Climate Control: Smart Thermostats, Demand Response, and Energy Efficiency in Austin, Texas

by

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Submitted to the Department of Urban Studies and Planning on January 15, 2015 in partial fulfillment of the requirements for the degree of Master in City Planning.

Abstract

Energy efficiency and demand response are critical resources for the transition to a cleaner electricity grid. Demand-side management programs can reduce electricity use during peak times when power is scarce and expensive, and they can help to integrate intermittent renewable energy resources by balancing real-time supply and demand for electricity. These programs are more cost-effective than large-scale energy storage technologies and are particularly important in cities and states with strong climate change and energy goals.

Since 2000, Austin Energy has managed a residential demand response program that enables it to reduce air conditioning usage by remotely adjusting thermostat settings at tens of thousands of homes. The utility distributed free thermostats to households that participated in this program; however, by 2012, it determined that only one third of them were working as intended. During the summer of 2013, Austin Energy decided to implement a new program utilizing new technology, Wi-Fi connected "smart" thermostats. Instead of providing free thermostats to reduce peak demand, the utility encouraged residents to bring their own device and receive a one-time $85 enrollment incentive.

This thesis analyzes these two approaches to residential demand response as measured by program enrollment rates and participant performance during demand response events. In addition, it assesses the smart thermostats' ability to reduce energy consumption (i.e. improve energy efficiency) over the course of the summer. My analysis indicates that smart thermostats were more effective at reducing peak demand than the free thermostats employed in the previous program. However, homes with smart thermostats used more energy for air conditioning over the course of the summer than homes without, indicating limited energy efficiency potential from smart thermostats among the study population.

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Introduction

When Thomas Edison opened the first central power station on Pearl Street in New York City in 1882, electric power was a local commodity. Edison's company served a five-block radius in lower Manhattan, and it charged customers according to the number of light bulbs illuminated (IEEE, 2013). Today's electric grid has grown into an international feat of engineering that transports electrons across thousands of miles to power myriad devices. And though it has been called the "world's largest and most complex machine," the electric grid is so reliable as to be taken for granted during the vast majority of the year (Schewe, 2007).

The grid may have outgrown Edison's hyper-local delivery model, but for nearly 15 percent of the U.S. population, electric power is still a locally managed commodity. Approximately one in seven Americans gets electric power not from an international conglomerate, but from the very city they live in, through one of the nation's more than 2,000 municipal utilities. Most municipal utilities serve communities of 3,000 customers or fewer; however, 9 of the nation's 25 largest cities, including Los Angeles, San Antonio, Seattle, and Orlando, operate their own electric utilities (APPA, 2014).

Municipal ownership of the electric system presents several benefits: The city gains increased control over its electricity supply and distribution network, it collects bondable revenue from citizens' electric bills, and it can move more swiftly than an investor-owned utility can to introduce innovative programs. Unlike an investor-owned utility, which answers to its shareholders as well as state and federal regulators, a municipal utility is governed by its local constituents, usually through the city council or a specially appointed administrative body. As a result, the Regulatory Assistance Project reports, "In general, [municipally owned utilities] have much more streamlined processes for setting rates and policies" (RAP, 2011).

This flexibility afforded to municipal utilities is particularly important in light of municipal efforts to promote environmental sustainability. A dozen U.S. cities have joined the international C40 Cities Climate Leadership Group and nearly 150 have adopted climate action plans with ambitious goals related to energy efficiency and carbon dioxide emissions reductions (U.S. Conference of Mayors , 2014). These efforts serve both environmental and economic goals. By cutting energy consumption, cities can reduce their contribution to climate change and limit energy-related expenditures. Furthermore, studies have found that energy-efficient homes tend to command higher prices, which may also increase future tax revenue (Khan & Kok, 2012). By turning to renewable energy, cities can take control of a portion of their electricity supply and ensure a predictable rate for carbon-free power.

As implementers of renewable energy and energy efficiency programs, electric power utilities are critical actors in urban sustainability efforts. Their contributions are particularly important in the American Southwest, which is expected to see exceptional growth in population and electricity use through 2025 (Cohen, Edwards, & Marnay, 2005). That growth would not be possible without the energy-intensive process of air conditioning. Indeed, as Stan Cox notes in *Losing Our Cool*, near ubiquitous climate control created the conditions for economic growth in the hottest areas of the country—the Southeast and Southwest—to outpace the rest of the U.S. for the full decade prior to the 2008 recession. "Without air conditioning," he writes, "Jacksonville would not have become an insurance and banking center, and Birmingham would not have moved from steel into health care and communications" (Cox 2010, page 91).

Air conditioning has also become commonplace in U.S. homes. Nearly 100 million American homes have air conditioning, and predictably, homes in the South are almost twice as likely to have central A/C as homes in the Northeast (EIA, 2011). In fact, the U.S. Energy Information Administration reports, "almost all new homes in the South have central air conditioning" (EIA, 2013). During the warmer months, air conditioning accounts for a large share of overall home energy use. A recent study by the energy research organization Pecan Street Inc. determined that air conditioning represented an average of 66 percent of the surveyed homes' daily electricity use during the summer of 2013 (Pecan Street, 2014). Air conditioning usage is also highly coincident, meaning that when one home turns on the A/C, its neighbors are likely to, as well. As a result, air conditioning accounts for approximately 45 percent of average summer peak electricity demand nationally—and between 50 to 70 percent in warm states like Texas—which creates both environmental and economic costs (Mowris & Jones, 2008; Henry, 2014). Clearly, if cities and their municipal utilities plan to curb residential energy use in the interest of meeting their climate goals, they have to do something about air conditioning.

This thesis examines two utility-run programs that aim to reduce A/C use in homes during peak periods. Both programs were created by Austin Energy, one of the largest municipal utilities in the United States serving approximately one million residents. The programs provide incentives for allowing the utility to control homeowners' thermostats during the hottest days of summer, and both remain in operation as of January 2015. I selected Austin Energy as research subject because the utility plays a central role in helping the city meet its climate change goals and because it has deployed a novel techology, namely programmable communicating thermostats, also known as "smart thermostats," to reduce electricity demand. In addition, the availability of high-quality energy consumption data from Austin-area homes enabled me to pursue an additional research question—whether smart thermostats can be used to improve energy efficiency by reducing electricity use not only during peak periods, but also throughout the summer.

I discovered that smart thermostats are well suited to reducing peak demand in single-family homes in Austin. Smart thermostats increase the average peak demand reduction from participating homes, reduce opt-out behavior, and have roughly doubled annual thermostat enrollments at single-family homes, as compared the average annual enrollment of a previous program with utility-sponsored free thermostats. However, smart thermostats do not appear to be more effective at cutting overall air conditioning-related energy use than traditional thermostats. My analysis shows that homes with smart thermostats used approximately 30 percent more electricity for air conditioning than comparable homes without smart thermostats over the course of the summer of 2014. This result is statistically significant; however, it may be the result of unobserved pre-existing differences within the homes studied and may be improved through access to additional data not available in the public realm, including the date of the thermostat's installation, which would facilitate a "pre/post" analysis.

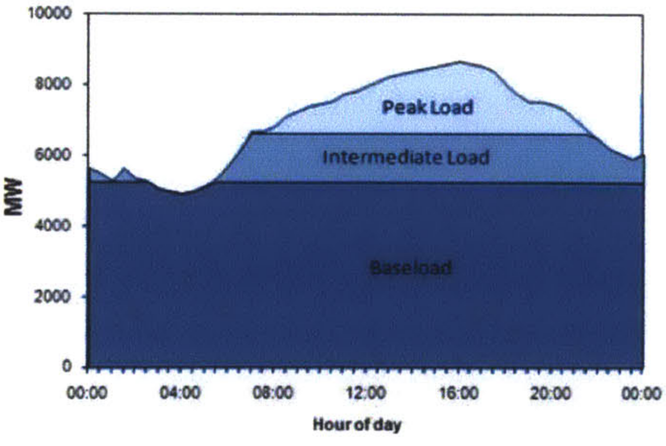
Despite these limitations, these results suggest that smart thermostats are excellent enabling technologies for residential "demand response" programs, yet they should not be relied upon for utility-sponsored energy efficiency programs, at least not without additional analysis or other interventions like behavioral cues, complementary home efficiency upgrades, or rate structures that encourage reductions in both peak and off-peak hours. These findings bear consideration for any utility—municipal or otherwise—that is interested in managing residential energy use through smart thermostats.

Why Peak Demand Matters To Utilities

Austin Energy is a municipal entity, but it is still in the business of selling electricity. Why would a utility company be interested in cutting sales of its only product? The answer to that question is rooted in the nature of electricity as a regulated commodity.

Electricity is difficult and expensive to store on a large scale. As a result, utilities and grid operators must constantly balance supply and demand. Every minute, power plants are throttled up or down or transmission paths are shifted to compensate for changes in consumer demand for electricity, also known as "load." Under the traditional model for electricity service, power comes from one of three types of generators: "baseload" power plants that operate almost continuously, reserve power plants that accommodate fluctuations in demand, and "peaking" power plants that only operate when demand is exceptionally high. (Figure 1 illustrates a typical daily load curve and power plant dispatch order.)

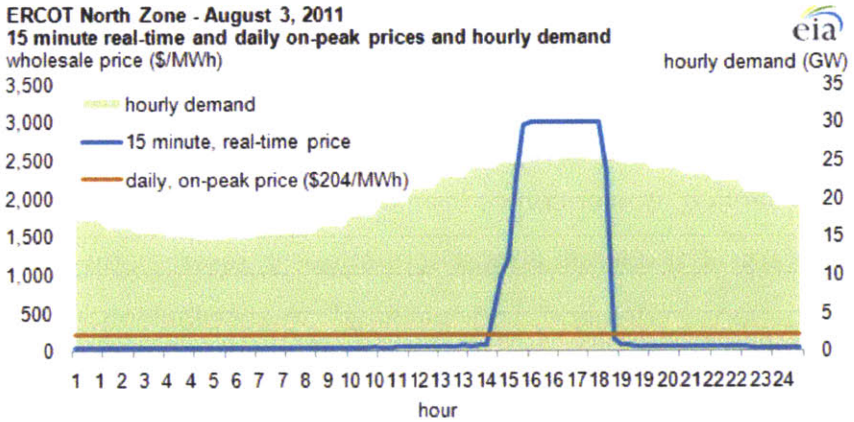
Figure 1. Typical Daily Load Curve



Source: Institute for Energy Research

In the utility industry, this is considered "supply-side" management of the electric grid; however, this one-sided approach comes at a cost. When demand for electricity is particularly high, the marginal cost of producing it can rise dramatically. During peak conditions—which often only occur during a handful of hours per year and are highly correlated with extreme temperatures—power producers turn to power plants that are typically older, more expensive to operate profitably, and generally produce more emissions per unit of generation. These marginal generating units command a much higher price for power and therefore drive up the overall price in the wholesale market. The result can be an order-of-magnitude or greater increase in electricity prices. For example, an August 2011 Texas heat wave drove real-time electricity prices from an average of $45 per megawatt-hour during off-peak hours to $1,937 per megawatt-hour between 2:00 p.m. and 7:00 p.m. (EIA, 2011) (Figure 2). Such short-term price increases are expensive for large power consumers who buy their power on the wholesale markets, including many municipal utilities.

Figure 2. 2011 Texas Power Price Spike



Source: U.S. Energy Information Administration

The high cost of providing power during peak periods is well known in the electric power industry; however, most utility customers are unaware of their individual impact on the grid. The majority of utility customers are billed a flat rate per kilowatt-hour, so there is little financial incentive to reduce consumption during peak times. From the customer's perspective, it costs the same amount to run the dishwasher during an August heat wave as it does on a mild evening in October. There is also little real-time communication from utilities about grid emergencies that would benefit from consumer action. If homeowners were informed that an outage was imminent unless they collectively cut power consumption, they might be willing to use a little less energy to prevent a blackout.

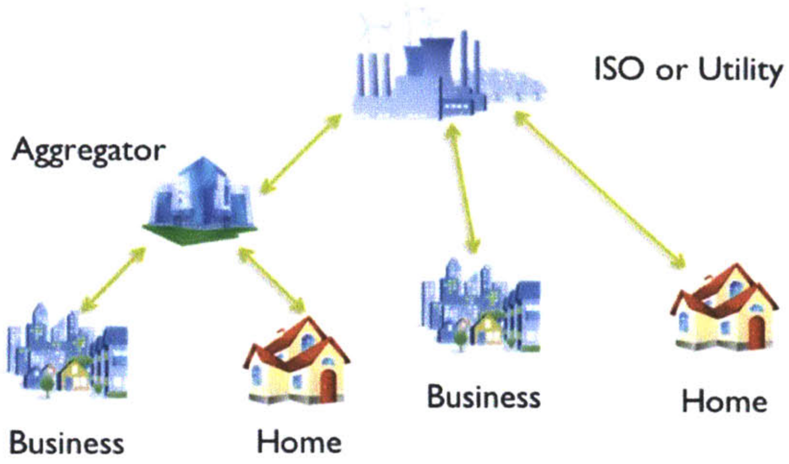
Due to these failures in both price signals and information, the "demand side" of the energy equation has traditionally played a passive role in shaping the electricity grid. But in recent years, "demand response" programs have changed that paradigm by providing the economic incentives and market access necessary to make consumers active participants in the electricity system.

Defining Demand Response

Synapse Energy Economics defines demand response as "the intentional modification of electricity usage by end-use customers during system imbalances or in response to market prices" (Hurley, Whited, & Peterson, 2013). Another definition popularized by the Rocky Mountain Institute's chief scientist Amory Lovins is the "negawatt," a term meant to signify the opposite of a megawatt, or any saved watts of electricity (Lovins, 1990). Demand response is related to energy efficiency, but it is important to distinguish between the two concepts. Energy efficiency refers to the ability to provide the same energy services—like lighting, cooling, or computing, for example—for less energy input. Efficiency improvements tend to be technical in nature and often permanent, such as replacing an incandescent light bulb with an LED bulb. Most demand response programs, on the other hand, create incentives for producing "negawatts" through *temporary* cuts in energy consumption during peak periods or emergencies, or for shifting energy consumption from one time period to another.

To participate in a demand response program, an office building might change its temperature set point by a degree or two or shut down one of several elevator banks, a shopping mall could temporarily turn off decorative lighting or water fountains, or a ski resort could suspend snowmaking operations until a later hour. (Figure 3 depicts a typical demand response dispatch.) Although such programs help consumers to save a small amount of energy during each demand response event, the bigger motivation is typically an incentive payment for offering this "load shedding" service, which helps the grid operator or utility company reduce operating costs and avoid blackouts. For large energy consumers, these incentives can be significant. For example, at the 2011/2012 clearing price for a megawatt of demand response in the PJM Interconnection market, a customer would have been paid $40,150 per year for one megawatt of load shedding capacity (Gottstein, 2011).

Figure 3. Typical Demand Response Dispatch Signal Path



Adapted from OpenADR Alliance

History of Demand Response

Demand response is not a particularly new idea. For decades, utilities have looked to the demand side to assist them during peak periods. Modern demand response programs have their roots in "interruptible rate" agreements, in which utilities offer large industrial consumers a discounted rate for electricity in exchange for the ability to cut off power during an emergency. These agreements benefit both parties: Utilities can avoid the difficulties of instituting rolling blackouts in residential neighborhoods, potentially angering thousands of customers in the process, and large energy consumers enjoy a favorable rate for electricity.[1]

Interruptible rate programs were commonplace when most U.S. electric power utilities operated as regulated monopolies. During the 1990s, that model changed dramatically. At the time, states like California were experiencing sharp increases in electricity prices and began considering deregulation as a way of curbing costs (Warwick, 2002). California's restructuring process followed a model that was previously implemented in the United Kingdom, and it set off a wave of utility restructuring across

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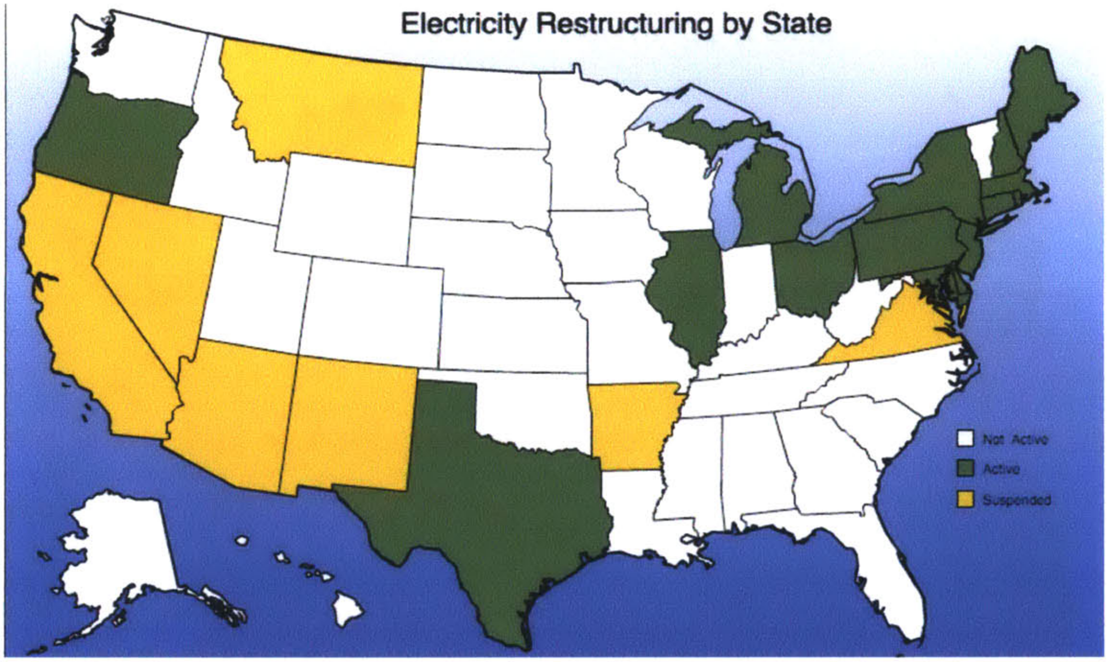
[1] Interruptible rate programs have also been designed for residential customers, usually by controlling homeowners' electric water heaters.

several U.S. states. Restructuring replaced the utility monopoly model with competitive markets for electric power generation. As a result, utilities in restructured states shed their generation assets and became transmission and distribution companies. In restructured markets, prices for power are determined through centralized auctions rather than through regulated rates, and this increased competition was intended to drive down prices. Although the fervor for utility restructuring diminished significantly in the wake of the Enron scandal, which revealed loopholes in California's original market design, today, 15 states have restructured and competitive wholesale power markets, including Texas (see Figure 4).

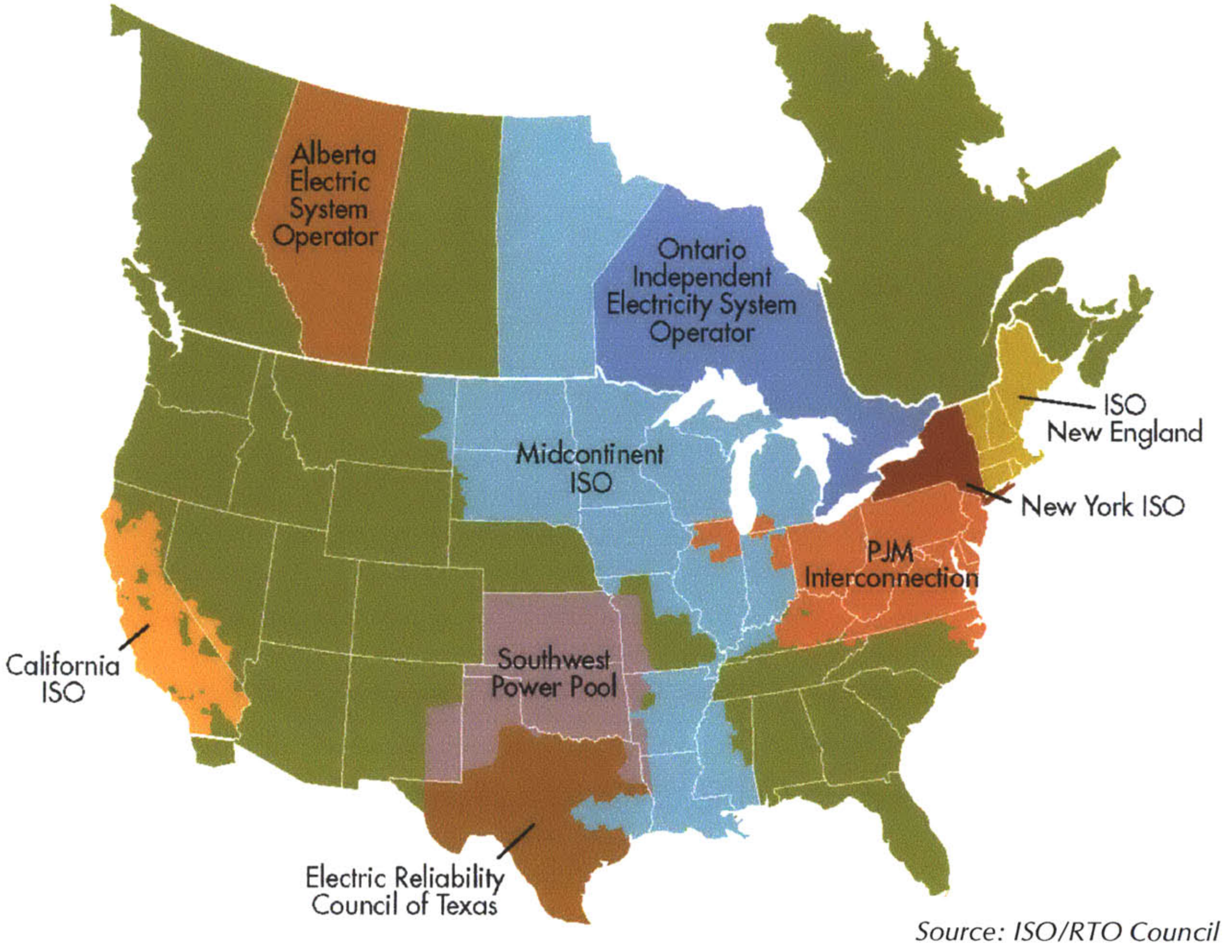
Figure 4. 2014 Status of U.S. Electricity Restructuring By State



Source: U.S. Energy Information Administration

The state-by-state nature of restructuring reflects the fact that retail electricity is regulated at the state level in the United States. At the national level, the Federal Energy Regulatory Commission (FERC) regulates interstate electricity sales and wholesale market rates, as well as transmission, natural gas, and oil pipelines. Recognizing that restructuring would affect the transfer of electricity across state lines and international borders, FERC initiated a reform that has increased demand-side participation in the energy markets. In 1999, FERC issued Order No. 2000, which recommended the creation of regional transmission operators—also known as RTOs or independent system operators (ISOs)—to manage power purchasing and transmission across multiple states. RTOs and ISOs play an important role in coordinating a complex array of services from thousands of different providers. They schedule transmission and coordinate auctions for capacity, energy, and "ancillary services" like frequency regulation. "A central point of control is necessary to ensure system reliability," observed a 2002 U.S. Department of Energy primer on electricity restructuring. "Consequently, the ISO has become the heart of the new competitive electricity industry" (Warwick, 2002). According to the ISO/RTO Council, an industry group, regional system operators now serve two-thirds of electricity consumers in the U.S. (IRC, 2014) (see Figure 5).

Figure 5. North American ISOs and RTOs

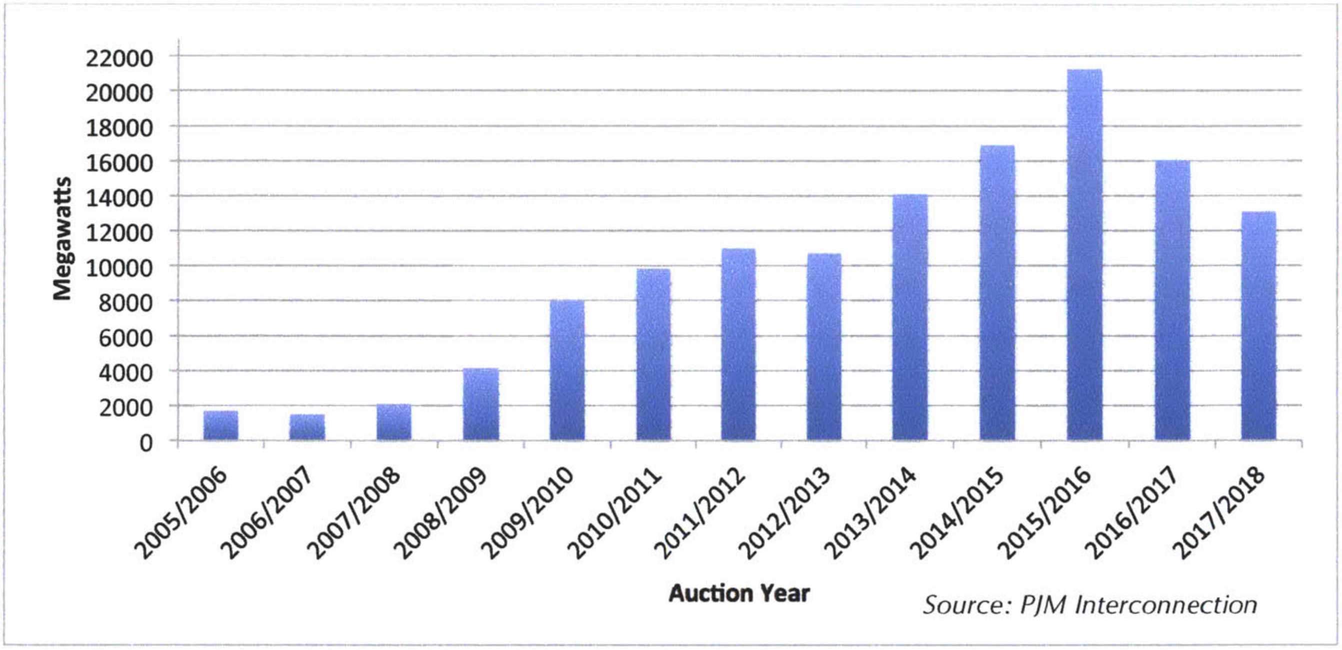


Source: ISO/RTO Council

The creation of the ISOs and RTOs also created favorable conditions for demand response by creating open markets for both energy and capacity. Energy markets compensate power provided in "real time," or as close as possible to the moment it is consumed, while capacity markets are meant to induce long-term investment in capital-intensive assets like power plants. Demand response can participate in both markets; therefore, rather than creating dozens of individual demand management contracts with local retail utilities, large energy consumers can bid their load-shedding capacity directly into these markets, just as an independent power producer might. For example, if an aluminum smelter decides it can cut its peak power demand by 10 megawatts in a particular area, it can enter a 10-megawatt bid in the regional capacity auction, often at a lower price than a power plant developer could. This arrangement is beneficial to large commercial or industrial customers who are sophisticated enough to understand the rules of the energy markets and can project their future demand for electricity. However, smaller commercial or residential consumers often lack the sufficient load or sophistication to participate directly in the demand response markets.

Recognizing this limitation, FERC issued Order No. 719 in October 2008. The order requires ISOs and RTOs to "permit an aggregator of retail customers (ARC) to bid demand response on behalf of retail customers directly into the organized energy market" (FERC, 2008). ARCs—companies like Comverge, EnerNOC, and EnergyConnect, among others—work with thousands of smaller customers who each contribute a smaller energy reduction during periods of peak demand. The firms then aggregate the combined demand response potential and bid the capacity together as a single unit in the auction. By reducing the complexity of participation through the ARC framework, Order No. 719 thus removed several large barriers for demand response. The result was a massive increase in the amount of demand response offered. In PJM Interconnection, the largest electric power control region in the U.S., demand response resources grew nearly tenfold in a period of eight years, from just over 2,000 megawatts in the 2007/2008 auction to more than 20,000 in the 2015/2016 auction—the equivalent of 20 large nuclear power plants (PJM, 2014) (see Figure 6). In December 2008, FERC Chairman Jon Wellinghoff called demand response "the killer application of the smart grid" (FERC, 2008).

Figure 6. Demand Response Participation in PJM Base Residual Auction



Source: PJM Interconnection

Economic Benefits of Demand Response

Under Wellinghoff's leadership, FERC consistently defended demand response's participation in the wholesale markets on economic grounds.[2] Since it is almost always less expensive to avoid consuming energy than it is to generate it, demand-side resources are delivered more cheaply than supply-side resources, and, in turn, they reduce wholesale market prices. Order No. 719 contains a concise catalogue of the economic benefits of demand-side management:

> Demand response can provide competitive pressure to reduce wholesale power prices; increases awareness of energy usage; provides for more efficient operation of markets; mitigates market power; enhances reliability; and in combination with certain new technologies, can support the use of renewable energy resources, distributed generation, and advanced metering. Thus, enabling demand-side resources, as well as supply-side resources, improves the economic operation of

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[2] FERC's most controversial decision during this period is Order No. 745, which was issued in 2011 and established that demand response should receive full market price—known as "full LMP," or locational marginal price, the market price for electricity in a particular place at a particular time—for every megawatt it provides to the wholesale energy markets. The Order provoked strong dissent from some electric power producers, who argued that FERC's ruling overstepped its jurisdiction by interfering with state-level retail markets. Their legal appeal is likely to rise to the Supreme Court in 2015 and is closely watched within the industry.

> electric power markets by aligning prices more closely with the value customers place on electric power. A well-functioning competitive wholesale electric energy market should reflect current supply and demand conditions (FERC, 2008).

Research has supported FERC's claims. In 2007 the Brattle Group determined that a 3 percent load reduction in PJM Interconnection during the 100 highest peak hours corresponds to a price decrease of 6 to 12 percent. Such a decrease would represent potential benefits to the entire PJM system in the range of $65 to $203 million per year. Studies of Texas's grid operator, the Electric Reliability Council of Texas (ERCOT), have yielded similar results. In a 2009 report, the Center for Commercialization of Energy Technologies found that, "Had a 'commercial-scale' demand response program been in effect during spikes in the price of balancing energy during the summer of 2008, wholesale prices could have been reduced by over 60 percent during the period of the spikes" (CCET, 2009).

Environmental Benefits of Demand Response

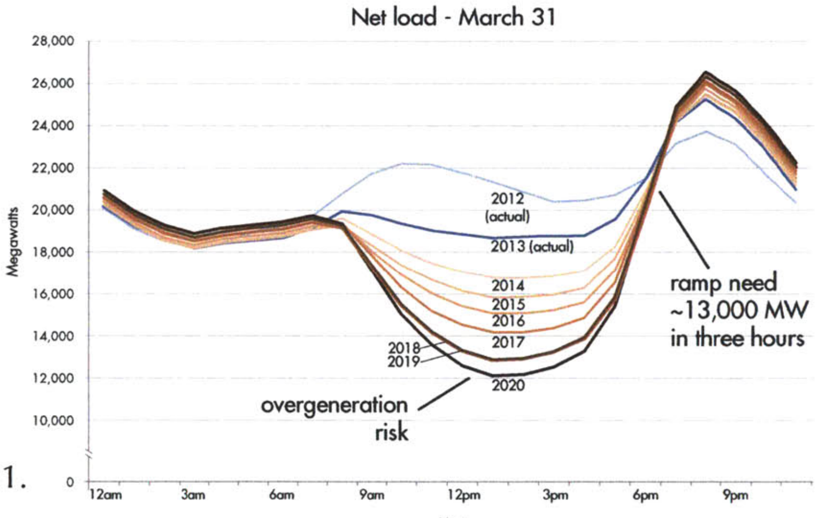
Environmental groups have also touted demand response for its ability to displace power plants and aid in the transition to a cleaner energy system. In July 2014, the Environmental Defense Fund's Vice President of U.S. Climate and Energy Jim Marston said, "As the U.S. advances into the clean energy economy, demand response should play an increasingly larger role in how our electricity is produced, delivered, and consumed" (EDF, 2014). The environmental benefits of demand response programs relate to the power generation it displaces, as well as its ability to balance intermittent generation from renewable sources, like solar and wind.

Demand response typically displaces peaking power plants, many of which are older and more polluting than newer plants (Navigant, 2013). These plants may emit more smog-producing sulfur dioxide or nitrogen oxides, for which plant operators must purchase allowances. Since generators typically build the cost of allowances into their auction bids, these plants are expensive to operate, in addition to being environmentally harmful. For this reason, some states have tightened emissions controls on peaking power plants. For example, New Jersey's higher bar for emissions under its High Electric Demand

Day (HEDD) is credited with shutting down 2,000 megawatts of high-polluting power plant capacity (Heidorn, 2014).

Furthermore, as greater quantities of renewable energy are added to the electricity grid, utilities and grid operators are looking for flexible resources to balance less predictable and more intermittent generation resources from wind and solar. Because solar power production is also concentrated during certain times of day, it can produce peaks and valleys in electricity demand that are difficult for grid operators to manage. In some states, however, they will have to learn quickly. In order to prepare to meet the state's goal of producing 33 percent of retail electricity from renewable sources by 2020, the California ISO modeled future scenarios of solar power penetration and produced the alarming finding that it may need to ramp up more than 13,000 megawatts of power in just three hours on a typical March day in 2020. This study produced the widely cited "duck graph," which illustrates the challenge of managing such large swings in renewable generation (see Figure 7).

Figure 7. California's "Duck Graph"



Source: California ISO

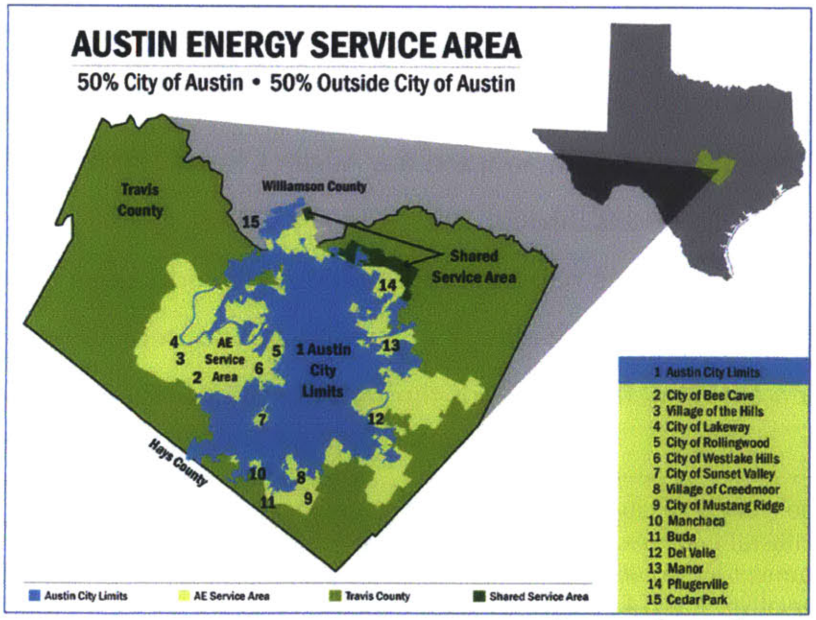
California could address this challenge by investing in energy storage. In fact, the California Public Utilities Commission determined in 2013 that Southern California Edison must procure 50 megawatts of energy storage capacity by 2021. However, despite this investment, the high cost of grid-scale storage technology remains a challenge according to the U.S Department of Energy (U.S. DOE, 2013). Demand response offers another, more cost-effective solution to the "duck graph" challenge. By providing a way to mitigate demand and even send excess generation to customers who can use it productively, a flexible demand side is a true asset in a green energy grid. Indeed, California ISO cites both energy storage and demand side solutions as complementary technologies that can help meet real-time system conditions in its report (CAISO, 2013).

Given its ample solar and wind resources, Texas is likely to see similar changes to its supply and demand curves as solar power generation becomes more widespread. In fact, that scenario appears likely in Austin, as Austin Energy recently set a goal to expand solar capacity by 500 megawatts, a 250 percent increase (Mele, 2014). That increase alone would justify an investment in demand-side management programs, and Austin Energy has already made strategic investments in its ability to adjust and control electricity consumption at homes and businesses across its service territory.

Austin Energy's Residential Demand Response Programs

As the eighth largest municipal electric power utility in the United States, Austin Energy serves more than 420,000 customers and approximately one million residents. It covers a service territory encompassing nearly 440 square miles, approximately 50 percent of which lies outside the city limits (Austin Energy, 2014) (see Figure 8). It is responsible for procurement and maintenance of transmission and distribution equipment, including transmission lines, substations, and meters, and it generates nearly 85 percent of the electricity used by its customers, the rest of which it purchases from ERCOT's energy market and the Southwest Power Pool (SPP) (Austin Energy, 2014). The utility owns a diverse generation portfolio, including coal, natural

Figure 8. Austin Energy Service Territory

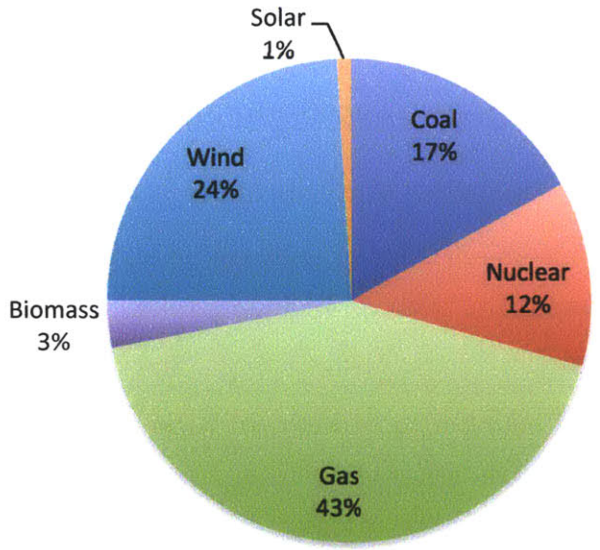


Source: Austin Energy

gas, nuclear, and renewable energy resources. As of 2013, approximately 25 percent of Austin Energy's generation capacity was made up of renewable sources, largely wind power (Figure 9).

Austin Energy is municipally owned and operated, but is funded by revenues it receives from customers, not taxes. The utility's board of directors is the Austin City Council, which is advised by Austin's Electric Utility Commission. This highly local oversight has made the utility an important factor in the city's sustainability planning.[3] In 2007 the City of Austin adopted the Austin Climate Protection Plan (ACPP) to guide its sustainability efforts through 2020. The ACPP set specific goals to "make Austin Energy the leading utility in the nation for greenhouse gas reductions" by "achieving 700 megawatts of new savings through energy efficiency and conservation efforts by 2020" and "meeting 30 percent of all energy needs through the use of renewable resources by 2020" (City of

Figure 9. Austin Energy Owned Generation Resources



Source: Austin Energy

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[3] In the context of city-level sustainability planning, it warrants mentioning that Austin's population is far more liberal than Texas as a whole, and that liberal populations like Austin's tend to be more accepting of government-led environmental initiatives. By contrast, Texas' other large cities tend to be much more conservative. A 2014 nationwide study of policy preferences of cities with populations larger than 250,000 people, Austin ranked 14th most liberal, while Arlington and Fort Worth were the 6th and 12th most conservative, respectively (Tausanovitch & Warshaw, 2014).

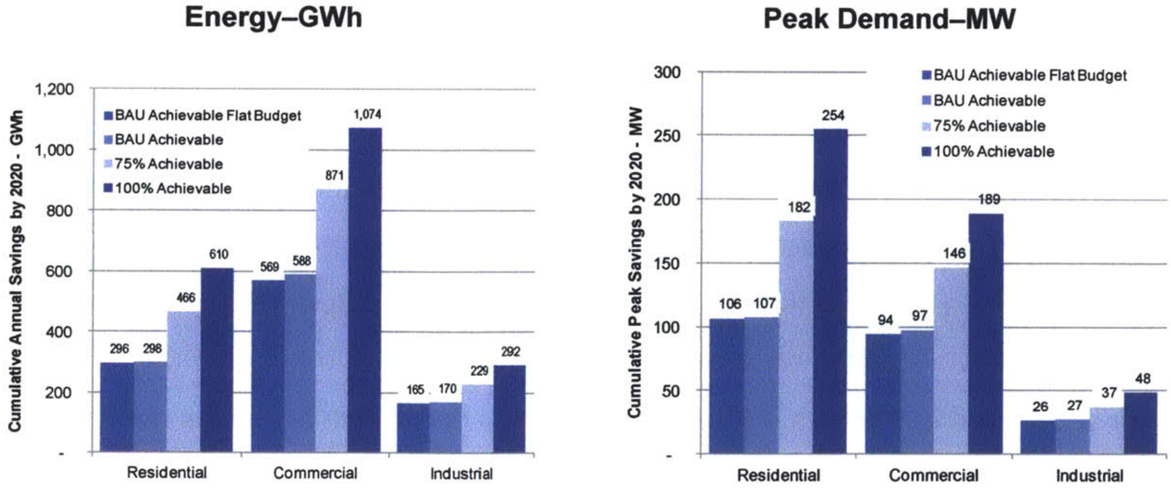
Austin, 2007). In 2010, the efficiency goal was increased from 700 megawatts to 800 megawatts, and the renewable energy goal was increased to 35 percent (Austin Energy, 2010).

Planning to Reduce Demand

In order to reach its 2020 demand reduction goal, Austin Energy hired energy consultancy KEMA to estimate the market potential for demand-side management in its service territory. In the resulting 2012 report, KEMA noted that Austin Energy needed to capture 531 megawatts of savings from current and future demand-side programs to reach its goal. The majority of expected savings—295 megawatts—would come from energy efficiency programs, while Austin Energy expects 236 megawatts to be captured from demand response and building codes (KEMA, 2012).

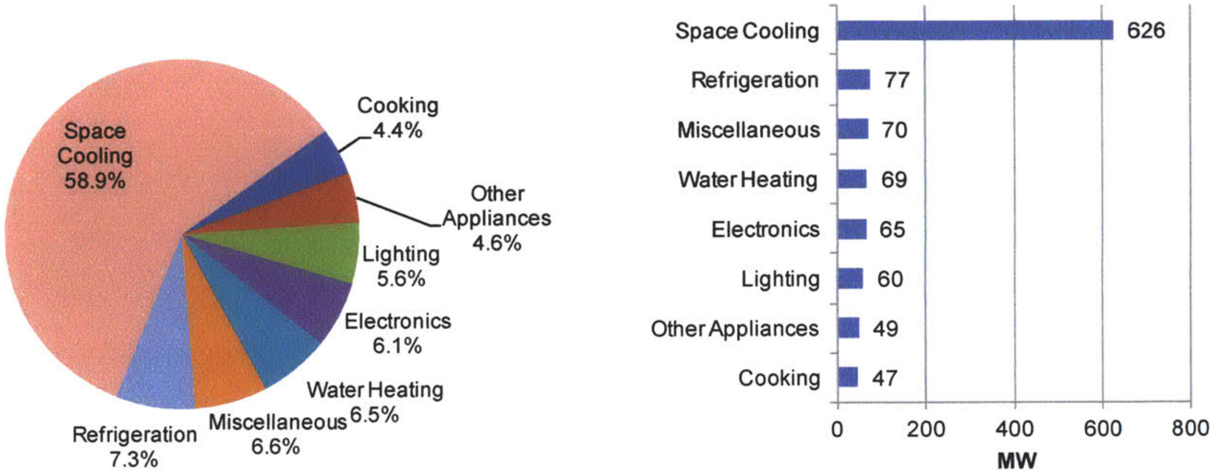
KEMA found that, although commercial and residential customers have similar economic energy savings potential in relation to base use, the peak-demand reduction potential is much greater for residential consumers, especially single-family homes (Figure 10). Furthermore, KEMA reported that space cooling represents approximately 59 percent of residential peak demand (Figure 11). Although the report does not make strategic recommendations for an optimal demand reduction plan to meet Austin Energy's goal, residential air conditioning load is a clear target.

Figure 10. Net Program Achievable Energy Savings By 2020 By Sector



Source: KEMA

Figure 11. Residential Peak Demand By End Use



Source: KEMA

Model 1: The "Free Thermostat" Program

KEMA's findings were well aligned with the utility's existing strategy for managing peak energy use. Since 2000, Austin Energy had invested in the ability to reduce residential customers' air conditioning use during peak periods by distributing free demand response-enabled thermostats to residential, small commercial, and municipal customers. These thermostats were equipped with a control algorithm that could reduce anticipated air conditioning usage by one third when triggered by a radio signal sent by the utility. Austin Energy designed these demand response "events" to coincide with periods of peak demand and to last for four hours. After the period of peak demand subsided, the thermostat would resume normal functionality. The utility could trigger 10 to 15 events each year, with a maximum of 17 annually.

The program was the result of a contract between the city and Comverge, a demand-response aggregator then based in New Jersey. Under the terms of the original contract, Austin Energy purchased 2,500 Comverge "Superstat" thermostats and 400 water heater switches for a reported total of nearly $500,000 (Austin Business Journal, 2000). At that time, the utility also retained an option to buy more equipment during the next two years for several million dollars. Although the specific per-device price was not reported in the 2000 agreement and was also redacted from a 2004 contract extension, the *Austin*

Business Journal report implies an approximate device cost of $170 per thermostat or water heater switch. White Rodgers and Honeywell manufactured Comverge's thermostats, and each one had an Austin Energy decal to serve as a visual reminder that the utility could control its settings during peak periods. (Figure 12)

Figure 12. Austin Energy's Free Thermostat

Source: Austin Energy

Homes and businesses enrolled in the program through an online application on Austin Energy's website or by calling a toll-free number. The main incentive for participation was the free thermostat, which Austin Energy reported was "valued between $200 and $280" and could be controlled remotely over the Internet (Austin Energy, 2003). Importantly, Austin Energy also assumed the responsibility for installing and maintaining each thermostat it enrolled. Although this was promoted as a benefit of the program—no technical expertise was required to install the thermostat—it also increased the utility's cost of implementation by requiring it to continually employ installation contractors. A report on the utility's demand-side management programs during fiscal year 2012 cites $360,000 in expenses for operations and maintenance of program hardware (Austin Energy, 2013).

Customers could enroll at any time of year, though the program was only called upon during the summer months, from June through September. On particularly warm days, when electricity demand was expected to be high, the utility would trigger the thermostats to "cycle" each home's air conditioner so that it would run 30 percent less often. The events were always four hours long, though the program's cycling schedules changed slightly over time. In 2003 the Power Partner website reported that cycling times would "not exceed 10 minutes per half-hour" and that cycling could occur from 4:00 p.m. to 8:00 p.m. By 2009 the hours had shifted slightly earlier—from 3:00 p.m. to 7:00 p.m.—and cycling would occur for "no more than 15 minutes every half hour." These changes were to accommodate a shift in the hours of peak demand, as well as a new incentive scheme. From 2007 through 2009, Austin Energy offered a one-time $25 bonus for single-family customers agreeing to an extra five minutes of cycle-off time, an incentive that reflected the additional value of demand response as the ERCOT market experienced price spikes in those years (CCET, 2009).

Measuring Impact

By several measures, the free thermostat program was very effective. As of April 2011, Austin Energy had installed more than 73,000 thermostats at homes, businesses, and municipal facilities, and by 2013 the utility proclaimed it was running "the largest free thermostat program in the country" (Austin Energy, 2013). Through measurement and verification tests, the utility determined the thermostats were capable of between 10 to 40 megawatts of peak demand-side management capacity. For perspective, one megawatt is enough power to serve about 200 homes during peak demand, according to Texas's grid operator (ERCOT, 2012).

Table 1. Number of Free Thermostats By Sector (as of April 2011)

	Commercial	Single Family	Multifamily	Municipal
Number of Thermostats	5,279	24,196	43,668	214

Source: Trowbridge, 2013

Due to high enrollment, the program was also able to cut peak power purchases and, in turn, reduce costs. Austin Energy's Scott Jarman described the program's two cost-saving strategies in a 2013 presentation to the Peak Load Management Alliance (Jarman, 2013). First, the program reduces Austin Energy's peak demand charges in ERCOT's energy market. During the peak months of June, July, August, and September, ERCOT measures a monthly demand peak for the entire system. During these system-wide peak periods, it also measures individual customers' demand. This is known the customer's "coincident peak." Each of the four coincident peaks is then averaged together to assign a transmission charge based on that entity's contribution to the overall system peak. Since Austin Energy acts as the "load serving entity" for its entire service territory, it accounts for a relatively large share of ERCOT's overall peak demand. From 2010 through 2013, the utility has contributed between 3.85 and 3.97 percent of overall peak demand in ERCOT. Given that ERCOT expects to complete more than $3.6 billion in additional projects between 2014 and 2018, Austin Energy has a strong incentive to keep its share of those costs low by reducing its coincident peak (ERCOT, 2014).

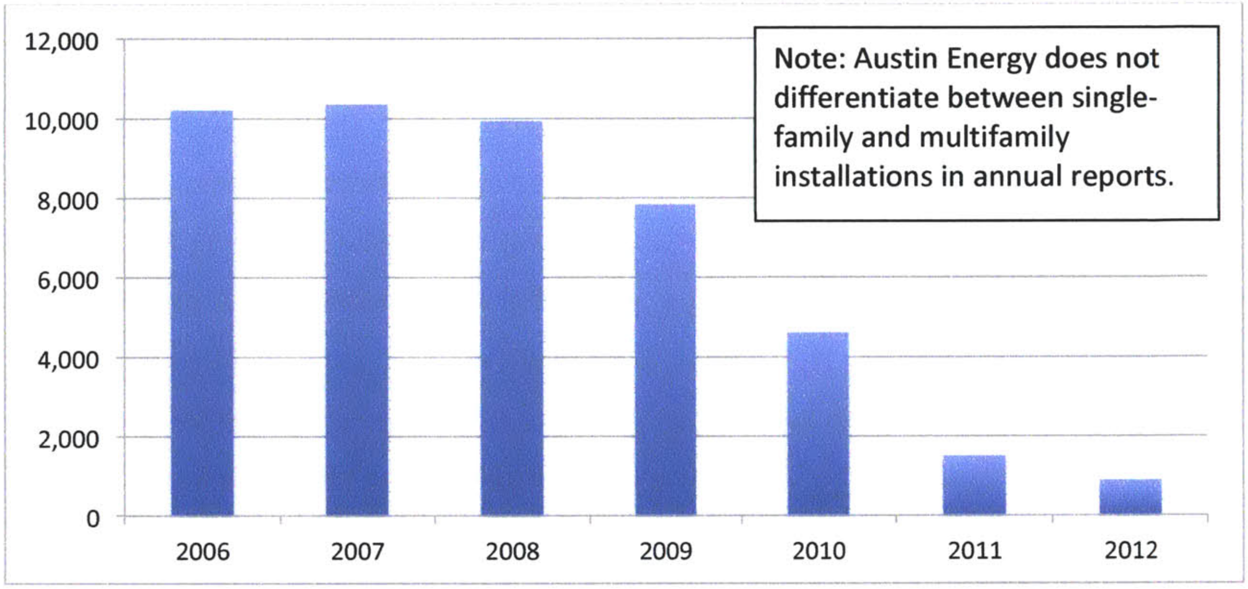
The second form of savings comes from reducing power imports from the neighboring transmission operator, Southwest Power Pool, or SPP. In this market, prices can also spike based on overall demand. For example, in July 2012 the price of electricity in the SPP averaged $27.28 per megawatt-hour. However, for just a handful of hours, the price surged above $200 per megawatt-hour, peaking at more than $500 per megawatt-hour (SPP, 2012). According to SPP, these price spikes may be caused "by lack of transmission lines, heavy use of specific grid segments, unplanned situations such as storms, or by the preferred energy source being located far away from customers" (SPP, 2014). If Austin Energy were importing power from SPP during this period, the utility and its ratepayers would be exposed to these high prices.

Over several years, the peak demand reductions from the free thermostat program amounted to millions of dollars in avoided power purchases. Between 2006 and 2008, the program was one of the utility's three most cost-effective demand-reducing programs on a dollars-per-kilowatt reduction basis (Austin Energy, 2010). In fiscal year 2012, Austin Energy reported a utility net benefit of $423,079 from the free thermostat program (Austin Energy, 2013).

Addressing Concerns

In spite of the program's effective enrollment and cost cutting performance, Austin Energy began to see diminishing returns from the program. From 2008 through 2012, new enrollments (and thus peak demand reductions) declined each year. In some years, the year-over-year decline exceeded 60 percent (Figure 13). Furthermore, there were concerns about maintaining connectivity with thermostats that had been installed in previous years. The radio signal used to adjust thermostats during a dispatch event is a one-way communication protocol. As a result, there is no way for the utility to confirm that its signal is received at each thermostat and whether or not that thermostat initiates its curtailment program.

Figure 13. Free Thermostats Enrolled in Multifamily and Single-Family Homes



Source: Austin Energy

In light of these trends, Austin Energy began a formal impact assessment and measurement and verification of the free thermostat program. The result was a paper published by John Trowbridge, an Austin Energy engineer, in *Energy Engineering* in September 2013. Trowbridge's study focused on thermostats installed at multifamily properties. Loosely defined as "a residence that has a unit number," multifamily properties represented 64 percent of the residential properties enrolled in the program at the time of Trowbridge's study, with more than 43,000 thermostats among them. Trowbridge analyzed the performance of two sample populations—a sample of 52 homes that allowed the utility to install a state logger on the condenser unit of their air conditioner during the study period, as well as a simple random sample of 149 homes using automatic meter read (AMR) data.[4]

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[4] Austin Energy was part of the first wave of utilities to adopt advanced meters. It began installing smart meters in January 2003 and reached full deployment to customers in 2009.

At its peak, the potential for demand response curtailment from residential customers enrolled in the free thermostat program reached 81 megawatts (Trowbrige, 2013). In actuality, Trowbridge's study observed a much lower overall peak demand reduction "ranging between 3.5 and 4.5 megawatts" for the 43,000 accounts enrolled in the multifamily program, far below the original 81-megawatt estimate. More troubling still, the measurement and verification exercise revealed that only 33 percent of thermostats helped to reduce peak demand during a dispatch event. Approximately 21 percent of the thermostats actually aggravated demand during a dispatch—indicating that many homes were using more A/C during events, not less. Forty-six percent of thermostats were deemed neutral.

In the paper, Trowbridge notes that this realization rate is similar to previous internal studies Austin Energy conducted for single-family homes. He speculates that a percentage of the thermostats do not receive the utility's signal, while others appear to be duplicates or bookkeeping errors on the part of Austin Energy's contractors. Still others may have been purposely disconnected or disabled by residents (Trowbrige, 2013). In fact, a web search reveals several blog and forum posts with instructions on how to reprogram Austin Energy thermostats to eliminate their intended control behavior (AskMetafilter, 2009; JTR Blog, 2009). Because Austin Energy was responsible for maintaining the thermostats in each home, it would bear the expense of sending engineers from house to house to determine whether or not a thermostat was operating as expected.

Trowbridge's study thus revealed a key vulnerability in the free thermostat program's model. Without two-way communication, there was no way for Austin Energy to know whether its signal was received and thus whether its investment in peak demand management was actually paying off. This reality led Trowbridge to a disturbing conclusion, that as many as 78 percent of the thermostats installed in multifamily units are "either duplicates or of little value for the program" (Trowbrige, 2013).

Model 2: "Bring Your Own Thermostat" Program

Beginning in 2012, the free thermostat program was moved into "maintenance only mode" as Austin Energy began to explore alternative technologies and program designs that could address the performance concerns identified by Trowbridge's study (Trowbridge, 2014). While the utility would continue to call upon the free thermostat program during periods of peak demand, it recognized that a new demand management program could supplement—and perhaps exceed—the value of the existing program. It began the planning process in a very different environment for home energy technology.

When Austin Energy first launched the free thermostat program in 2000, the idea of a "smart thermostat" was foreign to most households. By 2012 that had changed dramatically. Large, established companies like Honeywell and 3M were marketing connected thermostats in large retailers like Home Depot, Lowe's, and Amazon.com. Cable and telecommunications companies like Comcast, AT&T, and Verizon were offering smart thermostats as part of new home automation packages. Smaller technology and controls firms like ecobee and Nest Labs were beginning to offer new and innovative "connected home" products. Indeed, Nest's CEO Tony Fadell was one of the inventors of Apple's iPod and iPhone, giving his company's products a particular allure. In December 2013 Fadell claimed that the Nest thermostat was in "almost 1 percent of U.S. homes," which *Forbes* estimated to mean more than 1 million thermostats had been sold (Olson, 2013). In early 2014, Google purchased Nest for $3.2 billion, fueling further speculation that connected thermostats could become the new norm. "Think about automatic door locks," Tom Kerber, director of energy research for Parks Associates told the *Dallas Morning News*. "They used to be only on Cadillacs. And now you can't buy a car without automatic locks" (Osborne, 2014).

Recognizing this new paradigm, Austin Energy decided that rather than provide free thermostats, it could take advantage of the smart thermostats that were already being installed throughout its service territory. Under the new program model, customers could provide their own thermostat and receive a one-time $85 incentive check for allowing Austin Energy to control temperature settings during peak hours. Other utilities, including San Diego Gas and Electric, CenterPoint Energy, and NRG Energy had already created "bring your own" (BYO) thermostat programs, and Austin Energy staff hoped they could use this new model to address three important issues: enabling two-way communication between utility and thermostat; minimizing enrollment and maintenance costs; and maintaining performance during demand response dispatches, with as few customers opting out of events as possible. If successful, the BYO device model could revolutionize Austin Energy's approach to residential demand response.

To address the two-way communication problem, Austin Energy engineers began with a market assessment of existing technologies. One engineer described the search as follows: "We looked at every communications protocol out there, from ZigBee, to Z-wave, and we kept coming back to Wi-Fi" (Talkington, 2014). Wi-Fi is a widely used wireless communication protocol based on the 802.11 standards developed by Institute of Electrical and Electronics Engineers (IEEE). In 2000, home Wi-Fi networks were rare, which is one reason why the utility opted for radio-controlled thermostats for the free thermostat program. By 2013, Wi-Fi was prevalent in Austin Energy's service territory. An estimated 77 percent of Texas households subscribed to home broadband Internet service in 2013, up from 62 percent in 2010 (Connected Texas, 2014). That exceeds the national average of 70 percent, according to the Pew Research Center's Internet and American Life Project (Pew Research, 2013). Market research firm Strategy Analytics further estimates that more than 61 percent of U.S. homes have wireless (Wi-Fi enabled) internet, indicating that the majority of homes with Internet access have the ability to connect devices wirelessly (Watkins, 2014). This level of adoption gave Austin Energy the confidence to proceed with Wi-Fi as its communications protocol of choice.

Wi-Fi presents several additional benefits. Each thermostat could inform Austin Energy that its demand response signal was received and answered over the Internet. Wi-Fi enabled thermostats could also communicate other useful information, such as whether the thermostat was in cooling mode (and therefore able to reduce peak demand) or whether a user decided to adjust their settings during a dispatch, indicating that they had opted out of that particular event.

With the communications protocol selected, Austin Energy began the process of soliciting thermostat vendors who could provide appropriate Wi-Fi connected devices. The utility put out a request for proposals (RFP) and selected three manufacturers—Nest, ecobee, and EnergyHub—as the first approved for the 2013 enrollment season. It has since added models from Trane, American Standard, and other devices designed by the

Radio Thermostat Company of America and marketed by Alarm.com and Nexia Home Intelligence (Austin Energy, 2014) (Table 2).

Table 2. Thermostat Providers for BYO Thermostat Program

Participating Company	Thermostats
Alarm.com	Radio Thermostat CT-30
	Radio Thermostat CT-80
	Radio Thermostat CT-100
	Trane ComfortLink Control
ecobee	ecobee Smart
	ecobee Smart Si
	ecobee 3
Filtrete	Filtrete 3M-50 (WiFi)
Nest	1st Generation Nest Learning Thermostat
	2nd Generation Nest Learning Thermostat
Nexia Home Intelligence	American Standard AccuLink Remote Thermostat
	American Standard Silver XM Thermostat
	Trane ComfortLink Control
	Trane XL624 Control
Radio Thermostat	Radio Thermostat CT-30 (WiFi)
	Radio Thermostat CT-50 (WiFi)
	Radio Thermostat CT-80 (WiFi)
Vivint	Radio Thermostat CT-100

Source: Austin Energy

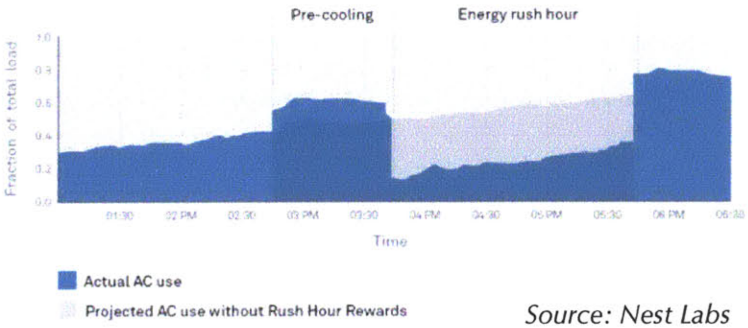
Beyond hardware, the vendors were also expected to contribute to the service aspects of the program. Specifically, vendors were expected to provide a portal for customer enrollment, through either their existing websites or mobile applications. Similarly, vendors were also expected to provide a utility dashboard, where Austin Energy could view the performance of participating households. Program marketing was also considered a shared responsibility. Just as it had with the free thermostat program, Austin Energy created a page on its website to describe the benefits of the BYO thermostat program, and it encouraged vendors to do the same. Some, including Nest and ecobee, market the program through automated e-mails. During Nest's installation process, the user is asked to enter an email and a zip code. If the thermostat is connected in an Austin Energy zip code, the company can send an automated email, alerting the customer to the $85 incentive. Some vendors also use messages on mobile applications and the screen of the thermostat itself to highlight the program.

Table 3. Design of Austin Energy's Residential Demand Response Programs

		Free Thermostat Program	BYO Thermostat Program
Program Design	*Launch Year*	Spring 2000	Spring 2013
	Eligibility	Single family homes, multifamily, commercial, and municipal facilities	Single family homes
	Cost of Hardware	Free to user; ~$170 to utility	$100-$500 to user, free to utility
	Financial Incentive	None	$85, one time to user
	Setback Strategies	30% cycling	Adjust thermostat settings by <4°F or 30% cycling
	Precooling Allowed	No	Yes; 1 hour prior
	Event Timing	Weekdays, June through September; 4:00 p.m. to 8:00 p.m. or 3:00 p.m. to 7:00 p.m.	Weekdays, June through September; 3:00 p.m. to 7:00 p.m.
	Maximum Number of Events	17	17

The operational design of the BYO thermostat program was meant to mirror that of the original free thermostat program, with two important modifications. (See Table 3) First, only single-family homes were eligible to enroll; multifamily and commercial properties could not qualify for rebates. Second, vendors were permitted ramp up cooling one hour prior to dispatch, so that the home's insulation and thermal inertia would keep the home cooler over the course of the four-hour event (Figure 14). This "pre-cooling" technique was intended to limit residents' tinkering with the thermostat during a dispatch. Both Nest and EnergyHub adopted this strategy for the 2013 program year, while ecobee did not.

Figure 14. Illustration of Pre-cooling



Source: Nest Labs

As a result, each vendor described the program somewhat differently. Nest's website states that events can occur earlier—starting at 2 p.m., to reflect the hour-long pre-cooling period—and that the thermostat "won't let the temperature rise more than a few degrees" (Nest Labs, 2014). Nest also branded the program "Rush Hour Rewards." By contrast, ecobee's website states that Austin Energy will adjust your thermostat "so it's either 4°F higher than your normal setting, or shut the system off for 15 minutes every half hour" during the hours of 3:00 and 7:00 p.m. (ecobee, 2013).

Comparing "Free" to "BYO"

Although the BYO thermostat program was designed to complement the free thermostat program, it is useful to compare how the programs performed in terms of enrollment and peak demand reductions. Table 4 summarizes the comparison, and it is described in detail below.

Enrollment Analysis

According to Trowbridge's report, from spring 2000 through spring 2011, Austin Energy had installed 24,196 free thermostats in single-family homes. This implies that the utility installed an average of approximately 2,200 thermostats each year at single-family homes, or 183 thermostats per month. Over the same period, the utility also installed tens of thousands more thermostats at commercial, multifamily, and municipal sites; however, for the purposes of comparison, this analysis will focus on single-family homes, since they are the only properties eligible for the BYO thermostat program.

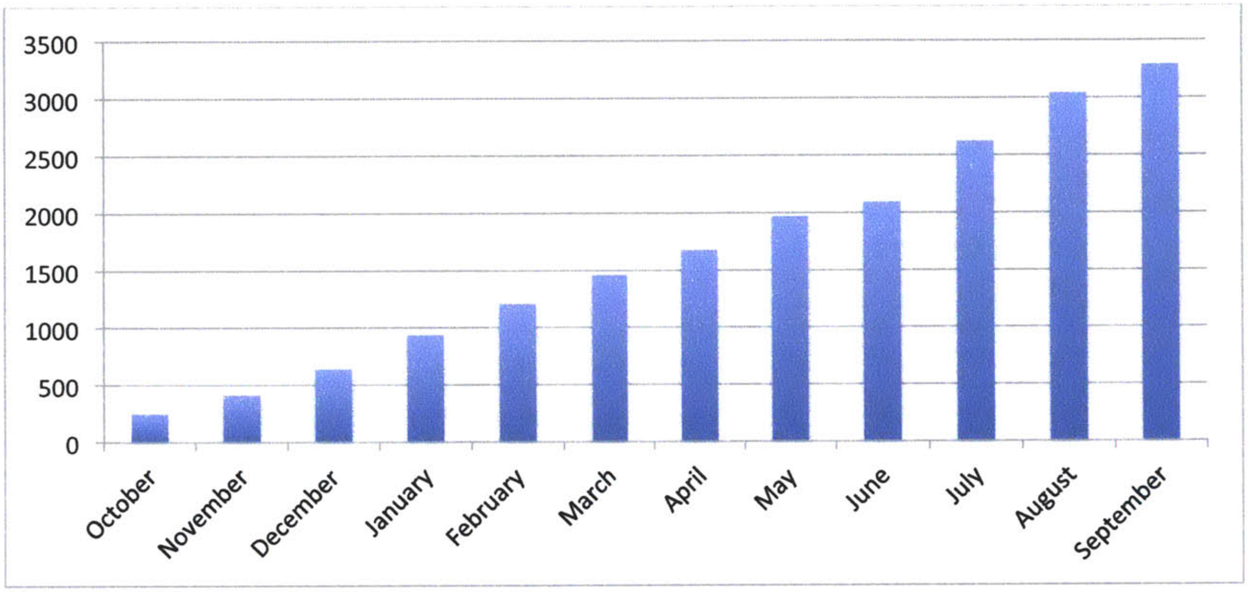
Table 4. Enrollment and Performance within Austin Energy's Residential Demand Response Programs

		Free Thermostat Program*	BYO Thermostat Program**
Enrollment	*Thermostats Enrolled in Single-Family Homes*	24,196	7,160
	Thermostats Enrolled Per Month	183	358
	Thermostats Enrolled Annually	2,016	4,296
Event Performance	*Minimum kW Reduction Per Meter*	0.074 (multifamily)	0.34
	Maximum kW Reduction Per Meter	0.321 (multifamily)	1.62
	Confirmation of Signal	None	96%
	Estimated Realization Rate	30%	88%
	Estimated Peak Demand Reduction (MW)	4.5	4.7

***Through April 2011; **Through September 2013**

Within the single-family customer class, the BYO thermostat program's enrollment rate compares favorably with free thermostat program. From May 2013 to September 2014, Austin Energy enrolled 7,160 thermostats, an average of 358 thermostats per month. Although this rate slowed slightly during the 2014 program year, Austin Energy still enrolled an average of 274 thermostats per month in 2014—3,289 in total—and achieved a compound monthly growth rate of approximately 25 percent (Figure 15). This indicates that the BYO thermostat enrollment is exceeding enrollment rates in Austin Energy's free thermostat program and remains strong. The program is also exceeding the utility's expectations. Prior to launch, Austin Energy set an internal goal of enrolling 1,500 thermostats in 2013 (Talkington, 2014). Demand quickly surpassed that goal. In 2013, more than 3,800 first-year enrollments overwhelmed the utility's mechanisms for delivering rebate checks, prompting an apologetic notice for any delays posted on the program website.

Figure 15. Running Total of BYO Thermostat Enrollments, FY 2014



Source: Austin Energy

Despite the challenges of serving the initial influx of demand in the program's first two years, the outlook for future growth is bright. Navigant Research projects a 40 percent compound annual growth rate for smart thermostats globally through 2020, which could bode well for future enrollments through the BYO device program (Callaway & Strother, 2014). It also warrants mention that 94 percent of the thermostats enrolled in 2013 were Nest devices (Trowbridge, 2014). At such a high rate of adoption, Nest has an outsized influence over the program's effectiveness, and the company's marketing efforts—now buttressed by its corporate parent Google—could determine how quickly smart thermostats are adopted in Austin Energy's service territory and across the country.

Event Performance Analysis

Austin Energy thus confirmed that its customers were interested in a BYO device program model, but how do smart thermostats perform as compared to the utility's free thermostats during events? Without access to individual meter data for each program participant, analysis of event performance relies on Austin Energy's program evaluations and manufacturers' reports. Based on this information, homes enrolled in the BYO thermostat program appear much less likely to opt out of events and are able to contribute greater peak demand reductions than homes enrolled in the free thermostat program.

Trowbridge's 2013 evaluation of the free thermostat program revealed that only 33 percent of the thermostats installed in multifamily homes reduced their demand for air conditioning-related electricity usage. The study also references a second internal evaluation of single-family homes that was conducted in 2010, which calculated a 30 percent realization rate among single-family homes—indicating that 70 percent of participants either did not respond to the utility's signal or opted out during an event. According to Trowbridge's forthcoming study on the BYO thermostat program, the new program demonstrates a significantly better realization rate. Ninety-six percent of the thermostats enrolled in the BYO thermostat program confirmed receipt of the utility's dispatch signal (Trowbridge, 2014). Austin Energy further estimates that only 12 percent of users opt out of events, which is also the figure Nest reports on its website (Talkington 2014; Matsuoka 2013). This is a vast improvement over the free thermostat program's realization rate—increasing it from 30 percent of thermostats to approximately 88 percent.

It is difficult to compare the relative reduction in peak energy consumption per participating household in each of the two programs. This is because Austin Energy's 2010 study of single-family homes in the free thermostat program was not released publicly. Trowbridge's 2013 evaluation of the free thermostat program indicated a maximum 0.085 kilowatt reduction per meter for multifamily properties, although this reduction is expected to be lower for apartments than it is for single-family homes. Trowbridge's 2014 study of the BYO thermostat program reveals a range of per-thermostat kilowatt reductions between 0.34 and 1.62 kilowatts per household, depending on the setback strategy used by its thermostat vendor (Table 5). This indicates that the smart thermostats have a much larger demand response potential per household.

Given that meter-level peak demand reduction comparisons between programs are not possible, it is useful to look at program-level peak demand reduction as an alternate measure of effectiveness. In October 2014, Austin Energy reported that BYO thermostat customers helped offset nearly 4.7 megawatts of peak demand during the summer of 2014, which exceeds Trowbridge's estimated impact of the "free thermostat" program, at 4.5 megawatts (Austin Energy, 2014). This indicates that the BYO thermostat program is—in just its second year of operation—already exceeding the overall peak demand reduction recorded by a program that has been in service for more than a decade.

Table 5. Average Per-Home Kilowatt Response from BYO Thermostat Participants

Vendor	Strategy	Pre-Curtailment Hour	Hour 1 (Curtailment)	Hour 2 (Curtailment)	Hour 3 (Post)	Hour 4 (Post
Ecobee	4° Setback		0.83	0.75	-0.18	-0.06
	Cycling 50%		0.34	-0.09	-1.08	-0.89
Energy-Hub	4° Setback		1.44	1.1	-0.57	-0.44
	4° Setback w/ 2° Precool	-0.13	1.62	0.99	-0.66	-0.53
Nest	4° Setback w/ 2° Precool	-0.38	1.25	1.1	-0.3	-0.17

***Negative values indicate increased energy consumption.**

Source: Trowbridge, 2014

The program also appears to have minimal impact on rates and to be cost-effective overall. A 2013 stakeholder presentation on energy efficiency programs and services indicates that the BYO thermostat program had the lowest Ratepayer Impact Test (RIM) score of any residential energy management program offered in that year. RIM is used to evaluate the impact of energy efficiency programs on overall electric power rates. While it is by no means Austin Energy's best performing energy efficiency program on the Total Resource Cost (TRC) test, a common measure of program cost-effectiveness, it fared comparably to a clothes dryer rebate program (Austin Energy, 2013).

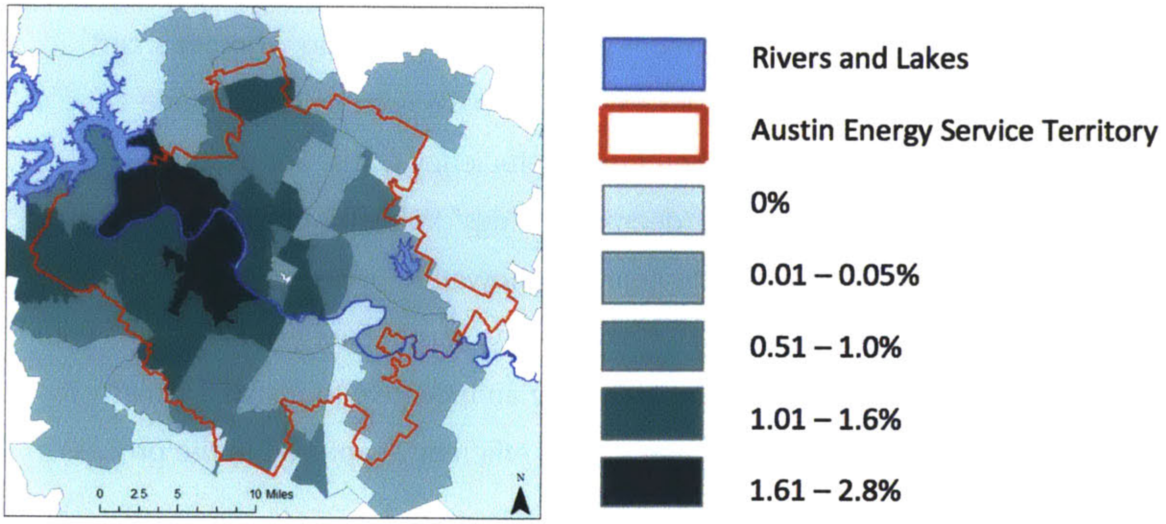
Distribution of Benefits

With these encouraging results, it is important to understand how the benefits of the program are distributed both spatially and demographically. A spatial analysis of thermostat enrollments in the BYO thermostat program indicates that the program is likely to disproportionately benefit the city's wealthier residents. The data show a strong correlation between program participation and both income and home value. This stands to reason, as low- or medium-income households are less likely have the disposable funds to purchase a $250 thermostat, even with an $85 enrollment incentive.

Figures 16-18 provide a view of the demographic relationships in program enrollment. The zip code areas of darkest green have the highest concentration of BYO thermostat installations, highest median home values, and highest median incomes, respectively. This indicates that high-income homeowners in high-value homes are far more likely to enroll in Austin Energy's new demand response program, whereas the free thermostat program could be expected to benefit both high- and low-income consumers equally.

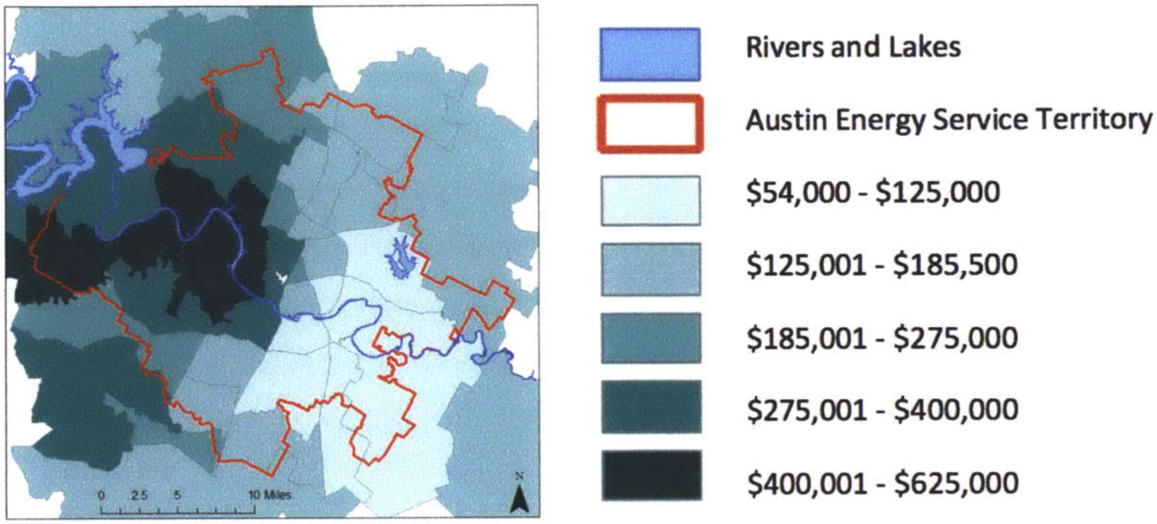
Although this discrepancy could raise red flags about equity, such concerns may be unwarranted. By their nature, rebate programs typically target higher-income consumers, and larger, high-income homes are more likely to use a significant amount of air conditioning during a period of peak demand. Therefore, Austin Energy is actually reaching the homes that are best able to cut peak power usage, and this disproportionate distribution of smart thermostats may actually be preferable to both the utility and its customers. In addition, Austin Energy provides additional programs, like free-of-charge weatherization services for low and moderate-income customers, including insulation, air sealing, and replacement of heating and air conditioning systems. These services are more likely to improve the energy performance of the home and reduce energy bills than the installation of a smart thermostat.

Figure 16. Percentage of Occupied Homes with BYO Thermostats By Zip Code



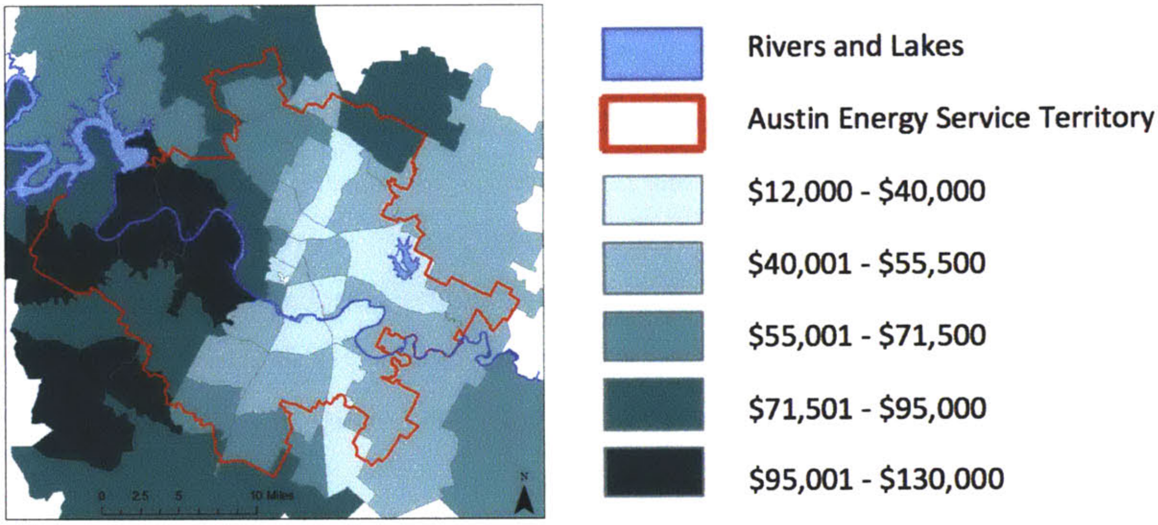
Sources: City of Austin, Austin Energy

Figure 17. Median Home Value By Zip Code



Sources: City of Austin, Austin Energy, U.S. Census Bureau, 2012 American Community Survey

Figure 18. Median Income By Zip Code



Sources: City of Austin, Austin Energy, U.S. Census Bureau, 2012 American Community Survey

This is at least in part because it remains an open question as to whether smart thermostats actually save energy. In other states, utilities have used programmable thermostat installations as credit toward their energy efficiency goals. For example, in Massachusetts, the maximum annualized "deemed savings" value for changing a standard thermostat to a programmable thermostat is nearly 1 kilowatt-hour per square foot of heated and cooled space (MassSave, 2012). Conceivably, Austin Energy's customers could benefit from similar energy savings, and, by providing an incentive to install a smart thermostat, the utility could take credit for the energy efficiency captured in the process and put that credit toward its ACPP goals. However, this would require the utility to verify that smart thermostats are actually more energy efficient than traditional thermostats.

Can Smart Thermostats Contribute to Energy Efficiency Goals?

Smart thermostats provide several benefits: They can be controlled from a smartphone, report on energy usage habits, or turn themselves off automatically when homeowners are away. But most of all, they are designed to save energy, and manufacturers make that explicit in their marketing materials. For example, Nest has published a white paper indicating "customers in southern California saved an average of 1.16 kilowatt-hour per day or 11.3 percent of A/C-related energy usage after installing a Nest Thermostat" (Nest Labs, 2014). To the extent possible, I wanted to verify whether the same could be true in Austin. If so, efficiency from smart thermostats could help Austin Energy and the city reach their climate change goals.

Data

Although Austin Energy could not provide meter-level data to support this project, I was directed to Dataport, an online research database of residential energy data that is owned and operated by Pecan Street Inc., a nonprofit energy research institute headquartered at The University of Texas at Austin. Dataport has compiled fine-grained electricity consumption data from nearly 1,300 homes—the majority of which are located in Austin. The data are freely available to academic researchers.

There are two aspects that make Dataport's data particularly appealing to researchers. Unlike monthly utility bills and many other academic energy data sources, Pecan Street records energy consumption at very short intervals—minute-by-minute, rather than monthly, daily, hourly, or at 15-minute intervals. In addition, the data are disaggregated, meaning that rather than reporting consumption at the meter level for the whole home, Pecan Street logs electricity consumption at the device level. This enables researchers to focus on particular energy-consuming devices and activities with much greater precision. The data make it a straightforward process to determine how much energy a home uses to wash and dry clothes, for example, or to calculate the daily cost of running a pool pump. Pecan Street staff have already used this data to generate several studies, including a report on summer 2013 heating, ventilation, and air conditioning (HVAC) energy use in 40 homes, which revealed that air conditioning accounted for two-thirds of summer electric use and over 80 percent of discretionary electric use in the homes studied (Pecan Street, 2014). I focused my analysis on consumption data logged on air conditioning condenser units.

Each home in the Dataport database is assigned a unique data ID number. The dataset also contains descriptive information about each home. These variables include city, square footage, presence of a solar panel array, and year of construction. The majority of the participating homes—791 of 1,279—are located in the city of Austin, although the dataset also contains homes in Boulder, Colorado; San Diego, California; San Antonio, Texas; and other cities. I looked only at Austin homes, not only because these homes are most pertinent to the utility, but also because they are exposed to the same weather patterns, which impact A/C usage. The dataset also differentiates between stand-alone residential structures and apartments in multifamily buildings. Only single-family homes were considered in this analysis. Most important, the dataset reports the number of Nest-branded smart thermostats installed in each home. This key variable enabled me to construct a quasi-experimental design with the thermostat as the treatment variable.

Pecan Street's dataset does have a few limitations. Most important, the basic dataset does not contain information on occupant demographics or the number of occupants in each household. Nor does it track employment status or income levels, variables that are highly correlated with energy consumption. Fortunately, Pecan Street conducts annual surveys on a subset of participants, which provide a wealth of information on of these topics. In 2013, 319 single-family households completed the survey. I was able to incorporate these responses into my analysis to account for several potential confounding factors.

Methods

The gold standard for energy efficiency program impact analysis is a randomized control trial (RCT). Technology vendors like Verizon are using Pecan Street's test homes to measure and verify savings from their products through RCTs. In such a trial, households are randomly assigned to either a treatment or a control condition, so that both groups are statistically identical. Researchers then compare differences in energy use, and the RCT design ensures that the comparison is unbiased. For this study, an RCT was not feasible, as there is no indication that Pecan Street actively assigned homes to treatment or control groups based on the presence of a Nest thermostat. Furthermore, there is no recorded installation date for the thermostat, so it is impossible to conduct a "pre-post" analysis, which would compare energy use prior to installing the Nest against energy use after its installation.[5]

With these options eliminated, propensity score matching offers another method for comparing households that adopt a "treatment" technology to households that do not, but have similar observable characteristics, including number of occupants, square footage, construction year, number of floors, number of weekdays spent at home, education level, and income. The matching process included 16 total variables and resulted in 33 single-family homes with Nests matched with 13 single-family homes with similar characteristics but without smart thermostats. Since several participating homes were built by the same developer and thus shared many physical characteristics, multiple treatments were occasionally matched with a single control home.

The next task was to maximize the comparison period for homes in the treatment and control groups. I expected the difference in air conditioning-related energy usage to be greatest during the summer months; therefore, I looked to compare energy use from June 2014 through September 2014, the same months targeted in Austin Energy's demand response programs. Air conditioning-related electricity usage was determined by creating a daily sum of hourly kilowatt demand readings from each home's air conditioning condenser unit over that period. I then calculated the treatment effect using a linear regression with matched homes' mean daily consumption over the course of the full 121-day summer period. Although I also conducted the analysis over shorter periods of time—

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[5] This is the method Nest used for its own study on southern California homes.

including daily, weekly, and monthly intervals—I did not find large differences in the results and thus opted for a full-summer comparison.

Results

The regression analysis revealed a statistically significant difference in air conditioning use between homes with smart thermostats and homes without them. However, I was surprised to discover that homes with smart thermostats used *more* electricity for air conditioning than homes without smart thermostats. Homes with Nests showed an average treatment effect of an increase of 5.83 kilowatt-hours of daily air conditioning-related electricity use over the full summer period. Extrapolating this average daily increase over the course of the 121-day summer, this indicates that homes with Nests used approximately 30 percent more electricity for cooling during the summer of 2014, as compared to the mean Austin single-family home in the database.

Because the propensity score matching algorithm matched multiple treated homes to a single control, the treatment effect varied slightly over the course of several runs of my regression model as individual homes were added or removed from the regression. However, the variation of the treatment coefficient was always within the range of 4.72 to 6.90 kilowatt hours and always indicated an increase in air conditioning electricity consumption from homes with Nests. The table below illustrates an average of the results of the regression over five runs that yielded statistically significant results.

Table 6. Regression Analysis of Average Treatment Effect

n=46	Coefficient	p-value
Treatment	5.8325516	0.0118
Standard Error	2.0820212	
t score	2.84	

Limitations

Although this finding suggests that smart thermostats could actually lead to *more* energy use than traditional thermostats do, there are several factors that affect my ability to link the observed differences in electricity usage in this study to the presence of a Nest thermostat. This is also apparent in the relatively high standard error term. First, it is impossible to know the counterfactual case, that is, how much energy "treated" homes would have used without the assistance of a Nest device. It could be that, prior to installing a Nest, these homes used even more electricity than they do today, and even though they continue to use more energy than their neighbors, these results could represent an improvement in efficiency. With access to pre- and post-installation data, I could have tested this theory; however, thermostat installation dates were not listed.

It is also possible that homes that install Nests are less sensitive to energy costs or simply value comfort more than their peers do, so they tend to use more air conditioning. As previously illustrated in the distributional analysis, Austin-based Nest users tend to be higher-income consumers. However, this theory is an incomplete explanation for these results, as the propensity score matching process takes income into account and only matches homes within the same income bracket. Of course, individuals within the same income bracket can also exhibit different behavior. Given that the Nest is a "learning" device that does not require the user to spend his or her time programming specific daily or weekly schedules, it is possible that Nest users are less motivated to change their behavior and are more reliant on technology to adjust on their behalf. Furthermore, it is also possible that some of the homes with Nest thermostats are enrolled in Austin Energy's BYO thermostat program. Because Nest pre-cools participating homes, it is possible that these homes use more energy than control homes do during these pre-cooling periods.

An additional limitation, as previously noted, is that the participants in Pecan Street's test homes are self-selected; therefore, there is a clear selection bias inherent in the data collected. Many of the participating homes are located in Austin's Mueller Neighborhood, a planned unit development completed in 2011, where more than 200 homes have solar panels, a much higher proportion than is found elsewhere in the city. In addition, *Time Magazine* reports that several of the participating homes are occupied by engineers and environmentally minded residents, indicating that their behavior may not reflect that of the average Austin Energy customer and therefore limits external validity (Walsh, 2014).

Furthermore, given the relatively small sample size of 46 homes, it is always possible that the differences in energy use are due to inherent randomness. Even though the propensity score matching process is meant to emulate a randomized control trial design, atypical behavior from a few households in either treatment or control conditions could affect the observed results. Therefore, these findings must be considered fairly limited and not taken to represent definitive results on the energy-saving capabilities of smart thermostats.

Discussion

Despite its limitations, this study can be helpful for municipal utilities looking to increase energy efficiency and demand response capacity through smart thermostats, and it yields several insights relevant to program design and implementation.

Ownership Matters

Given the marked differences in demand response realization rates between the free thermostat program and the BYO thermostat program, it is apparent that device ownership influences program performance. This may be due to the BYO thermostat program design creating a better alignment of incentives. With a utility-owned thermostat, residents have little incentive to ensure that the device functions properly during demand response events. In fact, as previously noted, some customers have tampered with the devices and are instructing others on how to do the same. This puts the resident's need for comfort at odds with the utility's need for control.

With a resident-owned thermostat, the utility and the customer share the benefits of having a connected and functioning device. Once the thermostat is installed, the homeowner wants to ensure that it is connected so that he or she can benefit from its web-enabled features, like remote control and energy dashboards. The utility shares the same goals, and it also knows it is enrolling a motivated customer—one who has not only expressed an interest in smart thermostat technology, but has actually gone out and spent her or her own money on a device. This investment reflects motivation, and by contrast, free thermostat programs run the risk of enrolling unmotivated households. This is in part because free is considered a "special price" and it can create irrational behavior.

As an illustration of this phenomenon, behavioral economist Dan Ariely conducted an experiment in which he offered subjects the choice of a Hershey Kiss for one cent or a Lindor truffle for 26 cents. Forty percent chose the Kiss, while another 40 percent chose the truffle. When the researchers reduced the price of each candy by one cent, making the truffle 25 cents and the Kiss free, 90 percent of participants took the free Kiss, even though the difference in price had remained the same (Ariely, 2009). Free offers have a magnetic effect, and even though the special price of free enabled Austin Energy to distribute more free thermostats than any other U.S. utility, the devices clearly did not have the expected impact in a majority of homes.

As Austin Energy expands its thermostat-based demand response programs, it should continue to require customers to pay a small amount to receive a utility-sponsored Wi-Fi thermostat. Since smart thermostats can be purchased for as little as $100 today, the fee could be nominal. For example, with a $15 out-of-pocket expense and the $85 incentive, the full cost of the thermostat would be covered. Yet, once the customer has invested even a small amount of money in the device, he or she may be more willing to ensure that it functions properly, increasing the utility's probability of generating valuable peak demand reductions.

Create Performance Incentives That Mitigate Risk

Austin Energy has shown that its enrollment incentive is sufficient to get customers signed up for the BYO thermostat program, but by providing a one-time $85 rebate check with no further incentive, it opens itself up to performance risk. It is possible that customers could receive the rebate check, then move out of the utility's service territory so that they provide no future benefit to the system. Furthermore, there is no incentive for good performance during an event, so it is possible that a home could enroll, receive its check, and never actually contribute a peak demand reduction during an event. Without a performance-based incentive, Austin Energy runs the risk of seeing the same pattern of declining results that plagued the "free thermostat" program. Utility staff recognize this risk and are considering offering incentives for better performance.

One option is a "peak time rebate" (PTR) program. These programs offer bill credits for kilowatt-hours saved during specific peak times. Customers receive an alert from the utility, letting them know that the rebate is in effect for a specified period. Customers can then shift energy consumption to different hours in an effort to earn rewards. Nest is already a technology provider for a PTR program run by Southern California Edison, in which the utility offers a $1.25 per kilowatt incentive for energy saved during events, with a maximum of $60 over the course of the summer (Nest Labs, 2014). Austin Energy already offers a similar $1.25 per kilowatt incentive for commercial customers who voluntarily save energy during peak periods, and it may wish to explore this model in future years if it forecasts declining performance in its residential demand response program.

Alternatively, the utility could implement a non-participation fee for poorly performing homes. For example, if a customer opts out of more than a certain number of events per summer, the account could be subject to an additional charge on their utility bill. This strategy is less preferred than a peak time rebate because it could limit enrollment. According to Nest staff, customers are very averse to penalties and put a high value on the ability to adjust their thermostat during an event. Nest's Head of Energy Partner Products Scott McGaraghan estimates that adding the ability to opt out of events can roughly double the number of homes that participate in demand response programs, more than enough to offset any reduction in performance by enabling opt-out provisions (McGaraghan, 2014). Any program structure that limits enrollments will limit the ultimate demand response resource available to the utility. Therefore, it is more important for utilities to incentivize "good" performance, rather than to penalize "bad."

Yet another option is to implement time-varying rates for electricity. Such a rate structure provides neither a "reward" nor a "penalty" for consuming energy during peak times. Instead, it simply charges consumers a rate that is more reflective of the actual price of power at that particular hour. Time-varying rates, also known as time of use (TOU) rates, have been piloted and studied broadly, and have stimulated decreases in peak consumption when adopted by residential customers (Faruqui, 2014). TOU rates have been implemented by even small municipal utilities like Marblehead, Massachusetts' Municipal Light Department and are soon to become the default rate structure throughout the Commonwealth of Massachusetts (GDS Associates, Inc., 2013). Still, nationwide adoption has been slow—less than two percent of the residential and small business customers in the U.S. are on time-varying rates.

Austin Energy is currently developing a TOU rate program that is specifically targeted at electric vehicle owners who can shift charging to later hours. Smart thermostat owners would also make an ideal customer class for this rate structure, especially if technology providers like ecobee and Nest can integrate real-time pricing information into their control algorithms, thereby automating the process of load shifting for homeowners.

Standardize Data Collection and Sharing

Smart thermostat programs create a significant amount of data, but collection and sharing practices are not always standardized in BYO device programs. Austin Energy is working to ensure that the quality of data it gets from vendors is sufficient to measure and verify their impact. It has, for example, requested that vendors report air conditioning runtime data; however, this practice has been optional in the first few years of the program (Trowbridge, 2014). In the absence of this data from some vendors, Austin Energy has relied on its metering infrastructure to determine program savings; however, that method presents difficulties.

As an early adopter of smart metering technology, Austin Energy has installed automated meter read (AMR) technology that is several generations behind today's cutting-edge smart meters. Each residential AMR meter can hold six hours of 15-minute data, which is then transmitted to a central "take out point" via radio signal, then uploaded and converted through several layers of data infrastructure before engineers can use it for analysis (Trowbridge, 2014). The result is a laborious and time-consuming process for querying the utility's database to verify program performance.

By contrast, Nest now has the data processing and storage capabilities of Google at its disposal and can analyze millions of customer data points in near real-time. Pecan

Street is also investing in large-scale data management infrastructure for its research. It currently collects 89.5 million electricity use and voltage readings each day and has already generated more than 900 terabytes of data from fewer than 1,300 homes (EDF, 2014). For many utilities that serve hundreds of thousands—if not millions—of customers, this scale of data management would be daunting. According to Pecan Street's Scott Hinson, director of its Pike Powers Laboratory and Center for Commercialization, "Even five-minute interval data would crush most utility's back offices" (Hinson, 2014).

The challenge then is to leverage participating vendors' data processing capabilities by ensuring that they provide—at minimum—runtime data and opt-out time stamps, so that Austin Energy can accurately measure the value of its demand response resources and see when homes opt out of events. As Trowbridge notes, this data "will be essential to verification for ERCOT-related DR activities [and enable] faster and more reliable verification" than relying on AMR data (Trowbridge, 2014).

Furthermore, although this study failed to find a decrease in energy usage in homes with smart thermostats as compared to those without, if smart thermostats are to be used to save energy at the utility scale, vendors will have to be willing to share information about when a thermostat was installed so that the utility can conduct sufficient "pre/post" studies to measure savings. For a utility with energy efficiency goals set as high as Austin Energy's, this information could be very valuable.

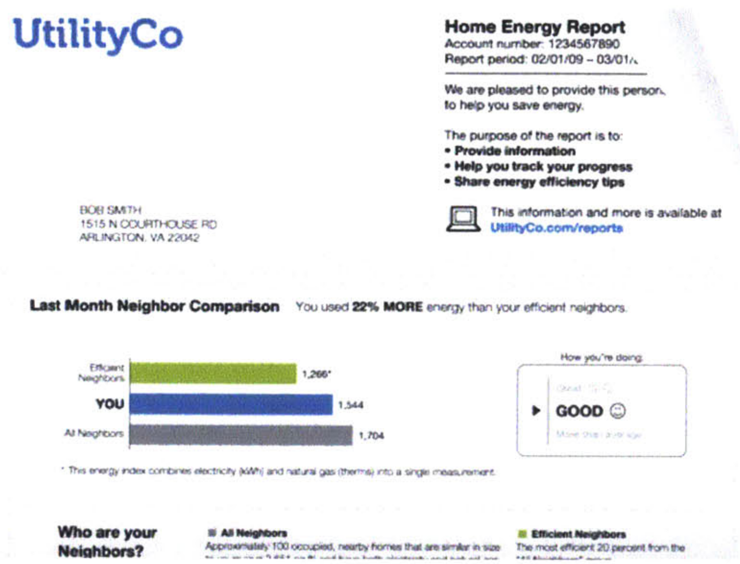
Overcoming Behavior Through Better Defaults

Finally, there are several utility-verified ways to use Wi-Fi connected thermostats for energy efficiency programs that Austin Energy should explore. Several of them focus on setting more efficient default set points via automated messages. These programs could present novel ways to extract energy savings from smart thermostats in order to reach the utility's energy efficiency goals.

Among Austin Energy's existing vendors, Nest offers a "Seasonal Savings" adjustment that suggests more efficient set points based on users' behavior and the particular thermal characteristics of their home. This program can save a reported 5 to 10 percent on heating and air conditioning by making slight changes to thermostat settings.

"Seasonal Savings may adjust the temperature a degree while you sleep, or tweak the temperature half a degree in the morning," according to Nest's website. Given that Nest Thermostats represent more than 90 percent of the installed devices in the "bring your own" device program, Austin Energy should explore the additional savings this service could unlock.

Figure 19. Sample Opower Bill



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Who are your Neighbors?

All Neighbors Approximately 100 occupied, nearby homes that are similar in size

Efficient Neighbors The most efficient 20 percent from the

Source: Opower

In addition to Nest, the energy efficiency services firm Opower is using a similar program design to nudge homeowners toward better set points. To date, Opower has largely focused on driving energy savings through normative comparisons of energy consumption across similar homes, which are delivered through a modified utility bill (Figure 19). By showing homeowners how their energy consuming habits compare to their neighbors', it has proven that a normative nudge can encourage them to use less. Opower has adopted a similar approach to its smart thermostat programs. The company does not manufacture hardware, but instead uses a smartphone application to guide homeowners to efficient set points on a range of thermostats.

One such program with Connecticut's United Illuminating Company uses Opower's application to send customers notifications indicating that "efficient homes" set their heating to a certain level. It then asks if they would like to adopt that set point for the day. If they accept, the app sends a signal to their thermostat—manufactured by Honeywell and provided free of charge by the utility—and makes the change immediately. Later on, they are asked if they would like to lock in this setting as the default. At that point, the app shows a dollar figure for their estimated savings if they agree. Through these real-time normative comparisons and savings estimates, the program creates "moments that matter" to the consumer, and it aims to deliver 5 to 12 percent savings on heating and cooling (Wells, 2014). Austin Energy should explore these and other programs to ensure that its investment in smart thermostats delivers its full value.

Conclusions

Austin Energy's residential demand response programs must be considered in perspective: Austin Energy has an 800-megawatt peak demand reduction goal, and these programs will provide only a small portion of that goal each year. In 2014, Austin Energy reported that it offset 67 megawatts of peak demand. Of that, thermostat-based demand response represented 14 percent, or 4.7 megawatts (Austin Energy, 2014). Even so, smart home technology has the potential to encourage participation in other energy-saving programs, including weatherization and equipment rebate programs as well as TOU rate structures, which can drive further efficiency. As Austin Energy's Jarman told *Electric Light and Power*, "One of the benefits of a [BYO thermostat] model is that we are able to better integrate with our other customer programs" (Martin, 2012).

That prediction is a best-case scenario for electric power providers, one in which the utility's investment in consumer-focused programs generates positive feedback from customers. It may indeed be possible—Opower cites a 50 percent "lift" in customer perception of the utility after participating in one of its technology-assisted demand response programs (Wells, 2014). Yet, not every prediction is as rosy. Smart grid investments, especially smart metering programs, have come under fire from consumer and privacy advocates. California's failed 2007 attempt to make programmable communicating thermostats required under state building codes faced stiff opposition from civil liberties advocates (Somsel, 2008). And smart metering programs represent significant capital investments with clear potential to raise rates in the short term without well-defined methods for lowering them in the longer term, a recipe for controversy (Wald, 2014). Optional programs like thermostat-based demand response can avoid the pitfalls of a full smart metering programs by targeting households who are interested in new technologies and are willing to partner with the utility to take advantage of them. However, unless thermostat vendors are willing to share more detailed data on thermostat performance, demand response programs will continue to require smart meters as a prerequisite for measurement and verification purposes.

In addition to these challenges, demand response is facing significant pushback from some electric power generators in the judicial system. In 2015, a case with the potential to undermine FERC's jurisdiction to regulate demand response is likely to reach the Supreme Court. Although the outcome would not affect Austin Energy's programs directly, it is closely followed by demand response aggregators and other technology providers who may see their business models upended by the decision. If demand response aggregation loses its value in the wholesale markets, will companies like ecobee and Nest still be interested in providing demand response services? A negative outcome for demand response providers could change the whole dynamic of the industry. On the other hand, it could increase the level of interest in utility-run programs like Austin's, since these programs will be shielded from regulatory risk.

Finally, to visit with the researchers at Pecan Street's Pike Powers Lab is to question the very nature of the centralized utility model and wonder whether its days, too, are numbered. Hinson believes that the technologies currently employed in the service of utility-based demand response programs are important, but not because they will ultimately serve utilities' interests. When everyone has a solar panel on the roof, a Tesla in the garage, and a battery pack that lasts a week or longer, why bother with the utility company at all? Under this scenario, Hinson sees consumers transitioning away from grid power and focusing on efficient operation of their homes through devices that can ensure that the solar panel array sends enough power to the electric vehicle in the garage while still running the air conditioner on a hot summer's day. He compares this scenario to the technologies in early personal computers, "You used to have to allocate a specific amount of memory to specific tasks. Now it's automatic. The same thing can happen to every energy-consuming device in our homes" (Hinson, 2014).

Hinson's vision may not be all that far off. In early 2014, California's Public Utilities Commission enabled solar power developers to package small-scale battery storage along with solar panels, a decision that has the potential to make grid power obsolete for homes with sufficient sunshine (Wesoff & St. John, 2014). And as the state grapples with the need to manage the "duck graph" as it moves toward its 33 percent renewable generation goal, California will need homeowners' smart devices to help it balance large swings in the available renewable power generation. Energy storage and responsive demand will play a complementary role in balancing real-time supply from intermittent renewable energy sources.

For the time being, Austin Energy must plan for the needs of today's grid, and its residential demand response programs are helping it to reach its 2020 demand reduction goals. When every home is its own utility, will centralized demand response programs matter? Perhaps not, but responsive demand-side technologies that can keep homes running comfortably certainly will. Austin Energy and its partners are demonstrating that smart thermostats can reduce peak demand, if not reduce overall energy consumption. These technologies will be an essential part of the home of tomorrow, and they should be supported by the cities, states—and utilities—of today.

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