWh)</strong></td>
</tr>
<tr>
<td><strong>Generation - Hourly Summer Average (KWh)</strong></td>
</tr>
<tr>
<td><strong>Household Size (Sq. Ft.)</strong></td>
</tr>
<tr>
<td><strong>Average Year of Household Construction</strong></td>
</tr>
<tr>
<td><strong>Average Number of Levels for Household</strong></td>
</tr>
<tr>
<td><strong>Average Number of Bedrooms for Household</strong></td>
</tr>
<tr>
<td><strong>Average Number of Residents</strong></td>
</tr>
</tbody>
</table>

In this analysis I examine 74 unique data IDs,\(^5\) 29 from the “Control Group” and 45 from the “Pricing Trial Group.” Data are measured in hourly intervals for this analysis,\(^6\) and the number of homes for which a sample is statistically significant is 23. Thus, the samples for the “CCET Control Group” and the “Pricing Trial Group” are statistically significant. Furthermore, as Table 1 displays, power consumption and key features that impact power consumption in these homes are virtually identical. Hence, the comparison of how the average home in each of these groups behaves during CPP days and wind enhancement periods is relevant, for the integrity of

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\(^5\) The Pecan Street database defines a data ID as “the unique identifier for the home-resident pair.” Thus, if a resident moves, the data collected from the home is associated with a new data ID.

\(^6\) The Pecan Street database enables users to analyze data and both more (minutes, seconds, etc.) and less (days, months, etc.) granular intervals.
the comparison is not compromised by differences in the fundamental power-usage-affecting features of the average home for each of these groups.

Table 4 highlights the reason why the 10/10 baseline cannot represent DR day electricity usage behavior accurately; electricity consumption is significantly higher on the average CPP day than on both the average 10/10 baseline day and the average non-CPP day. The traditional 10/10 baseline measures the average load for the ten previous non-weekend, non-holiday, non-DR days. The drawback to the 10/10 baseline is that DR days are called when the grid is expected to be particularly stressed; DR events are typically called on days that outdoor temperature are high that the corresponding uptick in air conditioning usage might stress the grid. Because DR events are called for days that are forecasted to be especially grid intensive, it can often happen that a home responding to a DR event consumes more power during peak hours than on the average 10/10 baseline day but less power than they would have consumed had the DR event not been called.

| Table 4 - CPP Day vs. 10/10 Baseline PV Generation, Power Usage, and Air Electricity Consumption |
|----------------------------------------------------------|----------------|----------------|----------------|----------------|----------------|
|                                                          | CPP Day        | CPP Day Summer Peak | 10/10 Baseline Day | Baseline Day Summer Peak | Non-CPP Summer Day | Non-CPP Day Summer Peak |
| Average Hourly Grid Electricity Consumption (KWh)        | 1.036 KWh      | 1.658 KWh          | 0.890 KWh         | 1.541 KWh         | 0.944 KWh       | 1.571 KWh          |
| Average Hourly PV Generation (KWh)                       | 1.011 KWh      | 1.439 KWh          | 0.959 KWh         | 1.420 KWh         | 0.891 KWh       | 1.284 KWh          |
| Average Hourly Power Usage (KWh)                         | 1.999 KWh      | 3.030 KWh          | 1.798 KWh         | 2.887 KWh         | 1.793 KWh       | 2.795 KWh          |
| Average Hourly Air Electricity Consumption (KWh)         | 1.288 KWh      | 2.052 KWh          | 1.112 KWh         | 2.000 KWh         | 1.082 KWh       | 1.890 KWh          |

Because of the reason above, the dataset used in this analysis is especially valuable. Because this sample has a “Control Group” comprised of households with features akin to those of the “Pricing Trial Group” – this analysis has the unique value added of a control group that functions as the baseline for how DR-affected homes would have acted had a DR event not been called, rather than relying solely on controversial formulae to discern a baseline. In this analysis, I compare results for the “Control Group” and the “Pricing Trial Group” to themselves via their respective 10/10 baselines in addition to comparing them to each other.
Data gathered reflect behavioral responses of Mueller neighborhood, where the CPP and wind enhancement events occurred, to DR events and TOU pricing. Using the data indicates Mueller residential behaviors, this paper discerns what the DR/TOU impacts would be using the fiscal year 2013 (FY2013) Austin Energy grid emissions factor normalized to the hourly level based on ERCOT’s hourly wind generation data. This part of the analysis conveys utility cost and water usage impacts of power usage and load shifting during 24 hour periods that include DR/TOU events, accounting for the fact that the generation mix is cleaner in Texas at some hours of the day relative to others.

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3. Methodology

3.1 Solar

3.1.1 Solar PV Financial Impact Analysis

The goal of this portion of the analysis is to determine the FY2013 utility cost savings due to household solar PV generation from this sample’s average 1 KW solar PV array. This section derive the grid-related utility electricity cost factor based on Austin Energy’s operating costs (see Appendix B for more details). Parity between Part I and Part II of this analysis stems from how grid-related electricity costs for utilities are measured.

Part I applies Austin Energy’s grid cost factor for the average hour to all EV electricity usage. One shortcoming of such a methodology is that household solar PV generation might occur more frequently at some hours relative to others, and not every hour has the same average electricity costs. For example, at night in Texas the grid is fueled by a higher proportion of wind than during the afternoon, and the costs of dispatching wind are negligible relative to rates for other fuels; so, as a low proportion of household solar PV generation occurred at night, utility cost savings from household PV generation might be higher than the catchall cost factor suggests.

The purpose of Part II is to more accurately account for utility cost savings from household solar PV generation by accounting for the fact that each hour of the day for FY2013 has a different average electricity cost, as well as the fact that household solar PV generation occurs more often at some hours of the day relative to others. More specifically, it provides the utility electricity cost savings from household solar PV generation using the FY2013 average hourly cost factor for Austin Energy normalized to the hourly level based on ERCOT’s Day-Ahead Market (DAM) average hub price for each hour of FY2013. This part of the analysis conveys utility cost savings from household solar PV generation, accounting for the fact that electricity is cheaper in Texas at some hours of the day relative to others. As Part II is not an independent work, it is not included in the text but in the Appendix E instead.

The methodology used is the following:

8 ERCOT (2015). “Historical DAM Load Zone and Hub Prices.” Data were accumulated for October 2012-September 2014. Data used for this EV analysis are for October 2012-September 2013, or Austin Energy’s FY2013. These ERCOT data were accessed via the following web address on February 26, 2015: http://mis.ercot.com/misapp/GetReports.do?reportTypeId=13060&reportTitle=Historical%20DAM%20Load%20Zone%20and%20Hub%20Prices&showHTMLView=&mimicKey
Part I – Financial impact using Austin Energy’s FY2013 average annual hourly grid cost factor, $0.098035/KWh

1.) Calculation of the average hourly amount of electricity generated per 1 KW PV array for the average home in this sample. For example, for all 110 solar homes in this sample, average hourly generation is 0.884 KWh and average PV array size is 5.642. Using these statistics, the average hourly generation per KW of panel size is 0.1567 KWh.

\[
\frac{0.884 \text{ KWh}}{5.642 \text{ KW}} = 0.1567 \text{ KWh of PV Generation per 1 KW PV Array}
\]

2.) Conversion of the rate calculated in Step (1) to a cost savings rate per 1 KW PV array. I assume homes with solar PV would have used the same amount of electricity if they did not have solar panels; and, thus, all electricity from PV generation equates to savings of grid electricity and the corresponding costs of producing electricity to Austin Energy. Calculated above, for all 110 solar homes in this sample, average KWh of PV generation per 1 KW PV array is 0.1567 KWh. Austin Energy’s electricity generation cost is $0.098035/KWh (see Appendix B for information on how I arrived at this metric). Using these statistics, the average hourly cost savings per 1 KW PV array is $0.015362.

\[
\frac{0.1567 \text{ KWh} \times 0.098035}{\text{KW of Panel Size}} = \frac{0.015362 \text{ $}}{\text{KW of Panel Size}}
\]

3.) Applying this cost savings rate to determine utility costs reduced from solar panels for homes included in this sample. As calculated in step (2), the average home in this sample saves $0.015362/hour per 1 KW PV array, equal to $134.57/year. Using this rate for this sample’s 110 homes, which have an average PV array size of 5.642 KW, FY2013 utility cost savings for Austin Energy from PV generation from 110 homes in Mueller Community is $83,518.

Part II – Normalizing Austin Energy’s annual average grid costs based on ERCOT’s Day-Ahead Market (DAM) average hub price for each hour of FY2013

See Appendix E.

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9 The reason I use ERCOT data is because Austin Energy hourly cost data are not public. The Day-Ahead Market (DAM) price reflects how expensive electricity providers foresee dispatch will be at various times of day. As electricity providers pass down costs to customers, I use DAM price as a proxy for the cost of electricity to customers; and, thus, the cost of charging an electric vehicle at a specific time.
3.1.2 Solar PV Water Impact

The goal of this portion of the analysis is to determine FY2013 household grid electricity savings and associated water savings attributable to residential solar PV deployment in this sample’s homes, located in the Mueller neighborhood in Austin, Texas. I derive the grid-related water factors based on Austin Energy’s grid water usage rate (see Appendix C for more details). Parity between Part I and Part II of this analysis stems from how I measure grid-related water usage.

Part I of this analysis applies Austin Energy’s grid water usage factor for the average hour of FY2013 to all household electricity usage, as well as all grid electricity savings due to household electricity generation from residential solar PV arrays (see Appendix C for how this water usage factor is derived). One shortcoming of such a methodology is that solar PV generation occurs more frequently at some hours relative to others, and not every hour has the same average grid water usage rate. For example, at night in Texas the grid is fueled by a higher proportion of wind than during the afternoon, and wind’s water usage is negligible relative to rates for other fuels; so, as a higher proportion of PV generation occurs during the day, water usage savings from PV generation might be higher than the catchall water usage factor suggests.

The purpose of Part II is to more accurately account for water usage savings due to household solar PV generation by accounting for the fact that each hour of the day for FY2013 has a different grid water usage factor. More specifically, I discern grid electricity-related water savings from household solar PV generation using the FY2013 average hourly grid emissions factor for Austin Energy normalized to the hourly level based on ERCOT’s hourly wind generation data.10 This part of the analysis conveys water savings from household solar PV generation, accounting for the fact that the generation mix is cleaner in Texas at some hours of the day relative to others. As Part II is not an independent work, it is not included in the text but in the Appendix E instead.

The methodology used is the following:

Part I – Water usage impact using Austin Energy’s FY2013 average annual hourly grid water factor, 0.46 gallons/hour.

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http://mis.ercot.com/misapp/GetReports.do?reportTypeId=13424&reportTitle=Hourly%20Aggregated%20Wind%20Output&showHTMLView=&mimicKey
1.) **Calculation of the average hourly amount of electricity generated per 1 KW PV array for the average home in this sample.** For example, for all 110 solar homes in this sample, average hourly generation is 0.884 KWh and average PV array size is 5.642 KW. Using these statistics, the average hourly generation per KW of panel size is 0.1567 KWh.

\[
\frac{0.884 \text{ KWh}}{5.642 \text{ KW}} = 0.1567 \text{ KWh of PV Generation per 1 KW PV Array}
\]

2.) **Conversion of the rate calculated in step (1) to a water savings rate per 1 KW PV array.** Here I assume homes with solar PV would have used the same amount of electricity if they did not have solar panels; and, thus, all electricity from PV generation equates to savings of grid electricity and corresponding water savings. Calculated above, for all 110 solar homes in this sample, average KWh of PV generation per 1 KW PV array is 0.1567 KWh. Austin Energy’s grid water consumption rate is 0.46 gal/KWh (see Appendix A for information on how I arrived at this metric). Using these statistics, the average hourly water savings per 1 KW PV array is 0.0721 gallon, equivalent to an annual water savings per 1 KW PV array of 631.44 gallon.

\[
\frac{0.1567 \text{ KWh} \times 0.46 \text{ gallon} \text{ KWh}^{-1}}{\text{KW of Panel Size}} = \frac{0.0721 \text{ gallon}}{\text{KW of Panel Size}}
\]

3.) **Applying this water savings rate to determine water saved by solar panels for homes included in this sample.** As calculated in step (2), the average home in this sample saves Austin Energy 631.44 gallon annually per 1 KW PV array. Using this rate for this sample’s 110 homes, which have an average PV array size of 5.642 KW, FY2013 water savings from PV generation is 391,883.8 gallons.

**Part II – Normalizing Austin Energy’s annual average grid water usage factor based on ERCOT’s hourly data for wind’s proportion of the generation mix**\(^{11}\)

See Appendix E.

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\(^{11}\) Full generation mix data is not publically available at the hourly level for ERCOT. What is available is hourly wind generation, total generation, and wind’s proportion of the ERCOT generation mix. This is the reason I do not use a more precise emissions factor, rather than normalizing the Austin Energy grid emissions factor based on ERCOT’s generation mix wind percentage data. The reason we use ERCOT data is because Austin Energy hourly generation mix data are not public.
3.2 Electric Vehicle

3.2.1 EV Financial Impact Analysis

The goal of this portion of the analysis is to determine the FY2013 fuel-related costs from this sample’s average EVs relative to an average all-gas passenger vehicle.

The only fuel costs traditional all-gas vehicles incur are from gasoline. For the average EV in this sample, by contrast, fuel costs have two components: (1) Grid-related electricity costs, and (2) Gasoline costs. The grid related electricity cost factor is calculated based on Austin Energy’s operating costs (see Appendix B for more details). Gasoline cost is based on the average cost per gallon in Texas during FY2013. Parity between Part I and Part II of this analysis stems from how grid-related electricity costs for EVs are measured.

Part I applies Austin Energy’s grid cost factor for the average hour to all EV electricity usage. One shortcoming of such a methodology is that EV charging might occur more frequently at some hours relative to others, and not every hour has the same average electricity costs. For example, at night in Texas the grid is fueled by a higher proportion of wind than during the afternoon, and the costs of dispatching wind are negligible relative to rates for other fuels; so, if a high proportion of EV charging occurred at night, costs from EV charging might be lower than the catchall cost factor suggests.

The purpose of Part II is to more accurately account for costs from electric vehicle charging by accounting for the fact that each hour of the day for FY2013 has a different average electricity cost, as well as the fact that owners tend to charge their EVs more often at some hours of the day relative to others. More specifically, I discern the electricity cost impacts from EVs using the FY2013 average hourly cost factor for Austin Energy normalized to the hourly level based on ERCOT’s Day-Ahead Market (DAM) average hub price for each hour of FY2013. This part of the analysis conveys cost impacts of electric power fueling EVs, considering the fact that electricity is cheaper in Texas at some hours of the day relative to others. As Part II is not an independent work, it is not included in the text but in the Appendix E instead.

The methodology used is the following:

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12 As utility cost is passed down to customers with only a marginal number, I assume that Austin Energy’s customers incur similar costs to their utility on average.
13 ERCOT (2015). “Historical DAM Load Zone and Hub Prices.” Data were accumulated for October 2012-September 2014. Data used for this EV analysis are for October 2012-September 2013, or Austin Energy’s FY2013. These ERCOT data were accessed via the following web address on February 26, 2015: [http://mis.ercot.com/misapp/GetReports.do?reportType=13060&reportTitle=Historical%20DAM%20Load%20Zone%20and%20Hub%20Prices&showHTMLView=&mimicKey](http://mis.ercot.com/misapp/GetReports.do?reportType=13060&reportTitle=Historical%20DAM%20Load%20Zone%20and%20Hub%20Prices&showHTMLView=&mimicKey)
Part I – Financial impact using Austin Energy’s FY2013 average annual hourly grid cost factor, 0.098035 $/KWh

1. Calculation of the average hourly EV electricity consumption for the average home in this sample and the corresponding cost. For the average hour, electric vehicles in this sample consume 0.267 KWh of electricity. Austin Energy’s electricity generation cost is $0.098347/KWh (see Appendix B for information on how I arrived at this metric). Using these statistics, the average hourly household electricity costs from EVs is $0.0263, equivalent to $230/year.

\[
0.267 \frac{KWh}{hour} \times 0.098347 \frac{\$}{KWh} = 0.0263 \frac{\$}{hour}
\]

Because traditional vehicles do not consume electricity, $230 is the amount by which the household electricity costs of EVs exceed those of traditional passenger vehicles.

2. Calculation of the average hourly gasoline costs for the average traditional all-gas vehicle vs. the average EV in this sample. For traditional all-gas vehicles, I use EPA gas consumption for the average passenger vehicle, according to the May 2014 report titled Greenhouse Gas Emissions from a Typical Passenger Vehicle.\(^\text{14}\) The average all-gas vehicle travels 11,400 miles per year using 528 gallons of gas. The average gasoline price in Texas from Oct. 2012 to Sep. 2013 is $3.427/gallon which corresponds to an annual gasoline cost of $1,809.5/year.

By contrast, for EVs, I determine annual gas usage based partly on Pecan St. data. For six electric vehicles, Pecan Street has monitored 1,984 car trips to accumulate data that reveal for which trips cars use only electricity and for which trips gas is used. Gas usage is above zero for trips that comprise 13.22% of the distance travelled by these vehicles. Assuming the EPA’s annual average vehicle miles traveled of 11,400, 13.22% of this number is 1,507 miles; thus, I conservatively assume that the average EV in this sample travels 1,507 miles/year using gasoline. Because all hybrids in this sample are Chevy Volts, which consume gas at 37 mpg, EV’s in this sample consume 41 gallons of gas annually, so – using the FY2013 Texas gasoline price, above, of $3.427/gallon – the average gasoline cost of the average EV in this sample is about $140.5/year.

3. Calculating the fuel cost savings from EVs, based on how much lower the sum of fuel cost from household electricity and gas consumption is for homes with EVs versus

---

homes with traditional vehicles. This step sums results from steps (1) and (2). For an EV, the average annual gasoline cost – from step (2) – is $140.50, and the average annual electric fuel cost – from step (1) – is $230; so average annual fuel cost for an EV is about $370.50. By contrast, for a traditional vehicle, there is no electricity fuel cost, and average annual fuel cost of gasoline – from step (2) – is $1,809.50. Thus, annual fuel cost savings from an EV equals $1,439, the difference between $1,809.50 and $370.50.

4. Applying the fuel cost savings rate for EVs over traditional vehicles to determine annual fuel cost savings from EVs for homes included in this sample. As there are 25 EVs in this sample and annual fuel cost savings for the average EV is $1,439, for all 25 EVs fuel cost savings for FY2013 was $35,975. It is noteworthy that the average price of EVs is normally higher than the price of conventional vehicles with internal combustion engine. I discuss the ownership savings considering sticker price of different type of vehicles in the Result Section.

Part II – Normalizing Austin Energy’s annual average grid costs based on ERCOT’s Day-Ahead Market (DAM) average hub price for each hour of FY2013

See Appendix E.

3.2.2 EV Water Impact

The goal of this part of the analysis is to determine FY2013 fuel-related water usage (gallons) from this sample’s average EV relative to an average all-gas passenger vehicle.

Fuel-related water usage from conventional vehicles with internal combustion engine all comes from the process of manufacturing gasoline (from crude oil exploration and production to refinery) before the fuel reaches the consumer. For electric vehicles, fuel-related water usage derives from two sources: (1) Grid-related electricity water usage, and (2) Water usage in manufacturing gasoline that fuels EVs. I derive the grid-related water usage factors based on Austin Energy’s grid water usage rate (see Appendix C for more details). Gasoline related water usage is based on rates of water usage for preparing car gasoline in the United States (also refer to Appendix C for more details). Parity between Part I and Part II of this analysis stems from how I measure grid-related water usage for EVs.
Part I of this analysis applies Austin Energy’s grid water usage factor for the average hour of FY2013 to all EV electricity usage (see Appendix C for how this water usage factor is derived). One shortcoming of such a methodology is that EV charging might occur more frequently at some hours relative to others, and not every hour has the same average grid water usage rate. For example, at night in Texas the grid is fueled by a higher proportion of wind than during the afternoon, and wind’s water usage is negligible relative to rates for other fuels; so, if a higher proportion of EV charging occurred at night, water usage savings from EV charging might be higher than the catchall water usage factor suggests.

The purpose of Part II is to more accurately account for water usage savings due to electric vehicle charging by accounting for the fact that each hour of the day for FY2013 has a different grid water usage factor, as well as the fact that owners tend to charge their EVs more often at some hours of the day relative to others. More specifically, this section discusses grid electricity-related water savings from EVs using the FY2013 average hourly water consumption factor for Austin Energy normalized to the hourly level based on ERCOT’s hourly wind generation data. This part of the analysis conveys water savings from electric power fueling EVs, considering the fact that the generation mix is cleaner in Texas at some hours of the day relative to others. As Part II is not an independent work, it is not included in the text but in the Appendix E instead.

The methodology used is the following:

Part I – Water usage impact using Austin Energy’s FY2013 average annual hourly grid water factor, 0.46 gallons/hour.

1. **Calculation of the average hourly EV electricity consumption for the average home in this sample and the corresponding water savings.** For the average hour, electric vehicles in this sample consume 0.267 KWh of electricity. Austin Energy’s grid water consumption rate is 0.46 gal/KWh (see Appendix C for information on how I arrived at this metric). Using these statistics, the average hourly household electricity water consumption from EVs is 0.1228 gallons, equivalent to 1,075.90 gallons/year.

\[
0.267 \text{ KWh} \times 0.46 \frac{\text{gallons}}{\text{KWh}} = 0.1228 \text{ gallons}
\]

http://mis.ercot.com/misapp/GetReports.do?reportTypeId=13424&reportTitle=Hourly%20Aggregated%20Wind%20Output&showHTMLView=&mimicKey
Because traditional vehicles do not consume electricity, 1,075.90 gallons/year is the amount by which the grid-related water consumption of EVs exceeds that of traditional passenger vehicles.

2. **Calculation of the average hourly EV vs. traditional vehicle gasoline water consumption for the average home in this sample.** I develop a model using data from EIA and a report from Argonne Nation Laboratory to estimate the water consumed in producing 1 gallon of gasoline used by the average gas-consuming passenger vehicle in the US. This conversion factor for gallons of water per gallon of car gasoline is 4.2713 (see Appendix C for information on how I arrived at this metric). The average all-gas vehicle travels 11,400 miles per year using 528 gallons of gas, which equates to an annual water consumption of 1,946.68 gallons/year.

By contrast, for EVs, I determine annual gas usage based partly on Pecan Street data. For six electric vehicles, Pecan Street has monitored 1,984 car trips to accumulate data that reveal for which trips cars use only electricity and for which trips gas is used. Gas usage is above zero for trips that comprise 13.22% of the distance travelled by these vehicles. Assuming the EPA’s annual average vehicle miles traveled of 11,400, 13.22% of this number is 1,507 miles; thus, I conservatively assume that the average EV in this sample travels 1,507 miles/year using gasoline. Because all hybrids in this sample are Chevy Volts, which consume gas at 37 mpg, EV’s in this sample consume 41 gallons of gas annually, equivalent to 151.15 gallons of water annually.

3. **Calculating the water savings from EVs, based on how much lower the sum of water from household electricity and gas consumption is for homes with EVs versus homes with traditional vehicles.** This step sums results from steps (1) and (2) to derive total water usage rates for EVs and traditional all-gas vehicles. This rate for EVs is 1,227.05 gallons/year. For traditional vehicles, this rate is 1,946.68 gallons/year. Thus, the water savings rate from an EV over a traditional vehicle is 719.63 gallons/year.

4. **Applying the water savings rate for EVs over traditional vehicles to determine water saved from EVs for homes included in this sample.** As there are 25 EVs in this sample, water savings from all these EV-owning homes for FY2013 are 17,990.75 gallons.

*Part II – Normalizing Austin Energy’s annual average grid water usage factor based on ERCOT’s hourly data for wind’s proportion of the generation mix*
3.3 Critical Peak Pricing (CPP) and Demand Response (DR)

3.3.1 Critical Peak Pricing (CPP)/Demand Response (DR) Financial Analysis

This analysis measures the impact of CPP events and wind enhancement events on the cost to Austin Energy for operating the grid. For the financial impact analyses of both CPP and wind enhancement events, parity between Part I and Part II of this analysis stems from how grid-related electricity cost is measured.

Part I applies Austin Energy’s grid cost factor for the average hour to all electricity usage. One shortcoming of such a methodology is that electricity usage might occur more frequently at some hours relative to others, and not every hour has the same average electricity costs. For example, at night in Texas the grid is fueled by a higher proportion of wind than during the afternoon, and the costs of dispatching wind are negligible relative to rates for other fuels; so, if a high proportion of electricity usage occurred at night, costs from electricity usage might be lower than the catchall cost factor suggests.

The purpose of Part II is to more accurately account for costs from electricity usage by accounting for the fact that each hour of the day for October 2012-September 2014 – the two-year period analyzed – has a different average electricity cost, as well as the fact that home owners tend to use electricity more often at some hours of the day relative to others. More specifically, I discern the electricity cost impacts from CPP and wind enhancement events using the FY2013 average hourly cost factor for Austin Energy normalized to the hourly level based on ERCOT’s Day-Ahead Market (DAM) average hub price for each hour of FY2013. This part of the analysis conveys cost impacts of electricity usage, accounting for the fact that electricity is cheaper in Texas at some hours of the day relative to others. As Part II is not an independent work, it is not included in the text but in the Appendix E instead.

The methodology used is the following:

16 ERCOT (2015). “Historical DAM Load Zone and Hub Prices.” Data were accumulated for October 2012-September 2014, or Austin Energy’s fiscal year (FY) 2013-FY 2014. These ERCOT data were accessed via the following web address on February 26, 2015:

http://mis.ercot.com/misapp/GetReports.do?reportTypeId=13060&reportTitle=Historical%20DAM%20Load%20Zone%20and%20Hub%20Prices&showHTMLView=&mimicKey
3.3.1.1 CRITICAL PEAK PRICING (CPP) DAY ANALYSES

Part I – Financial impact using Austin Energy’s FY2013 average annual hourly grid cost factor, 0.098035 $/KWh

1.) Calculation of the electricity consumption difference between CPP days and 10/10 baseline days for both the “Control Group” and the “Pricing Trial Group.” Calculate the difference in total household power usage on CPP days and 10/10 baseline days (detailed definition see Appendix D) for the “Control Group” and the “Pricing Trial Group.” For example, CPP day average hourly power usage is 1.884 KWh for the “Control Group” and for the “Pricing Trial Group”. Baseline day average hourly power usage for the “Control Group” and “Pricing Trial Group” is 1.691 KWh and 1.710 KWh, respectively. Thus, hourly power usage on CPP days exceeds that of baseline days by 0.193 KWh for the average “Control Group” home and 0.174 KWh for the average “Pricing Trial Group” home.

2.) Convert the electricity consumption difference between CPP days and 10/10 baseline days for both the “Control Group” and the “Pricing Trial Group” to a cost difference. For both the “Control Group” and the “Pricing Trial Group,” electricity consumption is higher for CPP days than for baseline days. This consumption increase is higher for the average “Control Group” home relative to the average “Pricing Trial Group” home by 0.019 KWh. With Austin Energy’s average electricity generation cost, 0.098035 $/KWh, this generation cost increase is higher for the average “Control Group” home relative to the average “Pricing Trial Group” home by $0.00186/hour. Here the assumption is that the average “Pricing Trial Group” home’s electricity consumption would have increased by the same amount relative to the 10/10 baseline as did the average “Control Group” home if the CPP event had not been called.

3.) Apply this generation costs savings rate to determine utility costs reduced from DR for homes included in this sample. As calculated in Step (2), the average generation cost savings rate from the average “Pricing Trial Group” home over the average “Control Group” home is 0.00186 $/hour. Using this rate, utility cost savings from all 45 “Pricing

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17 T-tests were run to discern the statistical significance of the difference in average hourly power usage between the “Control Group” and the “Pricing Trial Group” during baseline days. It is statistically significant at a 1% level that average hourly baseline day power usage for the “Pricing Trial Group” is higher than for the “Control Group.” For CPP days, however, the difference in average hourly power usage between the “Control Group” and the “Pricing Trial Group” is not statistically significant. As the CPP day values for the “Control Group” and “Pricing Trial Group” are similar, yet baseline day power usage for “Pricing Trial Group” exceeds that of the CPP group, the discrepancy in power usage between CPP days and baseline days for the “Pricing Trial Group” is significantly lower than that of the “Control Group.”
Trial Group” homes for the 27 CPP days in this sample are 54.2 dollars. If there had been 1 million homes in the “Pricing Trial Group” during this period, cost savings would have been 1,204,444.4 dollars.

Part II – Normalizing Austin Energy’s annual average grid costs based on ERCOT’s Day-Ahead Market (DAM) average hub price for each hour of FY2013-FY2014

See Appendix E.

3.3.1.2 WIND ENHANCEMENT DAY ANALYSES

The analysis for how wind enhancement days impact residential load curves and utility cost savings undergoes the following approach.

Part I – Financial impact using Austin Energy’s FY2013 average annual hourly grid cost factor, 0.098035 $/KWh

1.) Calculate the difference in power usage between “Control Group” homes and “Pricing Trial Group” homes on wind enhancement days during wind enhancement and non-wind enhancement hours. During the hours for which “Pricing Trial Group” participants are incentivized to consume power (10pm-6am) during wind enhancement months, the average “Pricing Trial Group” home consumes 0.1238 KWh/hour more power than does the average “Control Group” home. During the hours (6am-10pm) for which “Pricing Trial Group” participants are not incentivized to consume power during wind enhancement months, the average “Pricing Trial Group” home consumes 0.0280 KWh less power than does the average “Control Group” home.

2.) Convert these electricity consumption differences calculated in Step (1) to costs differences. As calculated in Step (1), the average “Pricing Trial Group” home consumes 0.1238 KWh/hour more electricity during 10pm-6am and 0.0280 less electricity during 6am-10pm on days the wind enhancement rate applies. These electricity differences are converted to utility cost differences using Austin Energy’s average electricity generation cost, $0.098035/KWh (see Appendix B for information on how we arrived at this metric). Using this conversion rate, the average home from the “Pricing Trial Group” saves utilities $0.00274/hour in costs during 6am-10pm on days the wind enhancement rate applies. Assuming Austin Energy’s grid emissions cost rate is the same during 10pm-6am, the average home from the “Pricing Trial Group” produces hourly utility
costs that are $0.0121/hour greater during these hours than does the average home in the “Control Group” on days the wind enhancement rate applies. This assumption, however, is unrealistic because utility costs of generating wind are negligible; this is the reason this rate structure exists in the first place. Part II is structured to estimate utility cost savings due to load shift on wind enhancement days, accounting for the fact that cost is lower during wind enhancement hours.

Part II – Normalizing Austin Energy’s annual average grid costs based on ERCOT’s Day-Ahead Market (DAM) average hub price for each hour of FY2013-FY2014

See Appendix E.

3.3.2 Critical Peak Pricing (CPP)/Demand Response (DR) Water Analysis

The goal of this portion of the analysis is to determine grid-related water usage impact from homes in this sample during CPP and wind enhancement events.

I derive the grid-related water usage factors based on Austin Energy’s water usage rate (see Appendix C for more details). Parity between Part I and Part II of analyses for both CPP and wind enhancement events stems from how I measure grid-related water usage from household electricity usage.

Part I of this analysis applies Austin Energy’s grid-related water usage factor for the average hour of FY2013\(^{18}\) to all household electricity usage (see Appendix C for how this water usage factor is derived). One shortcoming of such a methodology is that electricity usage might occur more frequently at some hours relative to others, and not ever hour has the same average grid-related water usage rate. For example, at night in Texas the grid is fueled by a higher proportion of wind than during the afternoon, and wind’s water usage is negligible relative to rates for other fuels; so, if a high proportion of electricity usage occurred at night, water usage from electricity usage might be lower than the catchall water usage factor suggests.

The purpose of Part II is to more accurately account for water usage rates due to electricity usage by accounting for the fact that each hour of the day for FY2013 has a different grid-related water usage factor, as well as the fact that households tend to use electricity more

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\(^{18}\) FY2013 entails October 2012-September 2013, as determined by Austin Energy. Household data analyzed in this sample is for FY2013-FY2014, or October 2012-September 2014. Because Austin Energy’s grid-related water data are not publicly available for FY2014, I apply the FY2013 grid emissions factor to this analyses of FY2014 data.
often at some hours of the day relative to others. More specifically, we discern the water usage impacts from households using the FY2013 average hourly grid-related water usage factor for Austin Energy normalized to the hourly level based on ERCOT’s hourly wind generation data.\(^{19}\) This part of the analysis conveys emissions impacts of electricity usage, accounting for the fact that the generation mix is cleaner in Texas at some hours of the day relative to others. As Part II is not an independent work, it is not included in the text but in the Appendix E instead.

The methodology used is the following:

**3.3.2.1 CRITICAL PEAK PRICING (CPP) DAY WATER ANALYSES**

*Part I – Water usage impact using Austin Energy’s FY2013 average annual hourly grid water factor, 0.46 gallons/hour.*

1.) **Calculation of the electricity consumption difference between CPP days and 10/10 baseline days for both the “Control Group” and the “Pricing Trial Group.”** Calculate the difference in total household power usage on CPP days and 10/10 baseline days for the “Control Group” and the “Pricing Trial Group.” For example, CPP day average hourly power usage is 1.884 KWh for the “Control Group” and for the “Pricing Trial Group”. Baseline day average hourly power usage for the “Control Group” and “Pricing Trial Group” is 1.691 KWh and 1.710 KWh, respectively. Thus, hourly power usage on CPP days exceeds that of baseline days by 0.193 KWh for the average “Control Group” home and 0.174 KWh for the average “Pricing Trial Group” home.

2.) **Convert the electricity consumption difference between CPP days and 10/10 baseline days for both the “Control Group” and the “Pricing Trial Group” to a water consumption difference.** For both the “Control Group” and the “Pricing Trial Group,” electricity consumption is higher for CPP days than for baseline days. This consumption increase is higher for the average “Control Group” home relative to the average “Pricing Trial Group” home by 0.019 KWh. As Austin Energy’s average hourly grid-related water usage is 0.46 gal/KWh, this increase of 0.019 KWh in electricity usage corresponds to a water consumption increase of 0.00874 gal/hour. Here the assumption is that the average “Pricing Trial Group” home’s electricity consumption would have increased at

the same rate relative to the 10/10 baseline as did the average “Control Group” home if the CPP event had not been called.

3.) **Apply this grid-related water savings rate to determine utility water consumption reduced from DR for homes included in this sample.** As calculated in Step (2), the average generation water savings rate from the average “Pricing Trial Group” home over the average “Control Group” home is 0.00874 gal/hour. Using this rate, utility water savings from all 45 “Pricing Trial Group” homes for the 27 CPP days in this sample are 254.86 gallons. If there had been 1 million homes in the “Pricing Trial Group” during this period, emissions savings would have been 5,663,520 gallons.

*Part II – Normalizing Austin Energy’s annual average grid water usage factor based on ERCOT’s hourly data for wind’s proportion of the generation mix*

See Appendix E.

**3.3.2.2 WIND ENHANCEMENT DAY WATER ANALYSES**

*Part I – Water usage impact using Austin Energy’s FY2013 average annual hourly grid water factor, 0.46 gallons/hour.*

1.) **Calculate the difference in power usage between “Control Group” homes and “Pricing Trial Group” homes on wind enhancement days during wind enhancement and non-wind enhancement hours.** During the hours for which “Pricing Trial Group” participants are incentivized to consume power (10pm-6am) during wind enhancement months, the average “Pricing Trial Group” home consumes 0.1238 KWh more power than does the average “Control Group” home during the average hour. During the hours (6am-10pm) for which “Pricing Trial Group” participants are not incentivized to consume power during wind enhancement months, the average “Pricing Trial Group” home consumes 0.0280 KWh less power than does the average “Control Group” home during the average hour.

2.) **Convert these electricity consumption differences calculated in Step (1) to water consumption differences.** As calculated in Step (1), the average “Pricing Trial Group” home consumes 0.1238 KWh/hour more electricity during 10pm-6am and 0.0280 less electricity during 6am-10pm on days the wind enhancement rate applies. These electricity differences are converted to utility water consumption differences using
Austin Energy’s average electricity generation water consumption, 0.46 gal/KWh (see Appendix C for information on how we arrived at this metric). Using this conversion rate, the average home from the “Pricing Trial Group” uses 0.01288 fewer gallons per hour of grid-related water during 6am-10pm on days the wind enhancement rate applies. Assuming Austin Energy’s grid-related water usage rate is the same during 10pm-6am, the average home from the “Pricing Trial Group” uses 0.0569 more gallons per hour of grid-related water during this period than does the average home in the “Control Group” on days the wind enhancement rate applies. This assumption, however, is certainly untrue because wind power comprises a significantly higher proportion of the generation mix during 10pm-6am than during 6am-10pm; so, Part 2 of this methodology normalizes the water usage rate to reflect wind power’s percentage of the generation mix.

*Part II – Normalizing Austin Energy’s annual average grid water usage factor based on ERCOT’s hourly data for wind’s proportion of the generation mix*

See Appendix E.
4. Result

4.1 Solar

*Part I – Financial impact using Austin Energy’s FY2013 average annual hourly grid cost factor, 0.098035 $/KWh.*

Table 5, below, displays the findings for solar generation and corresponding utility cost savings and water savings due to household PV generation in all solar homes, as well as for homes disaggregated by directions panels face.

Per 1 KW PV array, average hourly PV generation is 0.1567 KWh for all 110 homes in this study. Under the assumption that all PV generation offsets grid electricity consumption, the corresponding average hourly cost savings per 1 KW PV array is $0.0154, equivalent to $134.57 per year per 1 KW PV array. As the average home in this study has a 5.642 KW array, the average home offset $759.25 during FY2013. Together, the 110 homes in this study saved $83,518. If there had been 1.5 million homes with PV that behaved similarly to the average home for this sample, utility cost savings would have been $1.14 billion for FY2013.

Under the assumption that all PV generation offsets grid electricity consumption, the corresponding average hourly water savings per 1 KW PV array is 0.0736 gallons, equivalent to 645.12 gallons per year per 1 KW PV array. As the average home in this study has a 5.642 KW array, the average home offset 3,639.76 gallons during FY2013. Together, the 110 homes in this study saved 400,373.75 gallons during FY2013. If 1.5 million homes have been part of this sample and behaved similarly to the sample’s homes, water savings from household PV generation would have been 5.46 billion gallons during FY2013.

While this portion of the analysis finds that south-facing panels offset more utility costs per 1 KW of PV array than other directions, this finding comes with caveats. For example, west-facing panels generate more power during the early evening, when the grid’s peak demand usually occurs and the cost of consuming electricity, at least in Texas, is usually highest. The purpose of Part II is to account for this caveat, and to determine utility cost savings from household solar PV generation, accounting for hourly changes in utility cost factors.
<table>
<thead>
<tr>
<th>Orientation</th>
<th>All Solar Homes</th>
<th>South Facing PV</th>
<th>South &amp; West Facing PV</th>
<th>West Facing PV</th>
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</thead>
<tbody>
<tr>
<td>Average Hourly Generation (KWh)</td>
<td>0.884 KWh</td>
<td>0.8400 KWh</td>
<td>0.9018 KWh</td>
<td>0.7964 KWh</td>
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<tr>
<td>Ave. Hourly Gen. for a 1 KW PV Array (KWh)</td>
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<td>0.1651</td>
<td>0.1532</td>
<td>0.1483</td>
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<td>Ave. Hourly Gen (KWh) Assuming Ave. Panel Size of 5.642 KW</td>
<td>0.884 KWh</td>
<td>0.9315 KWh</td>
<td>0.8643 KWh</td>
<td>0.8367 KWh</td>
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<table>
<thead>
<tr>
<th>Corresponding Electricity and Utility Cost Savings, by Orientation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hourly Cost Savings from Solar Generation for a 1KW PV Array ($)</td>
</tr>
<tr>
<td>Annual Cost Savings for a 1KW PV Array ($)</td>
</tr>
<tr>
<td>Annual Cost Savings ($) Assuming Average Panel Size of 5.642 KW</td>
</tr>
<tr>
<td>FY2013 Dollars Saved from PV for Mueller Homes in this Study ($)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Water Savings, by Orientation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hourly Water Savings from Solar Generation for a 1KW PV Array (gal)</td>
</tr>
<tr>
<td>Annual Water Savings for a 1KW PV Array (gal)</td>
</tr>
<tr>
<td>Annual Water Savings (gal) Assuming Average Panel Size of 5.642 KW</td>
</tr>
</tbody>
</table>
Part II – Normalizing Austin Energy’s annual average grid costs based on ERCOT’s Day-Ahead Market (DAM) average hub price for each hour of FY2013

See Appendix E.

Based on the result from Part II, per 1 KW PV array, average hourly PV generation is 0.1567 KWh for all 110 homes in this study. Under the assumption that all PV generation offsets grid electricity consumption, the corresponding average hourly cost savings per 1 KW PV array is $0.0177, equivalent to $155.05 per year per 1 KW PV array. As the average home in this study has a 5.642 KW array, the average home offset $874.80 during FY2013. Together, the 110 homes in this study saved $96,228. If there had been 1.5 million homes with PV that behaved similarly to the average home for this sample, utility cost savings would have been $1.31 billion for FY2013.

Per 1 KW PV array, average hourly PV generation is 0.1567 KWh for all 110 homes in this study. Under the assumption that all PV generation offsets grid electricity consumption, the corresponding average hourly water savings per 1 KW PV array is 0.0736 gallons, equivalent to 645.12 gallons per year per 1 KW PV array. As the average home in this study has a 5.642 KW array, the average home offset 3,639.76 gallons during FY2013. Together, the 110 homes in this study saved 400,373.75 gallons during FY2013. If 1.5 million homes have been part of this sample and behaved similarly to the sample’s homes, water savings from household PV generation would have been 5.46 billion gallons during FY2013.

---

20 Here I still discuss the result from Part II as it is more accurate.
Figure 1 - ERCOT DAM Average Hourly Hub Price Adjusted RY 2013
Average Hourly Utility Cost Savings per 1 KW PV Array

- All Homes
- South
- South & West
- West

Cost Savings ($)

Hour

Figure 2 - ERCOT Wind-Adjusted Hourly FY2013 Water Savings per 1KW PV Array

- All Homes
- South
- South & West
- West

Water Savings (Gallons)

Hour
4.2 EV

Part I – Financial impact using Austin Energy’s FY2013 average annual hourly grid cost factor, 0.098035 $/KWh; Water usage impact using Austin Energy’s FY2013 average annual hourly grid water factor, 0.46 gallons/hour.

Table 6.1, below, displays the findings for fuel cost savings and utility water savings from EVs over traditional vehicles for the household car electricity consumption and car gasoline package.

<table>
<thead>
<tr>
<th>Table 6.1 - Vehicle Energy Consumption, Costs and Water Consumption for Homes with EV's and Traditional Vehicles (for homes without chargers at work and complete data sets for FY2013)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hourly Household Car Electricity Consumption (KWh)</td>
</tr>
<tr>
<td>0.267 KWh</td>
</tr>
</tbody>
</table>

Vehicle Energy Consumption Related Costs for Homes with EV's and Traditional Vehicles (for homes without chargers at work and complete data sets for FY2013)

| Hourly Vehicle Electricity Costs ($) | 0.0263 dollars | 0 | (-0.0263) dollars |
| Annual Vehicle Electricity Costs ($) | 230.0 dollars | 0 | (-230.0) dollars |

Car Gas Use and Costs

<table>
<thead>
<tr>
<th>Car Gas Consumption</th>
<th>41 Gallons^/1,507 Miles</th>
<th>528 Gallons^^/11,400 Miles</th>
<th>487 Gallons/9,893 Miles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hourly Car Gas Costs ($)</td>
<td>0.016</td>
<td>0.206</td>
<td>0.191</td>
</tr>
<tr>
<td>Annual Car Gas Costs ($)</td>
<td>140.5</td>
<td>1809.5</td>
<td>1668.949</td>
</tr>
</tbody>
</table>

Total Car Fuel Costs from Both Electricity and Gasoline
<table>
<thead>
<tr>
<th>Hourly Vehicle Total Costs ($)</th>
<th>0.0423</th>
<th>0.206</th>
<th>0.164</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual Vehicle Total Costs ($)</td>
<td>370.5</td>
<td>1809.5</td>
<td>1,439</td>
</tr>
<tr>
<td>FY2013 Fuel Cost Savings from All 25 EVs in this Sample</td>
<td>NA</td>
<td>NA</td>
<td>$35,975</td>
</tr>
<tr>
<td><strong>Water Consumption for Homes with EV's and Traditional Vehicles (for homes without chargers at work and complete data sets for FY2013)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hourly Vehicle Water Consumption (Gallons)</td>
<td>0.1228 Gallons</td>
<td>0</td>
<td>(-0.1228) Gallons</td>
</tr>
<tr>
<td>Annual Vehicle Water Consumption (Gallons)</td>
<td>1,075.90 Gallons</td>
<td>0</td>
<td>(-1,075.90) Gallons</td>
</tr>
<tr>
<td><strong>Car Gas Use and Water Usage</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Car Gas Consumption</td>
<td>41 Gallons^/1,507 Miles</td>
<td>528 Gallons^^/11,400 Miles</td>
<td>487 Gallons/9,893 Miles</td>
</tr>
<tr>
<td>Annual Water Usage from Car Gasoline (Gallons of Water)</td>
<td>175.12 Gallons</td>
<td>2,255.25 Gallons</td>
<td>2,080.13 Gallons</td>
</tr>
<tr>
<td><strong>Total Car Water Usage from Both Electricity and Gasoline</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hourly Vehicle Water Consumption (Gallons)</td>
<td>0.1428 Gallons</td>
<td>0.2574 Gallons</td>
<td>0.1146 Gallons</td>
</tr>
<tr>
<td>Annual Vehicle Total Costs ($)</td>
<td>1,251.02 Gallons</td>
<td>2,255.25 Gallons</td>
<td>1,004.23 Gallons</td>
</tr>
<tr>
<td>FY2013 Fuel Cost Savings from All 25 EVs in this Sample</td>
<td>NA</td>
<td>NA</td>
<td>25,105.75 Gallons</td>
</tr>
</tbody>
</table>

^ Assuming Chevy Volt mileage per gallon of 37 mpg, according to the DOE, http://www.fueleconomy.gov/feg/Find.do?action=sbs&id=31618&id=30980&id=33398

^^ Assuming mileage per gallon of 21.6 mpg, according to EPA's estimate for the average passenger vehicle http://www.epa.gov/otaq/climate/documents/420f14040.pdf

*Part II – Normalizing Austin Energy’s annual average grid costs based on ERCOT’s Day-Ahead Market (DAM) average hub price for each hour of FY2013*

See Appendix E.
**Financial Impact**

Average hourly EV electricity consumption for the 25 cars in this sample during FY2013 is 0.267 KWh, which corresponds to an average hourly electricity cost of $0.0263, equivalent to an annual cost of $230. Traditional vehicles consume zero KWh of electricity, so the annual household electricity cost from traditional passenger vehicles is $0.

A traditional passenger vehicles' annual average gasoline cost, by contrast, is $1809.5. For EVs, this value is $140.5. The sum of household electricity costs plus car gasoline costs from homes with EVs is $370.5. For households with traditional vehicles this number is $1809.5. Thus, the annual fuel cost savings from the average EV in this sample over the average traditional vehicle is $1,439. Using this number, the 25 homes in this sample saved $35,975 in fuel costs during FY2013 from using EVs instead of traditional passenger vehicles.

The differences between the results using Austin Energy’s FY2013 average annual hourly grid cost factor, 0.098035 $/KWh and using Normalized Austin Energy’s annual average grid costs based on ERCOT’s Day-Ahead Market (DAM) average hub price for each hour of FY2013 are marginal. The fact that results are so similar shows that the times of day this sample’s EV owners charged their cars during FY2013 was not an influential factor regarding EVs’ electricity-related fuel costs. Even after accounting for hourly fluctuations in car charging and electricity costs, the daily cost rate from fueling EVs with electricity increases from $0.0263/hour to $0.0272/hour, a difference of less than one cent per hour. The corresponding annual fuel cost savings for EV owners are only lower $8 using normalized cost, down to $1,431 from $1,439 using hourly grid cost in Table 4. The result of cost savings calculation using normalized Austin Energy’s annual average grid cost (Part II) can be find in Appendix E.

**Water Usage Impact**

For the 25 EVs in this sample, average hourly EV electricity consumption for a single EV is 0.267 KWh, which corresponds to an hourly water usage rate of 0.1228 gallons/hour, equivalent to an annual rate of 151.15 gallons/year. Traditional all-gas vehicles consume zero KWh of electricity, so the annual household electricity water consumption rate from traditional vehicles is 0 gallons/year.

A traditional all-gas passenger vehicle’s annual average gasoline-related water consumption rate, by contrast, is 2,255.25 gallons/year. For EVs, this value is 175.12 gallons/year. The sum of
household electricity water consumption plus car gasoline-related water consumption from homes with EVs is 1,251.02 gallons/year, whereas this statistic is 2,255.25 gallons/year for homes with traditional all-gas vehicles. Thus, the annual water savings rate from fueling EVs relative to traditional all-gas passenger vehicles is 1,004.23 gallons/year. Using this rate, the 25 homes with EVs in this samples saved 25,105.75 gallons in fuel-related water consumption during FY2013. Applying this water savings rate to a context in which 1.5 million electric vehicles behave like the ones in this sample, there would be an annual water savings of over 1.5 billion gallons.

The differences between the results Austin Energy’s FY2013 average annual hourly grid water factor, 0.46 gallons/hour and using Austin Energy’s annual average grid water usage factor based on ERCOT’s hourly data for wind’s proportion of the generation mix are marginal. The fact that results are so similar shows that the times of day this sample’s EV owners charged their cars during FY2013 was not an influential factor regarding EVs’ grid electricity-related water usage. Even after accounting for hourly fluctuations in car charging and grid-related water usage, the hourly water usage rate from fueling EVs with electricity increases from 0.1228 gallons/hour to 0.1230 gallons/hour, a difference of less than one thousandth of a gallon per hour. The corresponding annual water savings for EV owners are lower using normalized water usage factor, down to 1,002.65 gallons/year from 1,004.23 gallons/year in Table 6.2 in Appendix E with the result of water savings calculation using normalized Austin Energy’s annual average grid cost.

### 4.3 DR and TOU

#### 4.3.1 Financial Impact from Critical Peak Pricing (CPP) Event and Wind Enhancement Events

Table 7, below, displays the findings for CPP days and corresponding cost reductions to their utility from those who partake in demand response (DR) relative to those who do not.

| Table 7 - Control Group vs. Pricing Trial Group & CPP Day vs. Baseline Day Power Usage and Utility Costs Differences |
|---------------------------------------------------------------|---------------------------------------------------------------|
| Part 1: Using Austin Energy’s Annual Average Hourly Cost Factor of $0.098035/KWh for All Hours | |
| | CCET Control Group | Pricing Trial Group |
| | | | |

33
Hourly total power usage on CPP days exceeds that of baseline days by 0.193 KWh for the average “Control Group” home and 0.174 KWh for the average “Pricing Trial Group” home.\footnote{T-tests were run to discern the statistical significance of the difference in average hourly power usage between the “Control Group” and the “Pricing Trial Group” during baseline days. It is statistically significant at a 1% level that average hourly baseline day power usage for the “Pricing Trial Group” is higher than for the “Control Group.” For CPP days, however, the difference in average hourly power usage between the “Control Group” and the “Pricing Trial Group” is not statistically significant. As the CPP day values for the “Control Group” and “Pricing Trial Group” are similar, yet baseline day Power usage for “Pricing Trial Group” exceeds that of the CPP group, the discrepancy in power usage between CPP days and baseline days for the “Pricing Trial Group” is significantly lower than that of the “Control Group.”} Hence, the amount by which demand jumps on CPP days for the average “Control Group” home exceeds the jump for the average “Pricing Trial Group” home by 0.019 KWh, which – using the utility cost factor derived in Appendix B of $0.098035/KWh – means average hourly cost savings to utilities from the average home in the “Pricing Trial Group” on CPP event days is $0.00186/hour. Using this rate, utility cost savings from all 45 “Pricing Trial Group” homes for

| Hourly Average Power Usage - CPP Days (KWh) | 1.884 KWh | 1.884 KWh |
| Hourly Average Power Usage - CPP Baseline Days (KWh) | 1.691 KWh* | 1.710 KWh* |
| Hourly Average (CPP Days - Baseline Days) Electricity Difference (KWh) | 0.193 KWh | 0.174 KWh |
| (Control Group Elec. Diff. - Other Group Elec. Diff.) (KWh) | NA | 0.019 KWh |
| (Control Group Elec. Diff. - Other Group Elec. Diff.) – Average Hourly Cost to Utility ($) | NA | $0.00186 |
| Utility Cost Savings from the 45 Pricing Trial Group Homes for All 27 CPP Days (lbs. CO2e) | NA | $54.2 |
| Utility Cost Savings if there had been 1 Million Homes Part of the “Pricing Trial Group” over the 27 CPP Days | NA | $1,204,444 |

**Part 2: Austin Energy’s Annual FY2013 Average Hourly Cost Factor of $0.098035 Normalized Based on ERCOT’s Average DAM Hub Price for Each Hour**

| (Control Group Elec. Diff. - Other Group Elec. Diff.) – Average Hourly Cost to Utility ($) | NA | $0.00619 |
| Utility Cost Savings from the 45 Pricing Trial Group Homes for All 27 CPP Days ($) | NA | $181 |
| Utility Cost Savings if there had been 1 Million Homes Part of the “Pricing Trial Group” over the 27 CPP Days | NA | $4,011,120 |
the 27 CPP days in this sample are $54.2. If one million homes had been part of the “Pricing Trial Group” for the 27 CPP days, utility cost savings would have been $1,204,444.

Using hourly rates adjusted based on the ERCOT Day-Ahead Market (DAM) average hourly hub price significantly alters the above statistics. The average hourly cost savings to utilities from the average home in the “Pricing Trial Group” on CPP event days becomes $0.00619/hour, up from $0.00186/hour. Using this higher rate, utility cost savings from all 45 “Pricing Trial Group” homes for the 27 CPP days in this sample are $181. If one million homes had been part of the “Pricing Trial Group” for the 27 CPP days, utility cost savings would have been $4,011,120.

Figure 3, below, shows that – after normalizing hourly utility cost factors based on the ERCOT DAM average hourly hub price – the hours for which costs savings for the “Pricing Trial Group” are highest relative to the “Control Group” are 4pm-7pm, the time of DR events.

Table 8, below, displays my findings for wind enhancement days and corresponding utility cost impacts for the average “Pricing Trial Group” home relative to the average “Control Group” home.
Table 8 - Wind Enhancement Day Household Power Usage

<table>
<thead>
<tr>
<th></th>
<th>Power Usage - Hourly Average (KWh)</th>
<th>Power Usage - Hourly Average (KWh) (6am - 10pm)</th>
<th>Power Usage - Hourly Average (KWh) (10pm - 6am)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Control Group</strong></td>
<td>0.8968 KWh</td>
<td>0.9919 KWh</td>
<td>0.7069 KWh</td>
</tr>
<tr>
<td><strong>Pricing Trial Group</strong></td>
<td>0.9194 KWh</td>
<td>0.9639 KWh</td>
<td>0.8308 KWh</td>
</tr>
<tr>
<td><em>(Control Group - Pricing Trial Group)</em> Grid Elec. Consumption Difference</td>
<td>(-0.0226) KWh</td>
<td>0.0280 KWh</td>
<td>(-0.1238) KWh</td>
</tr>
<tr>
<td><em>(Control Group - Pricing Trial Group)</em> Electricity Generation Costs Difference Using FY2013 Austin Energy Annual Grid Electricity Generation Cost Factor of $0.098035/KWh for All Hours</td>
<td>(-$0.00222)/hour</td>
<td>$0.00274/hour</td>
<td>(-$0.0121)/hour</td>
</tr>
</tbody>
</table>

During the hours (6am-10pm) for which “Pricing Trial Group” participants are disincentivized to consume power during wind enhancement months, the average “Pricing Trial Group” home consumes 0.0280 KWh less power each hour than does the average “Control Group” home, equivalent to cost savings of $0.00274/hour assuming a flat utility cost rate for all hours that is equivalent to Austin Energy’s FY2013 hourly average (see Appendix B for the derivation of this flat utility cost rate).

During the hours for which “Pricing Trial Group” participants are incentivized to consume power (10pm-6am) during wind enhancement months, the average “Pricing Trial Group” home consumes 0.1238 KWh more power per hour than does the average “Control Group” home, equivalent to $0.0121/hour in additional costs to the utility, assuming a flat utility cost rate for all hours that is equivalent to Austin Energy’s FY2013 hourly average. This assumption is unrealistic, however, because a utility’s cost of providing electricity changes based on the time of day.

After normalizing hourly utility cost factors based on ERCOT’s FY2013-FY2014 Day-Ahead Market (DAM) average hourly hub price, full day utility cost savings from load shift become more apparent, as conveyed in Table 9.
Hourly cost savings from load shift to more wind intensive hours are $0.0020 for the full day - $0.051/hour for 10pm-6am and $0.0005/hour for 6am-10pm. Using this rate, utility cost savings due to load shift for the 45 “Pricing Trial Group” homes in the sample over the 153 wind enhancement days are $337. If one million homes had been part of the “Pricing Trial Group,” utility cost savings over the 153 wind enhancement days would have been $7,481,700.

Figure 4, below, shows that cost savings from load shift are highest during the early morning – the heart of the wind enhancement hours – from midnight-6am.
4.3.2 Water Usage Impact from Critical Peak Pricing (CPP) Events and Wind Enhancement Events

Table 10, below, displays my findings for CPP days and corresponding utility water consumption reductions from those who partake in DR relative to those who do not.

<table>
<thead>
<tr>
<th>Table 10 - Control Group vs. Pricing Trial Group CPP Day vs. Baseline Day Power Usage and Utility Water Consumption Differences</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Part 1: Using Austin Energy’s Annual FY2013 Water Consumption Factor of 0.46 gal/KWh for All Hours</strong></td>
</tr>
<tr>
<td>**</td>
</tr>
<tr>
<td>Power Usage - CPP Days (KWh)</td>
</tr>
<tr>
<td>Power Usage - CPP Baseline Days (KWh)</td>
</tr>
<tr>
<td>(CPP Days - Baseline Days) Electricity Difference (KWh)</td>
</tr>
<tr>
<td>(Control Group Elec. Diff. - Other Group Elec. Diff.) (KWh)</td>
</tr>
<tr>
<td>(Control Group Elec. Diff. - Other Group Elec. Diff.) – Generation Water Consumption (gal)</td>
</tr>
<tr>
<td>Utility Water Savings from the 45 Pricing Trial Group Homes for All 27 CPP Days (gal)</td>
</tr>
</tbody>
</table>
Utility Water Savings if there had been 1 Million Homes Part of the “Pricing Trial Group” over the 27 CPP Days (gal) | NA | 5,663,520
---|---|---
Part 2: Austin Energy’s Annual FY2013 Water Usage Factor of 0.46/KWh Normalized for ERCOT Hourly Wind % of Generation Mix
(Control Group Elec. Diff. - Other Group Elec. Diff.) – Water Consumption (gal) | NA | 0.0094
Utility Water Savings from the 45 Pricing Trial Group Homes for All 27 CPP Days (gal) | NA | 274.95
Utility Water Savings if there had been 1 Million Homes Part of the “Pricing Trial Group” over the 27 CPP Days (gal) | NA | 6,110,100

Hourly total power usage on CPP days exceeds that of baseline days by 0.193 KWh for the average “Control Group” home and 0.174 KWh for the average “Pricing Trial Group” home. Given that electricity consumption on CPP days exceeds that of baseline days by 0.188 lbs. CO2e/hour for the average “Control Group” home and 0.170 lbs. CO2e/hour for the average “Pricing Trial Group” home. Grid-related water usage, as a result, is higher for the average “Control Group” home than for the average “Pricing Trial Group” home by 0.00874 gallons. Using this rate, utility water savings from all 45 “Pricing Trial Group” homes for the 27 CPP days in this sample are 254.86 gallons. If one million homes had been part of the “Pricing Trial Group” for the 27 CPP days, utility water savings would have been 5,663,520 gallons.

Using hourly wind adjusted water usage rates slightly alters the above statistics. Utility water savings from all 45 “Pricing Trial Group” homes for the 27 CPP days in this sample are 274.95 gallons. If one million homes had been part of the “Pricing Trial Group” for the 27 CPP days, utility water savings would have been 6,110,100 gallons.

Figure 5, below, shows that – after normalizing hourly water usage factors based on wind generation’s percentage in the ERCOT generation mix – the hours for which water savings for

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22 T-tests were run to discern the statistical significance of the difference in average hourly power usage between the “Control Group” and the “Pricing Trial Group” during baseline days. It is statistically significant at a 1% level that average hourly baseline day power usage for the “Pricing Trial Group” is higher than for the “Control Group.” For CPP days, however, the difference in average hourly power usage between the “Control Group” and the “Pricing Trial Group” is not statistically significant. As the CPP day values for the “Control Group” and “Pricing Trial Group” are similar, yet baseline day Power usage for “Pricing Trial Group” exceeds that of the CPP group, the discrepancy in power usage between CPP days and baseline days for the “Pricing Trial Group” is significantly lower than that of the “Control Group.”
the “Pricing Trial Group” are highest relative to the “Control Group” are 4pm-7pm, the time of DR events.

Table 10, below, displays my findings for wind enhancement days and corresponding water usage impacts for the average “Pricing Trial Group” home relative to the average “Control Group” home.

<table>
<thead>
<tr>
<th>Table 10 - Wind Enhancement Day Household Power Usage and Corresponding Water Usage Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power Usage - Hourly Average (KWh)</td>
</tr>
<tr>
<td>-----------------------------------</td>
</tr>
<tr>
<td>Control Group</td>
</tr>
<tr>
<td>Pricing Trial Group</td>
</tr>
<tr>
<td>(Control Group - Pricing Trial Group) Grid. Elec. Consumption Difference</td>
</tr>
<tr>
<td>(Control Group - Pricing Trial Group) Grid-Related Water Usage Difference Using FY2013 Austin Energy Annual Grid</td>
</tr>
</tbody>
</table>
Electricity Generation Water Consumption Factor of 0.46 gal/KWh for All Hours

During the hours (6am-10pm) for which “Pricing Trial Group” participants are disincentivized to consume power during wind enhancement months, the average “Pricing Trial Group” home consumes 0.0280 KWh less power each hour than does the average “Control Group” home, equivalent to 0.01288 gallons/hour in utility water savings.

During the hours for which “Pricing Trial Group” participants are incentivized to consume power (10pm-6am) during wind enhancement months, the average “Pricing Trial Group” home consumes 0.1238 KWh more power per hour than does the average “Control Group” home, equivalent to 0.0569 gallons/hour increase in utility water consumption.

These results assume a flat water usage rate for all hours that is equivalent to Austin Energy’s hourly average, 0.46 gallons/KWh. This assumption is unrealistic, however, because a utility’s cost of providing electricity changes based on the time of day. After normalizing hourly water usage factors based on the percentage of wind power in ERCOT’s generation mix, full day water savings from load shift become more apparent, as conveyed in Table 11.

<table>
<thead>
<tr>
<th>Table 11 - Wind Enhancement Day Household Hourly Water Usage Impact, Using ERCOT Hourly Wind % of Generation Mix *</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hourly Water Savings from Load Shift to More Wind Intensive Hours (Full Day)</td>
</tr>
<tr>
<td>Average Hourly Water Savings from Load Shift to Less Water Intensive Hours on Wind Enhancement Days (10pm-6am)</td>
</tr>
<tr>
<td>Average Hourly Water Savings from Load Shift to Less Water Intensive Hours on Wind Enhancement Days (6am-10pm)</td>
</tr>
<tr>
<td>Daily Water Savings from Load Shift to More Wind Intensive Hours</td>
</tr>
<tr>
<td>Water Savings due to Load Shift for the 45 “Pricing Trial Group” homes in the Sample over the 153 Wind Enhancement Days</td>
</tr>
</tbody>
</table>
Hourly water savings from load shift to more wind intensive hours are 0.00103 gallons for the full day – 0.00274 gallons/hour for 10pm-6am and 0.00017 gallons/hour for 6am-10pm. Using this rate, water usage savings due to load shift for the 45 “Pricing Trial Group” homes in the sample over the 153 wind enhancement days are 170.1 gallons. Water savings if one million homes had been part of the “Pricing Trial Group” over the 153 wind enhancement days in this sample would have been 3,779,100 gallons.

Figure 6, below, shows that water savings from load shift are highest during the early morning, from midnight-6am.
5. Conclusion

5.1 Solar

FINANCIAL ANALYSIS

- The average residential PV array in this sample – with a size of 5.642 KW – reduces grid-related electricity costs to utilities – or the cost of delivering electricity to a particular residential customer – 73.7%-86.3%. Per 1KW PV array, utility grid electricity cost is reduced 13.1%-15.3% due to household PV.
- Annual utility cost savings of $134.57-$155.05 per 1 KW PV array. As the average home in this sample has a 5.642 KW array, the average home offset $759-$875 during FY2013.
- Directionally, south-facing panels offset more utility costs per 1 KW PV array than do panels facing other directions.

WATER ANALYSIS

- The average residential PV array in this sample – with a size of 5.642 KW – reduces grid-related household water usage by 73.7%-75.3%. Per 1 KW PV array, water usage is reduced 13.1%-13.3%.
- Annual water savings of 631-645 gallons per 1 KW PV array.
- As the average home in this sample has a 5.642 KW array, the average home saved 3,563-3,640 gallons of grid-relate water usage during FY2013.
- Directionally, south-facing panels save more grid-related water per 1 KW PV array than do other directions.

5.2 Electric Vehicles (EVs)

FINANCIAL ANALYSIS

- Electric vehicle owners save over $1,400 per year in fuel related costs. Put another way, imagine 20 households were to each buy a new Chevy Volt today at $34,670\(^{23}\) and 5 households were to each buy a new Nissan Leaf at $29,010.\(^{24}\) This group of 25 Volt and Leaf buyers would pay an average cost per vehicle of $33,538. Separately, a different 20 households each buy a new Chevy Impala today at $27,885\(^{25}\) and 5 households each buy


\(^{24}\) From Nissan website: [http://www.chooseonissan.com/austin-area/leaf-specs/?iploc=cn.ipsniff.AUS635.vsp_featuredoffers&dcp=zmm.113608714.&dcc=0.287189423&src=CY15_KBB_Text_RaQ](http://www.chooseonissan.com/austin-area/leaf-specs/?iploc=cn.ipsniff.AUS635.vsp_featuredoffers&dcp=zmm.113608714.&dcc=0.287189423&src=CY15_KBB_Text_RaQ)

a new Nissan Altima at $22,300. This group of 25 Impala and Altima buyers would pay an average cost per vehicle of $26,768. Assuming annual fuel savings of $1,400/year for the Volt/Leaf group, the sticker price difference is recovered in fewer than five years, and in 10 years the average Volt/Leaf owner would have an additional $7,230 in the bank than would the average Impala/Altima owner.

- Annual household car-related electricity cost is $230-$238 for the average EV and $0 for traditional all-gas vehicles.
- Annual car gasoline cost is $141 an EV and $1,810 for a traditional all-gas vehicle.
- Together, the 25 homes in this sample saved $35,775-$35,975 during FY2013 (October 1, 2012 – September 30, 2013) from using EVs instead of traditional passenger vehicles.

**WATER ANALYSIS**

- Fuel-related water usage for electric vehicles is 44.5% below fuel-related water usage from traditional all-gas passenger vehicles. Annual water usage from fueling this sample’s average EV is about 1,003 gallons lower than water usage from fueling a traditional all-gas passenger vehicle, whose average annual fuel-related water consumption is 2,255.25 gallons. Applying this water savings rate to a context in which 1.5 million electric vehicles behave like the ones in this sample, there would be an annual water savings of over 1.5 billion gallons.
- Annual grid-electricity-related water usage from fueling an EV is about 1,076 gallons, whereas there is no grid-electricity-related water usage from fueling a traditional all-gas passenger vehicle.

26 From Nissan website: [http://www.choosenissan.com/austin-area/altima-specs/?dcp=zmm.113608709.&dcc=0.287185584&src=CY15_KBB_Text_RaQ](http://www.choosenissan.com/austin-area/altima-specs/?dcp=zmm.113608709.&dcc=0.287185584&src=CY15_KBB_Text_RaQ)
• Annual car gasoline-related water usage from fueling an EV is about 175.12 gallons, whereas this statistic is 2,255.25 gallons for traditional all-gas passenger vehicles.
• Together, the 25 homes in this sample saved over 25,000 gallons of water during FY2013 from using EVs instead of traditional all-gas passenger vehicles.

5.3 Demand Response (DR) and Time-of-Use Pricing (TOU)

Whole Home Electricity Usage Impacts of Demand Response and Time-of-Use Pricing

CRITICAL PEAK PRICING (CPP)/DEMAND RESPONSE (DR)

FINANCIAL ANALYSIS
• Costs to utilities are reduced 1.1%-3.7% due to household participation in residential demand response (DR), or critical peak pricing (CPP).
• Utility cost savings were $54-$181 due to CPP participation from the 45 homes that were notified of the 27 CPP events in this sample.
• The hours during which cost savings from CPP participation are highest are 4pm-7pm, the time the CPP events occur (see Figure 3 in last section).

WATER ANALYSIS
• Grid-related water usage is reduced 1.1% due to load shift inspired by household participation in residential demand response (DR), or critical peak pricing (CPP).
• Grid-Related water savings from load shift were 254.85 gallons due to CPP participation from the 45 homes in this sample that were notified of the 27 CPP events.
• The hours for which grid-related water savings from CPP participation are highest are 4pm-7pm, the hours during which CPP events occur (See Figure 5 in last section).

WIND ENHANCEMENT PERIOD/TIME OF USE (TOU) PRICING

FINANCIAL ANALYSIS
• Costs to utilities are reduced 1.8% due to household participation in residential TOU, or wind enhancement events. Average hourly electricity usage during wind enhancement months from participating households is 0.9194 KWh, equivalent to $0.113/hour in costs to utilities. Utility cost savings on wind enhancement days due to load shift from participating households, relative to households that do not participate, are $0.0020/hour, a reduction of 1.8%.
Utility cost savings were $337 due to load shift from the 45 participating households on the 153 wind enhancement days in this sample. Applied to a larger scale, if one million homes had partaken in this sample’s 153 wind enhancement days and behaved similarly to this sample’s participants, utility cost savings would have amounted to $7.4 million.

The hours during which cost savings from wind enhancement event participation are highest are midnight-6am, the heart of the hours participants are incentivized to use electricity.

WATER ANALYSIS

- Grid-related water usage is reduced 0.244% due load shift from EV-owning household participation in residential time-of-use (TOU) pricing, or wind enhancement periods.
- Grid-related water savings were 170.1 gallons due to EV charging load shift from this sample’s 45 participating households on the 153 wind enhancement days.
- The hours during which grid-related water savings due to load shift from wind enhancement day participation are highest midnight-6am, the heart of wind enhancement hours (see Figure 6 in last section).
6. Further Discussion – Regression Analysis

Impact of Solar PV Generation and EV Charging on Grid Electricity Consumption

Introduction

This section’s purpose is to use a second methodology – regression analysis – to corroborate the findings from earlier sections regarding the impact of PV generation and EV ownership on grid electricity consumption. Value added from this section is the ability determine statistical significance of the impact of PV generation and EV charging on grid electricity consumption; and, then, to indirectly assess the statistical significance of the findings in the solar and EV sections of this report through comparing the values I arrived at in those other sections to statistically significant values in this section.

I use a random effects panel regression, represented in equation (1). A panel regression is appropriate for this analysis because it enables me to both group households together and account for the linear progression of time. According to the definition provided by Princeton University,

“Panel data (also known as longitudinal or cross-sectional time-series data) is a dataset in which the behavior of entities are observed across time. These entities could be states, companies, individual, countries, etc... Panel data allows you to control for variables you cannot observe or measure like cultural factors or difference in business practices across companies; or variables that change over time but not across entities... That is, it accounts for individual heterogeneity.”

For this analysis, the entity observed across time is the household, and this method enables us to control for the unique behaviors and habits individual households have regarding electricity usage. The regressions use random effects – as opposed to fixed effects – because the results from the Hausman Test indicate random effects are more appropriate for this sample.

\[
y_{it} = \beta_0 + \beta_1 x_{1it} + \beta_2 x_{2it} + \beta_3 x_{3it} + \beta_4 x_{4it} + ... + \beta_k x_{kit} + \varepsilon_{it} \tag{1}
\]


\[28\] According to the Hausman Test, the Chi-Squared value, testing the null hypothesis that company fixed effects are uncorrelated with the independent variables, is 4.11 and the “probability > Chi-Squared” value is 0.3913. These results signify that the null hypothesis is valid and the GLS model is appropriate. In other words, these results tell us to use random effects variation rather than fixed effects variation.
In this regression model, $Y_i$ represents the dependent variable, the X-terms represent independent variables, and $\varepsilon_{it}$ accounts for error. There are 82 $i$'s, which represent this sample's unique data ID's, or households, and there are 8,760 unique hours—from midnight-1am on October 1st, 2012 through 11pm-midnight on September 30th, 2013—that are represented by the subscript $t$.

In determining the sample for this regression, I used assumptions consistent with those made in the solar and EV sections earlier in this report. These assumptions are as follows:29

- The sample is limited to data ID’s with complete datasets for Austin Energy’s fiscal year 2013, spanning October 1, 2012 through September 30, 2013.
- None of the EV owners in this sample have multiple EVs.
- EV’s analyzed are 20 Chevy Volts and 5 Nissan Leafs.
- None of the EV owners in this sample have chargers at work.

Variables

The dependent variable is “Hourly Grid Electricity Consumption (KWh),” and the independent variables are categorized as follows:

- **Solar:** “Hourly Electricity Generation (KWh)” measures the amount of electricity households use at hourly intervals that derives from solar PV generation.31
- **Electric Vehicles:** “EV Ownership (Actively Charging EV)” indicates whether a household owns an EV. This is a binary variable that measures one for the 25 homes in this sample that have EVs and zero for the other 56 homes. As 23 homes are needed for a sample to be statistically significant, both groups comprising this binary variable are statistically significant.
- **Behavioral Variables:** The purpose of these variables is to control for non-EV/PV factors that contribute to a home’s electricity usage and, thus, account for omitted variable bias. The three behavioral variables for this section are:
  1. “House’s Year of Construction”: This variable indicates the year a home was built. All homes in this sample were built during 2007-2011. While this range is not large, I include this variable to control for the fact that newer

---

29 The Pecan Street database defines a data ID as “the unique identifier for the home-resident pair.” Thus, if a resident moves, the data collected from the home is associated with a new data ID.
30 Refer to the solar and EV sections for more information on why I make these assumptions.
31 As all but one home in this sample have solar panels, I do not include a binary variable differentiating those with PV to those without PV because the sample without PV is not statistically significant.
homes are built with more modern technology; and, thus, may be more energy efficient.

2. “Size of Home (Square Footage)”: This variable indicates the size of a home in terms of square footage. I include this variable to control for the fact that larger homes are more energy intensive for certain services, such as heating and cooling.

3. “# of Residents”: This variable indicates the number of people living in a home. I include this variable to control for the fact that a home with more residents has more people using energy intensive appliances.

- **Time Variables**: The purpose of these variables is to control for how the time of day and time of year contribute to a home’s electricity usage and, thus, account for omitted variable bias. The three time variables for this sections are:
  1. “Peak Hours (4pm-7pm)”: This variable is a binary variable that measures one for the hours between 4pm and 7pm and zero for all other hours. I include this variable to control for the fact that home electricity usage is highest at peak hours.
  2. “Wind Enhancement Hours (10pm-6am)”: This variable is a binary variable that measures one for the hours between 10pm and 6am. This variable is included to discern whether grid electricity consumption is higher or lower at night time in a sample in which 99% of homes own solar panels. While household electricity demand is relatively low at night, solar PV generation is zero at night; so, it’s unclear whether night time is off peak for grid electricity consumption for these homes at a statistically significant level.
  3. “Summer Day”: This variable is a binary variable that measures one for the hours that occur in summer months (June-September) and zero for all other hours. This variable is included to control for the fact that home electricity usage is relatively high during the summer.

**Analysis**

Table 12 presents results from random effects panel data regressions for which a household’s data ID is the entity and the time variable is disaggregated to the hourly level for October 1, 2012 through September 30, 2013. Through assessing the statistical significance of variables’ relationships with household grid electricity consumption when other variables are taken into account, these regressions compare the relative impacts of variables that could theoretically impact a household’s grid electricity consumption. For this analysis, the findings of focus pertain to coefficients associated with solar and EV variables.
### Table 12 - Wind Enhancement Day Household Hourly Water Usage Impact, Using ERCOT Hourly Wind % of Generation Mix

<table>
<thead>
<tr>
<th></th>
<th>Hourly Grid Electricity Consumption (KWh)</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td></td>
</tr>
<tr>
<td>Hourly Electricity Generation (KWh)</td>
<td>-0.9496***</td>
<td>-0.9496***</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EV Ownership (Actively Charging EV)</td>
<td>0.2275***</td>
<td>0.2453***</td>
<td></td>
<td></td>
</tr>
<tr>
<td>House's Year of Construction</td>
<td>-0.0503</td>
<td>-0.0387</td>
<td>-0.0472</td>
<td></td>
</tr>
<tr>
<td>Size of Home (Square Footage)</td>
<td>0.0003852***</td>
<td>0.0002591***</td>
<td>0.000408***</td>
<td></td>
</tr>
<tr>
<td># of Residents</td>
<td>0.1166***</td>
<td>0.0777*</td>
<td>0.0952**</td>
<td></td>
</tr>
<tr>
<td>Peak Hours (4pm-7pm)</td>
<td>0.5440***</td>
<td>0.9250***</td>
<td>0.5440***</td>
<td></td>
</tr>
<tr>
<td>Wind Enhancement Hours (10pm-6am)</td>
<td>-0.3375***</td>
<td>0.9658***</td>
<td>-0.3375***</td>
<td></td>
</tr>
<tr>
<td>Summer Day</td>
<td>0.9284***</td>
<td>0.7191***</td>
<td>0.9284***</td>
<td></td>
</tr>
<tr>
<td>Constant</td>
<td>100.7905</td>
<td>76.5428</td>
<td>94.5139</td>
<td></td>
</tr>
<tr>
<td>R-Squared</td>
<td>0.5961</td>
<td>0.1432</td>
<td>0.5921</td>
<td></td>
</tr>
<tr>
<td>Prob &gt; Chi^2</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
<td></td>
</tr>
<tr>
<td># of Homes</td>
<td>81</td>
<td>81</td>
<td>81</td>
<td></td>
</tr>
<tr>
<td>Observations</td>
<td>698,285</td>
<td>698,285</td>
<td>698,285</td>
<td></td>
</tr>
</tbody>
</table>

*** Statistically significant at a 1% confidence level; ** 5% confidence level; * 10% confidence level

Regression (1) includes the most variables and has the highest R-Squared value, 0.5961, meaning that about 59.61% of the variability in households' hourly grid electricity consumption is explained by the independent variables included. Regression (2) is the same as regression (1), except it excludes “Hourly Electricity Generation (KWh)”; this regression’s purpose is to show how much of an impact solar PV generation has on the R-Squared value in regression (1). Lastly, regression (3) is similar to regression (2), except it drops “EV Ownership (Actively Charging EV)” rather than dropping “Hourly Electricity Generation (KWh).” This regression’s
purpose is to highlight how much of an impact EV charging has on the R-Squared value in regression (1).
Key Findings

PV

- The fact that findings in this report’s solar section are so similar to findings from the regressions in this section – for which the solar PV variable’s coefficient is statistically significant at a 1% level – lends credence to the significance of the findings in this report’s solar section. Regression analyses indicate that hourly utility cost savings from a 1 KW PV array are $0.0146, very close to the result for this statistic derived in this report’s solar section, $0.0154-$0.0177. Lastly, regression analyses indicate that hourly grid-related water savings from a 1 KW PV array are 0.0684 gallons, very close to the range for this statistic derived in the solar section, 0.0721-0.0736 gallons.

- Solar PV generation accounts for about 45.29% of the variation in hourly grid electricity consumption.

EVs

- The fact that findings in this report’s EV section are so similar to findings from the regressions in this section – for which the EV ownership variable is statistically significant at a 1% level – lends credence to the significance of the findings in this report’s EV section. According to regression analysis, additional hourly grid emissions attributable to EV ownership are 0.2218 lbs. CO2e, very close to the range derived for this statistic in this report’s EV section, 0.260 lbs. CO2e-0.2601 lbs. CO2e. Regarding utility costs, regression analyses indicate that extra hourly utility costs for a household attributable to EV ownership are $0.0223, very close to the range derived for this statistic in this report’s EV section, $0.0263-$0.0272. For water usage, regression analyses indicate that extra hourly grid-related water usage attributable to EV ownership is 0.1047 gallons, very close to the range derived for this statistic in this report’s EV section, 0.1228-0.1230 gallons.

- EV ownership accounts for about 0.40% of the variation in hourly grid electricity consumption.
References


Appendix A – Derivation of Austin Energy’s Grid Electricity Emissions Rate

This analysis estimates Austin Energy’s grid electricity emissions rate to be 0.974792 lbs. CO2e/KWh, which equals 0.000487 short tons of CO2e/KWh and 0.000442 metric tons of CO2e/KWh.

The derivation of the numbers above stems from the Austin Energy 2013 Annual Performance Report. Austin Energy’s system average carbon intensity is calculated as total greenhouse gas emissions at the point of combustion in pounds of CO2-equivalents divided by the net generation in KWh from Austin Energy resources. Austin Energy generation resources include, 

“Natural gas, coal, and nuclear-powered units; renewable resources owned by Austin Energy; and purchased power from renewable and non-renewable resources. GreenChoice® energy sales are subtracted from the net generation total since GreenChoice® customers can claim their carbon intensity to be 0 lbs of CO2-equivalents/kWh.”

Table 1 on page 7 of that report conveys a grid emissions rate of 1.05 lbs. CO2e/KWh for calendar year (CY) 2013 (January 1, 2013 – December 31, 2013) and 1.03 lbs. CO2e/KWh for calendar year 2012 (January 1, 2012 – December 31, 2012).

The difference between our emissions rate and Austin Energy’s (AE) is that we include GreenChoice electricity consumption, so that the grid emissions rate is for all AE generation.

Austin Energy’s Emissions Intensity Calculation = \( \frac{\text{Total AE lbs. CO2e}}{\text{Total AE Generation (KWh)} - \text{GreenChoice Generation (KWh)}} \)

AE Emissions Intensity Used for this Report = \( \frac{\text{Total AE lbs. CO2e}}{\text{Total AE Generation (KWh)}} \)

For converting the CY 2013 and CY 2012 emissions rate to fiscal year (FY) 2013 emissions rates, we use the following formula, which proxies 3 months of 2012 and 9 months of 2013:

\[ (\text{CY 2013 Emissions Rate}) \times 0.75 + (\text{CY2012 Emissions Rate}) \times 0.25 = \text{FY2013 Emissions Rate} \]

OR

\[ 1.05 \times 0.75 + 1.03 \times 0.25 = 1.045 \text{ lbs. CO2e/KWh} \]

32 Appendix A is authored by Peter Sopher from EDF.
We base our calculation from the information above, combined with information (below) from Table 21, Table 42, and Table 43 of the *Austin Energy 2013 Annual Performance Report*:

- **Table 21**
  - Total renewable energy (RE) purchased by AE in FY2013 was 2,656,952,000 KWh
  - Green Choice sales for FY2013 was 861,972,633 KWh
- **Table 42**: The combined generation percentage of RE, nuclear, coal, and gas is 85.06%.
- **Table 43**: Total nuclear, coal, and gas generation for FY2013 was 8,256,118,000 KWh.

To determine total KWh of AE generation, we solve the following equation based on information above:

\[
\frac{100}{85.06} \times (8,256,118,000 \text{ KWh from Nuclear, Gas, and Coal} + 2,656,952,000 \text{ KWh from RE}) = 12,829,849,517.987 \text{ KWh}
\]

To determine total lbs. CO\text{2}e from AE generation, we solve the following equation based on information above:

\[
1.045 \text{ lbs CO2e} \times (12,829,849.517987 \text{ MWh total generation} - 861,972,633 \text{ MWh from GreenChoice}) = 12,506,431,344.811 \text{ lbs. CO2e}
\]

Lastly, to solve for our emissions rate, we solve the following equation based on information above:

\[
\frac{12,506,431,344.811 \text{ lbs. CO2e from AE generation}}{12,829,849,517.987 \text{ KWh of total AE grid generation}} = 0.974792 \text{ lbs. CO2e/KWh, which equals 0.000487396 short tons of CO2e and 0.0004421582135 Metric tons of CO2e}
\]
Appendix B – Deviation of Austin Energy’s Electricity Generation Cost

According to Table 28 on page 31 of the 2013 Austin Energy Annual Performance Report, Austin Energy’s FY2013 total expenditures were $1,257,770,945.

The total FY2013 generation I calculated in Appendix A is 12,829,849,517.987 KWh

Therefore, Austin Energy’s total costs of per KWh electricity in FY 2013 is $0.098035/KWh, as calculated below:

\[
\frac{\$1,257,770,945 \text{ Operating Budget}}{12,829,849,517.987 \text{ KWh of total AE grid generation}} = 0.098035 \$/\text{kWh.}
\]

As utility cost is passed down to customers with only a marginal bump, I assume that Austin Energy’s customers incur similar costs to their utility on average.
Appendix C – Derivation of Austin Energy’s Electricity Grid Water Consumption Rate and Water Consumption Rate of Gasoline Used by Vehicles in Muller Community

Electricity Grid Water Usage Factor

Derivation of Austin Energy’s Grid Electricity Water Consumption Rate

This analysis estimates Austin Energy’s grid electricity generation water consumption rate to be 0.46 gal/KWh.

The derivation of the numbers above stems from the *Austin Energy 2013 Annual Performance Report*. Austin Energy’s system average water intensity is provided as water usage rate with reclaimed water (gal/KWh) used by plants generating electricity for Austin Energy. The number is provided in Table 3b on page 9 of the report.

Car Gasoline Water Usage Factor

Derivation of Water Consumption Rate of Gasoline Used by Vehicles in Mueller Community

The data used in this model are from the EIA website and from the “Consumptive Water Use in the Production of Ethanol and Petroleum Gasoline – 2011 Update” report authored by Argonne National Laboratory (referred as “Argonne National Laboratory Report” below). In this report, researchers calculate the water consumption in the production of gasoline produced in the US, Canada, and Saudi Arabia. As crude oil refined for gasoline sold in the US does not come from a single country, I develop a model to estimate the water consumption rate of gasoline used by vehicles in the US.

\[
A = (B \times C) + (D \times E) + (F \times G) + (H \times I)
\]

- \(A\) = Average total water usage for US gasoline production (gallons water/gallons gas)
- \(B\) = Percentage of US gas production derived from US-based oil
- \(C\) = Water usage rate refining US-based oil into gas (gal water/gal gas)
- \(D\) = Percentage of US gas production derived from Canadian-based oil
- \(E\) = Water usage rate refining Canadian-based oil into gas (gal water/gal gas)
- \(F\) = Percentage of US gas production derived from Saudi-based oil

[33] https://greet.es.anl.gov/publication-consumptive-water
G = Water usage rate refining Saudi-based oil into gas (gal water/gal gas)
H = Percentage of US gas production derived from oil from other countries
I = Water usage rate refining oil from other countries into gas (gal water/gal gas)

The calculation below substitutes the appropriate numbers for corresponding variables from the equation above.

\[ 4.2713 = (51\% \times 4.2729) + (14.00\% \times 4.2765) + (6.93\% \times 4.228) + (28.07\% \times 4.2763) \]

From this model, average total water usage for US gasoline production is **4.2713 gal/gal gasoline**.

To arrive at this number, I calculate the average total water usage for gasoline production in the US, Canada and Saudi Arabia (see table 1, 3, and 4). Data necessary for determining water usage for refining oil into gasoline is not available for other countries; so, for those countries, I assume a water consumption rate that is the average of the rate for refining conventional crude oil and the rate for refining crude oil from oil sands.

A detailed methodology for how I calculate this rate is below.

1. The average total water usage for gasoline production in the US

   \[ \text{Average Total Water Usage for Gasoline Production in the US} = \sum_{\text{region}=\text{PADD II, PADD III, PADD V}} \text{Adjusted share of gasoline production in the United States} \times \text{Total water consumption for gasoline production in the US} \]

   \[ = 25.46\% \times 3.4 + 52.15\% \times 3.7 + 22.39\% \times 6.6 = 4.2729 \text{gal/gal gasoline} \]

PADD II, PADD III, and PADD V account for 81.3% of gasoline production in the United States. As these regions are the ones with strong water usage data, I apply the average water usage rate from these regions to arrive at a rate for the US as a whole.

<table>
<thead>
<tr>
<th>PADD Regions</th>
<th>Share of gasoline production in the United States (%)</th>
<th>Adjusted Share of Gasoline Production - % of PADD II, PADD III, and PADD V</th>
<th>Total water consumption for gasoline production in the US (E&amp;P + Refinery) (gal/gal gasoline)</th>
<th>Average total water consumption for gasoline production in the US (gal/gal gasoline)</th>
</tr>
</thead>
</table>
2. The average total water usage for gasoline production in Canada

First I calculate the average total water consumption for oil-sand based gasoline production in Canada.

\[
\text{Average Total Water Consumption for Oil Sand based Gasoline Production in Canada} = \sum_{\text{region=Muti-scheme, CSS, SAGD, Surface mining}} \text{share of oil sand crude production} \times \text{Total water usage for Canadian oil sand based gasoline production}
\]

\[
= 1.20\% \times 6.2 + 21.20\% \times 3.5 + 22\% \times 2.6 + 55.60\% \times 5.2
\]

\[
= 4.2796 \text{ gal/gal gasoline}
\]

<table>
<thead>
<tr>
<th>Regions</th>
<th>Share of oil-sand crude production (%)</th>
<th>Total water consumption from crude recovery to refining for Canadian oil-sand based gasoline (gal/gal gasoline)</th>
<th>Average total water usage for gasoline production from Canadian Oil Sand (gal/gal gasoline)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Muti-scheme (Peace River)</td>
<td>1.20%</td>
<td>6.2</td>
<td>4.2796</td>
</tr>
<tr>
<td>CSS (Cold Lake)</td>
<td>21.20%</td>
<td>3.5</td>
<td></td>
</tr>
<tr>
<td>SAGD (Athabasca)</td>
<td>22%</td>
<td>2.6</td>
<td></td>
</tr>
<tr>
<td>Surface mining (Athabasca)</td>
<td>55.60%</td>
<td>5.2</td>
<td></td>
</tr>
</tbody>
</table>

Source: Table 17 and Figure 39 from Argonne National Laboratory Report

Then I calculated the average total water consumption for gasoline production (including conventional oil and oil sand) in Canada. I use the rate derived in Table 1, 4.2729 gal/gal, as
a proxy for the Canadian water usage rate from refining conventional oil, and the rate derived in Table 2, 4.2796 gal/gal gas, for the Canadian water usage rate from refining crude oil.\textsuperscript{34}

<table>
<thead>
<tr>
<th>Year</th>
<th>Total Canadian Crude oil Production (including oil sands)</th>
<th>Eastern Canada Crude Oil Production (all conventional)</th>
<th>Western Canada Crude Oil Production</th>
<th>Average total water usage for gasoline production from Canadian Crude Oil</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013</td>
<td>3.5</td>
<td>0.2</td>
<td>3.2</td>
<td>1.3 (Conventional)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.9 (Oil Sands)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4.2765</td>
</tr>
</tbody>
</table>

Source: Canadian Association of Petroleum Producers (CAPP) release -- http://www.capp.ca/aboutUs/mediaCentre/NewsReleases/Pages/CAPPcrudeoilforecastOilsandsdevelopmentdrivessteadyCanadianoilproductiongrowthto2030.aspx

\begin{align*}
\text{Average Total Water Consumption for Gasoline Production in Canada} &= \sum_{\text{region=North'}AinDar,Ghawar} \text{share of crude production} \\
&= \text{Water Consumption for (Conventional) Gasoline Production in Eastern Canada} \\
&\quad + \text{Water Consumption for (Oil Sand) Gasoline Production in Western Canada} \\
&= \frac{0.2}{3.5} \times 4.2729 + \frac{1.3}{3.5} \times 4.2729 + \frac{1.9}{3.5} \times 4.2796 = 4.2765 \text{ gal/gal gasoline}
\end{align*}

3. The average total water consumption for gasoline production in Saudi Arabia

\begin{align*}
\text{Average Total Water Consumption for Gasoline Production in Saudi Arabia} &= \sum_{\text{region=North'}AinDar,Ghawar} \text{share of crude production} \\
&= \text{Total water usage for gasoline production} = 47.60\% \times 5.8 + 52.40\% \times 2.8 \\
&= 4.228 \text{ gal/gal gasoline}
\end{align*}

\textsuperscript{34} We should note that because of lacking of water consumption data of conventional oil production and refinery process in Canada, in the calculation above I use the average total water consumption for gasoline production in the US as an alternate. This number may not be 100% accurate, but due to the fact that the quality of crude oil in Canada and in the US are similar, so my calculations should lose too much accuracy through this assumption.
Table 4. Average Total Water Usage for Gasoline Production in Saudi Arabia

<table>
<thead>
<tr>
<th>Regions</th>
<th>Share of domestic crude oil production (%)</th>
<th>Water Consumption from Crude Recovery to Refining for SA Crude Based Gasoline (gal/gal gasoline)</th>
<th>Average total water usage for gasoline production from SA Crude Oil (gal/gal gasoline)</th>
</tr>
</thead>
<tbody>
<tr>
<td>North 'Ain Dar</td>
<td>47.60%</td>
<td>5.8</td>
<td>4.228</td>
</tr>
<tr>
<td>Ghawar</td>
<td>52.40%</td>
<td>2.8</td>
<td></td>
</tr>
</tbody>
</table>

Source: Argonne Nation Laboratory report, Table 16 and Figure 39

4. The average total water consumption for gasoline used in the U.S. Table 5 presents the sources of crude oil consumed in the U.S., and their corresponding water consumption. The result of this model is an estimation based on water usage data for refining crude oil from the US, Canada, and Saudi Arabia, which comprise 71.9% of U.S. daily crude oil consumption. The remaining 28.1% is imported from other countries, such as Mexico, Nigeria, Venezuela, etc., and there is not an accurate number of the water consumption from refining crude oil into gasoline in these countries available. For this calculations, I assume US oil imports from these countries are equally comprised of conventional and oil sand crude, and that water usage rates for refining this oil to gas are the same as in Canada and the US. The equation used is the following:

\[(\text{US water usage rate for refining conventional crude} + \text{Canadian water usage rate for refining oil sand crude})/2 = (4.2729 + 4.2796)/2 = 4.2763 \text{ gal/gal gasoline}.\]

Table 5. Sources and Their Percentage of Crude Oil Consumed in the U.S., and Corresponding Water Consumption

<table>
<thead>
<tr>
<th>Source of crude oil consumed in the U.S.</th>
<th>U.S. domestic</th>
<th>Canada</th>
<th>Saudi Arabia</th>
<th>The rest</th>
</tr>
</thead>
<tbody>
<tr>
<td>% of U.S. Domestic Crude Oil Production</td>
<td>51.00%</td>
<td>14.00%</td>
<td>6.93%</td>
<td>28.07%</td>
</tr>
<tr>
<td>% of Imported Crude Oil</td>
<td>NA</td>
<td>28.58%</td>
<td>14.14%</td>
<td>57.28%</td>
</tr>
<tr>
<td>water consumption per gasoline produced (gal/gal gasoline)</td>
<td>4.2729</td>
<td>4.2765</td>
<td>4.228</td>
<td>4.2763</td>
</tr>
</tbody>
</table>

Water Consumption per Gasoline Consumed by U.S. Motor ($\frac{\text{gal}}{\text{gal gasoline}}$)

$$= \sum_{\text{country} = X_i} = \text{share of gasoline production in Country } X_i \times \text{total water usage for gasoline production in Country } X_i$$
$$= \text{share of gasoline production in the US} \times \text{total water usage for gasoline production in the US}$$
$$+ \text{share of gasoline production imported} \times \text{total water usage for gasoline production imported}$$

$$= (51\% \times 4.2729) + (14.00\% \times 4.2765) + (6.93\% \times 4.228) + (28.07\% \times 4.2763) = 4.2713 \frac{\text{gal}}{\text{gal gasoline}}$$

Therefore, the average total water consumption for gasoline used in the U.S. is 4.2713 gal/gal gasoline.
Appendix D – CCET TOU Program Summary

Pecan Street’s electricity pricing trial consists of an experimental rate structure design, definition of resident groups (a volunteer TOU trial group and a control group), participant communication strategy, participant incentive credit accounts, energy data collection, data management and cyber-security considerations, data visualization, and data analysis.

The project’s goal is to use an integrated approach using current and available technology to study the impacts that TOU pricing has on consumer behavior. The experimental TOU trials are defined in two parts – a Critical Peak Pricing (CPP) model and a Wind Enhancement Pricing model – as detailed below.

The control group (60 homes) was defined and consists of residents received no communication regarding the TOU pricing. The TOU trial group (62 homes) is a volunteer group that agrees to respond to CPP and wind pricing by altering behavior to achieve energy savings that will build value in their incentive credit accounts, which they may ultimately claim as a cash payout at the end of the 20-month trial. They are not at risk of paying higher bills if they do not alter their behavior. Residents and their homes in both groups are of similar makeup, both having energy efficient homes, solar PV generation, and EVs. Both groups have their end-use appliance circuits sub-metered in similar fashion as described below.

Experimental Rate Structure Design and Incentive Account Tracking Over the course of this 20-month experiment (March 2013 – October 2014), the TOU group and control group will continue to receive and pay their usual Austin Energy electric bills which will reflect the normal Austin Energy electric rates. A monetary incentive is used to entice TOU group participants to either shift their energy load to “wind enhancement times” or to reduce energy consumption during critical peak times. The latter are called a day ahead based on forecasted weather conditions and ERCOT peak loads. The two TOU pricing structures do not coincide or overlap at any time.

The project established a credit account with an initial balance of $200 for each participant in the TOU group. The credit account balance trend reflects a participant’s degree of response to

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35 This Appendix is authored by Peter Sopher from EDF. It uses the words of the Center for the Commercialization of Electric Technologies (CCET) from the document they prepared on September 30, 2013 for the United States Department of Energy that describes the design of the TOU program conducted using Pecan Street homes. The citation for this document is as follows:

price signals. A participant is able to view their credit account through an online web portal as shown below.

![Figure 11. Web Portal’s Display of Representative Pricing Trial Information for One TOU Participant](image)

The value of the credit in the account is adjusted every month at the time the participant receives his or her electric bill. The adjustment will reflect the difference between what the participant actually pays Austin Energy and what they would have paid if the pricing trial rate were actually in effect. Account balances are a primary metric for this experiment.

The pricing trial electric rates are structured as follows and designed to be revenue-neutral to the utility:

1. A Critical Peak Price (CPP) applies only during certain designated hours (4 p.m. – 7 p.m.), is called a day ahead by Frontier Associates in the summer months (June, July, August, and September), and is designed to entice the customer to minimize load during forecast grid peaks.

2. A very low night-time “wind enhancement” price, which applies during the five windiest months (March, April, May, November, and December) and is designed to entice the customer to shift load into the 10 p.m. – 6 a.m. time frame where it can be served by wind generation.

During the remaining three months of January, February and October, the pricing trial rate will be the same as the current Austin Energy rate.

**CRITICAL PEAK PRICING TRIAL**
A CPP price of $0.64 per kilowatt (kWh) is only applied to the TOU group participant’s energy consumption during the weekday (Monday – Friday) afternoon hours of 4 p.m. – 7 p.m. on “critical peak” days. Up to 15 critical peak days will be called during the four summer months. The day-ahead critical peak call by Frontier Associates simulates a call by ERCOT anticipating extremely high next-day system load. The process used by Frontier Associates in determining and calling the critical peak days is charted below.

**CPP Decision Flow Diagram:**

By notification of a next day peak event, participants are enticed to take appropriate measures to shift energy use to outside the peak time frame the following day. The original goal is to call a maximum number of monthly critical peak events each month according to the table below. It defines each month along with the minimum threshold temperature and the maximum number of events to be called in that month.
WIND ENHANCEMENT PRICING TRIAL

For the wind enhancement pricing trial, the night-time electric rate for the TOU group during the five windiest months (March, April, May, November, and December) is lowered to $0.0265 per kWh. This price applies to energy consumption in the hours from 10 p.m. – 6 a.m. on all days during those months. There is an offsetting surcharge of approximately $0.02 per kWh on the participant’s energy consumption during all other hours of those five months.

CALCULATION OF PRICING TRIAL ELECTRIC BILLS

The pricing trial electric rates consist of these components:

1. Customer charge (the same as Austin Energy’s charge) – a flat rate of $10.
2. Baseline (existing Austin Energy) rates – applied only to consumption during non-wind hours and non-critical peak hours.
3. Surcharge rates – applied to total monthly consumption during non-wind hours.
4. Discount rates – applied to total monthly consumption during non-critical peak hours.

The pricing trial rate formulas:

1. Wind Enhancement Period:

   Customer charge + [Baseline rates x (consumption between 6 a.m. – 10 p.m.)] + [Wind Price x (consumption between 10 p.m. - 6 a.m.)] + [Surcharge Rate x (consumption between 6 a.m. – 10 p.m.)]

2. Critical Peak Period:

   Customer Charge + [Baseline rates x (consumption during all hours other than during called critical peak days, 4 p.m.-7 p.m.))] + [Critical Peak Price x (consumption during 4 p.m.-7 p.m. on called critical peak days)] + [Discounted rate x (consumption during all hours other than critical peak hours on called critical peak days)]

If the TOU participant’s pricing trial bill is lower than their actual Austin Energy bill, the difference is credited in their credit account. If the pricing trial bill is higher, the difference is deducted from their credit account. At the end of the pricing trial (after October 2014), payments will be issued to each participant equal to the amount of the final credit in their account, up to a maximum of $700 per customer. If there is a negative credit in a participant’s account, the participant will not owe anything.

PARTICIPANT COMMUNICATION STRATEGY
Recruitment of TOU participants began February 2013 with an outreach program designed by Pecan Street that targeted residents living at the Mueller community in Austin. Owners of single-family residential homes in Mueller were contacted via email by Pecan Street and asked for their participation in the TOU pricing trial. Most residents contacted were part of an earlier Energy Internet Demonstration (EID) program funded by another DOE cooperative agreement. EID participants enrolled into the pricing trial had the requisite HEM systems and legal participation agreements in place. The primary goal of recruiting from the EID pool for the pricing trial was to get a representative sample of participants that had an electric vehicle. The control group participants were also selected from the EID participant pool with an emphasis on those that had an electrical vehicle.

Before the official start of the experiment (March 2013), the TOU group received email communications outlining the experiment design and ways they can shift or reduce their energy consumption. For instance, shifting loads of laundry to after 10 p.m. during the wind enhancement period or reducing air conditioner operations during critical peak hours during the summer months. Pecan Street held one in person workshop for the TOU group to further detail the trial’s design, goal, and research benefits. Each of the TOU participants were given secure access to an online web portal to check the monthly status of their energy usage in kilowatt hours (kWh), pricing trial bill, Austin Energy bill, and any adjustment credit earned.

On the web portal, in addition to pricing trial information, the TOU participants have access to the following information:

- Monthly whole home energy use in kilowatt hours (kWh)
- Monthly energy cost in U.S. dollars per appliance
- Energy generation cost in U.S. dollars if the participant has solar panels
- Real-time energy consumption in kWh
- Monthly energy cost comparison to other participants within the same zip code
- Monthly energy usage trends

During the summer months, TOU participants also receive cell-phone Short Message Service (SMS or “text”) messages and email communications the day before a CPP day. Pecan Street uses a mass-messaging service to send out text and email notifications by 6:00 p.m. to TOU participants the day before the CPP day. The text message content shown below is strictly a factual reminder about the upcoming CPP day and their pricing rate.
Message: Tomorrow is a Critical Peak Pricing event
Your experimental electric rate will be
$0.64 per kilowatt hour from 4 p.m. - 7 p.m.
Pecan Street Inc.

Figure 13. TOU Group Text Message
Appendix E – Normalizing Austin Energy’s annual average grid water usage factor based on ERCOT’s hourly data for wind’s proportion of the generation mix or ERCOT’s Day-Ahead Market (DAM) average hub price for each hour of FY2013

As Part II is not an independent work, it is not included in the text but in the Appendix E. To make it easy to follow, I use the same section titles as what I use in the text.

3. Methodology

3.1 Solar

3.1.1 Solar PV Financial Impact Analysis

Part II – Normalizing Austin Energy’s annual average grid costs based on ERCOT’s Day-Ahead Market (DAM) average hub price for each hour of FY2013

1.) Normalize Austin Energy’s FY2013 average hourly grid electricity cost factor to the hourly level based on ERCOT’s FY2013 hourly DAM average hub price. ERCOT’s DAM average hub settlement price for FY2013 is $30.76/MWh; so, the normalization equation calibrates an hour with a DAM average price of $30.76 to Austin Energy’s average hourly FY2013 cost factor of $0.098035/KWh. An hour’s cost factor veers from $0.098035/KWh based on the percentage by which the DAM average hourly hub price strays from its FY2013 average hourly rate of $30.76/MWh, according to the following equation:

\[ \text{ERCOT DAM Price Adjusted Hourly Cost Factor} = 0.098035 - 0.098035 \times \frac{30.76 - x}{30.76} \]

\( X = \) ERCOT’s DAM average hub price for a specific hour
\( 0.098035 = \) Austin Energy’s FY2013 average hourly grid cost factor (lbs. CO2e)
\( 30.76 = \) ERCOT’s FY2013 DAM average hub price for the average hour

For example, the average ERCOT DAM price during midnight-1am in FY2013 is $23.67/MWh. Substituting 23.67 for “\( x \)”, the “ERCOT DAM Price Adjusted Hourly Cost Factor” for midnight-1am during FY2013 is $0.07544/KWh.\(^{36}\) The “ERCOT DAM Price Adjusted Hourly Cost Factor” is calculated for every hour of FY2013, then averaged for

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\(^{36}\) This equation is meant to alter the Austin Energy FY2013 cost rate by a percentage close to that by which the hour’s DAM average hub price differs from the ERCOT FY2013 average. Here for example, $23.67 is about 23% below the average hour’s DAM average hub price for ERCOT during FY2013 of $30.76; and, the corresponding cost rate of $0.07544/KWh is about 23% less than the Austin Energy FY2013 average cost rate of $0.098035/KWh.
each hour of the day, so that there’s an average utility cost rate for midnight-1am, 1am-2am, 2am-3am, …, and 11pm-midnight.

2.) **Multiply each hour’s household solar PV generation per 1 KW PV array by corresponding hourly cost factors, adjusted based on ERCOT DAM average hub settlement prices.** For example, FY2013 average hourly household solar PV generation per 1 KW PV array for 1pm-2pm is 0.5317 KWh. This number is multiplied by $0.1084/KWh, the utility cost factor for 1pm-2pm adjusted based on ERCOT FY2013 DAM settlement prices. As a result, average hourly utility cost savings from 1pm-2pm household solar PV generation per 1 KW PV array is $0.0576. This process is replicated for all 24 hours of the day. The average hour’s utility cost savings from household solar PV generation – using this approach - $0.0177 per 1 KW PV array.

3.) **Using the average hour’s utility cost savings from household solar PV generation per 1 KW PV array – $0.0177 as calculated in Step (2), above – repeat Step (1)-Step (4) from Part I.**

### 3.1.2 Solar PV Water Impact

*Part II – Normalizing Austin Energy’s annual average grid water usage factor based on ERCOT’s hourly data for wind’s proportion of the generation mix*

1.) **Normalize Austin Energy’s FY2013 average hourly grid electricity water usage factor to the hourly level based on ERCOT’s 2013 hourly generation mix wind percentage.**

Wind’s 2013 average percentage of the ERCOT generation mix is 10.737%; so, the normalization equation calibrates an hour with 10.737% wind generation to Austin Energy’s average hourly FY2013 water usage factor of 0.46 gallons. An hour’s emissions factor veers from 0.46 based on how much wind’s percentage of the generation mix strays from its average, according to the following equation:

\[
Wind \text{ Adjusted Hourly Water Usage Factor} = 0.46 + 0.46 \times \frac{10.737 - x}{100}
\]

- \(X\) = Wind’s % of ERCOT’s generation mix at a specific hour
- 0.46 = Austin Energy’s average hourly grid water usage factor (gallons)
- 10.737 = Hourly average wind % of ERCOT’s 2013 generation mix

For example, the average wind electricity percentage of the ERCOT generation mix during midnight-1am in FY2013 is 13.852. Substituting 13.852 for “x”, the “Wind Adjusted Hourly Water Usage Factor” for midnight-1am during FY2013 is 0.4457
gallons/KWh. The “Wind Adjusted Hourly Water Usage Factor” is calculated for every hour of the year, then averaged for each hour of the day, so that there’s an average water usage rate for midnight-1am, 1am-2am, 2am-3am, …, and 11pm-midnight.

2.) **Multiply each hour’s average household solar PV generation by corresponding wind adjusted hourly water usage factors.** For example, FY2013 average hourly solar PV generation for 1pm-2pm is 0.5317 KWh. This number is multiplied by the FY2013 wind adjusted water usage factor for 1pm-2pm, 0.4728 gallons/KWh. As a result, average hourly grid electricity water savings due to household solar PV generation is 0.2514 gallons. This process is replicated for all 24 hours of the day. The average hour’s grid electricity water usage savings due to household solar PV generation – using this approach – is 0.0736 gallons.

3.) **Using the average hour’s grid electricity water usage savings due to household solar PV generation – 0.0736 gallons as calculated in Step (2), above – repeat Step (1)-Step (4) of Part I.**

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### 3.2 Electric Vehicle

#### 3.2.1 EV Financial Impact Analysis

**Part II – Normalizing Austin Energy’s annual average grid costs based on ERCOT’s Day-Ahead Market (DAM) average hub price for each hour of FY2013**

1.) **Normalize Austin Energy’s FY2013 average hourly grid electricity cost factor to the hourly level based on ERCOT’s FY2013 hourly DAM average hub price.** ERCOT’s DAM average hub settlement price for FY2013 is $30.76/MWh; so, the normalization equation calibrates an hour with a DAM average price of $30.76 to Austin Energy’s average hourly FY2013 cost factor of $0.098035/KWh. An hour’s cost factor veers from $0.098035/KWh based on the percentage by which the DAM average hourly hub price strays from its FY2013 average hourly rate of $30.76/MWh, according to the following equation:

\[
\text{ERCOT DAM Price Adjusted Hourly Cost Factor} = 0.098035 - 0.098035 \times \frac{30.76 - x}{30.76}
\]

\(X = \text{ERCOT’s DAM average hub price for a specific hour}\)

\(0.098035 = \text{Austin Energy’s FY2013 average hourly grid cost factor (lbs. CO2e)}\)

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37 This equation is meant to alter the water usage rate by a percentage close to that by which the hour’s wind percentage differs from the average. Here for example, 13.852% is about 3.1% above the average wind percentage of 10.737%; and, the corresponding water usage rate of 0.4457 gallons/hour is about 3.1% less than the Austin Energy FY2013 average grid water usage rate of 0.46 gallons/hour.
30.76 = ERCOT’s FY2013 DAM average hub price for the average hour

For example, the average ERCOT DAM price during midnight-1am in FY2013 is $23.67/MWh. Substituting 23.67 for “x”, the “ERCOT DAM Price Adjusted Hourly Cost Factor” for midnight-1am during FY2013 is $0.07544/KWh. The “ERCOT DAM Price Adjusted Hourly Cost Factor” is calculated for every hour of FY2013, then averaged for each hour of the day, so that there’s an average utility cost rate for midnight-1am, 1am-2am, 2am-3am, ..., and 11pm-midnight.

2.) **Multiply each hour’s average EV power usage by corresponding hourly cost factors, adjusted based on ERCOT DAM average hub settlement prices.** For example, FY2013 average hourly EV power usage for midnight-1am is 0.2808 KWh. This number is multiplied by $0.07544/KWh, the cost factor for midnight-1am adjusted based on ERCOT FY2013 DAM settlement prices. As a result, average hourly costs for midnight-1am from EV power usage are $0.0212. This process is replicated for all 24 hours of the day. The average hour’s EV cost – using this approach – is $0.0272.

3.) **Using the average hour’s EV cost – $0.0272 as calculated in step (2), above – repeat Step (1)-Step (4) from Part I.**

### 3.2.2 EV Water Impact

*Part II – Normalizing Austin Energy’s annual average grid water usage factor based on ERCOT’s hourly data for wind’s proportion of the generation mix*

1.) **Normalize Austin Energy’s FY2013 average hourly grid electricity water usage factor to the hourly level based on ERCOT’s 2013 hourly generation mix wind percentage.** Wind’s 2013 average percentage of the ERCOT generation mix is 10.737%; so, the normalization equation calibrates an hour with 10.737% wind generation to Austin Energy’s average hourly FY2013 water usage factor of 0.46 gallons. An hour’s emissions factor veers from 0.46 based on how much wind’s percentage of the generation mix strays from its average, according to the following equation:

\[
\text{Wind Adjusted Hourly Water Usage Factor} = 0.46 + 0.46 \times \frac{10.737 - x}{100}
\]

\[
X = \text{Wind’s % of ERCOT’s generation mix at a specific hour}
\]

---

38 This equation is meant to alter the Austin Energy FY2013 cost rate by a percentage close to that by which the hour’s DAM average hub price differs from the ERCOT FY2013 average. Here for example, $23.67 is about 23% below the average hour’s DAM average hub price for ERCOT during FY2013 of $30.76; and, the corresponding cost rate of $0.07544/KWh is about 23% less than the Austin Energy FY2013 average cost rate of $0.098035/KWh.
For example, the average wind electricity percentage of the ERCOT generation mix during midnight-1am in FY2013 is 13.852. Substituting 13.852 for “x”, the “Wind Adjusted Hourly Water Usage Factor” for midnight-1am during FY2013 is 0.4457 gallons/KWh. The “Wind Adjusted Hourly Water Usage Factor” is calculated for every hour of the year, then averaged for each hour of the day, so that there’s an average water usage rate for midnight-1am, 1am-2am, 2am-3am, ..., and 11pm-midnight.

2.) **Multiply each hour’s average EV electricity consumption by corresponding wind adjusted hourly water usage factors.** For example, FY2013 average hourly EV electricity consumption for 1pm-2pm is 0.2297 KWh. This number is multiplied by the FY2013 wind adjusted water usage factor for 1pm-2pm, 0.4728 gallons/KWh. As a result, average hourly grid electricity water usage due to household EV charging is 0.1086 gallons. This process is replicated for all 24 hours of the day. The average hour’s grid electricity water usage due to household EV charging – using this approach – is 0.123 gallons.

3.) **Using the average hour’s grid electricity water usage due to EV charging – 0.123 gallons as calculated in Step (2), above – repeat Step (1)-Step (4) of Part I.**

### 3.3 Critical Peak Pricing (CPP) and Demand Response (DR)

#### 3.3.1 Critical Peak Pricing (CPP)/Demand Response (DR) Financial Analysis

**3.3.1.1 CRITICAL PEAK PRICING (CPP) DAY ANALYSES**

Part II – Normalizing Austin Energy’s annual average grid costs based on ERCOT’s Day-Ahead Market (DAM) average hub price for each hour of FY2013-FY2014

1.) **Normalize Austin Energy’s FY2013 average hourly grid electricity cost factor to the hourly level based on ERCOT’s FY2013 hourly DAM average hub price.** ERCOT’s DAM average hub settlement price for FY2013\(^ {40} \) is $30.76/MWh; so, the normalization equation calibrates an hour with a DAM average hub price of $30.76 to Austin Energy’s average hourly cost factor of $0.098035 (see Appendix B for how this cost factor is derived). An hour’s cost factor veers from $0.098035/KWh based on the percentage by

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\(^{39}\) This equation is meant to alter the water usage rate by a percentage close to that by which the hour’s wind percentage differs from the average. Here for example, 13.852% is about 3.1% above the average wind percentage of 10.737%; and, the corresponding water usage rate of 0.4457 gallons/hour is about 3.1% less than the Austin Energy FY2013 average grid water usage rate of 0.46 gallons/hour.

\(^{40}\) We use the FY2013 ERCOT DAM hourly average hub price because the cost factor we’re adjusting – as derived in Appendix B – is for FY2013.
which the DAM average hourly hub price strays from its FY2013 average hourly rate of $30.76/MWh, according to the following equation:

\[
ERD_{SCOT} \text{ DAM Price Adjusted Hourly Cost Factor} = 0.098035 + 0.098035 \times \frac{30.76 - x}{30.76}
\]

\[X = \text{ERCOT's DAM average hub price for a specific hour}\]
\[0.098035 = \text{Austin Energy’s FY2013 average hourly grid cost factor (lbs. CO2e)}\]
\[30.76 = \text{ERCOT’s FY2013 DAM average hourly summer hub price}\]

For example, the average ERCOT DAM price during midnight-1am in FY2013-FY2014 summer\(^{41}\) months is $28.24/MWh. Substituting 28.24 for “x”, the “ERCOT DAM Price Adjusted Hourly Cost Factor” for midnight-1am during summer months is $0.08999/KWh.\(^{42}\) The “ERCOT DAM Price Adjusted Hourly Cost Factor” is calculated for every hour of the year, then averaged for each hour of the day, so that there’s an average rate for midnight-1am, 1am-2am, 2am-3am, …, and 11pm-midnight.

2.) **Multiply each hour’s average load for CPP days and baseline days by corresponding hourly cost factors, adjusted based on ERCOT DAM average hub settlement prices.** For example, average hourly load during CPP days for the “Control Group” and the “Pricing Trial Group” for midnight-1am is 1.638 KWh and 1.856 KWh, respectively. These numbers are multiplied by $0.08999/KWh, the cost factor for midnight-1am adjusted based on ERCOT FY2013 DAM settlement prices. As a result, average hourly costs for midnight-1am on CPP days for the “Control Group” and “Pricing Trial Group,” respectively, are $0.1474 and $0.1670. Using the same process for “Control Group” and “Pricing Trial Group” baseline days, costs are $0.1204 and $0.1354 during midnight-1am of summer months. This process is replicated for all 24 hours of the day.

3.) **Calculate each hour’s average cost savings from the average member of the “Pricing Trial Group” relative to the average member of the “Control Group.”** Hourly cost savings are calculated as the amount by which CPP day hourly costs exceed those of baseline days for the “Pricing Trial Group,” subtracted from the same difference for the “Control Group,” as shown in the equation below:

\[X = (A - B) - (Y - Z)\]

\(^{41}\) We use summer months from 2013 – or June 2013 through September 2013 – because those are the months during which CPP events occurred in 2013. Because Austin Energy emissions factors are not available for 2014, analyses for CPP events from 2014 use emissions factors for the corresponding months of 2013.

\(^{42}\) This equation is meant to alter the Austin Energy FY2013 cost rate by a percentage close to that by which the hour’s DAM average hub price differs from the ERCOT FY2013 average. Here for example, $28.24 is about 8% below the average hour’s DAM average hub price for ERCOT during FY2013 of $30.76; and, the corresponding cost rate of $0.08999/KWh is about 8% less than the Austin Energy FY2013 average cost rate of $0.098035/KWh.
\[ X = \text{Cost Savings from CPP Day Participation of “Pricing Trial Group”} \]
\[ A = \text{Control Group CPP Day Cost Rate} \]
\[ B = \text{Control Group Baseline Day Cost Rate} \]
\[ Y = \text{Pricing Trial Group CPP Day Cost Rate} \]
\[ Z = \text{Pricing Trial Group Baseline Day Cost Rate} \]

For example, for midnight-1am, the equation would read as follows:

\[-0.0046 = (0.1474 - 0.1204) - (0.1670 - 0.1354)\]

Cost savings are calculated for all 24 hours of the day.

4.) **Average and aggregate each hour’s cost savings from the “Pricing Trial Group” relative to the “Control Group” to obtain the average hour’s cost savings and average day’s cost savings.** For all 24 hours of the day, the average hourly cost savings from those who belong to the “Pricing Trial Group” relative to those who belong to the “Control Group” is $0.00619/hour. Multiplying this number by 24, average daily utility cost savings from a single household are $0.14856/day.

5.) **Apply this cost savings rate to determine emissions reduced from DR for homes included in this sample and more broadly.** As calculated in Step (4), the average cost savings rate from the average “Pricing Trial Group” home over the average “Control Group” home is $0.00619/hour. Using this rate, cost savings from all 45 “Pricing Trial Group” homes for the 27 CPP days in this sample are $181. If there had been 1 million homes in the “Pricing Trial Group” during this period, cost savings would have been $4,011,120.

### 3.3.1.2 WIND ENHANCEMENT DAY ANALYSES

**Part II – Normalizing Austin Energy’s annual average grid costs based on ERCOT’s Day-Ahead Market (DAM) average hub price for each hour of FY2013-FY2014**

1.) **Normalize Austin Energy’s FY2013 average hourly grid electricity cost factor to the hourly level based on ERCOT’s FY2013 hourly DAM average hub price.** ERCOT’s DAM average hub settlement price for FY2013\(^{43}\) is $30.76/MWh; so, the normalization equation calibrates an hour with a DAM average hub price of $30.76 to Austin Energy’s average hourly cost factor of $0.098035 (see Appendix B for how this cost factor is derived). An hour’s cost factor veers from $0.098035/KWh based on the percentage by

---

\(^{43}\) We use the FY2013 ERCOT DAM hourly average hub price because the cost factor we're adjusting – as derived in Appendix B – is for FY2013.
which the DAM average hourly hub price strays from its FY2013 average hourly rate of $30.76/MWh, according to the following equation:

\[
ERCO\text{T DAM Price Adjusted Hourly Cost Factor} = 0.098035 + 0.098035 \times \frac{30.76 - x}{30.76}
\]

\( x = \) ERCOT’s DAM average hub price for a specific hour
\( 0.098035 = \) Austin Energy’s FY2013 average hourly grid cost factor (lbs. CO2e)
\( 30.76 = \) ERCOT’s FY2013 DAM average hourly summer hub price

For example, the average ERCOT DAM price during midnight-1am in FY2013-FY2014 during wind enhancement months\(^{44}\) is $29.00/MWh. Substituting 29.00 for “\( x \)”, the “ERCOT DAM Price Adjusted Hourly Cost Factor” for midnight-1am during summer months is $0.09242/KWh.\(^{45}\) The “ERCOT DAM Price Adjusted Hourly Cost Factor” is calculated for every hour of the year, then averaged for each hour of the day, so that there’s an average rate for midnight-1am, 1am-2am, 2am-3am, … , and 11pm-midnight.

2.) **Multiply each hour’s average load for the “Control Group” and the “Pricing Trial Group” by corresponding hourly cost factors, adjusted based on ERCOT DAM average hub settlement prices.** For example, average hourly load during wind enhancement months for the “Control Group” and the “Pricing Trial Group” for midnight-1am is 0.7036 KWh and 0.7892 KWh, respectively. These numbers are multiplied by the wind enhancement month wind adjusted cost factor for midnight-1am, $0.09242/KWh. As a result, average hourly costs for midnight-1am on wind enhancement days for the “Control Group” and “Pricing Trial Group,” respectively, are $0.0650 and $0.0729. The cost difference – the value for the “Pricing Trial Group” subtracted from the value for the “Control Group” – for midnight-1am is -$0.00791. This process is replicated for all 24 hours of the day.

3.) **Repeat Step (2) using $0.1232/KWh – the average hour’s utility cost rate\(^{46}\) during wind enhancement months – as every hour’s emissions rate.** Average hourly costs for midnight-1am on wind enhancement days for the “Control Group” and “Pricing Trial Group,” respectively, are $0.0867 and $0.0972. The cost difference – the value for the

---

\(^{44}\) Wind enhancement months for this sample were November and December of 2013 and March, April, and May of 2014.

\(^{45}\) This equation is meant to alter the Austin Energy FY2013 cost rate by a percentage close to that by which the hour’s DAM average hub price differs from the ERCOT FY2013 average. Here for example, $29.00 is about 5.7% below the average hour’s DAM average hub price for ERCOT during FY2013 of $30.76; and, the corresponding cost rate of $0.09242/KWh is about 5.7% less than the Austin Energy FY2013 average cost rate of $0.098035/KWh.

\(^{46}\) This statistic, $0.1232/KWh, is the average cost factor of all hours’ “ERCOT DAM Price Adjusted Hourly Cost Factor” for wind enhancement months.
“Pricing Trial Group” subtracted from the value for the “Control Group” – for midnight-1am is -$0.0105. This process is replicated for all 24 hours of the day.

4.) **Calculate each hour’s average cost savings due to load shift from the average member of the “Pricing Trial Group” relative to the average member of the “Control Group.”** Subtract each hour’s cost difference as calculated in step (3), which uses a flat emissions rate for all hours, from the cost difference calculated in step (2), which uses ERCOT DAM average hub price-adjusted cost factors for each hour. Cost savings are calculated for all 24 hours of the day.

\[
X = Y - Z
\]

\[
X = \text{Cost Savings from the “Pricing Trial Group” due to Load Shift}
\]
\[
Y = \text{Step 2 Cost Difference}
\]
\[
Z = \text{Step 3 Cost Difference}
\]

The cost difference for Step (2) and Step (3) is -$0.00791 and -$0.0105, respectively, for midnight-1am during wind enhancement months. Thus, the corresponding cost savings rate for the “Pricing Trial Group” due to load shift is $0.00263/hour. In other words, this value is the amount of costs saved for utilities by the “Pricing Trial Group” relative to the “Control Group” when accounting for cost factors fluctuating for each hour of the day instead of there being one flat cost factor for all hours of the day.

5.) **Average and aggregate each hour’s cost savings due to load shift from the “Pricing Trial Group” relative to the “Control Group” to obtain the average hour’s cost savings and average day’s cost savings.** For all 24 hours of the day, the average hourly cost savings due to load shift from those who belong to the “Pricing Trial Group” relative to those who belong to the “Control Group” is $0.0020. Multiplying this number by 24, average daily cost savings from are $0.0489.

6.) **Apply this rate of cost savings due to load shift to determine costs reduced from time-of-use pricing (TOU) for homes included in this sample and more broadly.** As calculated in Step (5), the average cost savings rate from the average “Pricing Trial Group” home over the average “Control Group” home is $0.0489/day. Using this rate, cost savings from all 45 “Pricing Trial Group” homes for the 153 wind enhancement days in this sample are $337. If there had been 1 million homes in the “Pricing Trial Group” during this period, cost savings would have been $7,481,700.
3.3.2.1 CRITICAL PEAK PRICING (CPP) DAY WATER ANALYSES

Part II – Normalizing Austin Energy’s annual average grid water usage factor based on ERCOT’s hourly data for wind’s proportion of the generation mix

1.) **Normalize Austin Energy’s FY2013 average hourly grid electricity water usage factor to the hourly level based on ERCOT’s 2013 hourly generation mix wind percentage.**

Wind’s 2013 average percentage of the ERCOT generation mix is 10.737%; so, the normalization equation calibrates an hour with 10.737% wind generation to Austin Energy’s average hourly FY2013 water usage factor of 0.46 gallons. An hour’s emissions factor veers from 0.46 based on how much wind’s percentage of the generation mix strays from its average, according to the following equation:

\[
\text{Wind Adjusted Hourly Water Usage Factor} = 0.46 + 0.46 \times \frac{10.737 - x}{100}
\]

\[X = \text{Wind’s \% of ERCOT’s generation mix at a specific hour} \]
\[0.46 = \text{Austin Energy’s average hourly grid water usage factor (gallons)} \]
\[10.737 = \text{Hourly average wind \% of ERCOT’s 2013 generation mix} \]

For example, the average wind electricity percentage of the ERCOT generation mix during midnight-1am in FY2013 is 13.852. Substituting 13.852 for “x”, the “Wind Adjusted Hourly Water Usage Factor” for midnight-1am during FY2013 is 0.4457 gallons/KWh. The “Wind Adjusted Hourly Water Usage Factor” is calculated for every hour of the year, then averaged for each hour of the day, so that there’s an average water usage rate for midnight-1am, 1am-2am, 2am-3am, … , and 11pm-midnight.

2.) **Multiply each hour’s average load for CPP days and baseline days by corresponding wind adjusted hourly water usage factors.** For example, average hourly load during CPP days for the “Control Group” and the “Pricing Trial Group” for midnight-1am is 1.638 KWh and 1.856 KWh, respectively. These numbers are multiplied by the summer wind adjusted water usage factor for midnight-1am, 0.4665 gallons/KWh. As a result, average hourly water usage for midnight-1am on CPP days for the “Control Group” and “Pricing Trial Group,” respectively, are 0.7642 gallons and 0.8656 gallons. Using the same process for the “Control Group” and “Pricing Trial Group” baseline days, water

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47 This equation is meant to alter the water usage rate by a percentage close to that by which the hour’s wind percentage differs from the average. Here for example, 13.852% is about 3.1% above the average wind percentage of 10.737%; and, the corresponding water usage rate of 0.4457 gallons/hour is about 3.1% less than the Austin Energy FY2013 average grid water usage rate of 0.46 gallons/hour.
usage is 0.6243 gallons and 0.7019 gallons during midnight-1am of summer months. This process is replicated for all 24 hours.

3.) **Calculate each hour’s average water usage savings from the average member of the “Pricing Trial Group” relative to the average member of the “Control Group.”** Hourly water savings are calculated as the amount by which CPP day hourly water usage exceeds that of baseline days for the “Pricing Trial Group,” subtracted from the same difference for the “Control Group,” as shown in the equation below:

\[
X = (A - B) - (Y - Z)
\]

Where:
- \(X\) = Water Savings from CPP Day Participation of “Pricing Trial Group”
- \(A\) = Control Group CPP Day Water Usage Rate
- \(B\) = Control Group Baseline Day Water Usage Rate
- \(Y\) = Pricing Trial Group CPP Day Water Usage Rate
- \(Z\) = Pricing Trial Group Baseline Day Water Usage Rate

For example, for midnight-1am, the equation would read as follows:

\[
-0.024 \text{ Gallons} = (0.7642 \text{ Gallons} - 0.6243 \text{ Gallons}) - (0.8656 \text{ Gallons} - 0.7019 \text{ Gallons})
\]

Water usage savings are calculated for all 24 hours of the day.

4.) **Average and aggregate each hour’s water savings from the “Pricing Trial Group” relative to the “Control Group” to obtain the average hour’s water savings and average day’s water savings.** For all 24 hours of the day, the average hourly water savings from those who belong to the “Pricing Trial Group” relative to those who belong to the “Control Group” is 0.0094 gallons. Multiplying this number by 24 hours, average daily savings are 0.2263 gallons.

5.) **Apply this water savings rate to determine water usage reduced from DR for homes included in this sample and more broadly.** As calculated in Step (4), the average water savings rate from the average “Pricing Trial Group” home over the average “Control Group” home is 0.0094 gallons/hour. Using this rate, water savings from all 45 “Pricing Trial Group” homes for the 27 CPP days in this sample are 274.95 gallons. If there had been 1 million homes in the “Pricing Trial Group” during this period, water savings would have been 6,110,100 gallons.

**3.3.2.2 WIND ENHANCEMENT DAY WATER ANALYSES**
Part II – Normalizing Austin Energy’s annual average grid water usage factor based on ERCOT’s hourly data for wind’s proportion of the generation mix

1.) **Normalize Austin Energy’s FY2013 average hourly grid electricity water usage factor to the hourly level based on ERCOT’s 2013 hourly generation mix wind percentage.**

Wind’s 2013 average percentage of the ERCOT generation mix is 10.737%; so, the normalization equation calibrates an hour with 10.737% wind generation to Austin Energy’s average hourly FY2013 water usage factor of 0.46 gallons. An hour’s emissions factor veers from 0.46 based on how much wind’s percentage of the generation mix strays from its average, according to the following equation:

\[
\text{Wind Adjusted Hourly Water Usage Factor} = 0.46 + 0.46 \times \frac{10.737 - x}{100}
\]

\[X = \text{Wind’s \% of ERCOT's generation mix at a specific hour}
\]
\[0.46 = \text{Austin Energy's average hourly grid water usage factor (gallons)}
\]
\[10.737 = \text{Hourly average wind \% of ERCOT’s 2013 generation mix}
\]

For example, the average wind electricity percentage of the ERCOT generation mix during midnight-1am in wind enhancement months is 16.744. Substituting 16.744 for “x”, the “Wind Adjusted Hourly Water Usage Factor” for midnight-1am during FY2013 is 0.4324 gallons/KWh. The “Wind Adjusted Hourly Water Usage Factor” is calculated for every hour of the year, then averaged for each hour of the day, so that there’s an average water usage rate for midnight-1am, 1am-2am, 2am-3am, … , and 11pm-midnight.

2.) **Multiply each hour’s average load for the “Control Group” and the “Pricing Trial Group” by corresponding wind adjusted hourly water usage factors.** For example, average hourly load during wind enhancement months for the “Control Group” and the “Pricing Trial Group” for midnight-1am is 0.7036 KWh and 0.7892 KWh, respectively. These numbers are multiplied by the wind enhancement month wind adjusted water usage factor for midnight-1am, 0.4324 gallons/KWh. As a result, average hourly water usage for midnight-1am on wind enhancement days for the “Control Group” and

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48 We use 2013 data for November, and December because those are the months during which wind enhancement days occurred in 2013. Because Austin Energy emissions factors are not available for 2014, analyses for wind enhancement days during March, April, and May of 2014 use emissions factors for the corresponding months of 2013.

49 This equation is meant to alter the water usage rate by a percentage close to that by which the hour’s wind percentage differs from the average. Here for example, 16.744% is about 6% above the average wind percentage of 10.737%; and, the corresponding water usage rate of 0.4324 gallons/hour is about 6% less than the Austin Energy FY2013 average grid water usage rate of 0.46 gallons/hour.
“Pricing Trial Group,” respectively, are 0.3042 gallons and 0.3412 gallons. The water usage difference – the value for the “Pricing Trial Group” subtracted from the value for the “Control Group” – for midnight-1am is -0.037 gallons. This process is replicated for all 24 hours of the day.

3.) **Repeat Step (2) using 0.4482 gallons/hour – the average hour’s emission’s rate**\(^{50}\) **during wind enhancement months – as every hour’s emissions rate.** Average hourly water usage for midnight-1am on wind enhancement days for the “Control Group” and “Pricing Trial Group,” respectively, is 0.3154 gallons and 0.3537 gallons. The water usage difference – the value for the “Pricing Trial Group” subtracted from the value for the “Control Group” – for midnight-1am is -0.038 gallons. This process is replicated for all 24 hours of the day.

4.) **Calculate each hour’s average water usage savings due to load shift from the average member of the “Pricing Trial Group” relative to the average member of the “Control Group.”** Subtract each hour’s water usage difference as calculated in step (3), which uses a flat water usage rate for all hours, from the water usage difference calculated in step (2), which uses wind adjusted water usage factors for each hour. Water savings are calculated for all 24 hours of the day.

\[
X = Y - Z
\]

\(X = \) Water Savings from the “Pricing Trial Group” due to Load Shift  
\(Y = \) Step 2 Water Usage Difference  
\(Z = \) Step 3 Water Usage Difference

The water usage difference for Step (2) and Step (3) is -0.037 gallons and -0.038 gallons, respectively, for midnight-1am during wind enhancement months. Thus, the corresponding water savings rate for the “Pricing Trial Group” due to load shift is 0.001 gallons/hour. In other words, this value is the amount of water saved by the “Pricing Trial Group” relative to the “Control Group” when accounting for water usage factors’ fluctuation for each hour of the day instead of there being one flat emissions factor for all hours of the day.

5.) **Average and aggregate each hour’s water savings due to load shift from the “Pricing Trial Group” relative to the “Control Group” to obtain the average hour’s water savings and average day’s water savings.** For all 24 hours of the day, the average

---

\(^{50}\) This statistic, 0.4482 gallons/hour, is the average water usage factor of all hours’ “Wind Adjusted Hourly Water Usage Factors” for wind enhancement months.
hourly water savings due to load shift from those who belong to the “Pricing Trial Group” relative to those who belong to the “Control Group” is 0.0010 gallons. Multiplying this number by 24 hours, average daily water savings from load shift are 0.0247 gallons.

6.) **Apply this rate of water savings due to load shift to determine water usage reduced from time-of-use pricing (TOU) for homes included in this sample and more broadly.** As calculated in Step (5), the average water savings rate from the average “Pricing Trial Group” home over the average “Control Group” home is 0.0247 gallons/day. Using this rate, water savings from all 45 “Pricing Trial Group” homes for the 153 wind enhancement days in this sample are 170.1 gallons. If there had been 1 million homes in the “Pricing Trial Group” during this period, water savings would have been 3,779,100 gallons.

4. Result

4.1 Solar

*Part II – Normalizing Austin Energy’s annual average grid costs based on ERCOT’s Day-Ahead Market (DAM) average hub price for each hour of FY2013*

Table 5.2, below, displays the findings for solar generation and corresponding utility cost savings due to household PV generation in all solar homes, as well as for homes disaggregated by directions panels face. We use cost factors adjusted for each hour of the day based on ERCOT’s Day-Ahead Market (DAM) average hub price for each hour of FY2013.

<table>
<thead>
<tr>
<th>Table 5.2 - Solar Generation and Corresponding Electricity and Utility Cost Savings, by Orientation, Adjusting for ERCOT DAM Average Hourly Hub Prices</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Hourly Generation (KWh)</td>
</tr>
<tr>
<td>0.884 KWh</td>
</tr>
<tr>
<td>Ave. Hourly Gen. for a 1 KW PV Array (KWh)</td>
</tr>
<tr>
<td>Ave. Hourly Gen (KWh) Assuming Ave. Panel Size of 5.642 KW</td>
</tr>
</tbody>
</table>
### Corresponding Electricity and Utility Cost Savings, by Orientation

<table>
<thead>
<tr>
<th>Hourly Cost Savings from Solar Generation for a 1KW PV Array ($)</th>
<th>$0.0177</th>
<th>$0.0182</th>
<th>$0.0174</th>
<th>$0.0175</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual Cost Savings for a 1KW PV Array ($)</td>
<td>$155.05</td>
<td>$159.43</td>
<td>$152.42</td>
<td>$153.30</td>
</tr>
<tr>
<td>Annual Cost Savings ($) Assuming Average Panel Size of 5.642 KW</td>
<td>$874.80</td>
<td>$899.51</td>
<td>$859.98</td>
<td>$864.92</td>
</tr>
<tr>
<td>FY2013 Dollars Saved from PV for Mueller Homes in this Study ($)</td>
<td>$96,228</td>
<td>$23,387</td>
<td>$55,898</td>
<td>$7,784</td>
</tr>
</tbody>
</table>

### Water Savings, by Orientation

<table>
<thead>
<tr>
<th>Hourly Water Savings from Solar Generation for a 1KW PV Array (gal)</th>
<th>0.0736 Gallons</th>
<th>0.0775 Gallons</th>
<th>0.0720 Gallons</th>
<th>0.0698 Gallons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual Water Savings for a 1KW PV Array (gal)</td>
<td>645.12 Gallons</td>
<td>679.17 Gallons</td>
<td>630.78 Gallons</td>
<td>611.34 Gallons</td>
</tr>
<tr>
<td>Annual Water Savings (gal) Assuming Average Panel Size of 5.642 KW</td>
<td>3,639.76 Gallons</td>
<td>3,831.86 Gallons</td>
<td>3,558.86 Gallons</td>
<td>3,449.16 Gallons</td>
</tr>
<tr>
<td>FY2013 Water Saved from PV for Mueller Homes in this Study (gallons)</td>
<td>400,373.75 Gallons</td>
<td>421,505.09 Gallons</td>
<td>391,474.81 Gallons</td>
<td>379,407.38 Gallons</td>
</tr>
</tbody>
</table>

### 5.2 EV

**Table 6.2 - Vehicle Energy Consumption, Costs and Water Consumption for Homes with EV's and Traditional Vehicles (for homes without chargers at work and complete data sets for FY2013)**
<table>
<thead>
<tr>
<th></th>
<th>EV</th>
<th>Traditional Vehicle</th>
<th>Savings from EV over Traditional Vehicle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hourly Household Car Electricity Consumption (KWh)</td>
<td>0.267 KWh</td>
<td>0 KWh</td>
<td>(-0.267) KWh</td>
</tr>
</tbody>
</table>

**Vehicle Energy Consumption Related Costs for Homes with EV's and Traditional Vehicles (for homes without chargers at work and complete data sets for FY2013)**

<table>
<thead>
<tr>
<th></th>
<th>EV</th>
<th>Traditional Vehicle</th>
<th>Savings from EV over Traditional Vehicle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hourly Vehicle Electricity Costs ($)</td>
<td>0.0263 dollars</td>
<td>0</td>
<td>(-0.0263) dollars</td>
</tr>
<tr>
<td>Annual Vehicle Electricity Costs ($)</td>
<td>230.0 dollars</td>
<td>0</td>
<td>(-230.0) dollars</td>
</tr>
</tbody>
</table>

**Car Gas Use and Costs**

<table>
<thead>
<tr>
<th>Car Gas Consumption</th>
<th>41 Gallons^/ 1,507 Miles</th>
<th>528 Gallons^^/ 11,400 Miles</th>
<th>487 Gallons/ 9,893 Miles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hourly Car Gas Costs ($)</td>
<td>0.016</td>
<td>0.206</td>
<td>0.191</td>
</tr>
<tr>
<td>Annual Car Gas Costs ($)</td>
<td>140.5</td>
<td>1809.5</td>
<td>1668.949</td>
</tr>
</tbody>
</table>

**Total Car Fuel Costs from Both Electricity and Gasoline**

<table>
<thead>
<tr>
<th></th>
<th>EV</th>
<th>Traditional Vehicle</th>
<th>Savings from EV over Traditional Vehicle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hourly Vehicle Total Costs ($)</td>
<td>0.0415</td>
<td>0.206</td>
<td>0.165</td>
</tr>
<tr>
<td>Annual Vehicle Total Costs ($)</td>
<td>378.8</td>
<td>1809.5</td>
<td>1,431</td>
</tr>
</tbody>
</table>

**FY2013 Fuel Cost Savings from All 25 EVs in this Sample**

<table>
<thead>
<tr>
<th></th>
<th>EV</th>
<th>Traditional Vehicle</th>
<th>Savings from EV over Traditional Vehicle</th>
</tr>
</thead>
<tbody>
<tr>
<td>FY2013 Fuel Cost Savings from All 25 EVs in this Sample</td>
<td>NA</td>
<td>NA</td>
<td>$35,775</td>
</tr>
</tbody>
</table>

**Water Consumption for Homes with EV's and Traditional Vehicles (for homes without chargers at work and complete data sets for FY2013)**

<table>
<thead>
<tr>
<th></th>
<th>EV</th>
<th>Traditional Vehicle</th>
<th>Savings from EV over Traditional Vehicle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hourly Vehicle Water Consumption (Gallons)</td>
<td>0.1230 Gallons</td>
<td>0</td>
<td>(-0.1230) Gallons</td>
</tr>
<tr>
<td>Annual Vehicle Water Consumption (Gallons)</td>
<td>1,077.48 Gallons</td>
<td>0</td>
<td>(-1,077.48) Gallons</td>
</tr>
</tbody>
</table>

**Car Gas Use and Water Usage**
The differences between the results conveyed in Part I and Part II in Section 4.2 are marginal. The fact that results in Table 6.1 and Table 6.2 are so similar shows that the times of day this sample’s EV owners charged their cars during FY2013 was not an influential factor regarding EVs’ grid electricity-related water usage. Even after accounting for hourly fluctuations in car charging and grid-related water usage, the hourly water usage rate from fueling EVs with electricity increases from 0.1228 gallons/hour to 0.1230 gallons/hour, a difference of less than one thousandth of a gallon per hour. The corresponding annual water savings for EV owners are lower in Table 6.2, down to 1,002.65 gallons/year from 1,004.23 gallons/year.

<table>
<thead>
<tr>
<th>Car Gas Consumption</th>
<th>41 Gallons^/1,507 Miles</th>
<th>528 Gallons^^/11,400 Miles</th>
<th>487 Gallons/9,893 Miles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual Water Usage from Car Gasoline (Gallons of Water)</td>
<td>175.12 Gallons</td>
<td>2,255.25 Gallons</td>
<td>2,080.13 Gallons</td>
</tr>
</tbody>
</table>

**Total Car Water Usage from Both Electricity and Gasoline**

<table>
<thead>
<tr>
<th>Hourly Vehicle Water Consumption (Gallons)</th>
<th>0.1430 Gallons</th>
<th>0.2574 Gallons</th>
<th>0.1144 Gallons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual Vehicle Total Costs ($)</td>
<td>1,252.6 Gallons</td>
<td>2,255.25 Gallons</td>
<td>1,002.65 Gallons</td>
</tr>
<tr>
<td>FY2013 Fuel Cost Savings from All 25 EVs in this Sample</td>
<td>NA</td>
<td>NA</td>
<td>25,066.25 Gallons</td>
</tr>
</tbody>
</table>

^ Assuming Chevy Volt mileage per gallon of 37 mpg, according to the DOE, http://www.fueleconomy.gov/feg/Find.do?action=sbs&id=31618&id=30980&id=33398

^^ Assuming mileage per gallon of 21.6 mpg, according to EPA’s estimate for the average passenger vehicle http://www.epa.gov/otaq/climate/documents/420f14040.pdf