Smart Columbus Grid Modernization

AMI INNOVATION ADOPTION

Amanda Echelberry, Matt Henderson,
Miki Huber, Ryan Northern, & Carly VanCucha

CAPSTONE PROJECT| ENVIRONMENT, ECONOMY, DEVELOPMENT, & SUSTAINABILITY

Table of Contents

Acknowledgements

The authors of this report would like to thank the Electrification Grid Modernization Priority Team for Smart Columbus and specifically the following people for their assistance and time over the course of this project:

Patti Austin, Columbus Division of Power

Wiley Elliot, AEP Ohio

Kristian Fenner, Columbus Division of Power

Ryan Houk, AEP Ohio

Scott Osterholt, AEP Ohio

Dr. Nicole Sintov, The Ohio State University

1. Executive Summary

Advanced Metering Infrastructure (AMI) is an integrated system of smart meters, communication networks, and data management systems that enables two-way communication between utilities and customers (AEP Ohio, 2014). American Electric Power (AEP) and the Columbus Division of Power (CDP) are currently in the process of AMI deployment in and around the city of Columbus. This technology is intended to improve efficiency, identify and respond to outages more quickly, and better monitor and control the distribution system (AEP Ohio, 2014). The increased capabilities of these "smart" meters also allow benefits on the consumer side. Utility-led consumer programs have allowed users to take control of their own energy use, enabling them to better monitor their usage, saving resources and money in the process. These programs have, and will continually, introduce a great deal of Columbus residents to a new, more sustainable and efficient way of thinking about their resource management. This new way of thinking will aid in enlightening the city's residents about the benefits of more efficient approaches to everyday activities. This more conscious approach has significant spillover potential into other Smart Columbus initiatives that could increase the impact of these initiatives in the Columbus area.

The only way to see direct benefits of this technology is to engage with the new features it provides. Uncertainty always comes with innovation adoption, often coupled with negative perception. This analysis highlights the strengths and weaknesses of AMI from the consumer perspective and will better allow the City of Columbus, as an extension of the Smart Columbus initiatives, to capitalize on positive sustainable behavior change in the Columbus area. To achieve this goal, our team established three research objectives to guide our project. First, benchmark research was done to compile information from AEP and other

AMI deployments nationwide in order to identify negative perceptions and best practices of utilities. Finding thorough reports and information for specific AMI deployments was difficult so our team redirected our focus on identifying common problems that were shared among different cities. Bill increases, health risks, fire hazard, cyber security, and "Big Brother" were identified as reoccurring negative perceptions among AMI adopters. Our second objective was to identify improved efficiency based on energy consumption and cost savings attributed to AMI and supplementary consumer programs. AEP Ohio provided an extensive technical report for their gridSMART Demonstration Project as of June 2014, detailing phase 1 of their AMI deployment which covered AMI consistent with 110,000 smart meters (AEP Ohio, 2014). This source had the most detailed information and calculations; therefore, projections for Columbus were based on these data. On average our assumptions predicted that annual savings from adopting AMI and engaging in consumer programs could be up to $239.21 or 23.52% of the average bills combined annually. The final objective of this report was to promote public perception and adoption of AMI through the understanding of behavioral science. Identification of motivators and barriers to sustainable innovation adoption guided strategy to ensure acceptance of this technology. Specific behavior influences on energy use discovered included awareness of the issue, social norms, attitudes about the technology, and perceived control of the behavior.

We concluded with four key recommendations based on our findings. First, AEP's consumer programs have proved tremendously effective both in cost savings and addressing influences of sustainable innovation adoption in accordance with the psychological science of behavior change. However, demographic differences of the Columbus area could further explain differences in motivators and barriers to sustainable innovation adoption as well and should be explored, per our second recommendation. For our third recommendation, as a factor of perceived control, future efforts should focus on emphasizing the power the consumer has with this technology (rather than the utility) to overcome the fears of “Big Brother”. For our final recommendation, we remind our audience that the negative perception issues outlined in our report not only require certain action, but should be anticipated at any given time. We are confident this report will help guide Smart Columbus in securing a successful AMI adoption for its city that may encourage more sustainable innovation related positive behavioral changes in the future as well.

2. Introduction

Deployment of AMI is one of the nine projects associated with the Smart Columbus initiative. American Electric Power (AEP) and the Columbus Division of Power (CDP) are currently in the process of deploying AMI technologies, specifically smart meters, around Columbus. AEP is currently rolling out its gridSMART Demonstration Project, which in its first phase has deployed smart grid technologies with now over 130,000 customers across northeast central Ohio (AEP Ohio, 2014). This deployment marks phase 1 of AEP's gridSMART project with an end goal of reaching nearly 900,000 consumers. The three main technologies being used to update the grid are smart meters, volt var optimization (VVO), and distribution automation circuit reconfiguration (DACR). Smart meters provide two-way communication between the home and the utility, providing quicker service and greater reliability. VVO controls and monitors voltage levels on circuits leading to reductions in KWh of electricity lost while distributing energy to consumers, and DACR allows for the rerouting of power potentially saving significant time where consumers may be out of power (AEP Ohio, 2014).

The adoption of new Smart Grid technologies impacts everyone and provides many benefits the average consumer may overlook. The adoption of smart meters will allow AEP and CDP to cut costs on meter readers who will no longer be needed to go from location to location checking usage levels. Not only will not needing meter readers save money, it will also reduce GHG emissions by eliminating the need to drive to each meter destination (AEP Ohio, 2014). We also expect to see cost savings due to the adoption of new consumer programs that encourage reduced energy consumption, for example, new pricing programs that will allow consumers to take advantage of real-time usage rates. These programs will enable the consumer to save money by choosing to use more power during off-peak times and cutting GHG emissions as fewer power plants will be needed online if peak generation drops.

Smart meters will provide consumers with constant, real time data of energy usage patterns across large areas. This data will provide a benefit over the long term as it is collected and then used to develop models for more efficient power generation and distribution. This will allow for a better understanding of anticipated peak demand. The benefits of these data, however, will be indirectly felt by everyone as they will create more efficient systems that will reduce waste power and overall emissions. As the grid becomes smarter with the adoption of these technologies, our communities and society as a whole will begin to see the greatest advantages. Two-way communication allows for consumption patterns and outages to be detected and resolved quickly. VVO allows for a more efficient distribution of power saving and DACR will allow for a quicker redistribution of power when an area has experienced outages. Overall, AMI deployment will lead to a net benefit for society by creating a more secure and resilient power generation and distribution system.

3.1 Negative Perception

Being a new, groundbreaking technological development, AMI adoption has faced some negative perception by the public. A specific source fueling these interpretations is negative media coverage aimed at questioning the accuracy and safety of these smart meters. Consumer complaints spiked in correlation to negative media coverage, not initial AMI deployment (Navigant, 2010). AMI concerns include bill increases, health risks, potential fires, cyber security, and government intervention in private affairs. The only concern that hasn't been well addressed according to our research is this governmental intervention, or fear of "Big Brother." With this new, connective technology, the public is uncertain if they are comfortable with detailed data of their behaviors being collected and used. This idea of being watched, monitored, and analyzed, is a large barrier to AMI adoption. Beyond "Big Brother," the remaining complaints have been disproven regarding accuracy and safety of AMI deployment. However, it is still imperative to address these concerns when planning an AMI installation.

3.1.1 Negative Media Coverage and Increased Bills

Navigant Consulting, a third-party firm, observed AMI deployment of three electric companies within Texas. These companies included Oncor, CenterPoint, and AEP Texas. Navigant looked at independent testing of the accuracy of advanced meters being deployed, customer meter and billing related complaints filed with the Commission related to advanced meters, the historical electricity usage of customers with advanced meters versus customers who had yet to receive an advanced meter, advanced meter testing, deployment and provisioning processes and controls, and advanced metering infrastructure including the controls in place to ensure that electricity usage information is accurately communicated from the advanced meter to the market for billing purposes (Navigant, 2010). Navigant consulting saw higher amounts of consumer complaints after AMI was deployed. In order to address these complaints, consumers' prior electric bills were analyzed and compared with current bills after AMI installation. For the most part, the increased energy usage that led to higher electric bills was consistent with past years. The exceptions are more appropriately attributed to the consumer simply consuming more based off new behavior.

Navigant found that the amount of consumer complaints had spiked after negative media coverage of AMI. For example, some statements made by the media were, "The recent cold weather has some North Texans seeing red over rising electric bills. But some customers are blaming new digital power meters for their increased electricity expenses" and "The new meter—Oncor's Smart Meter—has taken much of the blame from upset customers... In instances like these, the PUC has a system by which consumers may file a complaint" (Navigant, 2010). From this study, we can conclude that while smart meters do not see higher usage rates in comparison to traditional meters, it is important to stay in tune with rising bills when deploying AMI. Utilities must expect negative media coverage to affect their customer's perception of this new technology and prepare accordingly so that they may be able to defuse the situation when it arises. Additionally, the energy use analyzed by Navigant correlated to previous time lines, meaning the seasonal cycle aligned with AMI deployment at a time where energy usage naturally increases. While we may not be able to avoid the increased temperature during the extent of an AMI deployment of this size, communication with the consumer is important so they do not make false correlations.

In cases of consumers perceiving that AMI is that raising their bills back at home in Ohio, AEP has identified that transitioning from old, slow meters to the advanced meters can result in more accurate electricity usage reporting. To prevent this negative association, AEP has located older meters that may be reading slowly and replaced them with new standard meters until the time comes when smart meters will be installed (AEP Ohio, 2014). This transitional period is aimed to bridge the gap of where negative correlations can fester in the absence of communication and understanding.

3.1.2 Health Effects

The main health concern of AMI is the technology emits radio frequencies (RF). Some of the health concerns associated with RF are cancer, mutagenesis, and genotoxicity. The exposure levels of AMI RF are actually much less than more commonly-used technologies like cell phones, microwaves, and radios (Electric Power Research Institute, 2011). In other words, the emittance from smart meters are weaker waves in smaller densities. The following table from the Electric Power Research Institute shows in detail how smart meters compare to other RF emitted technologies in Table 1.

Table 1

Table 1 – Radio-Frequency Levels from Various Sources

Source	Frequency	Exposure Level (mW/cm²)	Distance	Time	Spatial Characteristic
Cell phone[1]	900 MHz, 1800 MHz	1–5	At ear	During call	Highly localized
Cell phone base station[2]	900 MHz, 1800 MHz	0.000005–0.002	10s to a few thousand feet	Constant	Relatively uniform
Microwave oven[3]	2450 MHz	~5 0.05-0.2	2 inches 2 feet	During use	Localized, non-uniform
Local area networks[4]	2.4–5 GHz	0.0002–0.001[a] 0.000005–0.0002[b]	3 feet	Constant when nearby	Localized, non-uniform
Radio/TV broadcast[5]	Wide spectrum	0.001 (highest 1% of population) 0.000005 (50% of population)	Far from source (in most cases)	Constant	Relatively uniform
Smart meter[6]	900 MHz, 2400 MHz	0.0001 (250 mW, 1% duty cycle) 0.002 (1 W, 5% duty cycle) 0.000009 (250 mW, 1% duty cycle) 0.0002 (1 W, 5% duty cycle)	3 feet 10 feet	When in proximity during transmission	Localized, non-uniform

Furthermore, it is the well-documented consensus of scientific studies that negative health effects from RF are not confirmed even with higher emitting technologies such as cell phones (California Council on Science and Technology, 2011). More research is needed in order to fully understand possible health effects. At these levels, health professionals have found that smart meters are well below the threshold for any concern of the stated health effects and therefore do not pose a risk to the public (California Council on Science and Technology).

Claims of health effects from smart meters, and even RF in general, are quite unfounded, but it's important to anticipate this popular perception. While they are highly unsupported factually, many anti-smart meter groups exist on the basis of health concerns and will target new deployments. It is important for utilities to communicate this information to their consumers so they will not fall victim to false claims of harmful smart meter effects.

3.1.3 Cyber Security

Another concern with smart meter adoption is cyber threats. These can be against the utility itself or on a homeowner's meter. Most smart meters use GSM, the 2G mobile standard equivalent to what we've used to connect our cellphones. This wireless method has a fairly well-known weakness in which an attacker with a fake mobile tower can cause devices to "hand over" data by simply providing a strong enough signal (Hern, 2016). In GSM, devices have to authenticate with towers, but not the other way round, allowing the fake mast to send its own commands to the meter (Hern, 2016). This also means that if a utility uses all the same hard coded credentials for its meters and one meter is compromised, all of them are (Colbeck, n.d.). In comparison to a customer's internet connection, smart meter data is not nearly as sensitive, but it's the customer's data nonetheless and must be protected.

To counter this problem, AEP constantly monitors for these threats with scheduled tests and a designated team to manage security systems (AEP Ohio, 2014). AEP's cyber security team continually works to learn and adapt to new attacker methods so they can respond quickly to prevent penetration of the system and mitigate the problem (AEP Ohio, 2014).

3.1.4 Fire Risks

Another threat smart meters pose that were previously nonexistent with traditional analog meters is an increased risk of fire. Rather than being made of primarily metal materials, smart meters are computers and therefore constructed mostly of plastic which is more susceptible to overheating. Analog meters also have circuit breakers between the incoming power and the meter, providing surge protection and decreased chance of fires where smart meters lack this feature (Colbeck, n.d.). AEP currently has plans in place to monitor risks of fire hazard, sending out someone to check the meters when they approach a temperature threshold to prevent any incidents (AEP Ohio, 2014). These mitigation efforts may not sound comforting to everyone, so another possible solution is to take a look at the actual construction of the meters to see if fire resistance can be improved and further safeguards may be able to be put in place. This is not a common event produced by smart meters but like the other risks outlined in this section, it is essential that the utility effectively communicate the actual risk and the plans in place to address the issue.

3.2 Consumer Programs

AMI goes hand in hand with consumer programs that utilize the new features of this technology. On March 1, 2012, Ohio moved from a regulated utility market to a competitive retail market (AEP Ohio, 2014). Therefore, AMI technology and the consumer programs that go with it are aimed at giving AEP a competitive advantage in this newly competitive market. Despite new opportunities to draw electricity from different suppliers, customers will be incentivized to stay with AEP because of the AMI's potential to help customers. The specific consumer programs developed and implemented by AEP have been analyzed to identify exactly how successfully consumers are engaged in AMI. Not only are economic benefits incentivized for all parties, but also efficiency and societal benefits.

3.2.1 eView

The eView program provides consumers with an in-home device that interacts with the smart meter to provide the consumer with current electrical usage and pricing information, which therefore enables them to be more aware of their energy consumption (AEP Ohio, 2014). This program is the most basic foundation by which consumers may be nudged to make better decisions about their energy consumption by means of a visible indicator. The device also saves usage and cost data from the past 30 days to help customers make connections to their consumption patterns (AEP Ohio, 2014).

3.2.2 SMART Shift

SMART Shift was "designed to enable consumers to lower their bills by shifting usage from higher priced time periods to lower priced time periods" (AEP Ohio, 2014). It works by deploying a two-tiered pricing option that gives consumers the opportunity to lower their off-peak rate in exchange for raising their rate during peak hours (1pm-7pm) (AEP Ohio, 2014).

3.2.3 SMART Shift Plus

This program is similar to SMART Shift but consists of a three-tiered pricing option. This program was deployed in congruence with in-home displays that would give pricing information as well as total current usage in real time. This program also included critical peak pricing (CPP) hours, or extra high rate hours, which AEP could call upon 15 times a year for up to 5 hours each time in order to balance demand (AEP Ohio, 2014). Energy consumed during these events was charged at a substantially higher rate, thus encouraging consumers to reduce their demand for power at these peak times (AEP Ohio, 2014). The pricing schedule for SMART Shift Plus is attached below in Table 2 from AEP's gridSMART Demonstration Project Report (AEP Ohio, 2014).

Table 2

Rate Level	Hours
Low	Midnight – 7 a.m. 9 p.m. – midnight And Weekends
Medium	7 a.m. – 1 p.m. 7 p.m. – 9 p.m.
High	1 p.m. – 7 p.m.
CPP	As called – up to 5 hours each event and up to 15 events per year

SMART Shift Plus also included the deployment of 33 Smart Appliances (AEP Ohio, 2014). These appliances allowed consumers to see their usage in real time and were programed to adjust consumption based off real time electrical rates.

3.2.4 SMART Cooling

This program allows AEP to increase the temperature on programmable thermostats installed in consumers' homes by up to 4 degrees Fahrenheit for up to 5 hours at a time from the months of May through September when demand for air conditioning is at its highest (AEP Ohio, 2014). AEP Ohio has been permitted to declare up to 15 non-emergency events during these months by the Public Utilities Commission of Ohio, as well as 10 potential PJM Interconnection LLC (PJM) emergency events for the same time period (AEP Ohio, 2014). Consumers are notified of the event prior to any adjustment in their thermostats and can choose to accept or decline the opportunity.

3.2.5 SMART Cooling Plus

SMART Cooling Plus utilizes all of the tools from SMART Cooling, but also includes load control switches for electric water heaters, pool pumps, and hot tubs to increase the amount of additional power demand that can be managed remotely (AEP Ohio, 2014).

3.2.6 SMART Choice

This program provides consumers the opportunity to participate in real-time pricing based on supply and demand so that they may save money by avoiding or pursuing certain times of the day to consume energy (AEP Ohio, 2014). Pricing occurs every five minutes for each circuit included in the program (AEP Ohio, 2014).

3.2.6 Evaluation

In the gridSMART Phase 1 demonstration project, the goal of these consumer programs is to enable consumers to make choices based on the way electric rates vary throughout the course of the day. AEP's initial pilot for these consumer programs was conducted using selected employees that lived in the demonstration area (AEP Ohio, 2014). This strategic deployment allowed AEP to hammer out any potential causes of concern for consumers prior to full-scale implementation. AEP then broke up their consumer base into groups and analyzed how each specific group was best targeted. They used the web, direct mail, telemarketing, email, door-to-door, community events and the development of a gridSMART Mobile application to "discover the best method or combination of methods to communicate with its consumers based on both the nature of the Project as well as the competition for electric service in the Project area" (AEP Ohio, 2014). Other more generalized efforts included creating a website and the creation of a gridSMART Mobile unit which "contained six interactive exhibits designed to educate consumers about different aspects of the Project" (AEP Ohio, 2014). The aim of the website and the gridSMART Mobile unit is to educate the public about benefits of new smart meters and to enroll potential consumers into the consumer programs of their choice. In addition, the customer web portal provides neighborhood comparisons, usage disaggregation, a detailed data browser, temperature overlay, high bill alerts, and display of dynamic rates (AEP Ohio, 2014).

To evaluate the success of the consumer programs, AEP sent out a survey to gauge people's motivation for signing up and to figure out how they learned about the programs. The results displayed are from graphs taken from AEP's gridSMART report, represented in Figures 1 and 2 below (AEP Ohio, 2014).

Figure 1

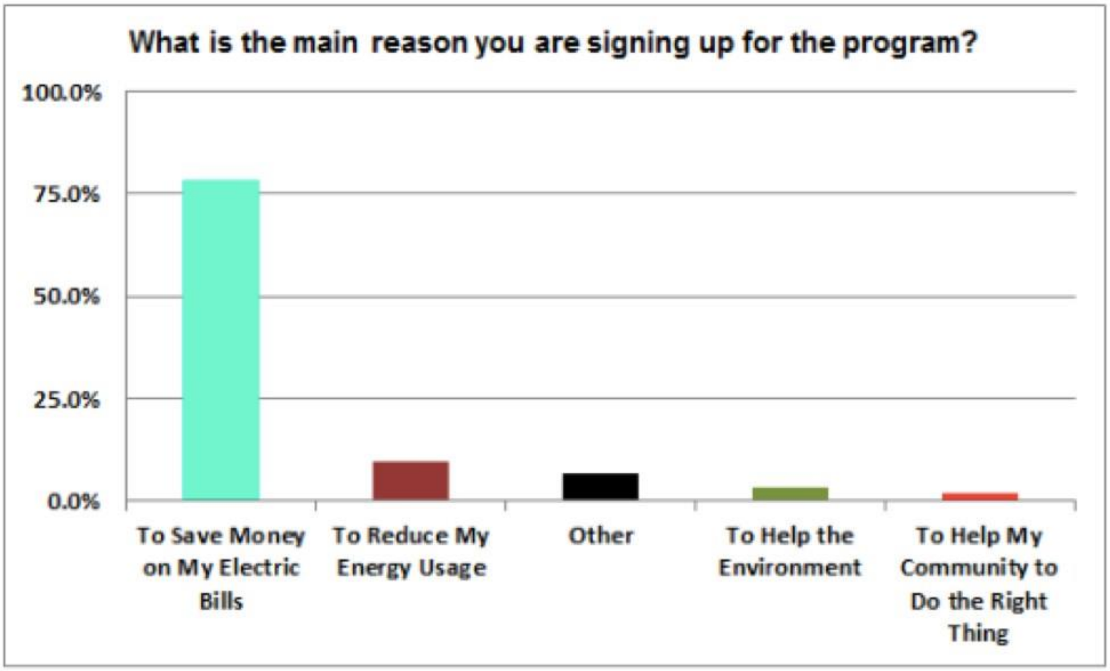
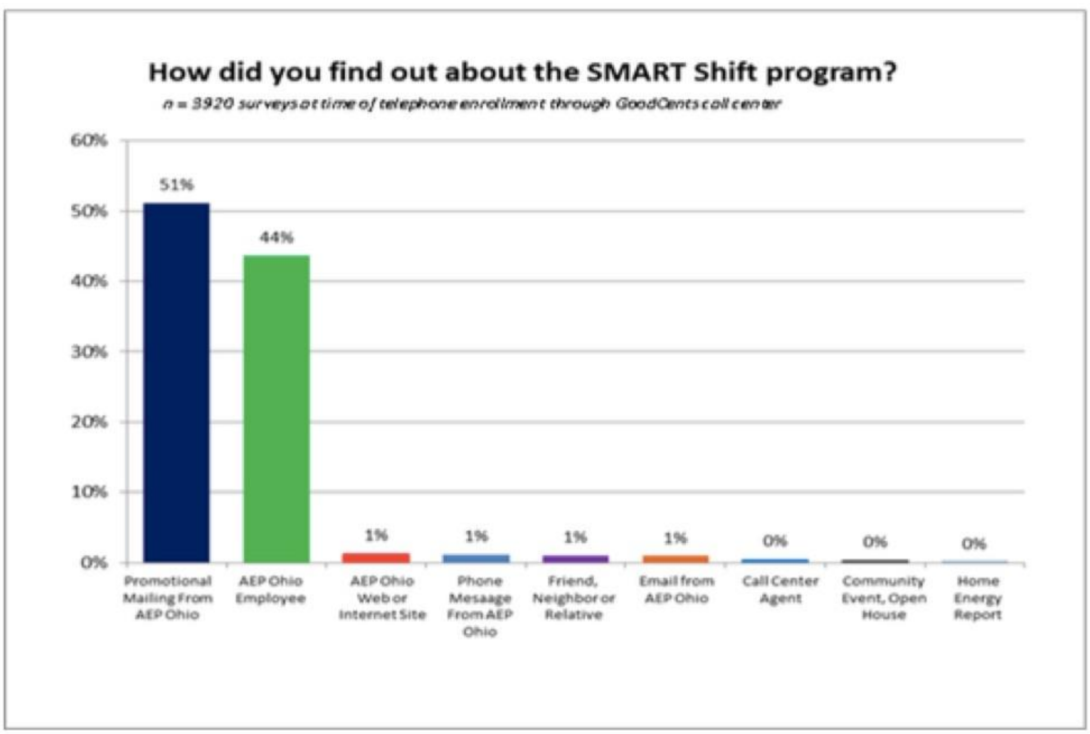


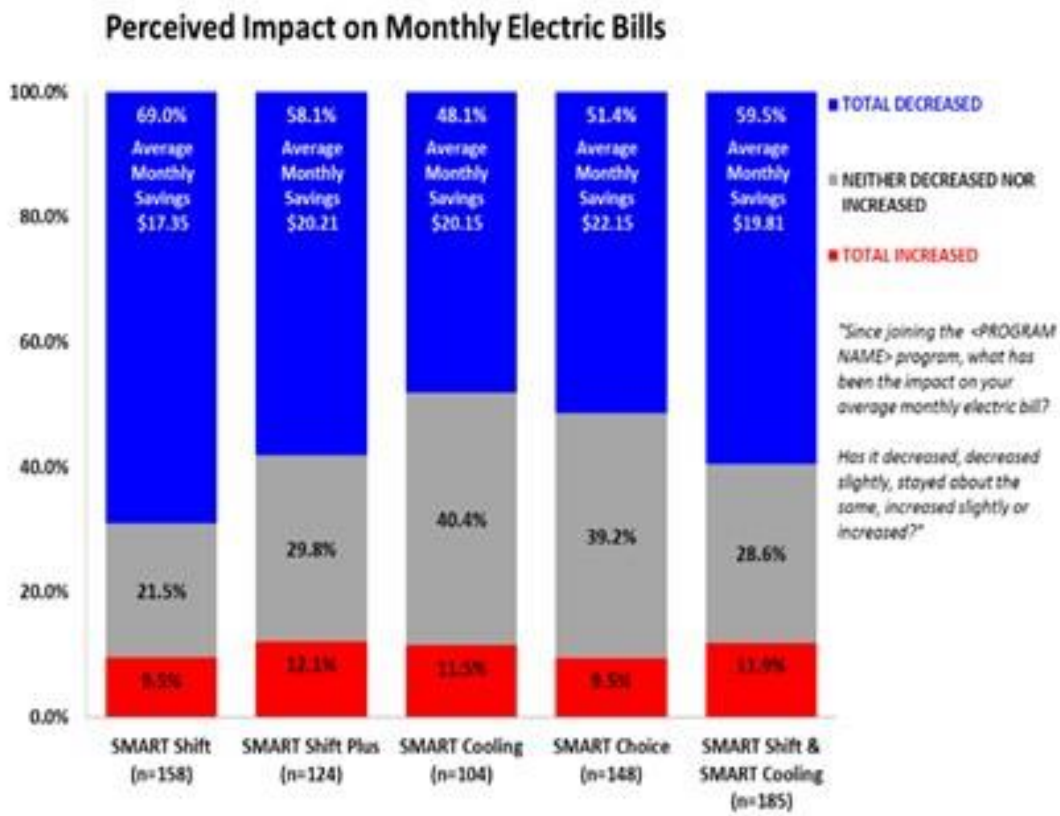
Figure 2



The first graph above shows that an overwhelming number of enrollees' primary motivation for enrolling in AEP's consumer programs was to save money on their electric bills. The second graph shows that most enrollees were informed about consumer programs through one of AEP's mailers or heard about the programs from an AEP employee. These key findings are important to note because it is likely to be similar motivators for Columbus since the phase 1 area of Northeast Central Ohio is in such close proximity to the greater Columbus area. The overall conclusion we can gather from these AEP surveys is that these consumer programs do have a positive impact and perception, and that a majority of participants want to see personal benefits rather than societal benefits. Those societal benefits were expressed using phrases like "to help my community do the right thing" and "to help the environment" as shown in Figure 1 for the surveys. While this finding is expected, it may indicate the need to highlight environmental benefits of improving efficiency in energy consumption. Additional exploration into how much consumers value societal impacts may attract more customers. Determining how emphasis on other benefits could hurt or help adoption could be a potential implication for further research.

AEP also conducted consumer satisfaction surveys to better understand the consumers who were participating in the various programs (AEP Ohio, 2014). These survey results corroborated the graphs above and again, indicated that the majority of participants were interested most in reducing their electricity usage and those desired benefits were confirmed with lower monthly electric bills (AEP Ohio, 2014). Analysis of the survey results showed that most consumers participating in consumer programs experienced a total decrease in their monthly electric bills (~60%), some saw no change (~30%), and a minority (~10%) saw their monthly bills increase. Figure 3 shows these results in a graph from AEP's gridSMART report in more detail below (AEP Ohio, 2014).

Figure 3



AEP's consumer programs were designed to give AEP a leg up on the competition in Ohio's newly competitive electricity market. These programs are meant to maximize cost savings experienced by the consumer and have proved successful at exactly that. If continually implemented by AEP, these programs have the potential to give AEP almost complete competitive advantage over their new competitors. However, it's important to emphasize the benefits of reduced energy consumption beyond monetary values in order to gain a larger audience. Expanding marketed benefits to be more inclusive beyond cost savings would still save the utility money at the end of the day because it's still engaging more costumers.

3.3 Projected Consumption Change & Cost Savings

In most cases, the amount of electricity consumed by the average household will be reduced through the usage of new AMI. One of the best ways to incentivize people to adopt new behaviors and technologies is to show possibilities of monetary savings. AEP and CDP will have the opportunity to educate residents in their AMI target zones by engaging them in consumer programs, allowing them the opportunity to take control of maximizing their savings, thus, leading to reductions in energy usage city-wide.

Throughout Phase 1 of the gridSMART project, multiple surveys were completed by AEP. These surveys found that through the usage of consumer programs such as SMART Shift, SMART Shift Plus, SMART Cooling, SMART Choice, and SMART Shift and SMART Cooling, consumers, on average, experienced significant monthly savings. One Survey specifically asked "Since joining the <PROGRAM NAME>, what has been the impact on your average monthly electric bill," (AEP Ohio, 2014). 69.0% of the surveyed costumers indicated that they were using the SMART Shift program and that they had experienced an average monthly savings of $17.35. 58.1% of the surveyed consumers said they used SMART Shift Plus the average monthly savings for this group was $20.21. SMART Cooling had the fewest number of consumers express seeing a decrease on their bill, with only 48.1% of the surveyed consumers showing an average monthly savings of $20.15. SMART Choice had 51.4% of the surveyed consumers showing an average monthly saving of $22.15. Lastly, 59.5% of the consumers participated in both SMART Shift and SMART Cooling, these participants showed an average monthly savings of $19.81. It can be concluded from this information that the program with the highest saving potential shown by the first phase of AEP's gridSMART project is the SMART Choice program with an average of $22.15 monthly savings. It is also important to note that the

SMART Shift program had the highest number of surveyed customers that saw an average monthly savings, even though this program also averaged the smallest amount of savings. A potential takeaway from this is that the full benefits of SMART Shift were not utilized because temperatures were mild for that summer. All of these programs had relatively positive outcomes, each showing some substantial savings on monthly bills.

In addition to these consumer programs, VVO will also lead to energy savings for the city of Columbus. VVO is defined by AEP as "a demand-sided management program that reduces energy consumption and demand without consumer interaction or participation," (AEP Ohio, 2014). This technology was first tested by AEP in 2010 and 2011. AEP initially used two different suppliers of the hardware needed for implementation of this technology in their tests. GE had a system that was tested between July 23 and September 20, 2010. It showed promising results of an energy reduction of 2.9% and peak demand reduction average of between 2% and 3% (AEP Ohio, 2014). In the following year between March 11 and June 20, 2011, a PCS system was deployed and showed an average energy reduction of greater than 3% and station peak demand reduction also greater than 3% (AEP Ohio, 2014). VVO will not only result in monetary savings though; AEP completed a CO2 reduction calculation that showed that 12,536 metric tons of CO2 could be avoided annually through the implementation of VVO technologies (AEP Ohio, 2014). The overall impact as documented by AEP's demonstration project is detailed in Table 3 and 4 below.

Table 3

Program	Quantity	Annual CO2 Avoided
Consumer Programs Energy Reduction	Appx 10% of consumers	69.12 metric tons
Total AMI Deployment	70 DACR circuits, ~11,000 Consumer Program Participants, Avoided truck rolls from ~110,000 AMI meters, 17 VVO circuits	12,819.28 metric tons

AEP Ohio's gridSMART Demonstration Project Phase 1 Results

Table 4

Program	Quantity	Annual CO2 Avoided	Car Equivalence
Consumer Programs Energy Reduction	Appx 10% of consumers	562.22 metric tons	~128 cars
Total AMI Deployment	250 DACR ciruits, ~89,400 Consumer Program Participants, Avoided truck rolls from ~849,000 AMI meters, 160 VVO circuits	120,237.47 metric tons	~27,327 cars

AEP Ohio's gridSMART Demonstration Project Phase 2 Projections

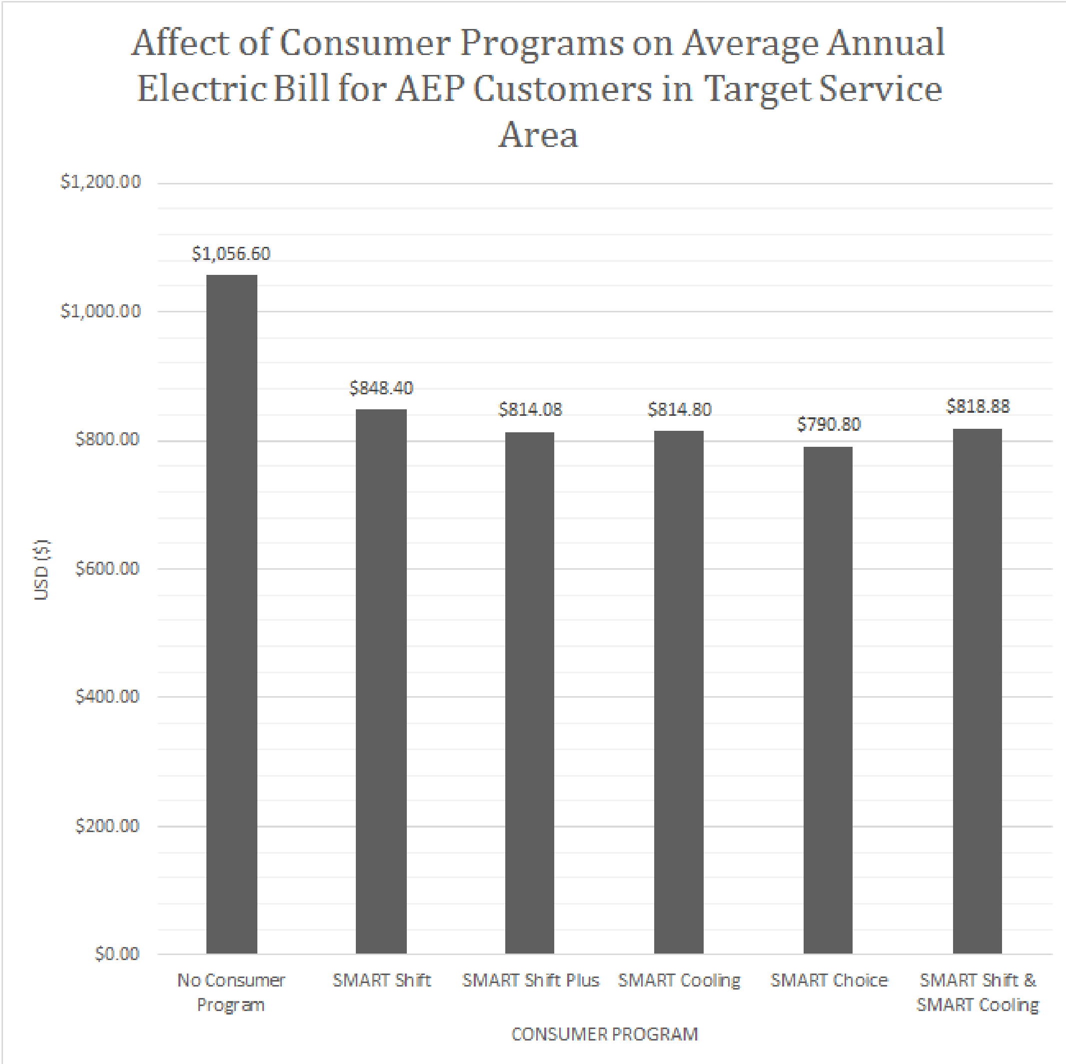
The target service area for AEP and the Columbus Division of Power is comprised of 25 zip codes. Through analysis of United States Census Data, each area's average income was calculated. This gave better insight into where savings would be most beneficial for the average consumer. AEP supplied information on the average annual electric bill for each zip code. Using this information a table and a bar graph showing the perceived annual savings that an average household could expect to see from the participation in a consumer program were created. The table shows perceived annual savings from participating in each individual program and the bar graph shows the average of these savings over the entire service area. Table 5 and Figure 4 are both attached below. Additionally, Table 6 is available in the appendices to identify the communities associated with the given zip codes.

Table 5

Average Savings by Program (Regular Cost-Customer Programs Perceived Savings)

Zip Code	Avg. Annual Electric Bill	SMART Shift	SMART Shift Plus	SMART Cooling	SMART Choice	SMART Shift & SMART Cooling
43123	$1,332.27	$1,124.07	$1,089.75	$1,090.47	$1,066.47	$1,094.55
43137	$1,743.53	$1,535.33	$1,501.01	$1,501.73	$1,477.73	$1,505.81
43201	$923.91	$715.71	$681.39	$682.11	$658.11	$686.19
43202	$820.68	$612.48	$578.16	$578.88	$554.88	$582.96
43203	$1,051.63	$843.43	$809.11	$809.83	$785.83	$813.91
43204	$1,098.45	$890.25	$855.93	$856.65	$832.65	$860.73
43205	$1,028.58	$820.38	$786.06	$786.78	$762.78	$790.86
43206	$1,113.37	$905.17	$870.85	$871.57	$847.57	$875.65
43207	$1,165.64	$957.44	$923.12	$923.84	$899.84	$927.92
43208	$1,259.19	$1,050.99	$1,016.67	$1,017.39	$993.39	$1,021.47
43209	$404.56	$196.36	$162.04	$162.76	$138.76	$166.84
43210	$1,078.68	$870.48	$836.16	$836.88	$812.88	$840.96
43211	$905.38	$697.18	$662.86	$663.58	$639.58	$667.66
43212	$1,047.66	$839.46	$805.14	$805.86	$781.86	$809.94
43213	$988.86	$780.66	$746.34	$747.06	$723.06	$751.14
43214	$980.76	$772.56	$738.24	$738.96	$714.96	$743.04
43215	$1,133.67	$925.47	$891.15	$891.87	$867.87	$895.95
43216	$1,243.95	$1,035.75	$1,001.43	$1,002.15	$978.15	$1,006.23
43217	$1,164.43	$956.23	$921.91	$922.63	$898.63	$926.71
43218	$1,061.31	$853.11	$818.79	$819.51	$795.51	$823.59
43219	$1,048.27	$840.07	$805.75	$806.47	$782.47	$810.55
43220	$1,059.35	$851.15	$816.83	$817.55	$793.55	$821.63
43221	$1,072.52	$864.32	$830.00	$830.72	$806.72	$834.80
43222	$1,206.26	$998.06	$963.74	$964.46	$940.46	$968.54
43223	$1,061.78	$853.58	$819.26	$819.98	$795.98	$824.06

Figure 4



While these projections on the Columbus area are quite assumptive, it gives us an idea of what can be expected. Specific demographic data was not obtainable give the sensitivity of the information and the time frame in which our project was limited. If more research could be conducted in this area, realizing how much a household spends on their utility bill for a specific income range or location would help identify exactly how much a consumer could expect to save by engaging in this technology. Additionally, understanding the geography could help determine average energy consumption patterns for communities as well as how energy efficient their homes are. These factors can help better develop a plan to engage and benefit all socioeconomic groups throughout Columbus.

3.4 Behavioral Science

Applying behavioral science to the adoption of AMI has allowed for better understanding of the theoretical foundations of energy use behavior, exploration of the effectiveness of interventions aimed at reducing energy and other resource use, identification of predictors of alternative energy resource acceptance, and proposition of models of sustainable energy technology acceptance (Sintov & Schultz, 2015). Our team specifically looked at research from Ohio State University's own Dr. Nicole D. Sintov, Assistant Professor of Behavior, Decision Making, and Sustainability. Dr. Sintov is an environmental psychologist who has done extensive research into the adoption and use of sustainable innovations. She provided us with a few articles she had written that related to our project and gave us deeper insights into the challenges facing successful AMI deployment. According to established theories, behaviors in relation to smart grid technology adoption and use can be influenced by intentions to take action (The Theory of Planned Behavior (TPB)), perceived control over the situation (TPB), attitudes (The Norm Activation Model (NAM)), value orientation (The Value-Belief-Norm Theory), awareness (The Value-Belief-Norm Theory), social norms (The Focus Theory of Normative Conduct), expected utility/economic benefit (Behavioral Economics approach), gain/loss framing (Behavioral Economics approach), individual autonomy (Self-Determination Theory), reinforcement/reward (The Theory of Operant Conditioning), and community-specific motivators and barriers (Community-Based Social Marketing (CBSM)) (Sintov & Schultz, 2015).

Sintov identifies action and control mechanisms to engage consumers with the technology. The ‘consumer programs’ she explores are demand response programs, time-of-use pricing, energy feedback, disaggregation technologies, and smart automation (Sintov & Schultz, 2015). AEP has done an excellent job designing consumer programs that meet these criteria. In general, the purpose of AMI is to provide energy feedback, but additionally, the company’s eView program and their customer web portal provides more detail to this like providing consumption history and neighborhood comparisons. The SMART Cooling program includes a thermostat that acts as a smart appliance that monitors and reports consumption, but AEP also is investing in other smart appliances that can be streamlined with gridSMART technology and provide disaggregation information. Smart automation programs are utilized in the SMART Cooling program and time-of-use pricing is represented by AEP’s SMART Shift program. Demand response is utilized not only by both programs, but also by the infrastructure in general through VVO and DACR to better respond to voltage demand and outage demand for overall better distribution of service. It is important to continue this correlation between consumer programs and behavioral science literature to ensure successfully changed practices among adopters. A breakdown of Dr. Sintov’s behavioral science tools are outlined in Table 7 from her literature below (Sintov & Schultz, 2015).

Table 7

TABLE 1 | Behavioral science tools for unlocking potentials of smart grid technologies.

Smart grid technology	Potential	Target behavior	Behavioral science tools
Demand response	Reduce peak demand	Increase program enrollment	Incorporate motivators/barriers into messaging; use flexible defaults
Time-of-use pricing plans	Reduce peak demand	Increase program enrollment	Incorporate motivators/barriers into messaging
Energy feedback	Increase energy efficiency	Reduce energy consumption	Leverage social influence; tailor feedback to address barriers/motivators
Disaggregation technologies	Increase energy efficiency	Reduce energy consumption	Provide high-resolution feedback and specific recommendations
Smart automation	Reduce peak demand	Maximize participation in demand response events	Use flexible defaults

This integrated approach not only applies to sustainable technologies, but to other environmentally-relevant behaviors as well (Sintov & Schultz, 2015). This literature found that spill-over effects should be anticipated. A recent study from 2015 based on the Norm Activation Model suggested that when awareness of environmental impact from energy use, mitigation ability potential, and sense of moral obligation were all increased, a correlating increase in motivation of other energy reduction behaviors would also be seen (Sintov & Schultz, 2015). In other words, if a consumer is successfully engaged in AMI and reduced energy consumption as a result, they will feel more motivated to engage in other sustainable behaviors that reduce energy use like purchasing a more energy efficient car like an EV or taking advantage of the COTA more. Therefore, it is the conclusion of this team that developing an AMI deployment strategy that is aligned with scientifically proven behavioral science research like Dr. Sintov's will not only result in successful adoption of AMI but also will enable behavioral change that consumers can carry on to other sustainable behaviors. Furthermore, we encourage the City of Columbus to consider this research when addressing other environmentally-relevant behaviors they'd like to encourage in the city as we believe they will see similar successes.

4. Recommendations

It is the recommendation of our team that Smart Columbus, Columbus Division of Power (CDP), and AEP Ohio take the findings of each of our research objectives into consideration as they prepare for AMI deployment in Columbus. While this technology is essentially unavoidable, it is important to anticipate and prepare for barriers and negative feedback. Not only will this strategy secure superior customer service for the city of Columbus by the electric utilities, it will also enable this technology to be as successful as possible in terms of reducing consumption, prices, and emissions—important objectives of Smart Columbus. Beyond this, we offer four key recommendations to conclude our AMI emissions—important objectives of Smart Columbus. Beyond this, we offer four key recommendations to conclude our AMI perception and adoption research.

First, AEP has excellent consumer programs that engage their customers with the benefits of AMI technology in accordance with energy use behavior theories identified by behavioral science studies. In conjunction with CDP, the City of Columbus should consider using AEP's customer programs as the foundation of engaging citizens with AMI. While providing information and constructive dialogue with consumers is important, the bulk of consumer benefits occur through active engagement with the technology that sparks behavioral change that may reduce consumption and bills. Not only will consumer benefits improve customer satisfaction, but they will also improve the overall footprint of the electric utility and the sustainability goals of Smart Columbus.

A second recommendation of our team is that greater emphasis may be put on the demographic differences of Columbus communities. Accurate data on income, consumption, and bills should be used to better understand the value orientation, expected utility, and other community-specific motivators and barriers that may hinder or fuel sustainable behavior change among different groups. While our research could not accurately draw in on how this information may affect benefits and perception of AMI, we believe identifying more detailed data will be beneficial to Smart Columbus in developing a strategy that favors all types of consumers and sets them up for success.

Directly linking the behavioral science indicators identified by Dr. Sintov to the negative perception research outlined in this report by our team, Perceived Control is a factor that has had little attention as far as addressing negative perception. To calm the fears of "Big Brother", future efforts must focus on gain/loss framing to highlight the benefits of connectivity rather than the misconception of being watched. Greater emphasis should be put on the empowerment of the consumer's abilities with this technology to overcome this insecurity. Furthermore, through our research we have discovered that benefits specifically carried by the consumers are much smaller than the weight of benefits produced by AMI as a whole by means of VVO, DACR, and overall improved efficiency. Attention should be put on the consumer benefits to capture disinterested customers as well as highlighting how the infrastructure benefits the community. Different audiences will appeal to one, if not both of these strengths of AMI. The adoption strategy developed by Smart Columbus should take note of when to emphasize consumer benefits like bill reductions, efficiencies, and convenience, and when to emphasize the environmental and community benefits of AMI. It is important to structure a gain/loss framing that encourages environmental and community benefits without infringing on or belittling the consumer benefits.

Finally, AMI deployment must continually consider negative perception that may be heightened by media at any given time, not just as at the beginning of deployment. It is important to remind consumers that fire and cyber risks are being monitored. Explanations of questions of health risks and bill increases should be developed using the energy use behavior influences that Dr. Sintov describes. By remaining sensitive to the public and communicating concisely when constructing risk communication efforts, the city can overcome the potential growth of these negative perceptions as well as provide effective mitigation if they arise along the way.

5. Conclusion

The implementation of Advanced Metering Technology Infrastructure in the Columbus area has the potential to act as a catalyst for positive change in the everyday operations of the city and its inhabitants. Educating consumers about their cost savings potential and possibility for improved service quality, which we suggest Columbus Division of Power implement as well, will introduce a vast array of Columbus residents to a new way of thinking about their resource management. By preparing to combat any negative perception and providing consumer programs that inform and engage the customer in this new technology, AMI deployment can successfully be implemented throughout Columbus in a manner that enables its people to experience positive behavioral change that makes the city more efficient as a result. Once consumers understand the potential benefits of a new "smart" way of thinking, the benefits of other Smart Columbus initiatives will become clearer to them as well. We believe a plan developed with the strategies outlined in this research project will allow Columbus to continue to grow as a smart city.

6. Appendices

Table 6

Average Household income by Zip code	Primary City/Neighborhood
43123	Grove City (Darbydale, Urbancrest)
43137	Lockbourne
43201	Columbus (Weinland Park/University District)
43202	Off Campus North/Clintonville
43203	Columbus (Near East/Downtown)
43204	Greater Hilltop
43205	Columbus (Near East/Downtown)
43206	Columbus (Near South)
43207	South Alum Creek
43209	Bexley
43210	University (on campus)
43211	North Linden
43212	Grandview (Grandview heights, Marble Cliff, Upper Arlington)
43213	Whitehall
43214	Clintonville
43215	Columbus (Downtown-Short North/Grandview Heights)
43219	Columbus (North East/Cassady)
43222	Franklinton (North)
43223	Columbus (southwest)
43224	Columbus (North of Linden west of Easton)
43227	Eastmoor (South Whitehall)
43228	New Rome
43229	Worthington (Northland)
43230	Gahanna
43232	Eastland (south of Whitehall)

This table provides a common neighborhood associated with the zip code to give a quick reference for which zip codes are covered under both American Electric Power and the Columbus Division of Power.

7. References

[1]*AEP Ohio. (2014). gridSMART Demonstration Project: A Community-Based Approach to Leading the Nation in Smart Energy Use Department of Energy (DOE) Smart Grid Demonstration Project (SGDP). Columbus: AEP Ohio.*

[2]*California Council on Science and Technology. (2011). Health Impacts of Radio Frequency Exposure from Smart Meters. Sacramento: California Council on Science and Technology.*

[3] *Colbeck, S. P. (n.d.). Safety and security concerns drive need for smart meter opt-out.*

[4]*Electric Power Research Institute. (2011). Radio-Frequency Exposure Levels from Smart Meters: A Case Study of One Model. Palo Alto: Electric Power Research Institute.*

[5]*Hern, A. (2016). Smart electricity meters can be dangerously insecure, warns expert. Hamburg: The Guardian.*

[6]*Navigant Consulting. (2010). Evaluating of Advanced Metering System (AMS) Deployment in Texas. San Jacinto: Navigant Consulting LLC.*

[7]*Sintov, N. D., & Schultz, W. P. (2015, April 09). Unlocking the potential of smart technologies with behavioral science. frontiers in Psychology, 6.*

[8]*U.S. ZIP Codes: Free ZIP code map and zip code lookup. (n.d.). Retrieved March 30, 2017, from https://www.unitedstateszipcodes.org/*