# Real Time Electricity Pricing: How Alternative Pricing Programs Can Be Used to Bring Awareness to Electricity Consumption, Encourage Smart Home Automation, Lower Monthly Electricity Bills and Improve the Electrical Grid

An Interactive Qualifying Project Report

Submitted to the Faculty
of the
Worcester Polytechnic Institute
In partial fulfillment of the requirements for the
Degree of Bachelor of Science

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Date: March 18, 2021

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# Abstract

The aim of the following project was to increase participation in real time pricing model by educating the consumers about existing electricity pricing models, while reducing their overall energy consumption and using IoT devices to spread out peak load hours on the grid. Based on the results of the survey, the group recommends implementation of alternative pricing models on a state level: Time of Use for the general public and Real Time Electricity Pricing for those with higher risk tolerance.

# Acknowledgements

We would like to thank our advisor, Adam Powell for his invaluable support during this project. Specifically, for providing resources, recommendations and suggestions for our research, for helping us distribute the survey and decide on the scope of the project.

Additionally, we would like to thank John Marczewski, Vice President of Electric Consulting for sitting down with us to talk about electricity companies, load on the grid, electric vehicles and his own research regarding the future impact of Electric Vehicles.

Lastly, we want to thank Barbara Kates Garnick, Professor of Practice at Tufts for talking with us about energy policies, pitfalls of real time electricity pricing and providing us with guidance on opening up alternative pricing methods to the public.

# Executive Summary

## *Introduction*

Energy consumption continues to skyrocket as both personal and private lives become increasingly dependent on an ever-expanding array of electronic devices. Naturally, higher consumption also brings forth issues in terms of the consumer spending ever more on their electricity bills, increased impact on the environment, and the grid itself taking on increasingly unsustainable loads. Use of Real-Time Electricity Pricing (RTP) or other alternative schemes such as Time of Use (TOU) can both incentivize consumers to change their usage habits and drive their consumption away from peak load hours on the grid to a more even distribution.

The objective of our investigation was to determine how realistic RTP may be as well as what would have to be implemented in tandem with it to make a successful transition. We delved into existing examples of RTP and TOU, as well as up and coming technologies such as electric vehicles (EVs) and solar panels, to model how these pricing schemes and technologies alter supply and demand. As these pricing schemes inherently involve more awareness and participation on the part of the consumer, a strong level of risk mitigation becomes necessary—thankfully, however, modern technology such as Internet of Things (IoT) devices allow automation to an extent previously unthinkable. However, the inherent drawback is the always-on Internet connection necessary to operate these devices. As such, we also explored various ways of making sure consumers use these devices within the range of their ability to keep themselves secure on the Internet.

This project was completed in three phases so that we could form our recommendations: first, research into the aforementioned topics. This was followed by a survey to help model real-world use of electricity, the willingness to change pricing schemes, and even changes to consumption that have been driven by contemporary events such as Covid-19. Finally, the results of this survey were rounded up and compared to the prior research as well as relevant pricing data points currently in use in New England to model what pricing schemes, behavioral changes, and technologies to use actually make sense given the population and current trends.

## *Findings*

### *Survey participant background (age, education, spending, location)*

We should note our survey participants have a mean age of 50, average electricity monthly spending bill of  $121 and education level of between Bachelor's degree and Master's degree. Most survey participants were located within Massachuesetts.

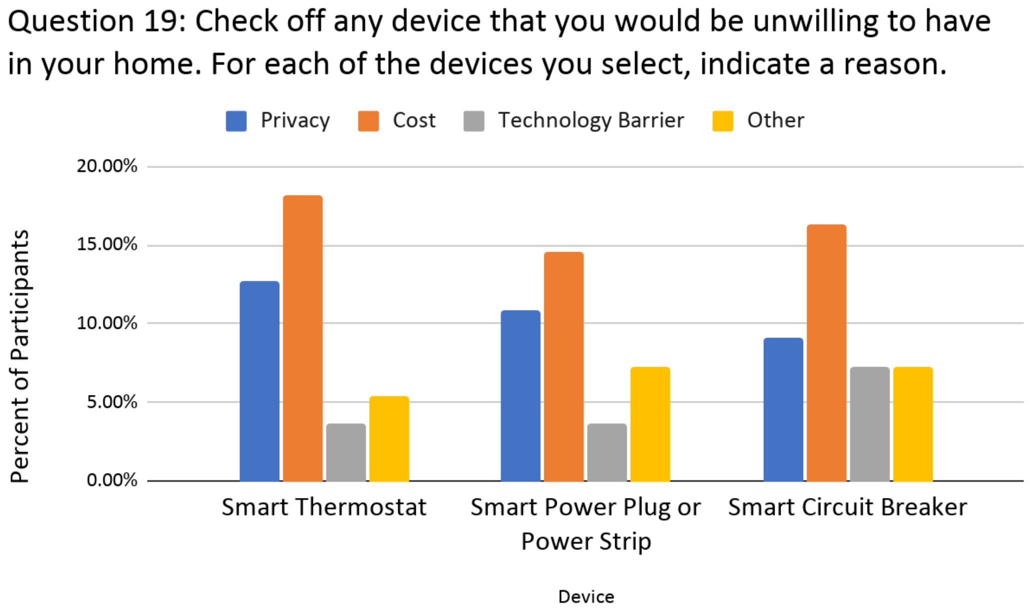
### *RTEP Awareness and Adoption*

We find a lack of alternative pricing scheme awareness to be one of the key obstacles in adoption of RTP. Figure 4.4 shows the familiarity survey participants had with pricing scheme terms. Only 29.1% of participants were aware of an alternative pricing scheme at all. As real time pricing is not the default pricing scheme awareness is a prerequisite to adoption and awareness can be significantly increase

We asked whether participants would consider implementing RTP in the future, our group concludes that our survey participants are generally receptive to the idea of RTP, with 47.3% giving a resounding yes and 34.5% saying that they are not sure. Only 3.6% explicitly said “No”.

*Idle Home Devices and Saving with Smart Home System*

We asked about idle home devices and smart home technology for savings and risk analysis. We found a low adoption rate of smart home technology and found the main reasons for adoption resistance were privacy and cost as visible in the figure below.



*Security*

We found that our survey participants had a less than acceptable level of security awareness for recommendation of smart devices. According to the results of the survey, only 14.8% (approximately 1/7) of participants use a password manager. The use of a password manager is also generally related to one’s competence with the secure use of computers.

*Shifting Electricity Usage and Smart Home Systems*

Figure 4.10 shows people’s willingness to shift time of usage on devices broken up by appliances. People are generally receptive to the idea of shifting their time of use for certain devices, for fiscal, environmental or other reasons.

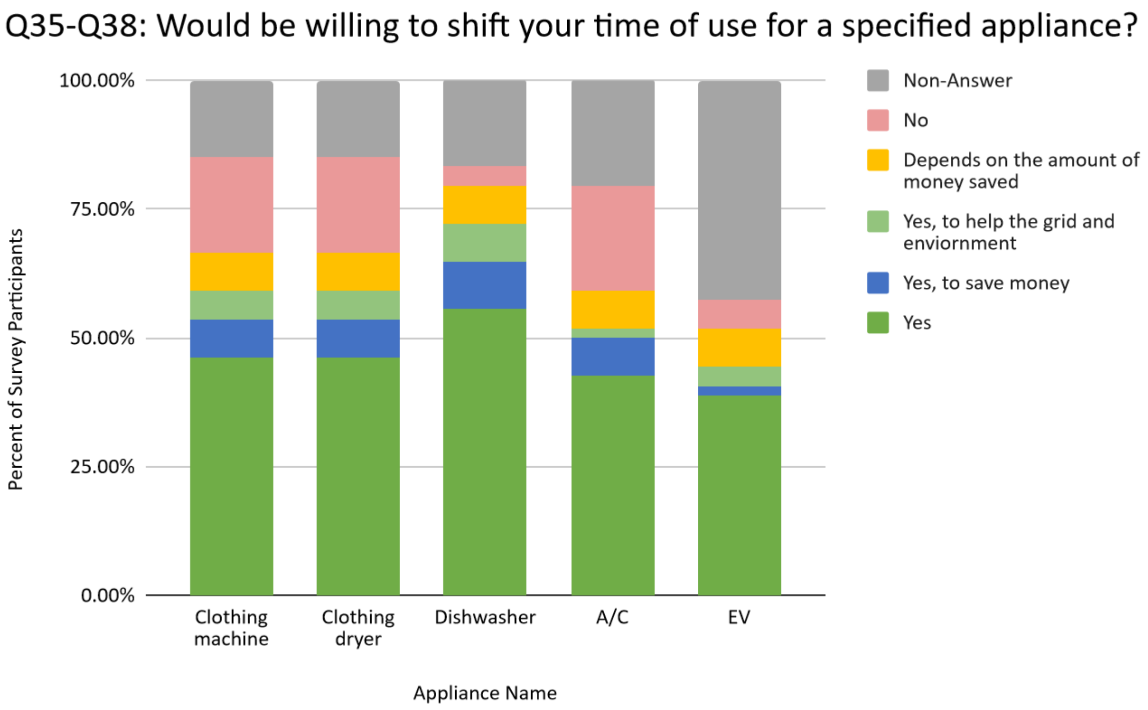


Figure 4.10. Participants willingness to shift time of use for specified appliances.

Although the participants were generally receptive of the idea, we also asked if they had any barriers to shifting their time of use for devices and analyzed top reasons to make better behavioral recommendations. More investigation needs to be done regarding "prefer not to answer", "other" and "distrust" categories as the proportionality was higher than expected. The portion of the "abnormal behavior" category could be diminished with a feedback loop in the direction of normalization.

*Solar Programs*

To establish the ability to participate in the solar programs, we asked our participants whether they owned or leased any solar panels in question 23. We found that 10.9% of survey participants owned solar panels, 1.8% leased them and 1.8% had a condo association that owned solar panels. For participants that did consider solar panels, but did not end up owning them, we asked about factors that prevented them from obtaining solar. Barriers indicated in the survey were indicated as follows: 19.6% lack of roof access, 10.7% lack of roof suitability, 25% upfront costs, 17.9 % lack of clarity of the process and 26.8% other. Technological improvement, fiscal incentivisation as well as education are all likely to reduce most of these barriers in the future.

*Savings from Reduction in Idle and load shifted devices*

The first part of our study was designed to calculate potential consumer savings that could be realized from paying greater attention to electricity consumption and taking steps to reduce idle electricity consumption. We found that, on average, for our 47 survey participants that did not skip the question, a person could save \$191.10 for all their devices per year if they employed smart home technology techniques to limit the amount of idle power wasted. Furthermore we found people would be able to save \$51.14 (\$135.05-\$83.91) if they were willing to shift the time of use for clothing washing/drying machines, dishwashers, ACs.

*Savings from Real Time Pricing*

We collected hourly real time electricity pricing points for the Boston region from ISO New England and plotted them against 116.15 \$/MWh Boston city generation service cost in MA estimated by our group which is the total cost - delivery and fees. We plotted all individual points and plotted them which is shown in Figure 4.17, then the mean of all the points and calculated average hourly price shown in Figure 4.18. The average of all the blue points on the graph, the real time price points is 23.65 \$/MWh.

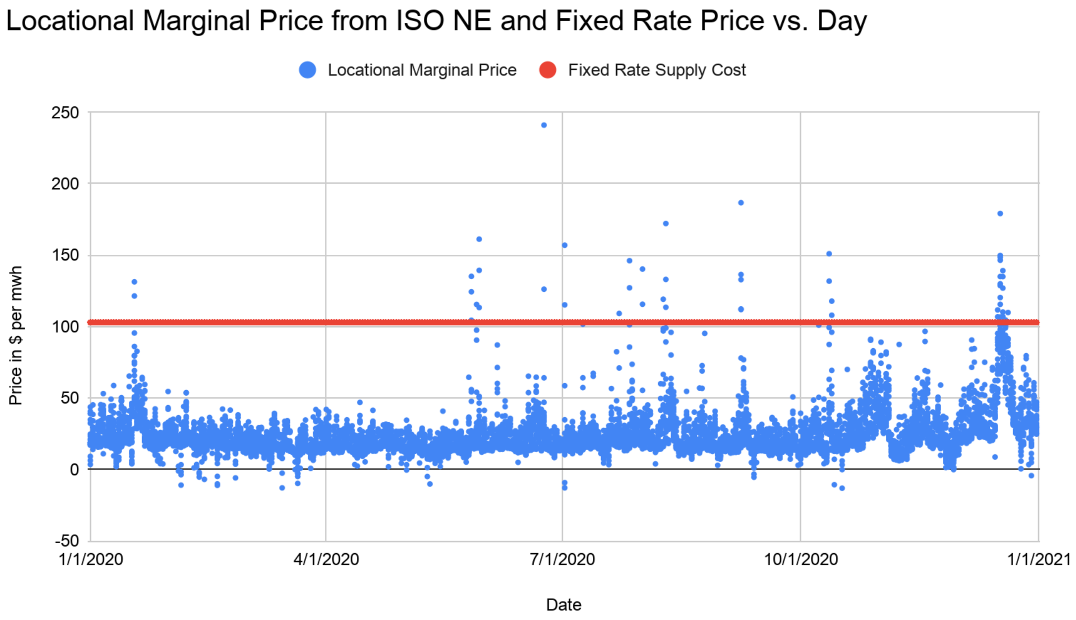


Figure 4.17. Hourly Locational Marginal Price from ISO NE and Fixed Rate Price vs. Day

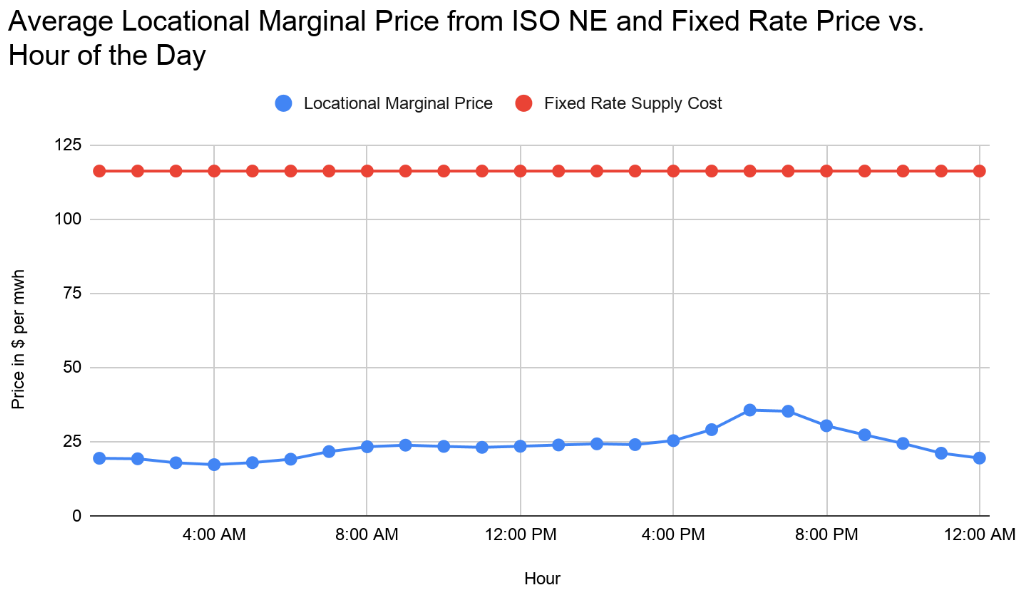


Figure 4.18. Average Locational Marginal Price from ISO NE and Fixed Rate Price vs. Hour of the Day

Initial observations imply that RTP rate is a much better deal than Eversouce and National Grid (electricity providers in MA). We should note that as price is a delayed representation of demand's relationship with supply then spikes in price will occur, thus skewing averages. This can be seen in the individual points of the price spikes in Figure 4.17 skewing the averages in Figure 4.18.

### ***Recommendations & Conclusions***

Based on background research and analyzed results from the survey, a series of recommendations have been drawn from the project objectives. In order to be used effectively, customers need to closely monitor and maintain their electricity usage. The usage of RTEP includes complex risks with potential benefits – similar to trading on the stock market. Time of use pricing (TOU) is more stable than RTEP, raising and lowering electricity prices at specific times instead of real-time usage. TOU should be recommended to most customers, with others who are more capable and interested potentially implementing RTEP. It is recommended that customers be provided with information on alternative forms of pricing for them to interact with and digest on their own. The provided information should appeal to a user's interest in both environmental and economic benefits. Customers may also modify their behavior to utilize public spaces during peak energy usage times in order to reduce load on the electric grid. In general, it is recommended that most users avoid Internet-connected smart home devices unless they are rather comfortable with cyber-security practices. Instead, users should be encouraged to install less-complicated technology such as motion-sensing powerstrips or outlet timers in order to reduce their wasted idle energy and better implement RTEP. To assist with research and consumer knowledge, it is recommended that companies provide information about how much energy their devices draw. It is also recommended that future IQP groups further investigate TOU pricing, how to efficiently charge electric vehicles, and how to reduce idle electricity waste.

In conclusion, Real time electricity pricing can be a good alternative to traditional fixed rate pricing for some customers, though time of use pricing may be a favorable solution for most customers who are interested in the benefits of alternative electricity pricing but with lower risks and less complexity. Electric vehicles, generally being more efficient than internal-combustion vehicles, will play a big part in energy pricing and environmental benefits – provided that the EVs' batteries are charged with efficient usage of the electric grid. Limiting the electricity waste from idle devices will also be an important step in benefiting the electric grid. IQP groups in the future should conduct more research into alternative forms of electricity pricing as well as how customers can better-manage their household's own energy use.

# Authorship

This report is a product of collaboration between Masha Goncharova, John Faria, Herbie Wolf and Zachary Ahearn throughout seven months. This work was done under the supervision of professor Adam C. Powell, PhD. Below is a more detailed description of individual member contributions.

Throughout the project Masha Goncharova took the leading role of the group by acting as a project manager, facilitating advisor and group meetings, scheduling meetings and making sure the logistics of the project were worked out, assigning report sections to group members, filling in the report section to make the report cohesive and comprehensive. More specifically, Masha was responsible for the Introduction, Background Sections 2.1-2.4 and 2.7-2.10 (except 2.8.2), coming up with the initial draft of the objectives for the project and survey questions, writing up the methodology to follow with the objectives for the project and uploading the questions into Qualtrics. In the later part of the project Masha was responsible for drafting up preliminary results of the survey and working with the rest of the group members to assign data analysis and diagram creation to different members. Masha worked on all the results sections alongside the rest of the team, but spent a significant portion of her time on exporting and graphing the real time pricing data points from ISO New England in order to assess whether RTP was a viable option for the public and make ultimate recommendations regarding RTP adoption. She ultimately calculated the potential savings that the consumers can expect to see from idle energy consumption reduction, load shifting appliances and switching to RTP from fixed rate pricing. Her discoveries informed the recommendations regarding TOU pricing in Section 5.2. Finally she wrote the conclusion by unifying and elaborating on the recommendations of all the group members from Section 5.

John Faria was primarily focused on researching smart home technology devices to reduce idle energy consumption and the cyber-security risk associated with them. Given his Computer Science and cyber-security background, he focused a lot of effort on investigating different smart home technology options on the market, assessing device security risks, assessing the cyber-security awareness among survey participants, and making the best recommendations that would allow people to safely take advantage of automation while still benefiting greatly from energy reduction and RTP. John Faria was the primary author and researcher for the background sections 2.6 and 2.7.1-2.7.3. John Faria also contributed to the survey portion - exploring potential solutions in section 3.5 as well as drafting questions to determine the technical literacy and security mindfulness of participants. He was also the analyst who studied related data from the survey in order to write section 4.2 of the Findings and Analysis section. John Faria assisted with the paper's recommendations, writing the electricity saving suggestions and security advice of section 5.4. Overall, John Faria brought his knowledge of electrical devices and security expertise to the project to assist the team with securely bringing technology to assist with real time pricing.

Herbie Wolff focused on the behavioral aspects of how consumers approach their electricity use as well as their ability to change behaviors in general. By having both a newfound background in Electrical Engineering and a longer held one in medical and drug outreach, they combined these into interfacing the often intimidating realm of changing one's habits in regards to complicated subject—and the balancing act between enough information to feel safe making a change yet not so much that a person may stop or even regress. Naturally, this background also brought about the research into how the Covid-19 pandemic would affect a consumer's behavior, electricity use, and even our own results. This also meant paying close attention to each of the other member's contributions for the chance to frame largely technical data and research in an approachable manner for any future outreach, as well as being heavily involved when the team coalesced around the survey, its results, and the final recommendations presented in this work towards enabling consumers to reduce energy consumption and feel comfortable with RTP.

Throughout the project Zachary Ahearn took a more supportive role in the group. His background in Actuarial Mathematics made him most useful in modelling, data, and math related aspects of the project. More specifically, Zachary was responsible for the findings section of the executive summary.  He also wrote the Background Sections 2.5- environmental concerns, 2.7.4-2.7.5 smart devices and security and 2.8.2 solar market limitations.Zachary performed the battery degradation extension analysis in the appendix as well as assisted or verified the other appendix calculations. He calculated the descriptive statistics and wrote the explanation of the descriptive statistics in section 4. He also wrote section 5.5 – future data collection and survey improvement. In addition, Zachary took part in the grammar, content and flow editing of each chapter.

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# 1. Introduction

There are several different pricing models that work for delivering electricity from the power grid to the consumer. The most popular and widely used model in the United States is a fixed price for kWh for electricity. This model obscures the hourly cost of electricity that the energy companies use to buy and sell electricity. In addition, because the customers pay a fixed rate regardless of the demand on the grid, they have no incentive to reduce their energy use during the peak load on the grid. However, there are alternative pricing models, such as real time electricity pricing, that can have many cost benefits for the consumers and positive impacts on the grid. There is promising research showing that when consumers are educated about their their energy consumption and given access to smart home technology and energy reduction techniques, they can adjust their use of electricity, especially during peak demand hours to lower their monthly electricity costs and reduce the peak demand on the power grid, something that many countries and states have been preoccupied with. This process is further improved when the consumers have access to real time pricing for electricity and can use smart home devices to make better choices about their energy consumption.

In order for a consumer to achieve the best results and get the biggest savings from the Real Time Electricity Pricing model, several important criteria have to be met. First criteria and a criteria that will be the cornerstone of our work is consumer education and awareness. RTP model can have a lot of benefits, however it also has a knowledge barrier to entry and can pose a financial risk, especially to those who do not understand how the price fluctuates during the day. Second, consumers need to have access to a public utility company that is willing to provide their customers with a RTP model. Third, customers must have access to a smart meter that has capability to receive and process RTP data. This has become less of a problem during the recent years due to the rise of smart devices and smart meters, however currently most of the meters on the grid in the US do not have the ability to function with RTP model and there would a significant investment required on the behalf of utility companies or the government to update the meters. The three criteria above are required in order for RTP models to work, however in order to maximize the benefit, solar panels could be added to the system. Solar panels are a great long term investment, however they require homeownership in a location suitable for solar panels and large upfront investment. In the future, with the improvement of lithium ion battery technology, batteries could be added to the system to sell excess energy back to the grid. Considering these challenges, adoption of RTP still remains low (Schneider & Sunstein, 2016).

If all of the requirements listed above were met, consumers could lower their monthly electricity usage, save money on the bills, help reduce peak load on the grid, all while operating off more clean, solar energy. We conducted an in-depth study into all aspects of the Real Time Electricity pricing model and examined the benefits and challenges of adoption on a residential level. The aim of the following project was to use a multi layered approach to increase participation in real time pricing model by educating the consumers about existing electricity pricing models, reducing their overall energy consumption, using smart home devices to spread out peak load hours on the grid, and put more clean solar energy into the grid.

# 2. Background

## 2.1 Electricity Pricing Models

Electricity in the United States is generally sold to consumers via a fixed price (per kWh) for electricity. What consumers might not know is that the electricity companies actually buy and sell electricity at wholesale markets on a per unit (kWh or mWh) basis during 15 minute or hour long periods (Schneider & Sunstein, 2016). The wholesale market is operated by Independent System Operators (ISOs) or Regional Transmission Operations (RTOs). "The ISO receives supply bids from generators and demand bids from utilities, who forecast the demand of their customers and place bids on their behalf; the ISO calculates the optimal dispatch given supply and demand bids and relevant system and transmission constraints" (Scheider & Sunstein, 2016, p.2). Five most common methods for charging electricity consumers are the following: Fixed Price (FP), Time-of-Use Price (TOU), Critical Peak Price (CPP), Time of Use with Critical Peaks (TOU + CPP) and Real Time Price (RTP) (Schneider & Sunstein, p.3, 2016). For the detailed description of each method see **Appendix A.** In this paper we will be examining a Real Time Pricing model which tracks the wholesale price of electricity and charges consumers based on the average price during 5 or 15 minute intervals since it has the biggest potential benefit for increasing consumer awareness about their energy consumption.

## 2.2 Existing Real Time Pricing Companies and Lessons Learned

In order for us to come up with a good proposal for increasing adoption of RTP model, we had to examine existing companies that operate under RTP model or offer it as an option to their customers to see what worked and what could be improved on.

Unfortunately, there aren't a lot of electric companies, public or private, that use real time pricing models. This largely can be attributed to the fact that the real time pricing model requires a smart meter that can transmit data instantly to the utility company or one that can keep a log of hourly data over at least the course of the month. However, as digital meters which can monitor consumption in real time became more popular, the introduction of real time pricing models can become more widespread (Schneider & Sunstein, 2016).

We carefully examined four cases: Griddy in Texas, ComEd Hourly Pricing and Ameren Power Smart Pricing in Illinois, Time of Use in California and Time of Use programs in Massachusetts to learn which aspects of the program worked well and which did not. Details about each of the programs are available in the **Appendix B.**

We learned from Griddy that pay-as-you billing is not ideal for the customers since their bank account can be charged with any amount at any time and customers prefer paying at the end of the month. We also learned that Griddy charges credit and debit card fees which can add significant and unpleasant cost to the consumer's bill. Lastly, we learned that educating the consumers is key and the best adoption of RTP happens when customers are equipped with the advanced knowledge of the potential price spikes and smart home systems that can automate the process for them. We learned from Illinois that mandating utility companies in the state to provide customers the option to try out the RTP model is an excellent approach to encouraging the adoption of the model, while still keeping the program opt in. We learned from Time of Use programs in California that under flat rate plans, consumers have no economic incentive to shift their usage so more states are seeking to implement optional or mandatory time of use or real time pricing rates to encourage mindful electricity consumption. This is especially important for our project since we are focusing on the consumers first and we are aiming to make recommendations for making this predicted future transition easier. Lastly, we learned from the National Grid program in MA, that the programs are possible in Massachusetts, have good retention numbers and customer satisfaction.

## 2.3 Risks of Real Time Rates

The biggest challenge of the real time pricing model are the spikes in price during the time when the demand is highest, for example hot months in the summer when everyone is running their A/C.

Griddy experienced the displeasure of their customers during the summer of August 2019, when the real time price spiked. Customers were absolutely outraged over the spike in electricity prices and many news sites picked up the story, claiming this is exactly the reason to stick with the traditional pricing models. The price spike in August 2019 in electricity was not unique to Texas, but rather all of the United States. Due to high temperatures and constant humidity, many people were running their A/C for longer than usual driving up the prices which meant the grid could not keep up causing unprecedented spikes. According to Griddy, the average price for wholesale electricity for the 12 months prior to August of 2019 was 8.9¢/kWh. The average rate during August was 26¢/kWh (Harvey, 2019).

While it was not possible to completely avoid the price spike in August while still cooling a home, it was possible to reduce the overall bill and that is where Griddy and companies that want to practice RTP need to educate their consumers further. In August of 2019, users that were able to shift their usage away from peak times by pre-cooling their homes, automatically adjusting their thermostat and set up smart home automation were able to avoid a large bill increase (Harvey, 2019). This is why we propose implementing RTP in residential homes only in combination with smart home devices. This is important because other research studies, such as the one conducted by Schneider and Sunstein show that the best way to reduce consumer bias towards when to use their electricity vs. when to shut it off is through the use of home automation systems and smart devices that can automatically monitor electricity prices and make decisions for consumers (Schneider & Sunstein, 2016). There are also consumers that express having a lack of desire to monitor real time prices all day and continuously making decisions, only adding to their daily decision fatigue.

## 2.4 Reducing Peak Load on the Grid

A big part of this project is using smart home devices and automation technologies to use electricity when prices are lowest to benefit the consumer, while at the same time disturbing the demand to the grid over time and reducing peak demand. It is important to balance out the amount of power generated and consumed on the grid. A failure to meet the demand will result in "voltage fluctuation, grid instability and can even lead to a total brownout" (Anjum, 2013). Peak demand characteristics in electricity has been a popular topic of research for the last decade. An IQP from 2013, examined electricity demand in the New England area since it has been growing exponentially and electricity prices continued to rise (Anjum, 2013).

Demand Response programs have been introduced in the US to reduce the peak electricity consumption during high demand hours. This can be achieved through a request from a utility company or financial incentives like variable price rates. However, there are several problems with that approach. First, "customers are unwilling to let utility companies take control of their appliances" (Anjum, 2013) and we hope that by giving the control back to the consumers we can achieve the same goal that the demand response was designed to do while increasing consumer awareness about the balance of the power grid and providing a financial incentive.

## 2.5 Environmental Concerns and Modeling

One of the goals of this project is to not only help the consumer fiscally, but also environmentally. Models that give only a financial value can encourage decision making biased against the environment. As such a holistic economic model should have an environmental weight added. Ideally we would model this as *Environmental weight = (Benefit – Damage) * Action Set New – (Benefit – Damage) * Action Set Old.* While this general model is accurate, it requires a numerical representation and conversion into a monetary value. A carbon tax partially reflects this model, and William Nordhaus earned a Nobel Prize in economics for his modeling of an economic activity on carbon emissions as well as being the pioneer in the field of environmental economics (Cho, 2018).

Solar panels and batteries reduce net carbon emissions, but the non-carbon damages and potential future damages are less easy to measure quantitatively as $CO_2$ levels. As renewable energies are built from nonrenewable materials the non-carbon damages are produced in the allocation and disposal of materials. The dislocation of indigenous life, decreased biodiversity, and alteration of the environment due to the allocation of materials required for renewable energy is a growing concern among ecologists, especially as the demand and required supply is exponentially increasing (Stumvol, 2019). Quantifying these damages is much less philosophically straightforward unless we default to an anthropocentric view of the environment. Under this view we would assume that losses have value proportionally to their manifestation on humanity. Otherwise we could create a guided utility function with parameters being the number of each type of loss ($n_{\text{square meters of Earth destroyed}}$, $n_{\text{species endangered}}$, $n_{\text{organisms lossed}}$) and their value of each type of loss ($x_{\text{square meters of Earth destroyed}}$, $x_{\text{species endangered}}$, $x_{\text{organisms lossed}}$).

While financially quantifying the non-$CO_2$ damages is more dependent on our ecological philosophy we can more adjust for recycling. If p = percentage of material recycled in one iteration and there is negligible cost to recycle then the adjusted materials per material:

$$\sum_{i=0}^{\infty} p^{i} = \frac{1}{1-p}$$

Alternatively we can use Median Voter Theory where politicians will choose the outcome that is preferred by the median voter. The aggregate preferences captured by the median are thus policy is a reflection of the median (Gruber, *Political Economy*, 2019). Thus we model environmental impact with governmental bill proposals and policy as representation for damages. For example we could use the *America's Clean Future Fund Act* which would "Once the U.S. economy is no longer in economic turmoil due to the current pandemic (but no later than 2023), institute a carbon fee of $25 per metric ton of $CO_2$ equivalent, applied upstream (and to non-fossil fuel high emission facilities). The fee would increase by $10 per year above the consumer price index" (*Durbin Introduces Bill to Fund a Clean Climate Future: U.S. Senator Dick Durbin of Illinois* 2020).

## 2.6 Idle Home Devices

Another big part of this project is not only reducing peak load on the grid, but also reducing the overall consumption of electricity for consumers by bringing attention to idle home devices, otherwise known as "vampire devices". Many previously purely mechanical devices have gone digital, such as washers, dryers, heated towel racks and bathroom floors now can have electronic controls and Internet connectivity. And despite that fact the smart home technologies hold a lot of potential for reducing overall electricity consumption, when used without a well configured smart home management system they can add on average 1,300 kwH or $165 using average national rate to the households yearly bill (Delforge et. al, 2015). Importantly, Delforge's study used 12.5 cents per kWh as the average national rate when converting wasted kW to electricity costs, however the average national rate for electricity has risen since then and in Massachusetts in particular, as of 2019 the rate is 21.92 cents per kwH bringing the total to $285. The detailed 2015 study found that on average Americans had 65 permanently connected devices (Delforge et. al, 2015) and it is our assumption that the number has only grown since 2015. The hope is that when consumers are switched to RTP rate, they can increase their awareness about their idle devices that are increasing their bill costs.

Fortunately, the same 2015 report found that a lot of the idle load energy can be saved through no cost or low cost actions by motivated consumers, especially once they are informed about the money being wasted.  of the actions that the paper recommends are unplugging devices that are rarely used, and plugging other devices into smart outlets with timers and schedules so they turn on only when needed (Delforge et. al, 2015) . Those findings have also informed our own set of recommendations and methodology which will be covered in detail in Chapter 3. Of course part of the solution relies on enacting strict energy standards for the manufacturers so they are required to disclose idle load electricity on the consumer labels and strive to design products with the goal of minimizing idle power to save the consumer's money and help the environment (Delforge et. al, 2015). However, while those are important policy goals, this paper will focus on the actions that the consumers can take in their own lives immediately to reduce their carbon footprint and save money on electricity.

Importantly, the study also found that there is little relationship between idle loads and how recently the home was constructed, limited correlation between the number of occupants and a moderate, but not a strong relationship between the idle load and the size of the home indicating the the consumer habits play a much more crucial role in the amount of idle load rather than when the house was built, how many residents are there, and the size of the home (Delforge et. al, 2015) which is important for our study and our methodology because our recommendations can benefit people across different home sizes, regardless of the year the house was built and the number of residents living there.

## 2.7 Smart Home Technology

### 2.7.1 Smart Power Strips and Smart Plugs

In 2015, inactive appliances accounted for an estimated 23% of energy consumption in the United States (Delforge et al, 2015). Smart power strips can be used to help consumers monitor and reduce their energy usage, learn about where they are wasting energy, and help them automate energy conservation. These devices have multiple outlets and can be easily installed by simply plugging-in electrical appliances. There is a wide range of smart power strips that can track energy usage and control the flow of electricity in a variety of ways. Smart power strips try to reduce a consumer’s energy usage by switching-off the flow of electricity when it is not needed. This can be accomplished by having the device recognize when appliances are in low-power mode (also referred to as stand-by or sleep), notice when the user leaves the area for a long period of time, or learn when the energy is not needed (Chandler, 2009). smart power strips offer users in-depth control of how and when the power is switched-off.

There are also smart circuit breakers and smart fuse boxes which act similarly to a smart power strip, just on a larger scale. Smart circuit breakers can monitor and intelligently control the energy consumption of an entire house (Sense, 2020). These devices may function better in helping consumers manage their wasted energy across their entire house, however they are significantly more difficult to install and manage.

### 2.7.2 Smart Thermostats

Home heating and cooling systems can also be controlled by smart IoT technologies. Smart thermostats have been developed to track local weather, learn how homes are efficiently heated, and even monitor local electricity needs (Nest Labs, 2017). The information gathered by these smart devices allows them to adapt how the temperature is controlled to both fit the needs of the users and minimize wasted electricity.

A famous example of a smart thermostat is the Nest Thermostat by Google. According to the company's own research from 2013, the Nest Thermostat helped homeowners save approximately 10% to 12% on heating their house and approximately 15% on cooling their house. Overall, Nest estimates that the yearly electricity savings for the average home could be $140 a year (Nest Labs, 2015). Similar smart thermostats, such as those made by Honeywell and Ecobee, are popular with consumers and help them limit energy waste in their homes.

However, since we are focusing on consumer education and barriers to entry it is important to note that many smart thermostats are not just a simple thermostat that is stuck on the wall. Instead, these smart home devices need to be installed by professionals and directly connected to a home's heating and cooling system. The smart thermostats themselves can cost a couple hundred dollars. Knowledgeable home owners can follow installation guides created by manufacturers, learning how to install the smart thermostat themselves.  home owners may not have this educational background or may need to make further modifications to their heating system - requiring contractors to be brought in. The costs of a smart thermostat, educational barrier, and potentially the need for contractors can be barriers of entry for lower-income individuals or people with minimal education or capability.

### 2.7.3 Interactions with Smart Meter

A smart meter is similar to any normal electricity meter that measures the amount of electrical energy consumed by a house or residence. A smart meter differs in its capability to perform calculations, store data, and communicate with other computers. The advanced capability of smart meters allows them to track energy consumption and communicate the data to the electricity provider.

Electricity meters are devices which are owned and maintained by a customer's electricity provider - not the users themselves. To help users understand the timing of their entire house's electricity usage, electricity providers will need to make the electricity usage data available to the users.

### 2.7.4 Cyber-security Considerations Applicable to Smart Home Technology

Smart home technologies can be useful for limiting and controlling electricity usage, however if the devices are not carefully implemented they can become a security risk. Smart home devices commonly request the user to identify themselves by providing personally identifiable information (PII) or even by signing-in to an online account. Smart home devices have sensors so that they can take-in information and interact with the house. By correlating the information from the user's interaction with their smart device along with the information known about their identity. The accessed information could be anything relating to power flowing to certain devices at particular times. The information can be leveraged by advertisers, political organizers, and even criminals for the purposes of exploiting the user. Limiting the amount of data that a smart home device can collect - and how that information can be shared or correlated - is important for protecting the user.

The existence of smart home devices on a network dramatically increases the attack surface of that home network. IoT devices are designed to be easily connected to (with no security considerations) making the devices notoriously vulnerable for network attacks). There are tens-of-thousands of attackers constantly scanning the Internet for potentially vulnerable IoT devices and always looking for new ways to break smart home technologies. Once an attacker has broken-in to the IoT device, they can extract information about the owner and their home, use the device as a pivot to attack other devices on the network, and even add the computational power of the user's IoT device to their criminal botnet (Fagan et al. 2020, p. 6).

Smart home devices are not only highly-connected computers, but they also possess the ability to control parts of the house. The compromising of an IoT device could lead to changes in home heating, lights being turned on or off, other connected devices such as a burglar alarm being disabled, and even sensors producing false data. Depending on how embedded the smart home devices are into a real-time electricity pricing plan, an attacker could even cause the prices of electricity to fluctuate or attack the local electricity grid. In the United States, the main cyberthreats that target the electricity grid are hacking groups backed by nation states. In the past, their attacks have mainly focussed on gathering personal information about workers, and attempting to fluctuate the flow or availability of electricity (Larson, 2018).

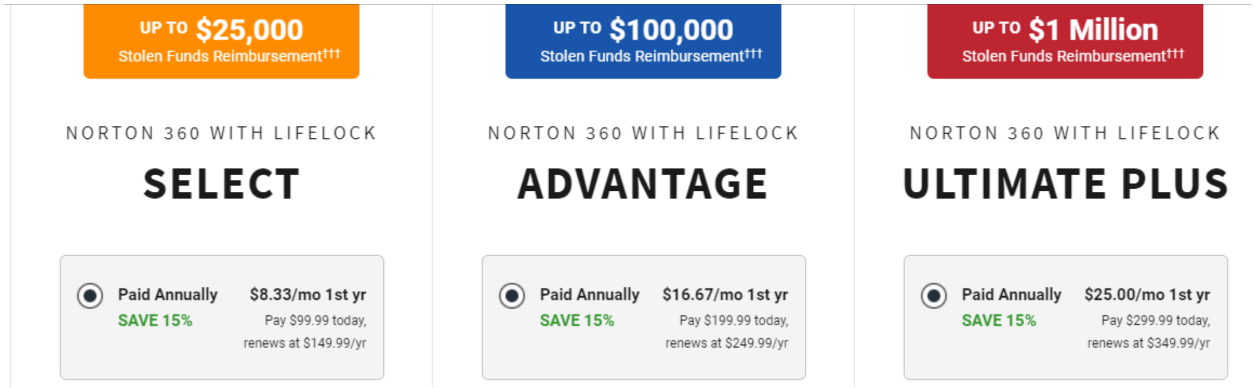
Smart home devices are notoriously vulnerable and pose a great risk to their users, yet manufacturers do not take the appropriate steps to secure them. When a device is being manufactured, its security is not usually considered until after the initial product has been planned. Security is generally a cost center that also slows-down production of an IoT device. Therefore many manufacturers will put minimal effort into securing their device. Smart home devices are also designed to have a positive user experience where the device can be easily setup and connected to. Increased networking and connectivity allows not only the user to connect easily, but attackers and cybercriminals can access the device as well (Sattler, 2018). Getting users to implement security patches and updates for their IoT device can be difficult as well. Most users are not IT system administrators and will not take the time to periodically access their device to check for vulnerabilities or patches. Security is just not a consideration of most consumers when they go to buy a new smart home device. When buying a smart toaster, one is not concerned with the toaster spying on them, being used to attack one else, or a hacker causing toast to catch fire - the consumer just wants to be able to start their toaster from their smartphone.

### 2.7.5 Possible Models for the cyber-security Risk

Modeling the risk of cyber-security analytically on an individual basis requires knowledge of variables that go beyond the scope of what is achievable in this IQP. This is because there can be no assumptions of independent risks between devices and device risk distribution risks cannot be assumed to be identical. As such risk can only be best estimated from the expected aggregate household risk. However, for the purposes of this project our group examined various parameters from cyber-security insurance companies.

We can derive or estimate this distribution using prices for various coverage parameters from cyber-security insurance companies. For insurance on individual loss there are 3 parameters: a coinsurance, a deductible and a limit to coverage. We use the formula $E[x] = E[x\text{^}d] + [x - d]_+$ . Expected losses equals the expected loss up for a coverage with a limit set to d plus the expected loss for a cover with a deductible of d. We then look at the moments and see if they line up to the moments of any known distributions, splices or mixtures of them (Klugman et al., 2019).

Lifelock, one of the cyber-security companies we examined has three coverage options represented in the Figure 2.1.



UP TO $25,000
Stolen Funds Reimbursement†††

NORTON 360 WITH LIFELOCK
SELECT

● Paid Annually $8.33/mo 1st yr
SAVE 15% Pay $99.99 today, renews at $149.99/yr

UP TO $100,000
Stolen Funds Reimbursement†††

NORTON 360 WITH LIFELOCK
ADVANTAGE

● Paid Annually $16.67/mo 1st yr
SAVE 15% Pay $199.99 today, renews at $249.99/yr

UP TO $1 Million
Stolen Funds Reimbursement†††

NORTON 360 WITH LIFELOCK
ULTIMATE PLUS

● Paid Annually $25.00/mo 1st yr
SAVE 15% Pay $299.99 today, renews at $349.99/yr

Figure 2.1. Lifelock cyber-security insurance website showing coverage options.

Based on the information from Lifelock, we have 3 data points. All 3 have no deductible or coinsurance factor. The first data point has a limit of $25,000 implying $100 for a one year coverage, the second data point has a limit of $100,000 implying $200 for a one year coverage, and the third data point has a limit of $1,000,000 implying 300 for a one year coverage. These imply the following equations:

$$\int_{0}^{25{,}000} x\, f(x)dx \; + \int_{25{,}000}^{\infty} 25,000\, f(x)dx \; = \; 100$$

$$\int_{0}^{100{,}000} x\, f(x)dx \; + \int_{100{,}000}^{\infty} 100,000\, f(x)dx \; = \; 200$$

$$\int_{0}^{1{,}000{,}000} x\, f(x)dx \; + \int_{1{,}000{,}000}^{\infty} 1,000,000\, f(x)dx \; = \; 300$$

(Klugman et al., 2019).

These equations are abbreviated as: E[x^25,000]=100, E[x^100,000]=200, E[x^1,000,000]=300 (Klugman et al., 2019) With only 3 points there may be multiple distributions that fit this data set. The reason 3 data points is not enough is because the distribution type is not known to begin with. With just 3 data points this could be fit to virtually all 3 parameter distributions.

In conclusion, while it would be beneficial for the group to be able to make predictions regarding the risks involved in purchasing individual IoT devices, cyber-security risk prediction is still a complex and not precise calculation because the data is limited, as represented in the example above. The impact is hard to calculate, knowing what caused the issue is difficult and trying to predict the vulnerability of the devices themselves and how much having said devices increases vulnerability increasing risk is outside the scope of the project. Instead of giving a numerical value for the risk of the devices, we used the cyber-security experience from two of our group members and made a logical assumption about the risk of certain devices vs. others and made recommendations based on our research and our experience.

## 2.8 Solar Panels

### 2.8.1 Clean Energy and REC's

Putting more clean and renewable energy into the grid and reducing the need for big power plants to turn on to keep up with the electricity demand spikes during the day is a crucial part of our project. RTP can help the grid operate on cleaner energy in several ways. First, if the consumers reduce their energy consumption during the day, that creates less need for non-renewable energy sources like coal power plants to turn on and that means more houses can use cleaner energy during the day. Second, if the customer chooses to participate in solar programs as well as RTP, and power their home with energy from the solar panels, they have a guarantee that their energy supply will actually be "green".

In order to understand green energy and what electricity companies can claim as green energy, we need to understand Renewable Energy Certificates (RECs). 33 states in the US mandate that utilities have to buy more green electricity and due to the growing environmental concerns by the customers, more and more companies want to claim that they are “powered by 100% clean electricity!”. However, it is important to recognize that once the electricity is put into the system, it blends with all other electricity. There is no way to track this “clean electricity” through the grid (Roberts, 2015).

RECs are the US electricity system's answer to that question. REC’s represent the social and environmental benefits of a MWh of clean energy, it puts a positive value on clean generation rather than a negative value on carbon emissions. Once a renewable energy generator, wind farm or a solar power plant, generates a MWH of power, it receives a REC certificate. REC’s then are bought and sold on the market and when a company says it is getting 20% of its energy from clean sources, all it means is that it bought a number of RECs equal to 20% of the power sold. Compliance REC’s have serious restrictions and regulations, such as having to be bought from the utility's own region and are always more expensive. However, voluntary RECs do not face the same scrutiny, they can come from anywhere in the country, from any technology such as sources like methane from landfills and poultry litter. By far the biggest buyers of voluntary REC’s are large companies that buy them in order to make green claims (Roberts, 2015). Therefore, customers have to be cautious of companies that claim they get 100% of their energy from renewable sources and adding solar panels to their homes is a way to ensure that they are actually operating from clean energy.

### 2.8.2 Limitations of Solar Market

Solar has limitations that affect long term investment. The individual investment strategy of solar is that of buy and hold as one invests in the solar panels and the installation and is rewarded in the free energy over a long period of time. The limitation is similar to that of investing in a US treasury bond. While there is a certainty beyond a reasonable doubt of profiting, but a loss of market capitalization within that time frame. The cost of solar has been rapidly decreasing in the past decades and can be modeled based on the consumption as seen in Figure 2.2.

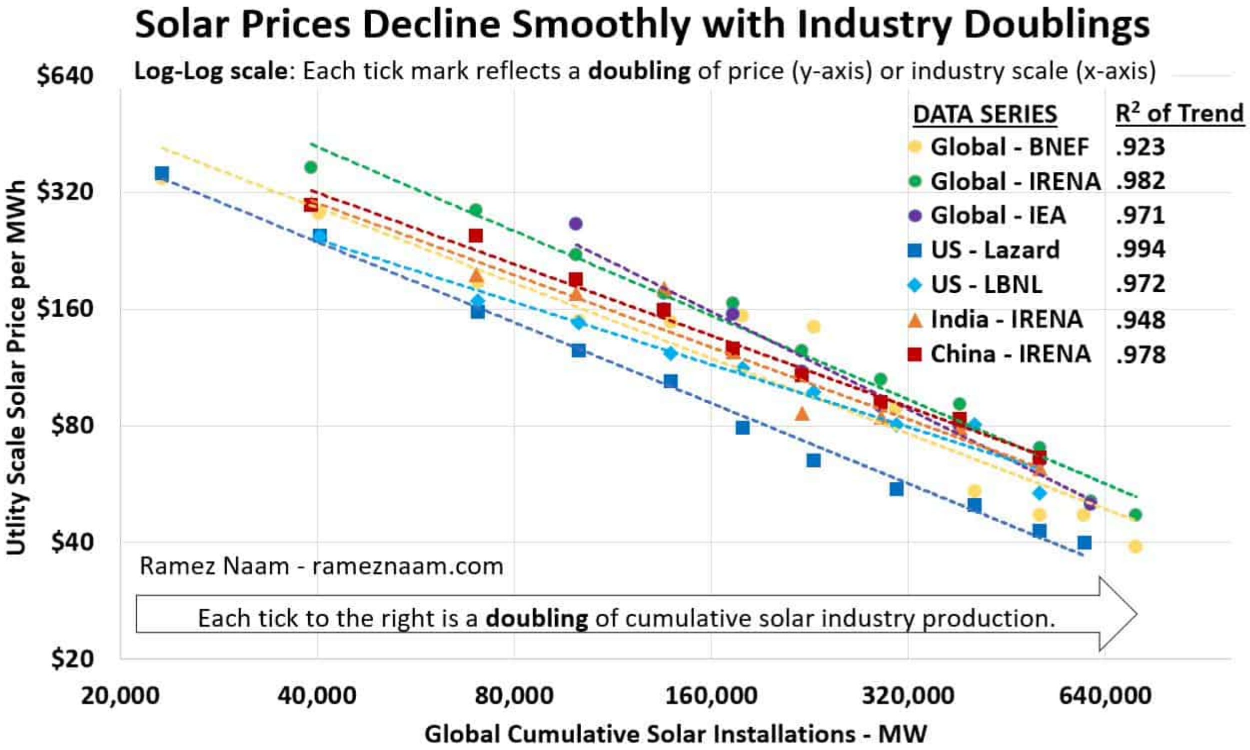


Figure 2.2. Decrease in the cost of solar panels and installation (Naam, 2020).

The simplicity of exponential relation between consumption and cost is lost in translation onto the relation between cost and year. As energy investor Ramez Naam puts it ”Predicting how fast the world reaches that scale is an altogether harder problem, as that depends not just on technology or economics, but also on policy choices, the resistance of incumbent players, and ultimately, politics” (Naam, 2020). While experts have tried to make models predicting the future prices they do a poor job being that even the best ones were decades off as can be seen in the Figure 2.3. The predicted prices which are represented as “costs forecasts” in the figure are clearly different and a big overestimation of the actual costs of solar.

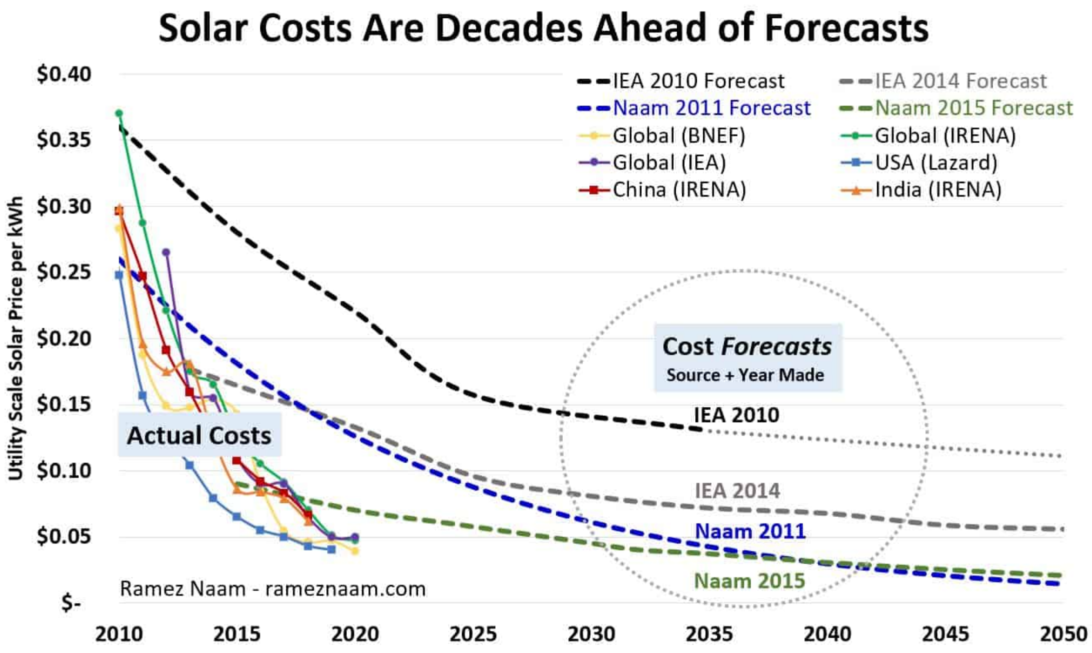


Figure 2.3. Difference between the predicted costs of solar vs. actual costs (Naam, 2020).

For this reason it can not be determined when the optimal time to invest into solar is, but it will always be beneficial hence we will include solar panels in our set of recommendations for the consumers.

## 2.8.3 Cost Benefit Analysis of Solar

When it comes to analyzing cost benefits of the solar system, there are a lot of factors to be taken into consideration. These factors will vary based on the country and state a customer lives in, how much is their average monthly electricity bill, how much roof space do they have or whether their roof is eligible for solar. We performed a detailed analysis for a solar system for a resident in Massachusetts that uses 607 kwH on average during the month. A detailed analysis can be located in **Appendix C**. It includes factors such as the production ratio of the solar system, federal incentives, several MA state tax incentives, degradation rate of the batteries, increased home value and the environmental benefits.

We found that residents can save $10,484.2 during the first 10 years and $30,308.36 over 25 years in net present value. Residents are also likely to see a 3-4% increase in the value of their home and have the potential to save between 198,000 to 299,640 pounds of $CO_2$ over 25 years.

## 2.8.4 Lease Your Roof and Massachusetts Solar Loan Programs

Our analysis above assumes that the homeowner has the upfront capital to invest in solar panels and our analysis is performed assuming no loans are taken. However, in many cases it might be beneficial for homeowners to consider a loan or lease your roof programs. Both of those options allow the residents to harness the environmental and financial benefits, while not having to worry about putting a large sum up front. There are two most common options available to the residents that either don't have the funds to put up front for the solar or simply want to invest the money where else.

The first option is lease your roof programs. There is a lot of variation and caveats to these programs and we will not cover all of them in this paper. All the residents have to know is that energy companies and other businesses are able to get various state incentives when they invest into renewable energy sources. One of those options is installing solar panels on the resident's roofs. Under that agreement, the company receives all of the state provided tax exemptions and credits and get's to use the extra roof space, while the residents are able to save a percentage on their monthly electricity costs, while helping the environment with no upfront costs. However, the biggest challenge with the programs is that residents that enter into the program can find it hard to move out of their residence. Even though the program is called lease your roof, the company providing the panels essentially owns the panels and the residents roof for a period on average of 25 years. Residents that wish to sell their house have to negotiate not only with the potential buyers, but also the company who owns the panels to facilitate the transition of ownership and new residents might be unwilling to buy a home that will not belong entirely to them (Tims, 2018). Lease your roof programs should only be considered by the residents that are absolutely sure they will not want to sell their residence or move in the next 25 years .

The second, new and innovative state level program called "Mass Solar Loan Program" allows homeowners to own solar panels by making fixed, low interest loan payments. This financing program was greater by the legislators who wanted to incentivize ownership of solar panels rather "than getting into complex third party ownership agreements" ("Massachusetts solar rebates and incentives"). The program is also credited as a major reason for solar rising popularity in the state. Full details of the program are available at masssolarloan.com. According to data from 2020, customers can expect a 5.25% loan interest rate and a 120 month loan term. 71% of the loans have been given to those with a 720+ FICO score, 15% to those with a 681-719 score and 15% to those with a 680 or less score (MassSolarLoan). Like with other loan programs, the better the credit score of the customer, the better loan terms and the interest rate will be. Although the program itself does not contain specific criteria for the score, it is evident from the data that those with better credit history will be more likely to receive the loan and receive the best terms which can exclude certain populations. Although, it is worth noting that we are talking about homeownership which requires a good credit score in the first place.

## 2.9 Battery for Excess Solar Storage

In addition to using RTP with smart home technology and solar panels, there have been several proposals and plans to add another layer of storing excess solar energy generated by the home system and selling it back to the grid to make profit. We performed extensive research into lithium ion batteries to determine whether they are a cost-beneficial addition to our proposal.

There have been two majors works before us that examined existing home battery storage systems and performed cost benefit analysis. The work in 2017 examined Tesla's Powerwall version of a lithium ion battery (Xu et. al., 2017) and the work in 2020 explored a generic lithium battery based on the average life, efficiency and the number of cycles during its life (Koethe, 2020). Our work makes an important contribution by analyzing the previously stated numbers and providing corrections. Detailed cost-benefit analysis and considerations for the lithium ion batteries as excess solar storage solutions are available in the Appendix D, including Tesla Powerwall. We ultimately found that it is not cost-beneficial in the long term to purchase a lithium ion battery, such as Tesla Powerwall, for the purposes of daily cycling due to the total number of cycles per the battery's lifetime limitations. Similar to calculations of Xu et al. in 2017, we also came to the conclusion that the battery cannot yield a profit to the residents so it will be excluded from our recommendations.

## 2.10 Electric Vehicles as Distributed Energy Resources

Electric vehicles are another crucial component to this conversation because EV load is dispatchable, which means they only need to charge 2-4 hours/day and there is a lot of flexibility in when the car can be charged, making them the most eligible device for using cheapest off-peak renewable electricity and stabilizing the grid. Estimates on the number of electric vehicles sales are constantly changing, but by moderate estimates, electric vehicles could make up 20% of all car sales by 2025. As the EV market continues to grow, the implications for customers and service providers are rapidly growing and evolving. An electric vehicle with a 30 kwH battery, stores as much electricity as an average US residence uses in a day which opens a conversation to using vehicle batteries as another addition to the grid (Nelder, 2016). Companies have a unique opportunity to use tariffs and incentive structures (such as RTP) to dictate where and when electric vehicles are charged and how batteries can be used for discharge back into the grid. As the EV market continues to grow and more customers will be charging their electric vehicles at home, pricing plans put forth by the electric companies can either help balance out the grid and improve demand response programs, or put further strain into the grid creating more need for more coal power plant operations when owners get back from work and all charge their vehicles simultaneously.

A few key factors can make EV technology more successful than ever before. First, customer interest is rising dramatically. Tesla Model 3 attracted nearly 400,000 reservations in two weeks despite the $35,000 list price. Second, like mentioned in the previous sections, advances in battery technology are boosting the performance and costs of electric vehicles. According to Godlman Sachs, battery capacity and range will improve by 50% and 72% in the next five years respectively. Third, advances in manufacturing technology and increased scale of production make electric vehicles more affordable every year. And last, a growing number of public charging outlets incentives the consumers to switch to electric vehicles and save on the cost of petroleum since more and more leading retailers such as Whole Foods, Walmart, Wegmans and others offer free charging to increase shopping time in the store (Nelder, 2016).

Electric Vehicles can be a crucial part of the demand response programs and the timing of the vehicle charge is crucial to the equation. Therefore, there are many pilot programs in different states encouraging consumers through different incentives to shift their charging time to off peak pricing times. Eversource in Massachusetts offers “EV Home Charger Demand Response Program” which rewards their customers with a $300 bonus if they enroll their vehicle into the program and promises savings to customers who use the program for using less energy during peak demand in an effort to reduce the strain on the grid (“EV Home Charger Demand Response”).

Electric Vehicles can also be used as an alternative battery supply in case of an outage. Given the current state of the battery technology inside electric vehicles, it is not recommended to use them for daily cycling like the Tesla Powerwall was designed to do. EV batteries can be used as an excellent source of a backup energy in case of an outage or a natural disaster, and they can be used to store excess solar if a resident chooses to charge it through a combination of solar and traditional electricity from a public utility company. As the technology improves, we anticipate that in the future electric vehicles will be able to serve as another battery than can be used for daily cycling and make a profit, however at the moment, given the cost of a car and the design of the battery, there would be a huge loss if the battery was used as a daily cycling source. Because of the reasons stated above, in our own work we will be recommending optimizing charging behavior and charging at the best time for the grid, but will not be considering EV’s for daily cycling.

## 2.11 Behavior Considerations

When it comes to electricity consumption and human behavior, one of the biggest considerations is habits and breaking the undesirable ones. For most people, habits become ingrained in their lives as an “auto pilot,” of sorts, as well as a source of comfort and familiarity. In *An Evolutionary Perspective on the Economics of Energy Consumption*, it focuses on habits, how they're not always logical, and when we get around to changing them. This is then directed towards using known psychology of habits towards changing energy consumption specifically, in an effort to hopefully lead to “greener” lives and target the various invisible components of electricity consumption (Maréchal, 2009). Which begs the question—how do we get consumers to ask the questions they do not even know to ask in the first place?

In short, according to Maréchal, people's habits have both social and psychological inertia. Socially, we have the need to not "rock the boat,” in that behaviors that are considered novel or otherwise not the norm are highly discouraged both by the individual and their community. Psychologically, people get a "behavior lock-in," which in short is the sensation of being emotionally unprepared to accept change while finding a great degree of comfort in performing the same habits in response to similar stimuli. Both of these also aid in putting routine tasks in the background of their minds, allowing other tasks to get more attention (Maréchal, 2009). However, this also allows considerations for change to be overlooked, especially in regards to fields such as energy consumption, bill paying, and the like, where there could be greener or even outright cheaper approaches that not only never occur to the consumer. Furthermore, increasing levels of time pressure and information overload in the digital age increase burdens on consumers to the point of needing to rely on habits to reduce mental strain.

To expound on these habits, barriers and incentives we considered previous behavioral studies related to real time pricing such aversion to complexity, status quo bias, loss aversion and others. For a detailed list of factors, see Appendix E.

Even beyond the individual consumer, from *Dynamics in Socio-Technical Systems,* we find that the eponymous Socio-Technical Systems describe technologies—such as our current electricity usage and pricing models—that are adopted in such vast quantities and so thoroughly connected between people, industries, and organizations that any change in them is inherently an uphill battle (Geels & Kemp, 2007). This, combined with an already existing resistance to a change in habits, makes adoption of real time pricing and other changes to electricity consumption both slow and difficult, as well as often met with resistance from both the consumers themselves as well as societal factors.

From these points, we have tried to gauge both a consumer's willingness and ability to break away from old habits to adopt new, greener, and cheaper models when collecting data. Most pressingly, these habits are prone to persisting even in the face of consumer education and calls to action. Breaking these habits most often requires a dramatic paradigm shift in a consumer's life. As suggested by Wood, et al. (2005) throughout their work, one of the most notable times to induce a change in habits is when moving house; it is at this time that a consumer has the overall intention to bring change into their life anyhow and has caused a significant enough disruption to follow through. This could be achieved through incentives for new residents to adopt greener technologies, discounts on smart technology, or even having a threshold at which new residents are automatically opted in to real time pricing.

## 2.12 COVID-19 and Electricity

As touched on earlier, dramatic events such as Covid-19 and its aftermath pose as an opportunity to bring light to electricity consumption habits. With work from home and other quarantine measures, consumption and economics have become much more personal with the advent of mass telecommuting--and, naturally, the increase in reliance upon electronic technologies. Kanda and Kivimaa note in their article that Covid-19 is exactly the sort of "landscape shock" needed to break socio-technical systems, and allows a unique outlook on how dramatic events in general can affect sustainability efforts (2020). They also point out how it counters the narrative that such changes have to be slow and methodical, since the changes to society due to the pandemic have been relatively rapid. And as Ruan, et al. (2020) modeled, electricity use overall has actually declined since the onset of the pandemic; however, this includes massive energy sinks such as office parks, retail, and the like. While modeling on individual use is largely unavailable as of writing, it does not detract from the fact the Covid-19 outbreak has provided a much more immediate opportunity to both educate consumers and give a more immediately obvious demonstration of personal electricity consumption, as well as ways to break old habits as the “new normal” settles in.

# 3. Methodology

## 3.1 Project Objectives

The purpose of our project is to increase awareness about real time electricity pricing models and smart home automation technologies to increase participation in RTP, help consumer's save on their monthly electricity bill, reduce energy consumption, stabilize the grid by shifting electricity usage away from peak times and increase awareness and participation in solar programs. In order to achieve this goal, we developed the following research objectives:

1. Establish the general demographics for our audience to determine who can benefit from the program, the level of awareness about RTP pricing models and figure out what factors would encourage consumer participation in the program.
2. Establish the number of idle home devices in resident's homes and the potential for reducing idle energy consumption with smart home technology.
3. Assess the interest and the ability to shift electricity usage away from peak times, from the cost and education perspective for the smart home systems and devices.
4. Establish the level of interest, barriers to entry and challenges for participation in solar programs.
5. Calculate consumer savings through participation in RTP model, change of habits, reduction of electricity and participation in solar.
6. Develop a set of recommendations based on the previous findings to increase participation in RTP, reduce energy consumption and peak load on the grid, and encourage adoption of smart home automation systems, solar and electric vehicles.

In order to achieve the objectives above, we developed a survey that assessed the demographics of the consumers, their education levels and potential barriers to entry for participation in RTP, their typical electricity consumption, the number of electronic devices they have, the ability to shift their electricity usage and reduce it. The following sections explain each project objective and demonstrate the questions that we asked.

## 3.2 Research Methods: Survey

In order to determine the best ways to ask survey questions, we consulted several sources to learn about the best way to ask questions, how to avoid bias in the question and how to avoid four most common errors that render surveys ineffective.

First, we consulted an IQP from 2007 titled "Demand Response Programs in the Greater Boston Area" that also conducted a survey and their topic of focus was similar to ours. We looked at how the team chose to organize the survey, what types of questions they asked, how they worded them and how they avoided the top four errors in the survey process: coverage error, sampling error, non-response error, and measurement error (Abebe, 2007, p.36). They structured their survey as follows:

1. Preliminary questions on energy use
2. Explanation of demand response programs and generic questions
3. Presentation of prospective programs
4. Demographic questions

We followed a similar approach to organizing our survey, however given that our work had a lot more objectives, we re-organized the sections.

We also referred to the "How To Conduct Surveys: A Step-by-Step Guide" by Arlene G. Fink, a book that is highly regarded by various professors in humanities and teams that conduct research. A few key takeaways from the book that influenced our work are below:

1. **Define Terms:** Define any terms that the reader might find ambiguous. This is especially important for our terms such as "RTP".
2. **Make Sure You Can Get the Information:** If one is unable to find the information needed from the survey because it is difficult to estimate or answer, remove the questions and find another data source. This is applicable to our questions regarding idle energy consumption. It would be difficult to ask participants to estimate how much idle energy their appliances are consuming, so we used a source by Delforge to give an estimate of device idle energy use and we asked participants to simply check off which devices they have.
3. **Open-Ended and Closed Questions:** Use multiple choice questions since they are more reliable and easier for participants to answer. Open ended questions are helpful, but require more analysis on our part and take more time for the participant to fill out. In multiple places we provided an open ended option if a participant chooses "Other", however for every question we tried to provide a good list of options to make it easier on them in terms of answering and on us in terms of analysis.
4. **Each question should be meaningful to respondents:** create a meaningful order and flow in the survey, and if one is asking the questions that might seem irrelevant to the participant, explain the question si there. We organized our survey into four parts and made sure the questions flowed from one to another. For every part we provided a short explanation regarding the section.
5. **Use standard language rules**: use standardized language and proper grammar and avoid specialized terms unless absolutely necessary. If the term is necessary, such as "Real Time Pricing", define and explain it well. We avoided too many specialized terms and only used "real time pricing" and "idle energy" and defined both.
6. **Make questions concrete:** Make questions concrete and ask about the person taking the survey and their personal experience, not the experience of other people. We made sure to ask participants about them by using the words such as "you" and not asking them to

make assumptions about others. The only time we ask about other people is when we ask how many people live in the household.

7. **Avoid biased words and phrases and check biases:** it is extremely important to avoid biased words, and emotionally charged phrases to avoid influencing people's responses. Our topic of electricity is not too emotionally charged, however we were careful with questions that asked about a person's finances and how much they would save/lose on electricity.
8. **Use caution when asking for personal information**: there can be a lot of bias that comes from intimating the response with questions such as "how much do you earn per year?" and people might not give good answers. We did not ask for specific salaries to avoid gathering more identifying information than necessary and instead we asked how much they are currently spending on electricity and how much they are willing to spend.
9. **Each question should have just one thought**: Do not use questions in which a respondent's truthful answer could be both yes and no at the same time. It is acceptable to give an option to say "Don't Know", however word the question so there is no ambiguity or gray area in the question. We tried our best to avoid ambiguity, also we did provide open response options for participants to give explanations.
10. **Rating Scales:** there are a yes or no answers, a few different rating scales including categorical and ordinal, and checklists and they all have their place and purpose. We will used all of the above in the survey, depending on the question. Checklists help participants remember items they might have forgotten so for questions like "Which devices do you own?" it is much better to provide a checklist, rather than asking participants to write out the answer.
11. **Sensitive Information:** For questions asking about sensitive information, it is better to provide an option to not answer such as "prefer not to answer". While this can reduce the number of entries per question, it is respectful to the person and is better than them providing false information. For every question in the survey, we provided an option "Prefer Not to Answer".

We also considered the previously established behavioral factors in our survey, as noted in the Chapter 2.11 and **Appendix E**.

- **Aversion to complexity**: we aimed at proposing the simplest options to consumers, especially with smart home devices so we asked which smart home devices they currently own and which devices they would be willing to add to their homes.
- **Trust as a decision heuristic**: we asked in the survey whether participants would be more likely to trust RTP programs if it was advertised by the utility company like Eversource or Nstar, a local municipal utility company, at school or college that their kids attend, or other community events.

- **Normative social influence**: we asked if the participants would be more willing to participate in the program if most of their neighbors were enrolled in the program, if the neighbors were enrolled and spoke highly of the program, or if their children in college or school told them about the program.
- **Status quo bias:** we asked the participants in the survey whether they preferred the program to be opt in vs. opt out. Studies have shown that customers are displeased with opt out programs and claim that they prefer to be given a choice, however other programs such as the Smart Pricing program in Worcester from National Grid have shown that opt out programs when it comes to RTP do not bring discomfort to the customers, as long as they are educated and result in a much greater adoption rate.
- **Loss aversion and risk tolerance**: we asked the participants in the survey if they would be willing to pay more during summer months, if it meant that they could save overall in their yearly costs to determine their risk tolerance and the financial ability to handle varying prices month to month.
- **Time inconsistency and spatial and temporal discounting**: we considered this factor for both the question above, about their ability to tolerate price spikes month to month and our solar questions. We asked whether consumers would consider investing in solar if they knew it could save them on average $30,000 over 20 years, or if they would prefer to keep the capital money.

## 3.3 Survey Audience

In terms of the survey audience, we were interested in individuals between ages of 18-70 who are currently paying electricity bills or have paid them in the past. In Section 1, question 1 we asked about age groups of our survey participants and we were predicting that not a lot of people under 18 will take it, only because they are unlikely to pay electricity bills unless they are emancipated or live on their own and our target audience were those that currently pay for electricity and have smart home devices, even if they are do not have the capital for solar or electric vehicles.

## 3.4 Objective 1. Awareness of Real Time Pricing Models and Factors for Participation

**Objective: Establish the general demographics for our audience to determine who can benefit from the program, the level of awareness about RTP pricing models and figure out what factors would encourage consumer participation in the program.**

In order to assess awareness about real time electricity pricing models, we asked about the  basic demographic information from our survey participants, such as what state they live in because benefits of RTP and savings vary state-state and we were able to make the best recommendations based on our price and law research regarding Massachusetts. We also also asked about their current electricity provider and typical electricity usage month to month because cost-saving benefits of RTP vary depending on their current consumption habits. Specifically, we asked about their typical bill in the Summer, because RTP prices spike during the day in the summer the most, and the difference between their summer bill vs. fall bill gave us insight into how much A/C they might be using. We also asked whether they are aware of terms such as RTP, TOU and FP, to see whether they would consider switching from their Fixed Price system and what factors, financial, environmental or others would influence them to the most. Lastly, we asked about any current smart home devices they already possess to determine how easy it would be for them to implement RTP in their homes.

## 3.5 Objective 2. Electricity Consumed by Idle Home Devices

**Objective: Establish the number of idle home devices in resident's homes and the potential for reducing idle energy consumption with smart home technology.**

In order to achieve the objective above, we assessed the electricity consumed by idle home devices in participants' homes. Not a lot of studies have been conducted examining exactly how much electricity individual electronic devices are wasting. There is a general consensus that idle home devices are a problem for consumers and their electricity bill costs, for the planet and for the electrical grid. However, detailed statistics about idle home devices are sparse. There is one study in particular, by Delforge and the team from 2015, that actually audited 20 homes and worked with several other partners to get concrete numbers about the idle load of devices.

Ideally, we should have repeated the study by Delforge from 2015, in which they visited 20 different homes, noted idle home devices and measured watts consumed in the idle mode. However, given the constraints of the COVID-19, we could not visit other people's homes and evaluate their idle home devices. Instead, we took the data from the Delforge study and used the calculations from their study in order to calculate how much idle electricity consumers are wasting. Since the number of idle devices varies greatly by home, as determined in the Delforge study, in order to make our results more precise, we asked the participants in our survey to check off any devices from our provided list to estimate their costs for idle energy. We primarily focused on the devices that can be put onto a smart plug or a smart power strip since it was a big part of our recommendations. After gathering the results from the participants and using the average idle electricity consumption numbers from Table 3.1, we were able to calculate the potential for savings for our survey participants. Table 3.1 is a list of devices that we focused on and asked about in our survey. The full table is available in Appendix F.

Table 3.1. List of Devices That Consume the Most Idle Energy, according to Delforge 2015 study that we focused on in our survey

| Device Name | Average idle power consumed (watts/year) | Idle Energy in kwh[1] | Pages from the Study | Potential Savings (given 21.92 cents/kwH rate) in dollars per year |
|---|---|---|---|---|
| Dishwasher | 2.66 | 23.3016 | p.30-36 | 5.11 |
| Clothes washer | 2.25 | 19.71 | p.30-36 | 4.32 |
| Clothes dryer | 3.33 | 29.1708 | p.30-36 | 6.39 |
| Electric Workout Equipment (ex. Treadmill) | 14 | 122.64 | p.30-36 | 26.88 |
| Alarm clock/radio | 4.63 | 40.5588 | p.30-36 | 8.89 |
| Cable Box/Set Top Box | 16 | 140.16 | p.17, p.18, p.19, p.26 | 30.72 |
| TV | 13 | 113.88 | p.17, p.18, p.19, p.26 | 24.96 |
| Audio/video (surround sound, VCR, amplifier, DVD player, speakers, woofer, subwoofers) | 6.4 | 56.064 | p.30-36 | 12.29 |
| Game console (ex. Wii) | 3 | 26.28 | p.30-36 | 5.76 |
| Computer (desktop, laptop) | 7.1 - 9.5 | 62.196-83.22 | p.17, p.18, p.19, p.26 | 13.63-18.24 |
| Computer accessories and peripherals (monitor, mouse, data storage, external disk drive, network disk storage) | 5-5.25 | 43.8-45.99 | p.30-36 | 9.6 - 10.08 |
| Tablet | 4.5 | 39.42 | p.30-36 | 8.64 |
| Networking equipment (modem, router) | 5.5-11 | 48.18-96.36 | p.17, p.18, p.19, p.30-36 | 10.56-21.12 |
| Printer, Scanner, Copier, Fax | 6.3 | 55.188 | p.18, p.19, p.26, p.30-36 | 12.10 |
| Shredder | 8 | 70.08 | p.30-36 | 15.36 |
| Coffee Maker | 4.75 | 41.61 | p.30-36 | 9.12 |
| Microwave | 3.57 | 31.2732 | p.30-36 | 6.86 |

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[1] Watts to kWh converted using *Watts to kWh Calculator* listed in the references.

In terms of solutions to the problem of devices that consume a lot of idle energy, we investigated most popular smart home technology devices on the market.There are many different types of devices on the market that can be used to help limit and monitor electricity usage. The device types are not limited to the devices in this table, and all of these devices are made by many different manufacturers – this table simply lists the most popular models that reflect the type of device. The table includes the approximate cost for these types of devices as well as how difficult the device can be to install and use. For example, an Internet-connected plug simply needs to be plugged to a power socket and connected to via web browser. Contrariwise, a learning thermostat will require a team of contractors to install and can take weeks to months to be working properly.

As per security concerns of these “smart devices”, a good rule of thumb is “the more complicated and connected a device is, the more of a security risk it can be.” Power strips that do not connect to the Internet and are switched-off by environment are secure from a cyber-security perspective. Any Internet-connected device with sufficient control or sophisticated communications channels can be a great risk (especially if the manufacturer is not especially reputable). Before purchasing any smart device, please do research on the security risks for that device and for the manufacturer’s responsibility on dealing with insecure products. Make sure to understand how the manufacturer will communicate secure warnings and device patches to you.

Table 3.2. Table of smart home devices that our group determined are suitable for the smart home recommendations

| Type of Device: | Specific Name: (product link in footnote) | Cost ($)[2] | Barriers to Entry (Setup/Education) |
|---|---|---|---|
| Internet-connected plug | Gosund Smart Wi-Fi Plug (x4)[3] | $25 | low |
| Internet-connected plug and energy monitoring | Kasa Wifi Plug with Energy Monitoring[4] | $85 | medium |
| Internet-connected power strip | APC SurgeArrest Wi-Fi Power Strip[5] | $35 | low |
| motion-sensing power strip | TrickleStar Motion Sensor PowerStrip[6] | $40 | very low |
| Internet-connected home energy monitor | Sense Energy Monitor[7] | $300 | high |
| Internet-connected Thermostat | Honeywell T9 Smart Thermostat with Sensor[8] | $200 | high |
| Internet-connected and learning thermostat | Nest Learning Thermostat[9] | $250 | very high |

## 3.6 Objective 3. Ability to Shift Electricity Use Away from Peak Times

**Objective: Assess the interest and the ability to shift electricity usage away from peak times, from the cost and education perspective for the smart home systems and devices.**

Previous group that conducted an IQP in 2017 found that only about 3.1% of electrical energy could be shifted away from peak times, which yields a cost savings of about 1.7% (Xu et. al, 2017, p.1). Our group build on their work, taking into consideration other factors of the market, such as the growing popularity of electric vehicles, and the importance of their charging times, as well as the explosive growth of smart home systems and devices and the ever growing

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[2] Cost is for devices only, without taking into consideration installation costs.

[3] *Gosund Smart Wi-Fi Plug WP5*. (n.d.).

[4] *Kasa Smart Wi-Fi Plug with Energy Monitoring*. (n.d.).

[5] *APC Home Office SurgeArrest 6 Outlets 3 Smart Outlets With 4 USB Ports 2 Smart Ports 120V*. (n.d.).

[6] *Motion Sensor PowerStrips*. (n.d.).

[7] *Sense Product*. (2020).

[8] *T9 Smart Thermostat with Sensor*. (n.d.).

[9] *Nest Learning Thermostat*. (n.d.).

ability of the consumers to control their electricity consumptions automatically through the use of smart devices.

We considered five different categories of the devices that are most eligible for load shifting, promising the biggest cost benefit to the consumer, while reducing the potential inconveniences. We looked at clothes washing machines, clothes dryers, dishwashers, A/C's (window, wall and others) and electric vehicle charging stations.

In terms of the survey, we asked our participants which of the following devices they had in their homes, and when do they typically run each appliance (for example morning, afternoon, evening, any time). Knowing which devices our participants possessed and when they usually used them, gave us an ability to calculate how much money they are spending on their appliances now, and how much they would be able to save if they shifted their use to the off peak hours. We also explicitly asked questions regarding each device category, such as "Would you be willing to run your dishwasher in the evening/night?" and we asked whether consumers would be more likely to consider it for environmental reasons or financial ones.

Similar to the situation with idle devices, not a lot of studies have been conducted looking at different makes and models of devices and establishing their average power consumption. For the washing machine alone, there are hundreds of different blog posts and articles on the web that claim different numbers, in the range of 300 to 1500 watts. The numbers vary significantly depending on the model and the year the appliance was manufactured. The older appliances tend to have poorer energy efficiency. For our methods, in order to get an accurate picture of the distribution of the energy consumption for each device, we have gathered the information ourselves by looking at the best selling devices on the market at 2020 and writing down their estimated annual kwH consumption.

Table 3.3. Estimated average annual electricity consumption numbers for the devices eligible for load shifting that our group focused on during the project

| Category of the Device: | Estimated Average Annual Electricity Consumption in kWh per year[10] | Range of Annual Electricity Consumption in kWh per year | $ average per year using 21.92 cents/kwh | $ per year using 21.92 cents/kwh | Standard Deviation | 95% Confidence |
|---|---|---|---|---|---|---|
| Dishwasher | 261.93 | 239-270 | $55.78 | $52.38-59.18 | 8.96 | 261.9375 ±4.392 (±1.68%) |
| Washing machine for clothes | 140.65 | 90-300 | $42.74 | $19.72-65.76 | 56.9 | 140.65 ±24.941 (±17.73%) |
| Drying machine for clothes | 631.6 | 607-644 | $137.1 | $133-141.16 | 21.4 | 631.6667 ±24.173 (±3.83%) |
| AC (wall) | 1643 | 660-4180 | $530.46 | $144.67-916.25 | 1172 | 1,643 ±726.805 (±44.24%) |
| AC (window) | 776.3 | 370-2740 | $340.86 | $81.1-600 | 716 | 776.3 ±443.814 (±57.17%) |
| Electric Vehicle Charger[11] | 4216.21 | 3021-6211 | $923.77 | $661-$1360 | 1152 | 4,216.21 ±798.362 (±18.94%) |

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[10] According to Best Buy top 20 best selling products

[11] These numbers vary significantly. Detailed calculations are available in Appendix H.

## 3.7 Objective 4. Solar Benefits and Barriers

**Objective: Establish the level of interest, barriers to entry and challenges for participation in solar programs.**

Based on our extensive research and calculations in section 3.6 and Appendix C, we came up with a list of questions to ask for the survey regarding participation in Solar programs. First, we asked whether they own or rent their residence. In order to be eligible for solar panel purchase, participants should be homeowners. While it is possible to negotiate with a landlord to install solar panels, we did not consider that scenario in our research, we only looked at homeowners, who have access to their roof space and can install solar. Then, we asked whether they do have solar, and if not whether they have considered solar panels and what barriers prevented them from accessing the technology. We also asked the participants if they are aware of the various federal and state incentives that can make purchasing solar panels cheaper. Those sets of questions allowed us to establish whether participants could own panels, if they already did, and what barriers are there for them.

We also asked about the average size of their residence, and their monthly electricity bill consumption in order to calculate based on our formulas, what size of the solar system they would need and how much it would cost.

After gathering all of the information above, we were able to assess the interest in solar, the ability and the barriers to obtain the technology and calculate the potential savings for each participant who was eligible for solar.

## 3.8 Objective 5. Calculations of Potential Savings

**Objective: Calculate consumer savings through participation in RTP model, change of habits, reduction of electricity and participation in solar.**

We are going to calculate potential savings for consumers based on the survey, the Delforge 2015 study about idle devices, prices of real time electricity and cost benefit of solar. In addition, we are going to use real time electricity pricing data from ISO New England website to compare prices of electricity across a 24 hour span and 365 days in the year to find out at which points is it the most beneficial for consumers to be taking advantage of pricing.

We expect models to fit to a compound distribution of individual utility functions.

An RTP pricing model would be

$$S + \sum_{h=1}^{24} P_h C_h = \mathrm{I}$$

Where I is daily income for energy, C is daily consumption of energy in hour h, P is price in hour h of 1 unit and S is income saved.

Consumption can be modeled. This model accounts purely for energy reduction.

$$V_S S + \sum_{h=1}^{24} V_{h,+} C_{h,+} + V_{h,-} C_{h,-} = U$$

$$V_S S + \sum_{h=1}^{24} V_{h,+} C_{h,+} + V_{h,-} C_{h,-}$$

$$C_{h,+} + C_{h,-} = C_h$$

## 3.9 Objective 6. Cohesive Set of Recommendations

**Objective: Develop a set of recommendations based on the previous findings to increase participation in RTP, reduce energy consumption and peak load on the grid, and encourage adoption of smart home automation systems, solar and electric vehicles.**

After all of the objectives above were achieved, and we collected the data from the survey, we were able to gain a much better understanding of the demographics, electricity consumption, challenges and behavior of our participants and residents of Massachusetts. We used that data to come up with a comprehensive set of recommendations regarding RTP, so that utility companies, the states and the federal government were able to promote RTP more successfully to benefit the electrical grid and the environment, all the while saving money and creating the least amount of discomfort for the consumers.

## 3.10 Survey Questions

For the purposes of our survey, we took all of the questions we needed data about and combined them into a one cohesive survey broken up into four sections: Demographics, Electricity Provider and Consumption, Devices and Appliance Assessment and Behavior. Below is the full list of survey questions. The survey was ultimately built using Qualtrics platform and the final survey with all the questions and reasons behind questions can be found in Appendix G.

# 4. Findings and Analysis

## 4.1 Basics of RTP Awareness and Adoption

**Objective 1. Establish the general demographics for our audience to determine who can benefit from the program, the level of awareness about RTP pricing models and figure out what factors would encourage consumer participation in the program.**

We paused our survey collection on January 7th, 2021 and we got a total of 55 responses. However, out of 55 responses  were partial, with only  questions answered due to the fact that we did not make any questions mandatory. We ended up distributing our survey to our neighbors, WPI students and to various faculty using Potpourri platform. Due to the mix between WPI students and the faculty that generally tend to hold a PhD and tend to be on the older end of the spectrum, we got a nice distribution between younger population and older population and levels of education. For the purposes of our survey, we were interested in seeing older populations because they are more likely to have experience renting/owning property and paying electricity bills. Below are the distributions for the age and education levels we saw in our survey. We also had 100% response rate to the age question and 98% response rate for the education question giving us solid data about the background of our survey participations.

We first analyzed the results shown in Figure 4.1 regarding the age of our participants. For this data we had only interval inputs, so we had to make several reasonable assumptions to best estimate the distributions of values within the intervals or extract statistics from them. For the data entries of age less than 18 if they indicated they were a high school graduate then we could reasonably conclude that they were 17. For ages 70 or older we assumed an age of 75 on the fact that our survey population were typically non-retired/ actively working. For the other intervals we assumed the mean of the interval. Other different assumptions could be made, such as that the interval are discreetly distributed, uniformly distributed , continuously uniformly distributed, continuously gaussian distributed or that the densities are continuously distributed that is we connect the density or (count for discrete) of people age 49 to be the same density of people age 50. Our choice of assigning  a number to a range of values as that is one of the most natural simple assumptions we do with age. For example the common person assigns a number of days old to a baby then weeks, months and then eventually years. The most natural next step is to choose decades which is what we chose for the most part. These are all lower bounds, but a mean of an interval is much of an accurate representation than a lower bound (for example if one said they were 40 years old meaning they have reached their 40th birthday and not their 41st birthday it would be a better approximation of 40 years and 6 months that 40 years and 0 months). The general statistics of our data are shown in Table 4.1. All of the metrics are fairly normal with little skewness and a reasonable excess kurtosis.

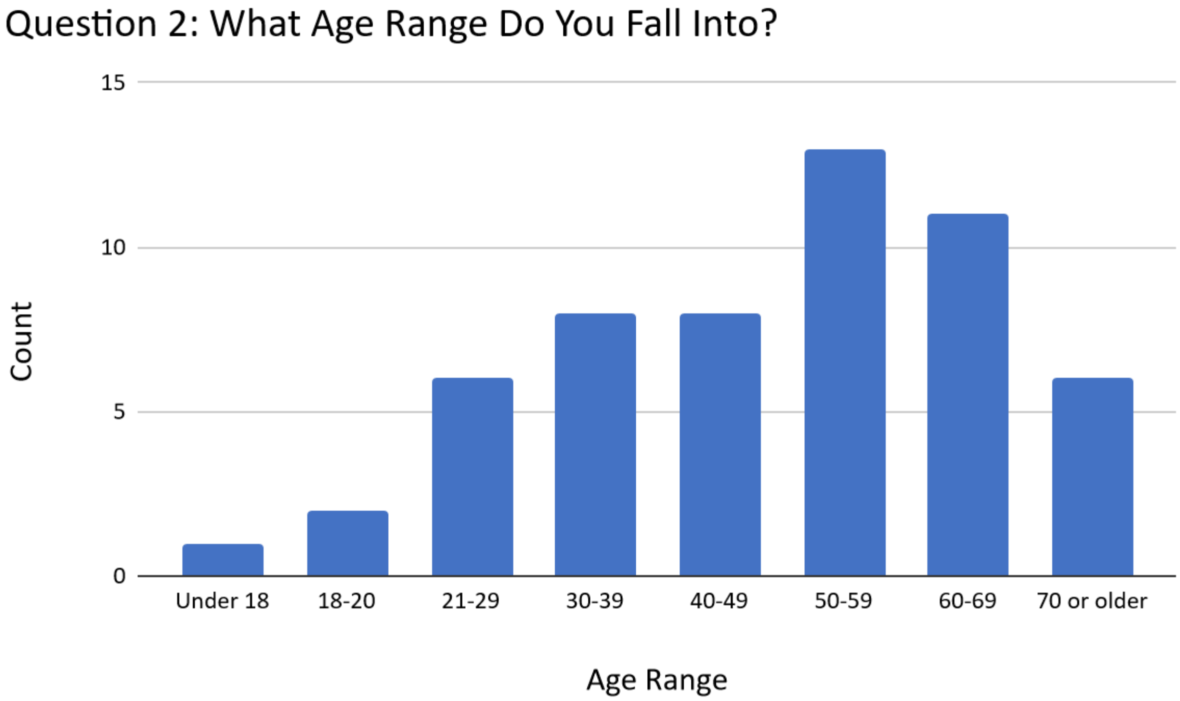

Figure 4.1. Age distribution in the survey.

| Table 4.1. Descriptive statistics for the age distribution. | |
|---|---|
| Mean | 50.09090909 |
| Standard Error | 2.314537969 |
| Standard Deviation | 17.16507299 |
| Excess Kurtosis | -1.002075312 |
| Skewness | -0.278743817 |

We also analyzed the distribution of the education question. As shown in Figure 4.2, our data was skewed to the right, towards a more educated population.

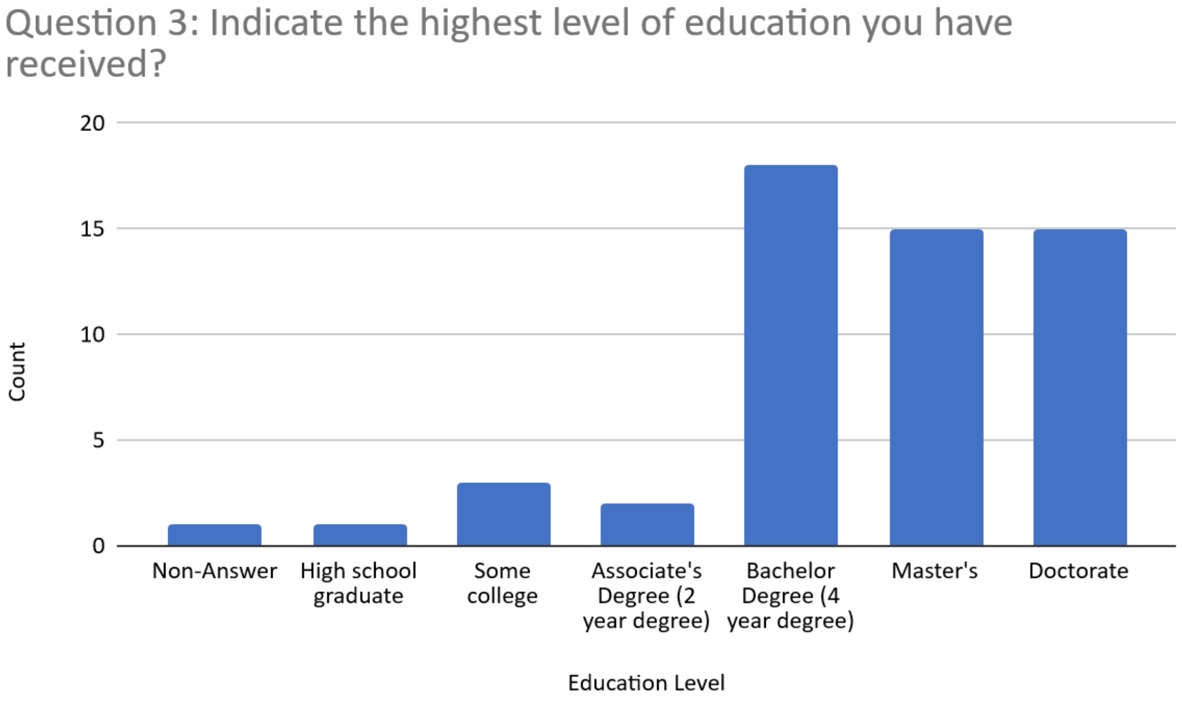

Figure 4.2. Education level distribution in the survey.

In order to perform a quantitative analysis we assigned a numerical value equal to the numbers of years usually required to attain the level of education: highschool graduate = 0, college = 1, 2 year degree = 2, 4 year degree = 4, Master's = 6, doctorate = 8. The descriptive statistics are shown in Table 4.2. The mean being between bachelors and masters is what we expected. The kurtosis is within a reasonable range and the skewness is what we expect as there is no level of education greater than doctorate, so the equate tail is squeezed to the center.

| Table 4.2. Descriptive statistics for education questions. | |
|---|---:|
| Mean | 5.351851852 |
| Standard Error | 0.296918023 |
| Standard Deviation | 2.181892959 |
| Kurtosis | -0.427883759 |
| Skewness | -0.448347843 |

We were also interested in seeing the correlation between age and education level in our sample because other data points or variables in next questions may seem to be caused by either age or education despite assumptions to the contrary. There was a correlation of .476 between age and education, so there is only a moderate correlation.  College was assumed to have a value of 1 year for the ease of calculation, since associate is usually two years, although we did not specifically ask about years so it could be less than a year or more than a year.

We also got a good distribution balance between those that rent their property and those that own it; 25.5% of the participants rent and 74.5% own. Several of our survey participants choose the “other” option allowed on the survey, but after examining their free text fill, all indicated that they have a mortgage on the house which for the purposes of our survey we will categorize as “owning”. In the future work, it is important to clarify that mortgage counts as owning. We were most interested in the participants that own their property to get an idea about their willingness and ability to adopt solar panels and install electric vehicle chargers, and the distribution that we got is ideal to give us an idea about homeowners and renters ability to participate in RTP.

We also asked our survey participants about their monthly electricity spending. Table 4.3 shows the responses, means, standard deviations, kurtosis, skewness and standard error. Not surprisingly, the highest spending occurred during Summer and Winter, most likely due to the increased use of AC and heat during those seasons.

Table 4.3. Electricity Spending Descriptive Statistics

| | Mean | Standard Deviation | Excess Kurtosis | Skewness | Standard Error |
|---|---|---|---|---|---|
| Average Monthly Cost | 120.77 | 76.46 | .81 | 1.11 | 11.27 |
| Summer | 131.54 | 98.97 | .38 | .99 | 15.65 |
| Fall | 109.44 | 79.85 | .67 | 1.22 | 12.32 |
| Winter | 132.28 | 13.47 | .95 | 1.16 | 13.47 |
| Spring | 105.81 | 76.37 | .66 | 1.23 | 12.08 |

The data was about as leptokurtic and skewed as we would expect given our sample size and type of collection and is definitely within reason for our purposes (less than 1.5 skew and excess kurtosis) The positive skewness is definitely what one would expect being that it is easier to spend more money on electricity than save, so the expansive tail should be larger than the economic tail.

Note that in an ideal scenario, if we had 100% response rate for the bill question then the average monthly cost would be the same as the average of summer, fall, winter and spring values provided. However, we had more non-response in the second part of the question which asked participants to identify their costs by specific season. Also all of the values are likely to be participant estimates, hence the average values are different. Table 4.4 is a correlation table (aka correlation triangle or correlation matrix) for the monthly average, summer, fall, winter, and spring. This is read by looking at the leftmost column for the category concerned with and reading right then down after reaching the diagonal for the correlation between two. Correlation ranges from -1 to 1. 0 has no correlation and 1 is perfectly correlated. -1 is perfectly negatively correlated. As we would expect winter and summer would be at least strongly correlated, but the least strongly correlated with the rest being strongly correlated and spring and fall being almost perfectly correlated.

Table 4.4. Correlation table for the electricity spending question.

| Correlation | Monthly average | Bill, Summer | Bill, Fall | Bill, Winter | Bill, Spring |
|---|---|---|---|---|---|
| Monthly average | 1 | | | | |
| Bill, Summer | 0.925099394 | 1 | | | |
| Bill, Fall | 0.881532907 | 0.927800367 | 1 | | |
| Bill, Winter | 0.861218427 | 0.750981999 | 0.828930953 | 1 | |
| Bill, Spring | 0.971080193 | 0.919439071 | 0.990055224 | 0.848023857 | 1 |

Our team was also glad to find that in general survey participants were receptive to the idea of alternative pricing schemes and many have the finances to tolerance price fluctuations month to month; as shown in Figure 4.3, a third know of the existence of alternative pricing schemes and many would be willing to consider switching to RTP, especially if they were able to benefit financially, although many indicated they would switch for environmental reasons alone as well. Even more importantly, we were concerned with participants' ability to tolerance price fluctuations month to month, given that we anticipate higher electricity bill in the summer regardless of the smart technology adopted, so the results from the survey that indicate most people are able to tolerate higher prices in the summer, is a positive finding for our goals.

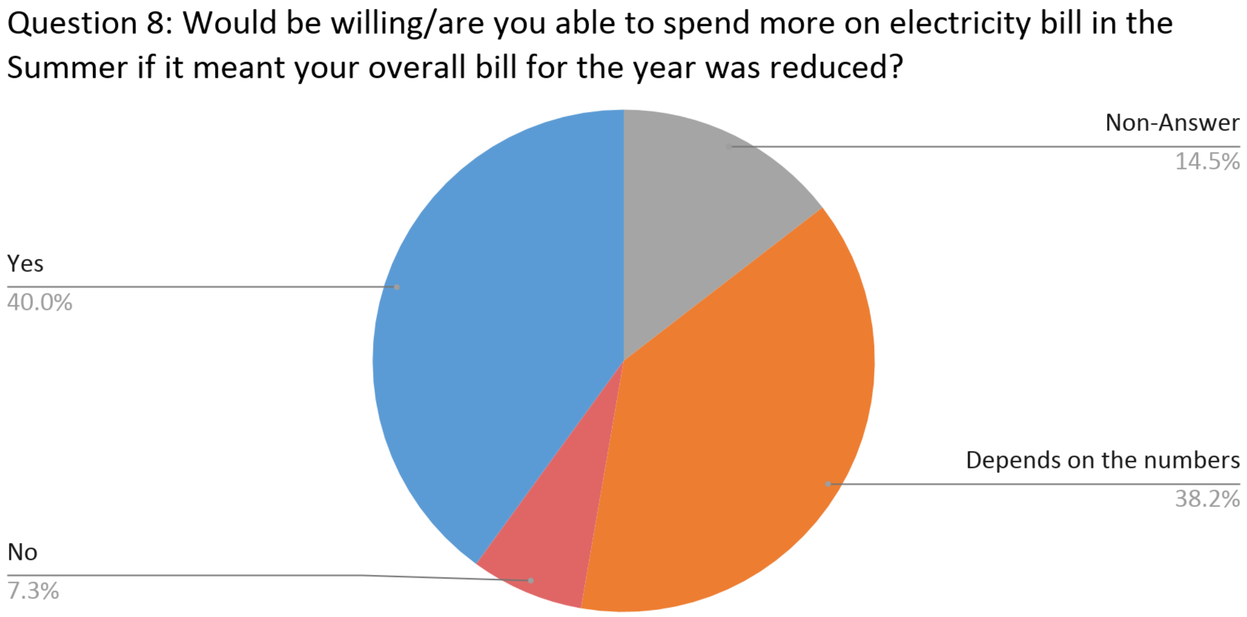

Figure 4.3. Participant's ability to spend more on their electricity bill in the summer.

In question 11, which asked whether participants are aware of any alternative electricity pricing plans, we found that 29.1% of the participants are aware of at least  alternative electricity pricing schemes which is promising meaning that the awareness about electricity consumption and billing schemes is growing, although it is still relatively low. We also investigated whether there is any correlation between the years of education vs. the term awareness. There is a negative correlation between the years of education that our survey participants received and the likelihood they will be familiar with alternative pricing schemes. However, it is worth mentioning that there was a large non-response percentage for this question, and as the years of education increased, the percent of non-response decreased, meaning people with more education were more likely to answer the question, but not necessarily be familiar with the term.

Based on question 12, shown in Figure 4.4, 29% of the participants know of Time of Use and 21% know of Real Time Electricity Pricing. It is not surprising that the knowledge about time of use is higher among the participants, given that the program is what more widespread as established by our background research and easier to understand. Participants were most familiar with "Fixed Rate" Pricing and increasingly people are becoming aware of "Time of Use Pricing", most likely because more states are starting to consider and promote those options. Awareness of the term "Real Time Electricity Pricing" still remains fairly low, indicating a strong need for more awareness through education. The fact that about one third of the participants knew of  alternative pricing schemes and the same third knew of time of use pricing, means positive outlook for utility companies or government programs that wanted to reach out to the people.

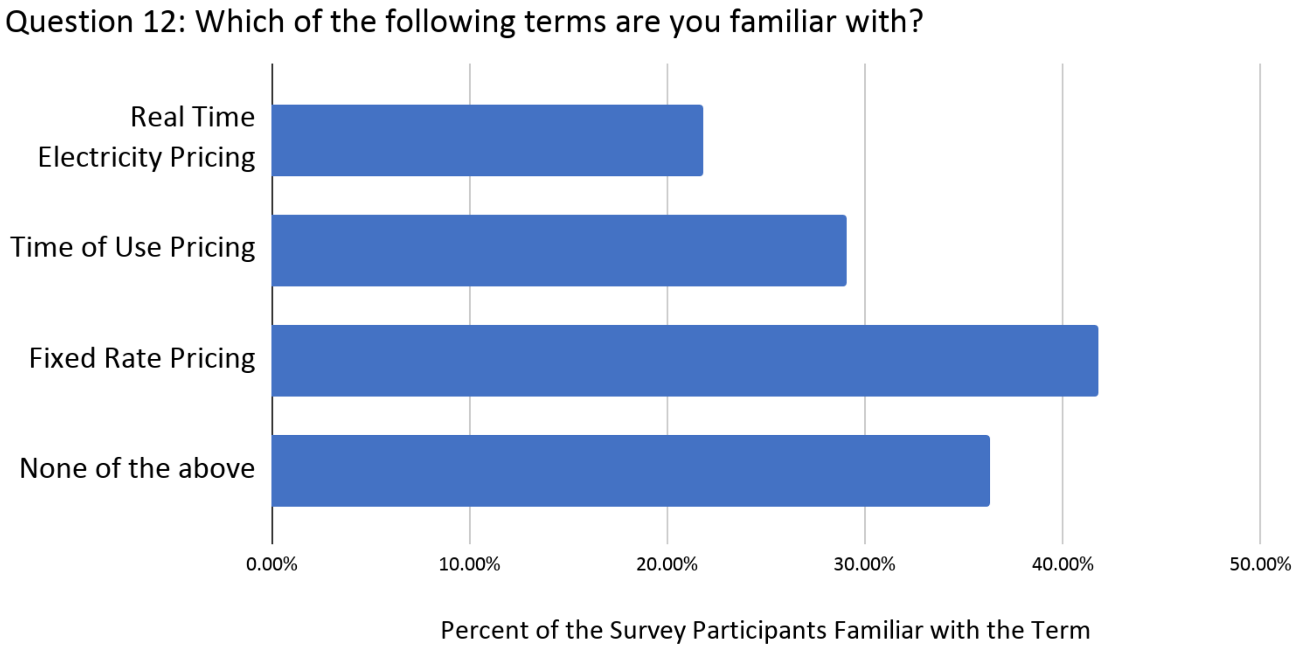

Figure 4.4. Percent of the survey participants familiar with electricity pricing terms.

Based on question 13 which asked whether participants would consider implementing RTP in the future, our group concludes that our survey participants are generally receptive to the idea of RTP, with 47.3% giving a resounding yes and 34.5% saying that they are not sure. Only 3.6% explicitly said “No”. Adding those two percentages means that about 80% of people would be at least open to the idea of RTP meaning that municipal companies would have a much easier time promoting RTP programs than assumed at the beginning of the project and than assumed by other studies.

We were interested in the connection between education in awareness, so we looked at the percentage of an education level aware vs not aware for each education level. It was important to compare the percentage of the group aware vs not aware at an education level as we had a lot of nonanswers and our population was nonuniform. This is shown in Table 4.5 where level of education is given the same numeric value as previously assigned  in level of education.

| Table 4.5: Level of Education vs. Percentage of the Education Group Aware of Alternative Terms | |
|---|---|
| Level of Education | Percentage of the education group aware |
| 0 | 100% |
| 1 | 50% |
| 2 | 50% |
| 4 | 50% |
| 6 | 14.3% |
| 8 | 27.35% |

| Table 4.6. Linear correlation between education and awareness | | |
|---|---|---|
| Linear Correlation | Education | Awareness |
| Education | 1 | |
| Awareness | -0.287750456 | 1 |

| Table 4.7. Regression Statistics | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Multiple R | 0.288 | | | | | | | |
| R Square | 0.0828 | | | | | | | |
| Adjusted R Square | 0.0620 | | | | | | | |
| Standard Error | 0.466 | | | | | | | |
| Observations | 46 | | | | | | | |
| ANOVA | | | | | | | | |
| | *df* | *SS* | *MS* | *F* | *Significance F* | | | |
| Regression | 1 | 0.864 | 0.8648 | 3.97 | 0.0525 | | | |
| Residual | 44 | 9.57 | 0.218 | | | | | |
| Total | 45 | 10.4 | | | | | | |
| | *Coefficients* | *Standard Error* | *t Stat* | *P-value* | *Lower 95%* | *Upper 95%* | *Lower 90.0%* | *Upper 90.0%* |
| Intercept | 0.693 | 0.186 | 3.72 | 0.000562 | 0.317 | 1.07 | 0.380 | 1.006 |
| education | -0.0656 | 0.0329 | -1.99 | 0.0525 | -0.132 | 0.000736 | -0.121 | -0.01034 |

Rather than looking at ‘yes’ or ‘no’ categorical responses we converted the response to binary values (yes = 1(100%), no = 0 (0%) and directly performed a regression analysis. ) We thought it was important to keep the table as although the correlation statistic gives a clear measure of the linear fit of the data it can be an oversimplification to model data to a linear fit. Obviously it is impossible to have below 0% awareness or greater than 100%, but a linear regression model allows for those possibilities. With that said a -.29 correlation statistic is much farther from 0 than we expected (as our output variables were heavily restricted above and below). We should note that in the regression analysis the coefficient for slope has a p-value of .052 which means if applying the p > .05 standard and only an elementary understanding of p value then we would accept the null hypothesis and designate our linear regression slope as ‘not statistically significant’. That would be inappropriate here as our objective is to make the most informed decisions and recommendations based on the totality of evidence and not to simply make an assertion about the linear fit itself. For the purposes of transparency we decided to provide the anova statistics, regression statistics and the 5%, 10%, 90% and 95% bounds of the linear regression coefficients. We can state that most of the likelihood of association between awareness and education is negative association. However, apparent decrease in awareness with education could reasonably be attributed to the hyperfocus structure of academia and age to some degree.

More importantly than studying the general attitudes toward RTP pricing scheme, we studied the factors that would increase participation to be able to tie survey findings with our behavioral background research in order to make comprehensive recommendations for interested parties to encourage RTP participation. Figure 4.5 shows the distribution for the number of participants who indicated which factors would encourage them to consider participating in the RTP. Notably, the greatest number of participants indicated that their own interest in the program would sway their decision which was not anticipated by our group. The next two popular options are municipal companies reaching out to participants directly and their family members telling them about the program. Participants' interest in the program and the receiptivivness of the participants to engage with utility companies were both unexpected factors for our group, since other research has shown that the adoption of the program remains relatively low and we expected a lot of more hesitation towards utility companies. However, based on our findings participants are receptive to the program in general, and would be willing to consider it as an option if a utility company reached out to them or they were interested in alternative pricing. Both of those factors still need to be tested in practice, since behavioral research has shown that what participants times think and indicate on the surveys is not always what they will end up doing in practice which also ties into our next question.

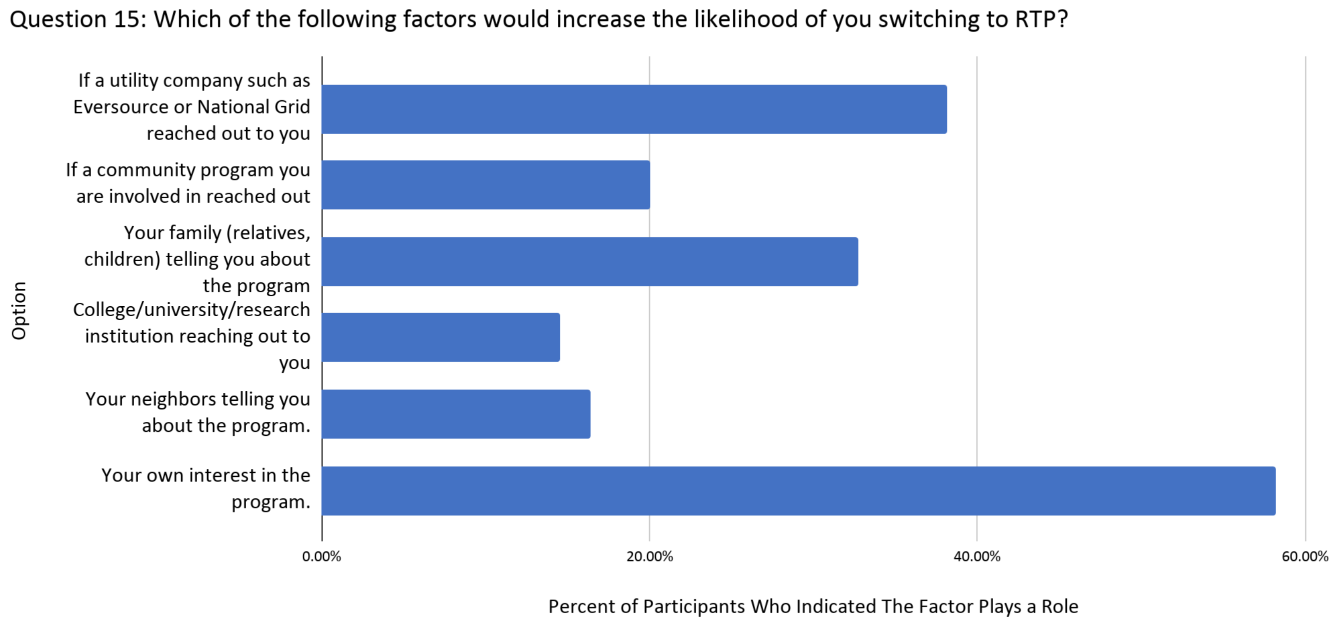

Figure 4.5. Factors influencing participation in Real Time Pricing.

Question 16, in which examined opt out vs. opt in preference, indicated that 63.6% prefer opt in, 12.7% prefer opt out and 9.1% have no preference. This is not a particularly surprising finding for our group based on the background research we conducted. As explained in the background before, opt in is a much safer choice, especially for riskier options and reduces the risk of consumer displeasure, however this does mean that the adoption of whatever the option is remains lower. For RTP, given that it is a still new and risky option, our group believes opt in choice to be best. On the other hand, for another program such as Time of Use which is less risky and easier to understand, opt out option could be considered to increase adoption more rapidly, like California has done with its new Time of Use programs.

### 4.1.1 COVID Impact

Two important questions from our survey that warranted their own subsection were the questions about COVID given that we conducted our research during unprecedented COVID times. While our work did not deeply dive into the impacts of COVID on individual’s finances or their electricity, we did want to get an idea of whether COVID affected their typical electric bill and whether it has increased or decreased the total.

We found that 47.3% of the survey participants did experience COVID-19 affecting their bill and all of those participants who indicated their bill was affected, indicated that their electricity bill increased.

Figure 4.6 shows the relationship between participants' answers regarding whether COVID-19 affected their bill and their receptiveness to try RTP. For those whose bills changed during the Covid-19 pandemic – all of whom had an increase in their bills – a notably larger percentage of those whose bills were affected were outright willing to try RTP at 61.5% saying yes, with 34.6% saying they would need more information rather than outright rejecting it. This corroborates prior research indicating that massive, life-altering events introduces opportunities for people to change their behaviour. Furthermore, the newfound emphasis on the importance of electronics, coupled with the inevitable rise in costs when consuming power on a fixed-price model, suggests that attitudes towards new pricing schemes for electricity delivery would be more welcome as life settles into the "new normal."

Even beyond those who answered no to their bill being affected, both those who answered yes to being willing to try RTP and those who needed more information to decide came in at 47.6%. While obviously a fair bit less than those whose bills had been affected, leaving less of a personal impact that would drive a willingness to change, these numbers still show at least a level of openness to changing their habits. Although the pandemic may not have hit their electricity consumption, the point remains that they likely have been affected financially otherwise nobody who has—or, if nothing else, have been made acutely aware of the increasing importance of technology use in our lives.

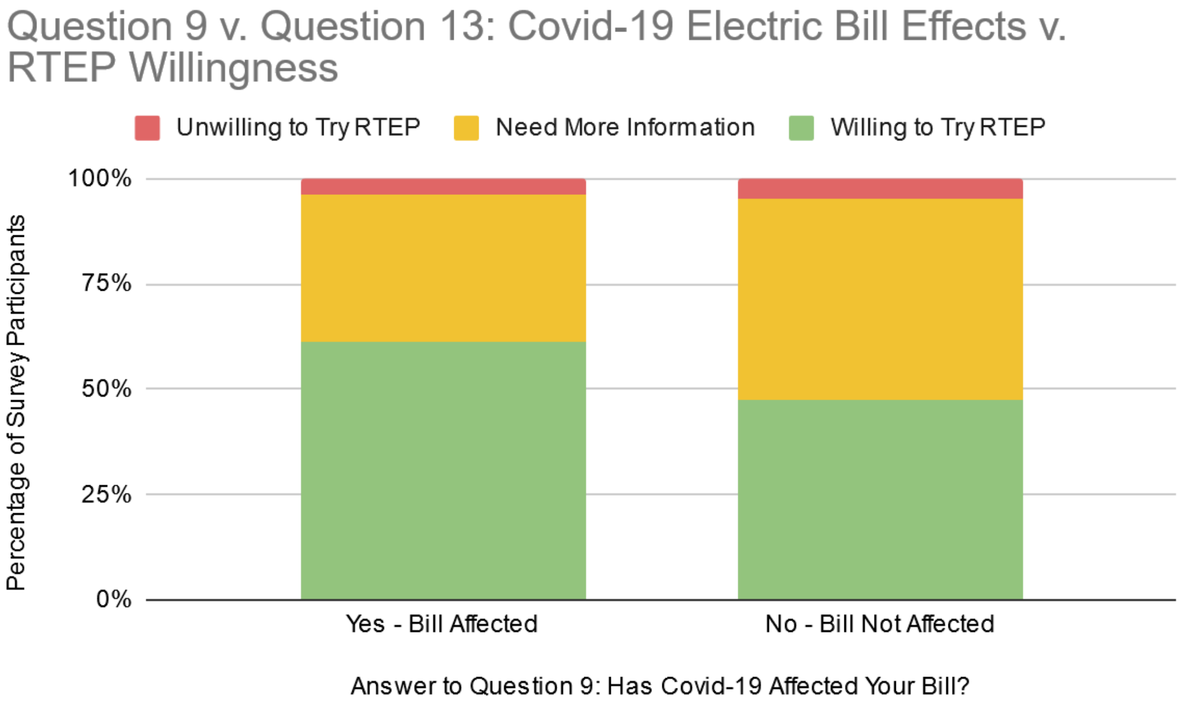

Figure 4.6. COVID-19 Electricity Bill vs. Willingness to Consider RTP

In tandem with our recommendations for smart technology, load shifting, and overall mindfulness of electricity use—all of which likely to be in the forefront of people's minds as they increasingly rely on the household as a workplace, with many workplaces now offering it indefinitely through *and* beyond the pandemic—the truly massive scale of upheaval presents an opportunity for the introduction of RTP as a desirable method of electricity delivery. Further, it could even tie into giving people more agency: they can personally control their usages, load shifting, and devices in their homebound lives to meet their desired budget and lifestyle with RTP.

## 4.2 Idle Home Devices and Saving with Smart Home Systems

**Objective 2. Establish the number of idle home devices in resident's homes and the potential for reducing idle energy consumption with smart home technology.**

The next big objective of our project was to establish the number of idle home devices in the resident's homes and establish the potential for home much energy and money they could save with smart home technology. We also asked a series of cyber-security questions to make informed recommendations based on participants' awareness of cyber-security threats.

In order to make comprehensive recommendations regarding the best smart home devices that would also be the easiest to adopt by the participants, we asked which smart home devices did participants already have in their homes. 12 participants indicated they have a smart thermostat and 12 participants indicated they have a smart power plug/strip, notably there was overlap between the two (there were participants that had both), these were not all the same 12 people. Zero participants indicated that they had a smart circuit breaker, and while not surprising, means that it will be excluded from our final recommendations. Our team did hope to see a greater adoption of the smart home technology, however given that the number of participants with smart home devices is relatively low according to the survey, that means there is more of a barrier to the adoption of smart technology than initially anticipated.

As shown in Figure 4.7, a few of our participants answered that they do currently have a smart thermostat or smart power plug in their home. Smart thermostats can have great benefit to the cost savings of a household. Smart power plugs are easy to install and easily lend themselves to automated energy savings. None of the participants currently have a smart circuit breaker, which makes sense because of the many barriers of entry to that technology.

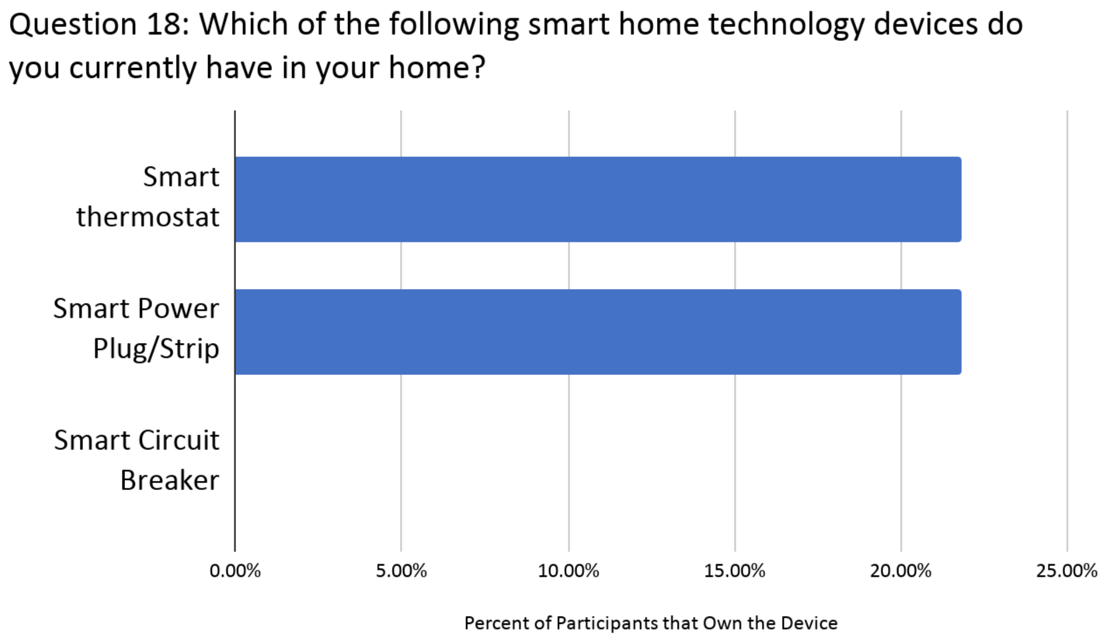

Figure 4.7. Percent of participants that owned smart thermostats and smart power plugs.

More importantly, especially given the relatively low adoption of smart home technology, we asked participants about specific reasons they would be unwilling to have certain devices in their homes. Figure 4.8 shows the breakdown of the factors by the device. As evident from Figure 4.8, more people are concerned about the privacy of the devices than initially anticipated, which is great given the cyber-security experience of the group members on our team. Cost also remains the single most selected reason and something our group has to seriously take into the consideration, especially given the survey results. Many people are not usually aware that installing a smart thermostat at home does not only cost whatever the device costs, but oftentimes requires an experienced electrician to install the system which can quickly add to cost. Smart power plugs have decreased in price over the last several years, however still do not present themselves as the cheapest option and of the power strips our group examined during background research can be quite costly. Given the concerns breakdown shown by the diagram above, our final recommendations do take cost, privacy and technology barrier seriously, although technology barrier was not as common of a barrier as can be seen according to participants.

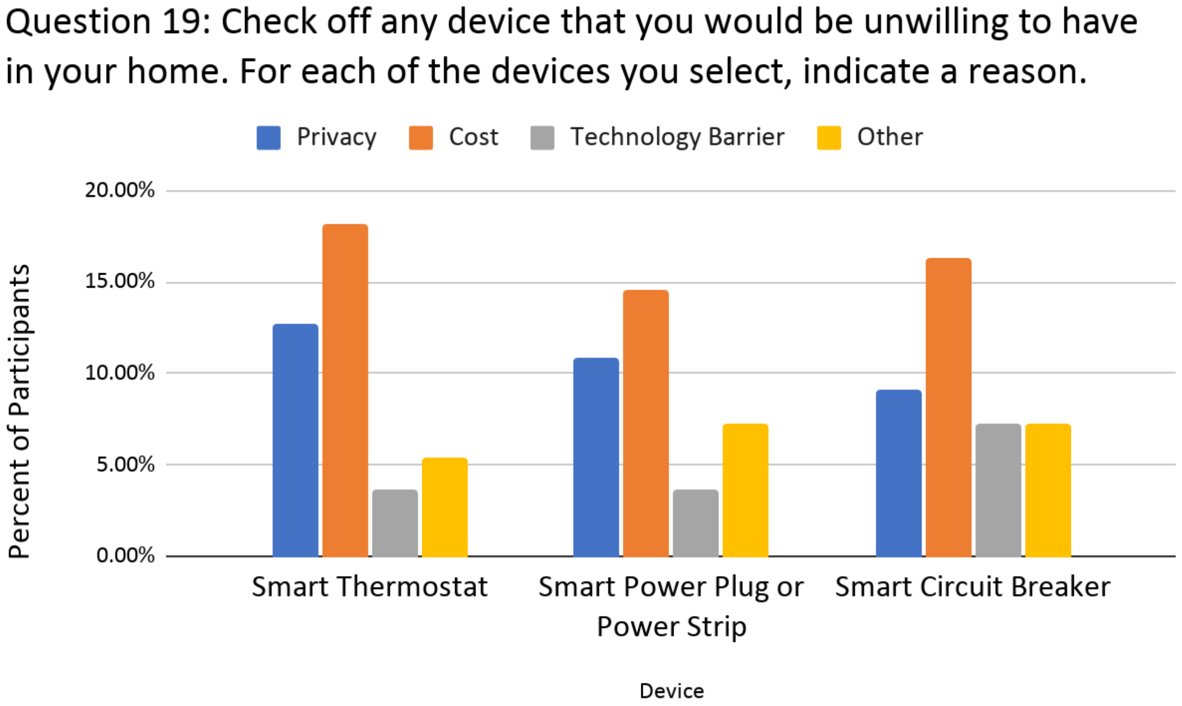

Figure 4.8. Factors influencing willingness to have smart devices in one's home.

In order to gauge the level of security knowledge and awareness, we asked our participants three basic questions regarding password manager use, updates to IoT devices and anti-tracking tools, to gain a better idea about how skilled the participants might be at securing their devices.

A password manager is an application which generates and securely stores user passwords. It is commonly accepted among security experts that all users should use a password manager. According to the results of the survey, only 14.8% (approximately 1/7) of participants use a password manager. One's use of a password manager applies to their ability to secure an IoT device because they will be more protected from password reuse and authentication phishing attempts on both IoT devices themselves and other areas. The use of a password manager is also generally related to one's competence with the secure use of computers.

As shown in Figure 4.9, almost half of survey participants (45.5%) check for updates to their devices either weekly or monthly. On the other hand, 27.3% of participants never check for updates – indicating that they would need to adopt new habits if they are to securely use a software-dependent IoT device. It is possible that the question was asked poorly and did not take automatic updates into account, leaving the differentiation up to participants to decide. The results of this survey question may be skewed and should not be relied upon implicitly. Curiously, while almost half of the participants follow the good security advice of checking for updates, only about 1/7th of them used a password manager. The variation in participants' use of good security hygiene may be due to password managers only being a recent trend in security advice. The need to update software and check for updates has been common knowledge and solid security advice for decades. Password managers on the other hand have only been around for a few years, as the push for more and more complex passwords began to fail.

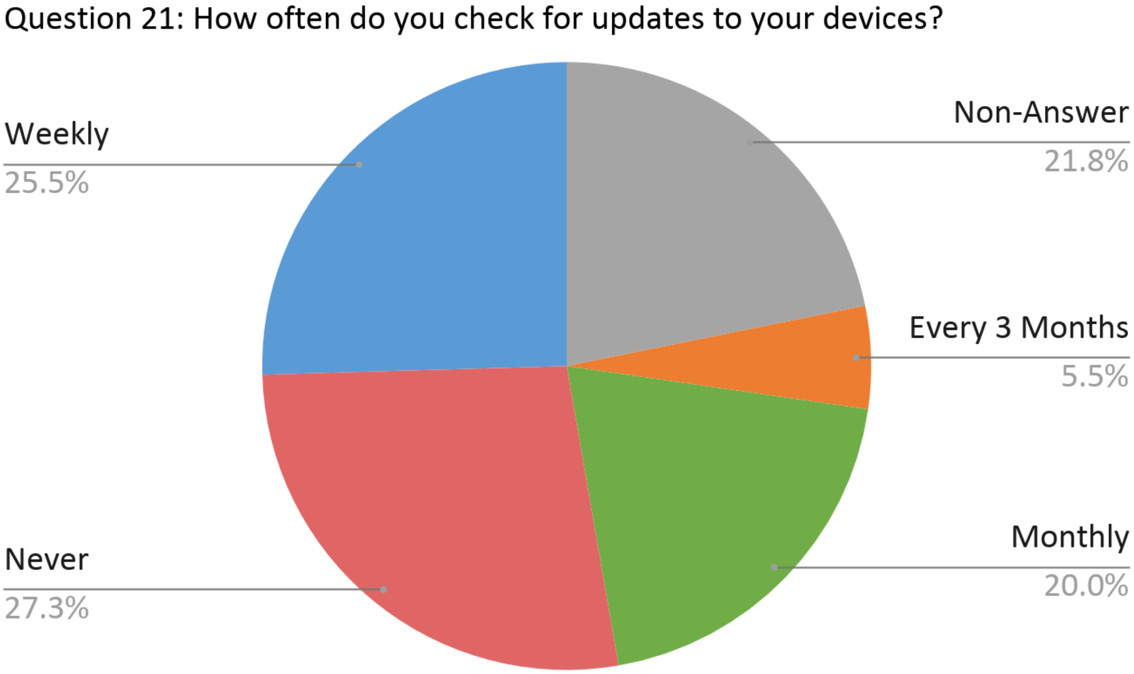

Figure 4.9. How often participants check for updates on their IoT devices

As discussed in the background section 2.7, users checking for backups is important for securing IoT devices. Software bugs and vulnerabilities for IoT devices are commonly uncovered by security researchers and attackers alike. If the device manufacturer is still supporting the device, they will write a software patch after hearing about the problem that will help fix the problem – releasing the patch for users to install in a device software update. These updates will likely not be installed automatically and may not even be well communicated to the user. It will be important for users to be well aware of their devices fallibility and to develop habits of checking for updates to their devices.

According to the results of our survey, over half of the participants (56.4%) take steps to block trackers online. The exemplified blockers in the question included limiting software permissions, using privacy extensions, or refraining from using a service. Almost everywhere on the web there are tools and programs that study user behavior and relate it to create a profile. The result that over half of the survey participants are not only concerned about this tracking but also take steps to mitigate it, indicates that they should also have concerns about the privacy of IoT devices (assuming that they understand the risks). The steps taken by over half of participants also shows that they are competent with configuring computers to be more secure per their personal concerns. The general lack of privacy settings on IoT devices means that devices with less information gathering should be recommended.

## 4.3 Shifting Electricity Usage and Smart Home Systems

**Objective 3. Assess the interest and the ability to shift electricity usage away from peak times, from the cost and education perspective for the smart home systems and devices.**

In order to establish how receptive participants are to shifting their load heavy devices to a different time of use, we asked them whether they would be willing to do so and if yes, would they be willing to do it to save money, help the environment or for any reason. Below are the results. Figure 4.10 shows people's willingness broken up by appliances. Big takeaways are that people are generally receptive to the idea of shifting their time of use for certain devices, if it means helping the environment, saving them a little bit of money or for any of the reasons. People are the most receptive to shifting their dishwasher time of use, and then washing machine and A/C in order of receptiveness. The biggest non-answer percentage comes in a form of the electrical vehicle question, likely because many of the participants do not have a charger at home or do not own an electric vehicle in the first place, but both the participants that do and do not own an EV have indicated that theoretically they are also receptive to the idea. Given, how receptive the participants are to the idea of time of use, especially for appliances like a dishwasher, if it could be done automatically, our group anticipates this idea to be well received and it will be a part of the recommendation to make sure that there are options on the market for devices and smart home device integrations that allow people to shift their use of appliances, to help environment, the grid and the planet.

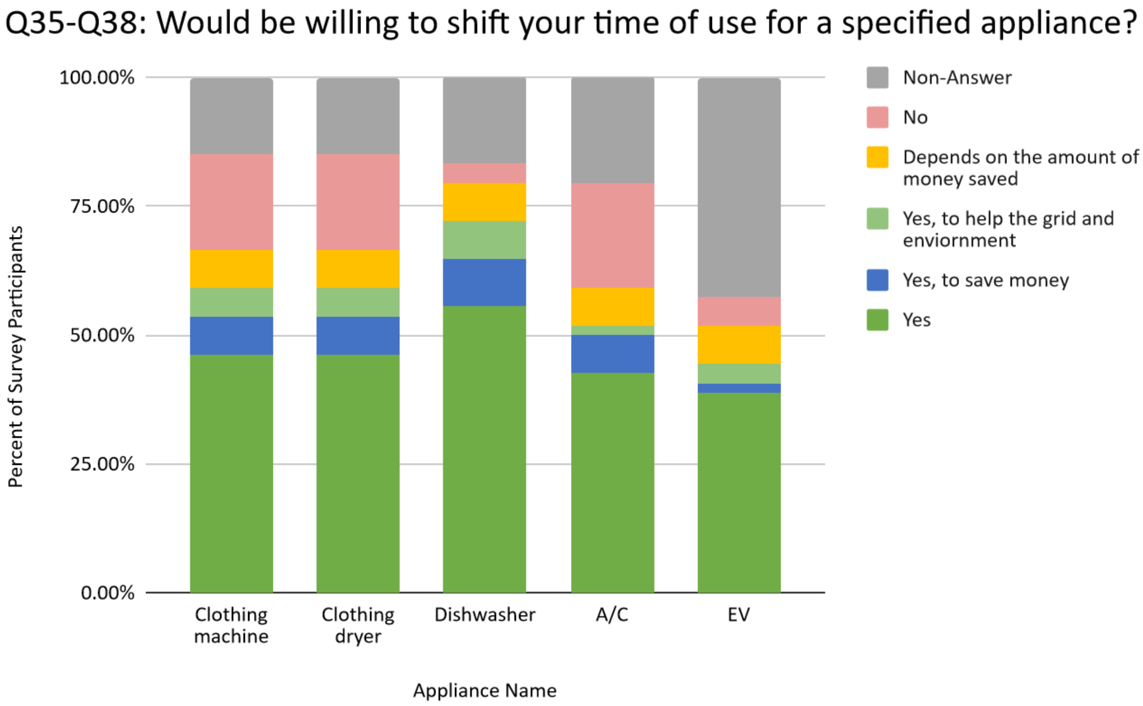

Figure 4.10. Participants willingness to shift time of use for specified appliances.

Although the participants were generally receptive of the idea, we also asked if they had any barriers to shifting their time of use for devices and gave them a few options and the breakdown of the answers is shown in Figure 4.11. More investigation needs to be done regarding “prefer not to answer”, “other” and “distrust” categories. Resistance to change is not a surprising factor, and generally can be mitigated with  education and implementation of automation like smart home technology. Work scheduling conflict can be harder to overcome, but for certain devices such as a dishwasher can be mitigated with a behavioral change (loading the dishwasher before) and then putting the device on a smart plug that can be automatically triggered to start the device, as described further in Section 5.4. Abnormal behavior can be a deceptively difficult psychological barrier to overcome in terms of changing habits, however, with an exceptional 13.9% of our participants being concerned with it. The nail that sticks out often gets hammered down, and as such performing new habits when in stark contrast not only to one’s own old habits but to those around them can be especially daunting. This, too, can be at least partially addressed by solutions like home automation technology with a “cool” factor: when something stands out as exceptional or otherwise desirable rather than purely unorthodox, it then has the opposite effect to what was described earlier. Therefore—as potentially juvenile as it sounds—we will need to be mindful of how trendy and otherwise desirable our recommendations appear to any given audience.

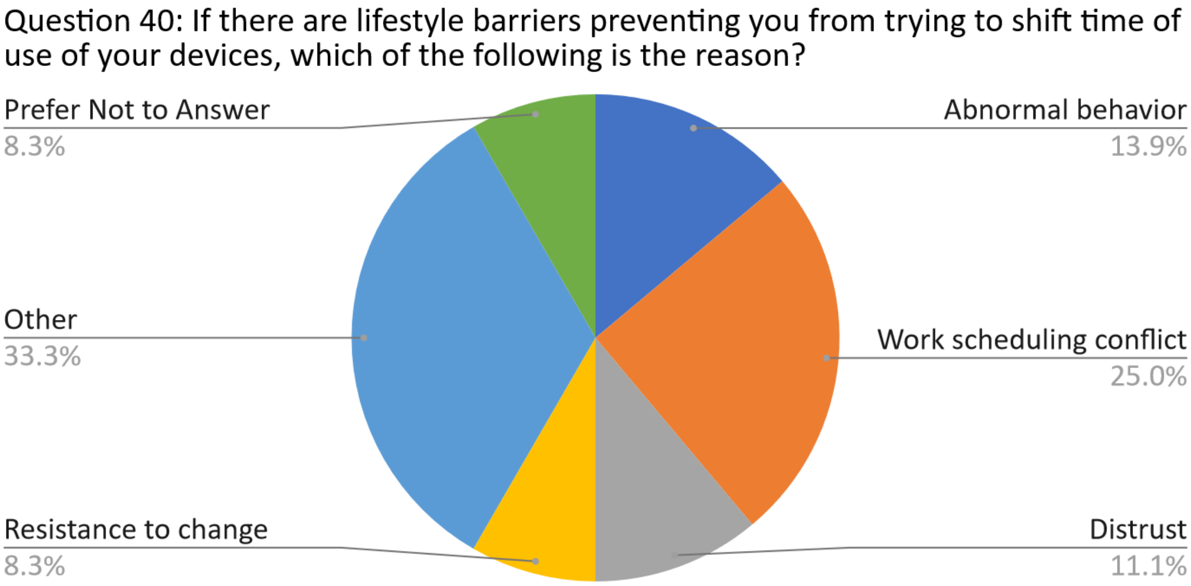

Figure 4.11. Lifestyle barriers preventing shifting time of use of appliances.

One of the most important load shifting eligible devices are the electric vehicles. As John Marczewski pointed out in an interview and we established during our background research, the incentives and the regulations that the utility companies will be able to put in place regarding EV charging will significantly impact the grid; either in a positive or negative way. The adoption of EV's still remains relatively low. According to our survey results, only 5.5% of the participants owned electric vehicles. 1.8% owned plug-in hybrids. We also asked the participants that did not own an electric vehicle, what was the barrier for them to access it. As shown in Figure 4.12, we got an expected mix of usual concerns: 18.2% worry about upfront cost and 18.2% worry about range. Interestingly, 3.6% indicated they are not sure about options, 18.2% said they have no interest in buying one and 20% indicated other reasons without providing a text explanation. The latter three options are more interesting and indicate a potential consumer market, especially those that are simply not sure about their options. Further study needs to be done regarding the 20% who indicated other reasons which could potentially include serviceability, safety (such as news stories about EV fires), charging availability and charging time. Still, despite the low EV adoption numbers, by nearly all studies and projections EV adoption is only set to increase and depending on the incentives that the utility companies will offer regarding charging, will either increase the peak demand on the grid during already heaviest hours, or encourage consumers to shift their time to the off peak hours.

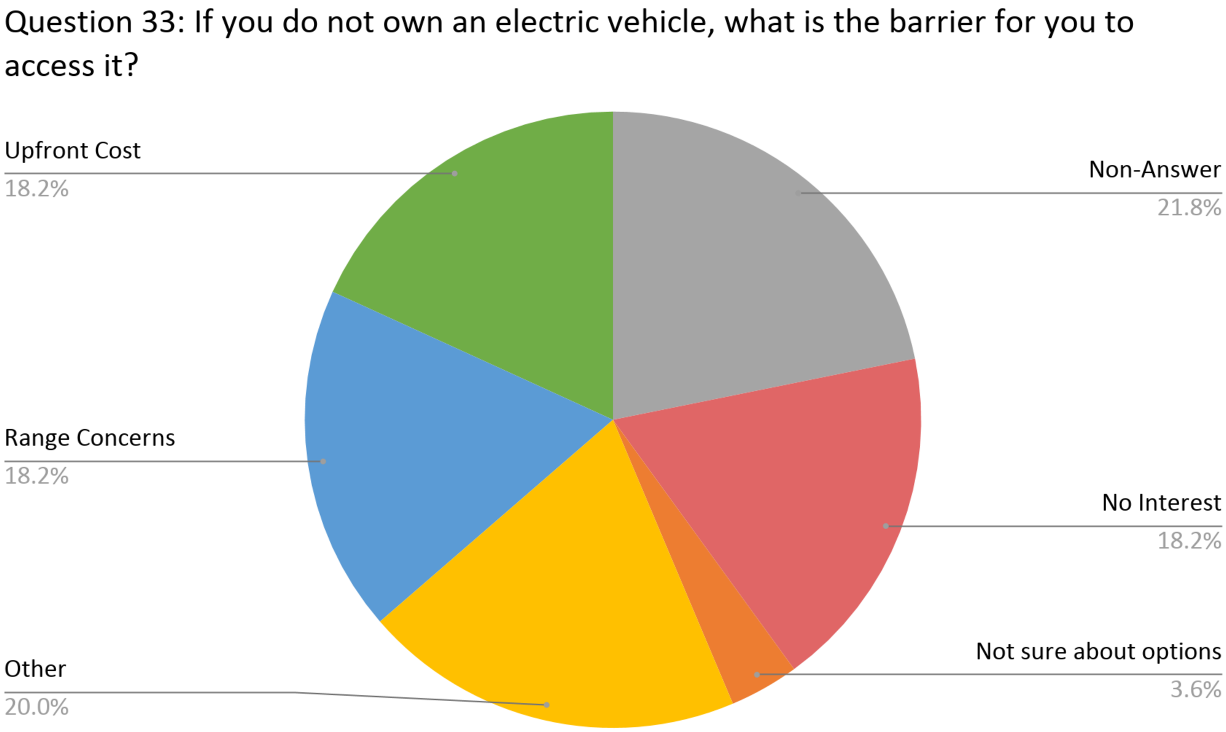

Figure 4.12. Barriers for access to EV's.

## 4.4 Solar Programs

**Objective 4. Establish the level of interest, barriers to entry and challenges for participation in solar programs.**

To establish the ability to participate in the solar programs, we asked our participants whether they owned or leased any solar panels in question 23. We found that 10.9% of survey participants owned solar panels, 1.8% leased them and 1.8% had a condo association that owned solar panels. The condo associated note was particularly interesting to our group. We did not include condo association as an option however a participant selected the "other" option and provided an explanation. Condo association owning panels may or may not be an attractive option for people depending on the terms of the contract with the condo association. If the participants of the condo all contribute financially and all reap the benefits of the solar, it might be an attractive option for many, especially those who have concerns about the upfront cost. However, if the condo association puts all the money into the panels and the residents don't reap any benefits, or worse have to put in the money and then don't see any benefits, the option is less attractive.

For participants that did consider solar panels, but did not end up owning them, we asked about factors that prevented them from obtaining solar. Figure 4.13 shows the barriers indicated in the survey. About 30% are ineligible for solar due to the roof not being eligible for solar or not having access to roof space, however at least 43% are potential candidates for solar since they indicated cost and lack of knowledge about options and process being a barrier. Upfront cost still remains a big factor, however it is likely that at least of the 25% of the participants who indicated upfront cost being the biggest barrier are not fully aware of all the tax benefits, financing options and long term savings. Federal tax incentives are also needed to continue to make the hurdle of upfront cost lower. Especially for 18% of people who are not sure about the options and process, companies need to reach out to and give them a potential cost and process estimates.

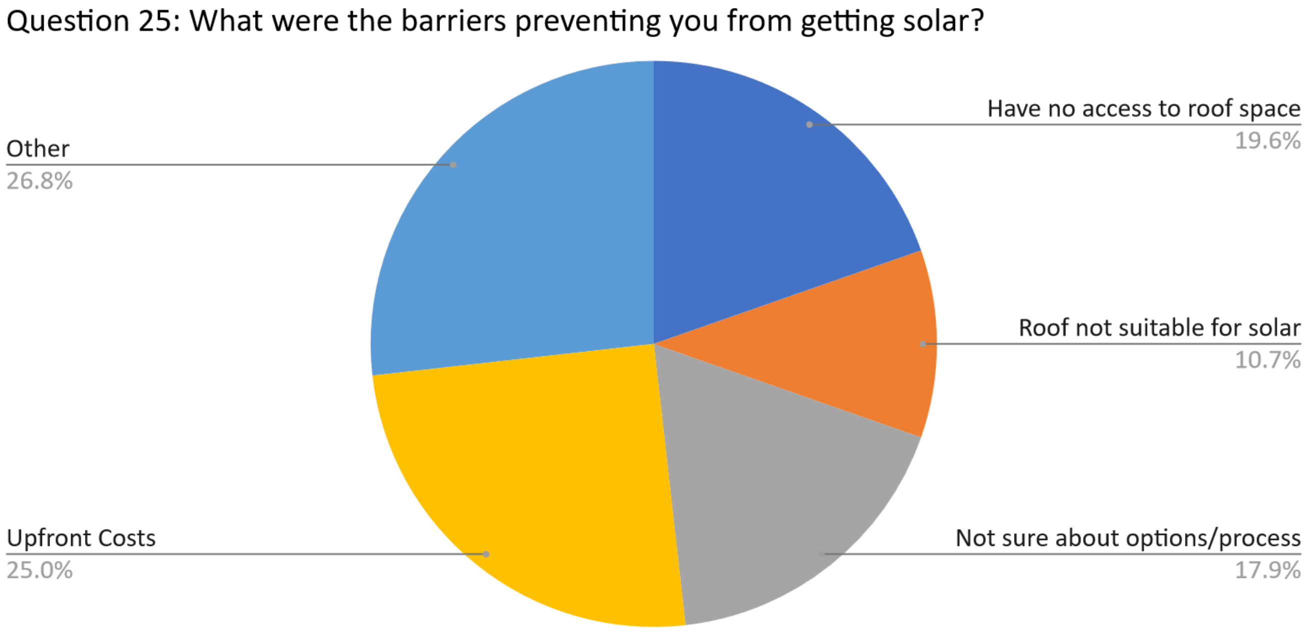
Question 25: What were the barriers preventing you from getting solar?

Figure 4.13. Barriers preventing access to solar.

Given that 25% of the survey participants indicated that their biggest barrier to getting solar is upfront costs, it is not great to see that for question 26, which asked about awareness regarding federal/state tax incentives for solar, only 30.9% of people said yes, while 50.9% said no. There can be a variety of reasons why the awareness of incentives remains low. The biggest and easiest tax break to understand and claim was the federal solar tax credit, which stood at 26% as of 2020. However, a huge issue is that in 2021 and subsequently 2022 the credit is supposed to decrease significantly. In 2021 it is supposed to drop to 21% and in 2022 eliminated completely for people and drop to 10% for retail. Excluding individual homeowners' from the equation is especially dangerous. While it is understandable why the government wants to incentive businesses to invest a lot of capital into solar, the small scale projects matter as well as we have indicated can increase the value of the house and mean large long term savings for individuals.

We also assessed how long participants are willing to wait for their solar panels to pay back the cost of installation and results are shown in Figure 4.14.

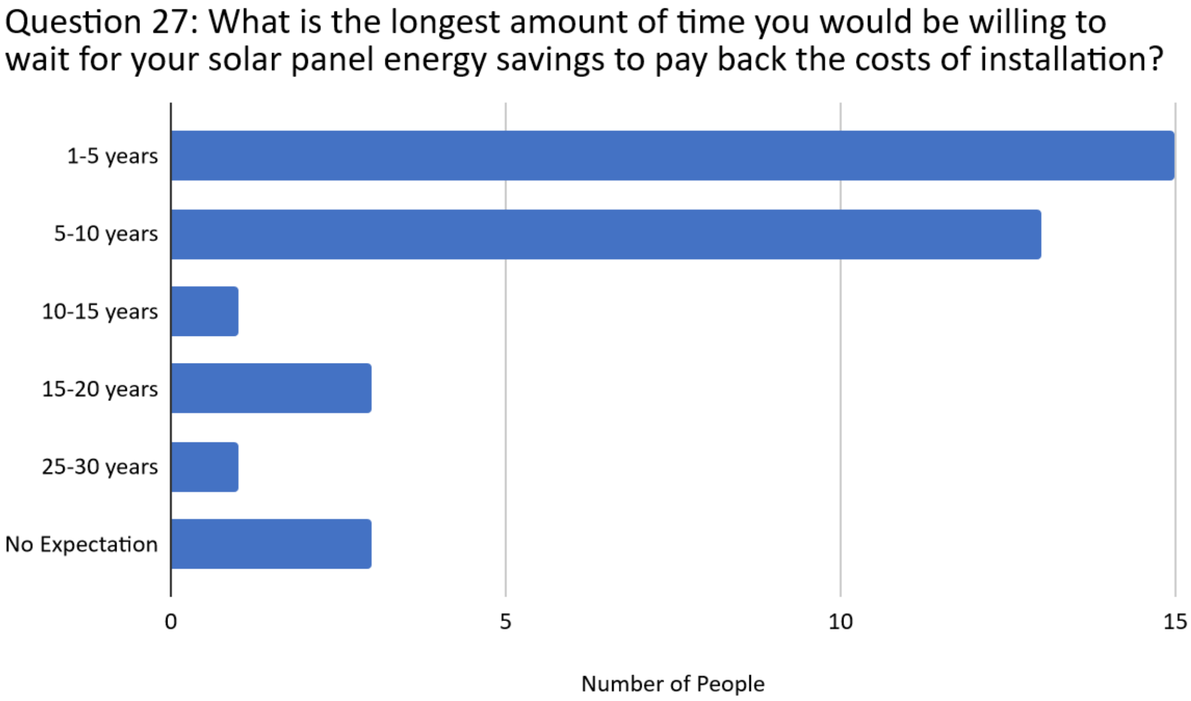

Figure 4.14. Expected time for solar panels to pay back the costs of installation.

In calculating the general statistics we used the mean of each interval as we did for the previous interval question. We redacted the no expectation data from the calculation due to the ambiguity of no exception meaning 0, infinity or unknown. The general statistics are given in Table 4.8.

Table 4.8. Descriptive statistics regarding the amount of time the participants are willing to wait to the solar panels to pay back the cost of installation

| | |
|---|---:|
| Mean | 7.03 |
| Standard Error | 1.04 |
| Standard Deviation | 5.87 |
| Kurtosis | 3.89 |
| Skewness | 1.85 |

The high kurtosis and positive skew is probably due to the environmental benefit making people more willing to wait longer. The implicit, but objective and measurable environmental benefit value is warped through one's morality making the subjective environmental value much more dispersed. As the function of our morality has the dia of inherit value we cannot assume the input set of bound values will map onto a bounded set (that is if one infinitely values x then twice of that may not map as twice as much or any amount more than previous value) The no expectation answer could easily be a direct mapping of the environmental value, but the comparatively unusually high 'outlerness' that is kurtosis is also highly indicative of presence of environmental and not just fiscal value.)

A note needs to be made regarding the "No Expectation" option. When our group designed the question, the assumption was that the "no expectation" meant "I don't have any expectation of the panels paying for themselves ever", however could be interpreted by participants as simply they don't know, but hope they pay for themselves.

## 4.5 Potential Savings

**Objective 5. Calculate consumer savings through participation in the RTP model, change of habits such as reduction of idle electricity consumption, and participation in solar.**

### 4.5.1 Savings from Reduction in Idle

The first part of our study was designed to calculate potential consumer savings that could be realized from paying greater attention to electricity consumption and taking steps to reduce idle electricity consumption. In order to calculate the potential savings per participant, in our methodology we used the Delforge study to estimate idle kwh per commonly owned devices and we asked the participants in the survey to indicate which devices from our pre-built list they have at home, and if they have more than one, then indicate the number. Then we were able to multiply the number of devices participants had and calculate savings per participant. The percent of participants that owned each device are shown in Figure 4.15 and in one of the columns in Table 4.9.

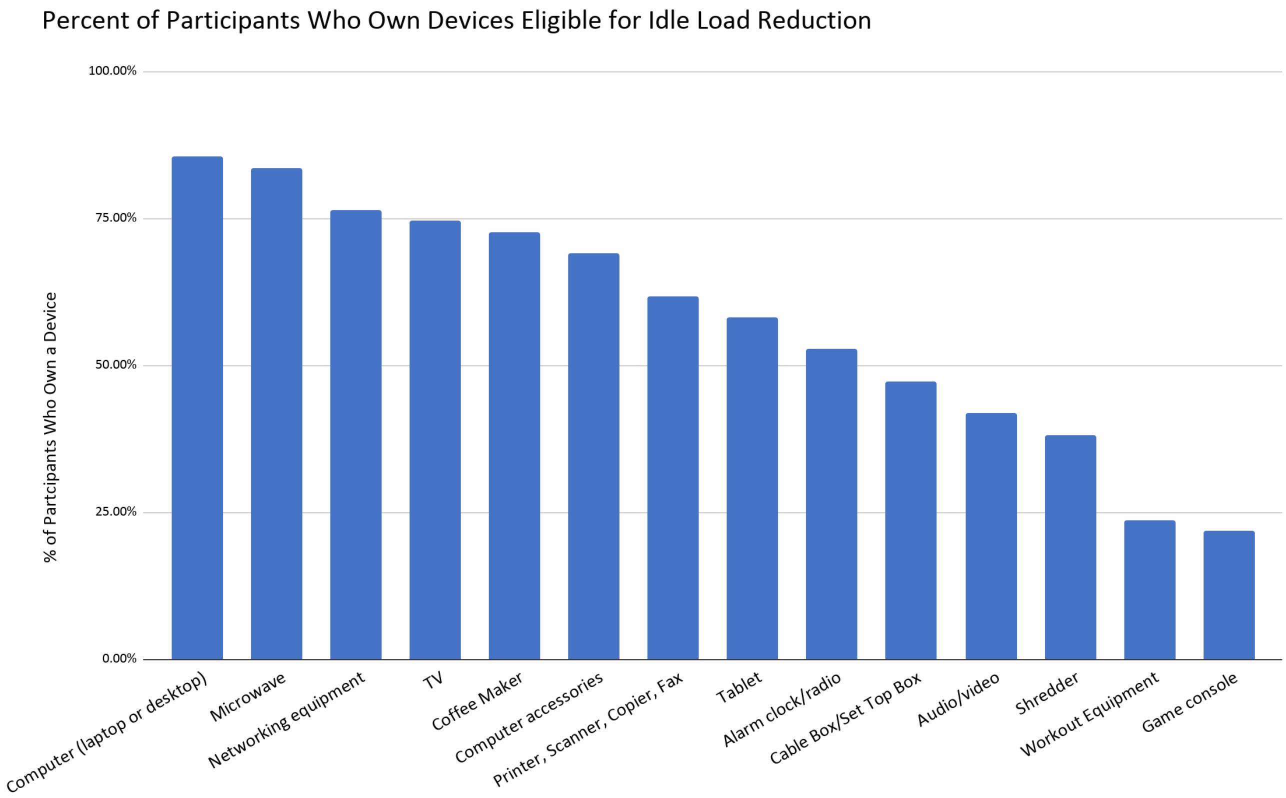

Figure 4.15. Percent of participants who own devices eligible for idle load reduction.

We had the numbers of how many devices each participant had, we multiplied those numbers by the averages from the Delforge study (Delforge, 2015) and found the average by adding up all the sums of dollars calculated for each participant by the 47 participants that answered the question about the idle devices. We purposely eliminated 8 participants that skipped the question entirely. The results are presented in Table 4.9.

Lower Bound and Upper Bound were calculated as follows:

Σ(Number of units of a said device participant owns * yearly estimated idle electricity consumption of the device from Methodology) / 47

Note: 47 was the number of participants out of 55 that provided some sort of response to this question and did not leave it completely blank.

Table 4.9. Percent of participants who own idle load reduction eligible devices and estimated annual savings per device.

| | % of Participants Who Own a Device | Lower Bound $ | Upper Bound $ | Average |
|---|---|---|---|---|
| Computer (laptop or desktop) | 85.45% | $ 26.10 | $ 34.93 | $ 30.51 |
| Microwave | 83.64% | $ 6.86 | | $ 6.86 |
| Networking Equipment | 76.36% | $ 11.91 | $ 23.82 | $ 17.86 |
| TV | 74.55% | $ 37.71 | | $ 37.71 |
| Coffee Maker | 72.73% | $ 7.76 | | $ 7.76 |
| Computer Peripherals | 69.09% | $ 18.59 | $ 19.52 | $ 19.05 |
| Printer, Scanner, Copier, Fax | 61.82% | $ 9.53 | | $ 9.53 |
| Tablet | 58.18% | $ 9.93 | | $ 9.93 |
| Alarm clock/radio | 52.73% | $ 7.38 | | $ 7.38 |
| Cable Box/Set Top Box | 47.27% | $ 20.26 | | $ 20.26 |
| Audio/video | 41.82% | $ 7.06 | | $ 7.06 |
| Shredder | 38.18% | $ 6.86 | | $ 6.86 |
| Workout Equipment | 23.64% | $ 8.01 | | $ 8.01 |
| Game console | 21.82% | $ 2.33 | | $ 2.33 |
| Sum | | | | **$ 191.10** |

We found that, on average, for our 47 survey participants that did not skip the question, a person could save $191.10 for all their devices per year if they employed smart home technology techniques to limit the amount of idle power wasted. Considering that in MA people spend an average of $125.89 on electricity per month that means savings of almost a month and a half worth of electricity.

### 4.5.2 Savings from Load Shifted Devices

Another part of our research was to estimate how much people would be able to save if they were willing to shift the time of use for clothing washing/drying machines, dishwashers, ACs, and EV's. We followed similar calculations from section 4.5.1 above and calculated for people who indicated that they own each device, how much they might be able to save from using lowest RTP rates. The lowest RTP rate occurs between the hours of 11pm and 6am. The average price during those hours varies from $17.1 per mwh to $19.39 per mwh, with the average being $18.53 per mwh, or 1.853 cents per kwh. We assumed our participants would get an average rate of those hours. Percentages of participants who own appliances eligible for load shifting are shown in Figure 4.16.

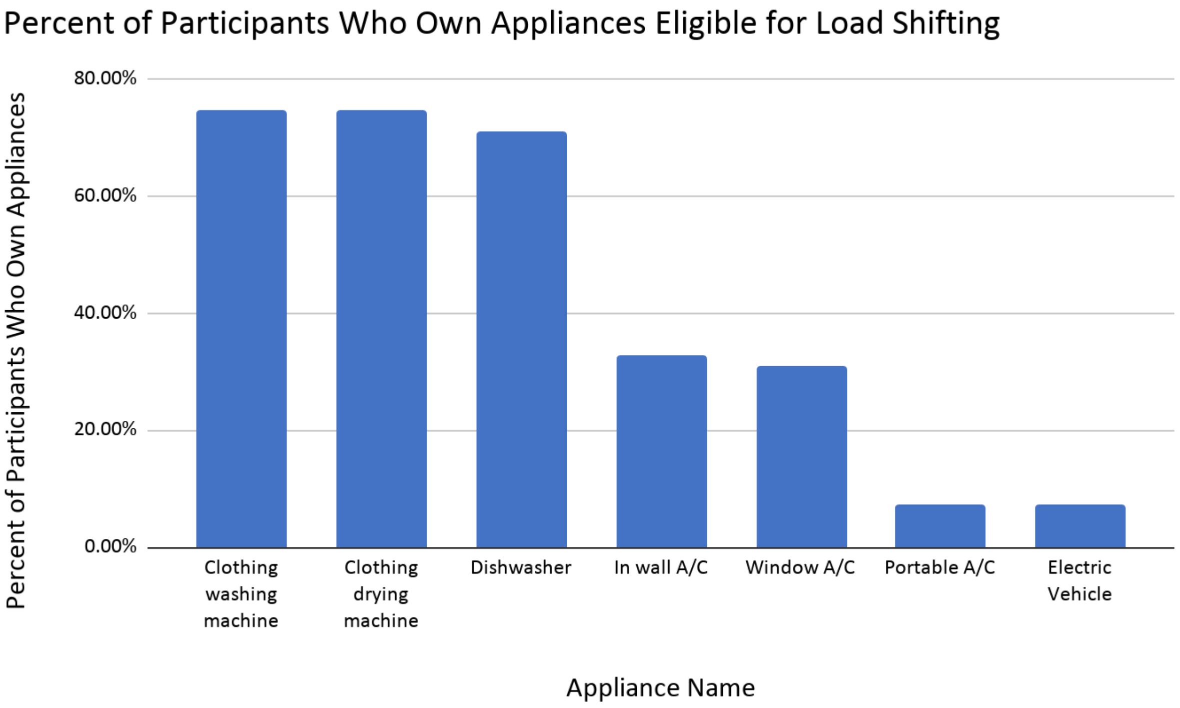

Figure 4.16. Percent of participants who own appliances eligible for load shifting.

To calculate participant spending per device and potential savings, we used the same method from Chapter 4.5.1 and found the lower and upper bound for the spending per appliance.

We previously noted that the average fixed rate price including the supply and delivery in MA is 21.92 cents per kwh. Out of that cost, our group estimates that 11.615 cents per kwh is the cost of the generation or the supply, while the rest is a sum of various fees and price to deliver the electricity. This means roughly 52.98% is the cost for supply while the other 47.02% is the cost of the fees and delivery. 18.53 $ per mwh is the average RTP rate of the lowest points, 1.853 cents per kwh. In order to make a fair calculation and calculate the total cost, our group added 47.02% of cost to the price giving us the final number of 2.724 cents per kwh.

Table 4.10. Load Shifting Eligible Devices and estimated savings with RTP.

| Name of the Appliance | Lower Bound | Upper Bound | Average | % of People Open to Shifting | Average Shifted Rate 2.724 cents per kwh |
|---|---|---|---|---|---|
| Clothing Machine | $ 17.20 | $ 57.37 | $ 37.28 | 63.00% | $4.63 |
| Clothing Dryer | $ 116.02 | $ 123.14 | $ 119.58 | 63.00% | $14.86 |
| Dishwasher | $ 43.46 | $ 49.11 | $ 46.29 | 72.30% | $5.75 |
| In Wall AC | $ 61.56 | $ 389.89 | $ 225.73 | 51.90% | $28.05 |
| Window AC | $ 58.67 | $ 434.04 | $ 246.36 | 51.90% | $30.61 |
| Sum | $ 59.38 | $ 210.71 | $ 135.05 | 60.42% | $83.91 |

We found that currently for all of the devices listed above, our survey participants are spending $135.05 a year on their devices and they would spend $83.91 using the average lowest RTP rate if everyone was willing to shift their time of use which amounts to $51.14. This is not an insignificant number and could serve as a good incentive to encourage RTP or TOU participation, assuming that electricity providers and the state extended these alternative rates options to customers and did not increase the fees for providing electricity.

In terms of savings for the biggest load shifting eligible device - the calculation is more complicated. Detailed calculations are available in Appendix H. We estimate that it would cost on average $923.77 to charge an EV per year, a range is between $661.10 - $1360.90 using fixed rate price. We also calculated that it would cost approximately $1,308.42 to fuel a gas vehicle using the same approximated mileage. Note that just as with other calculations, this varies significantly depending on the model of the car, the size of the car, how much a person drives, where a person drives (city streets with traffic or mostly highways) and more. Generally speaking though, assuming we compare two similar models of vehicles, such as a gas sedan and Tesla Model S for example, people can reap almost 50% in savings in terms of fueling the vehicle. At the same time, again generally speaking, the cost of the EV still tends to be higher than a non-luxury gas vehicle, so it is up to the individual person to decide whether the value proposition is worth it to them. For the purposes of our project, EV's are a good investment and become even more attractive if participants can get access to RTP/TOU, and bring down the $923.77 price even lower. Using proposed 2.724 cents per kWh, that price could be as low as $82.29 - $169.19, or an average of $114.85.

### 4.5.3 Savings from Real Time Pricing

Most importantly for our work, we collected hourly real time electricity pricing points for the Boston region from ISO New England and plotted them against 116.15 $/mwh generation service cost in MA estimated by our group which is the total cost - delivery and fees. We plotted all individual points and plotted them which is shown in Figure 4.17, but we also found the averages of all the points and calculated average hourly price shown in Figure 4.18. The average of all the blue points on the graph, the real time price points is 23.65 $/mwh.

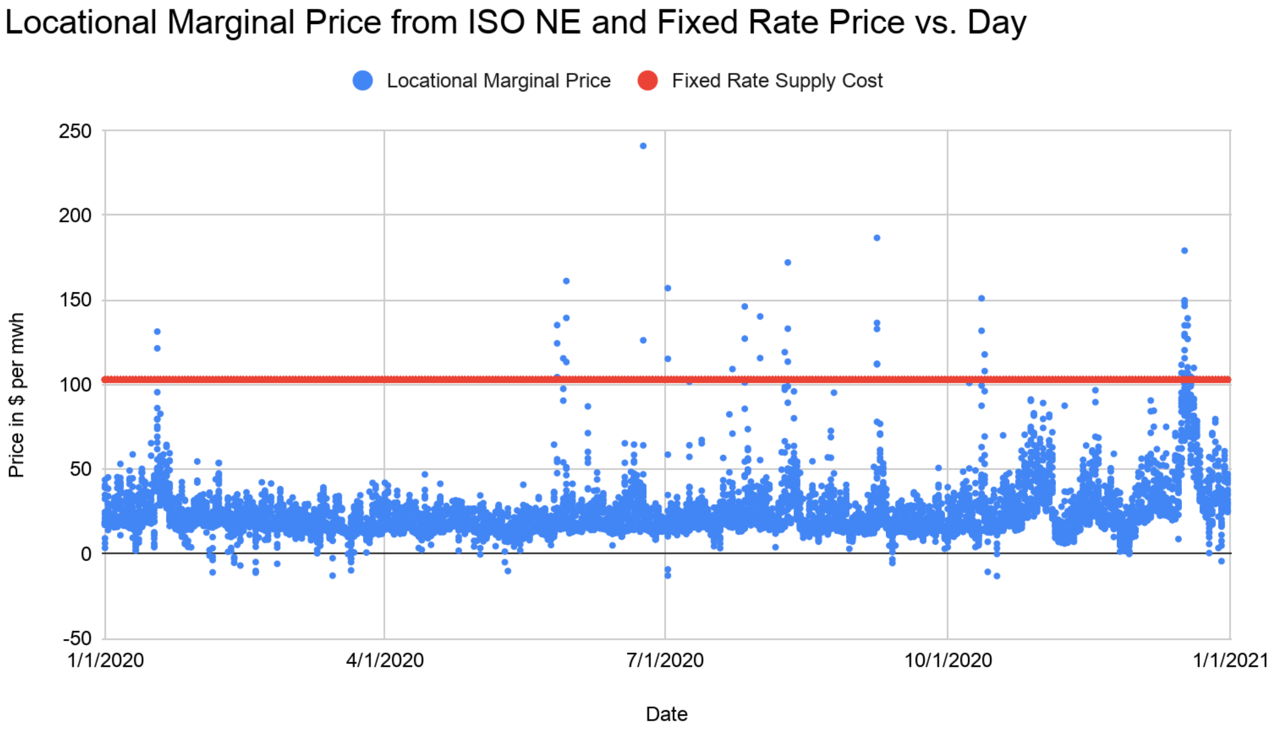

Figure 4.17. Hourly Locational Marginal Price from ISO NE and Fixed Rate Price vs. Day

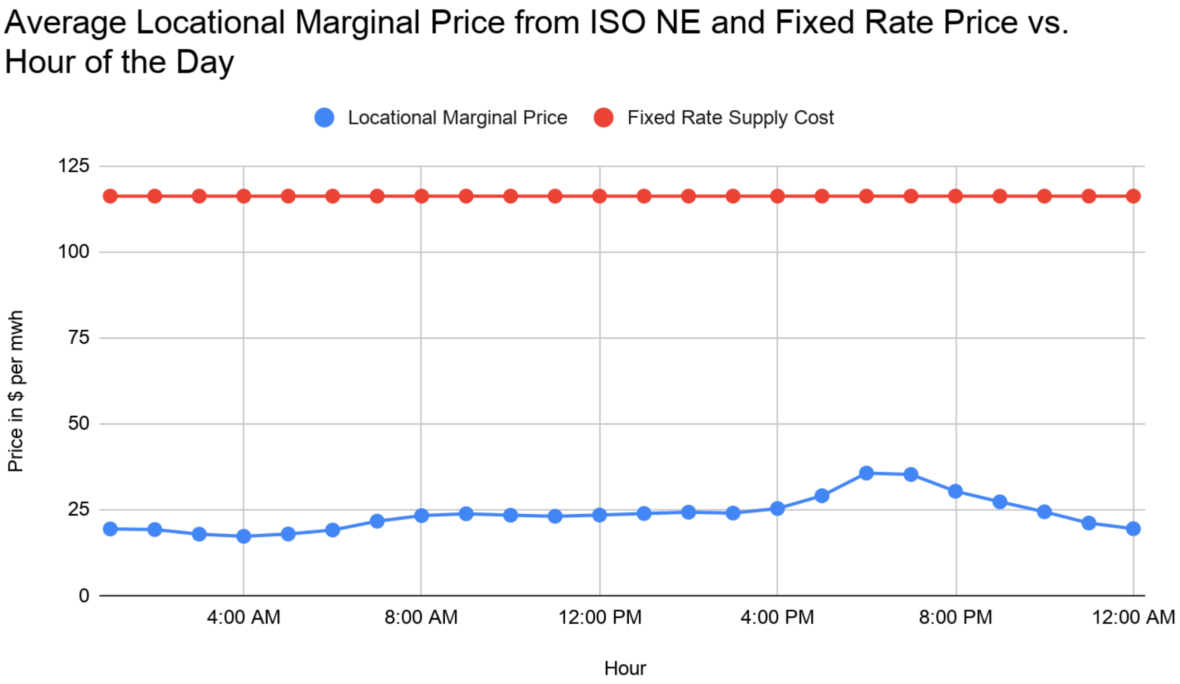

Figure 4.18. Average Locational Marginal Price from ISO NE and Fixed Rate Price vs. Hour of the Day

By initially looking at the graph, we can conclude that RTP rate is a much better deal than Eversouce and National Grid (electricity providers in MA). However, there are two factors that come into play here: the demand to price relationship and the way we calculate averages. First, the demand of electricity and price are tied together and the demand tends to drive electricity prices, although the relationship between them is not immediate, meeting that a demand in electricity will not instantly drive the price up massively. However, at a certain point the demand reaches a peak more than the supplier of electricity anticipated and the prices spike as can be seen from individual points on Figure 4.17, which in turn skew the averages in Figure 4.18.

In terms of pure numbers, we estimate the fixed rate supply cost to be $116.15 per mwh, the average on the graph with all the data points included is $23.65 per mwh. There are 8,760 data points on the chart (24 hours a day * 365 a year). Out of those data points, 8752 were less than the fixed rate supply cost, or nearly 99% of the time. However, the real danger is in 32 data points that were higher than the fixed rate supply cost and even though it only accounts for less than 1% of the time, we have seen from Griddy what happens when the consumers are not properly warned about the price spikes (for more detail see Appendix B). Also, only 29 points which means or 0.003% of the time the prices on electricity were negative. This means that there is a danger in trying to advertise RTP to consumers with the promise of negative prices, since they only happen 0.003% of the time.

In order to see how the price curve would look most of the time, we took out the outliers following the standard quartile method in which we found the median and excluded more than 1.5 Interquartile Range data points. For Figure 4.17 that contains all the hourly data points for 2020, our median is 19.01. Q1 = 14.97, Q3 = 27.29 so lower outliers are less than -3.51 and upper outliers are greater than 45.77. With all the outliers taken out, the average price is $20.73 per mwh. The new average price curve without outliers is shown in Figure 4.19.

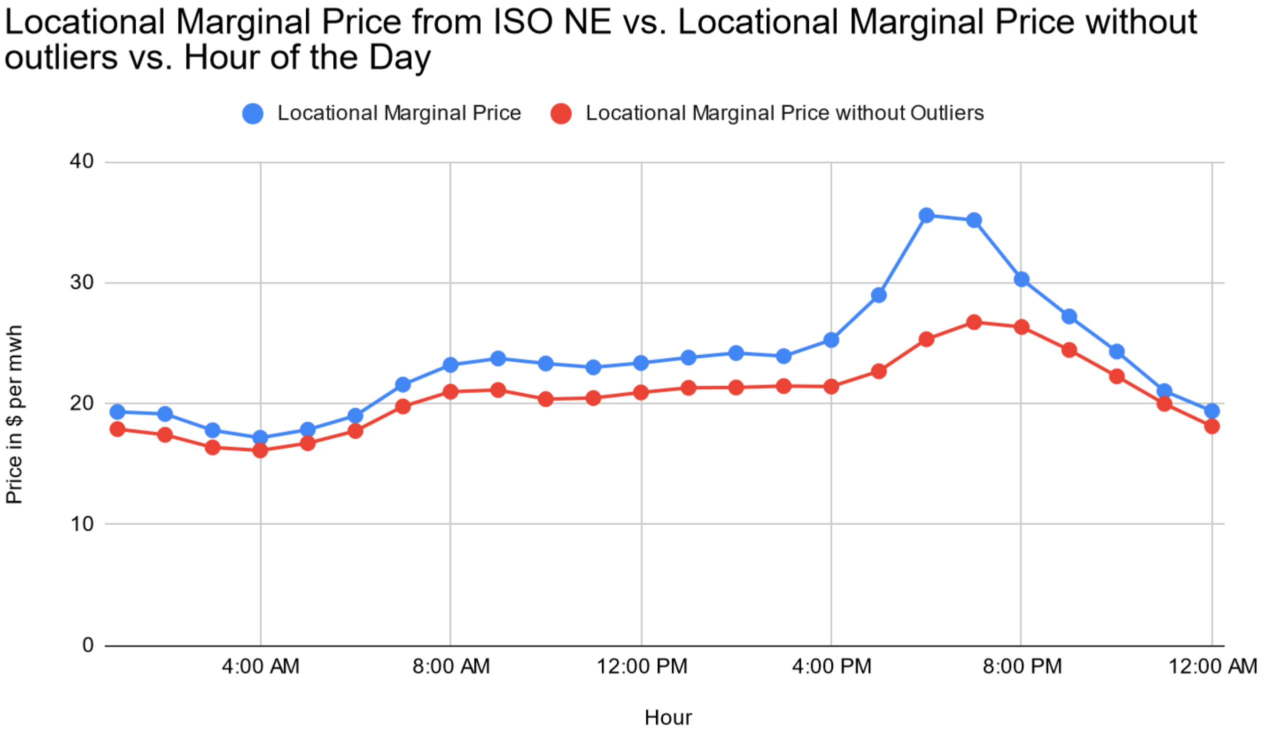

Figure 4.19. Locational Marginal Price from ISO NE vs. Locational Marginal Price without outliers vs. Hour of the Day

# 5. Recommendations

**Objective 6. Develop a set of recommendations based on the previous findings to increase participation in RTP, reduce energy consumption and peak load on the grid, and encourage adoption of smart home automation systems, solar and electric vehicles.**

## 5.1 Recap by Objective

Based on the results of this survey, here are some lessons learned:

- RTP Program
    - RTP is case-by-case/individualized and not a better or worse blanket statement.
    - Lack of understanding of RTP. But, nearly 80% of the participants are receptive to the idea of RTP and are receptive to learning more about the program on their own and from utility companies.
    - Participants prefer opt in vs. opt out.
    - Nearly a half of the participants experienced an increase in their 2020 electricity bill due to COVID. Participants who experienced COVID-19 affecting their bill, were much more likely to consider RTP.
- Idle Energy and Smart Home Devices
    - Smart devices have a purpose and saying no is not the best solution.
    - People update their devices more often than we thought, but not nearly enough people use a password manager.
    - More education will be needed, recommendation devices will be conditional on one's security skills.
    - People are more aware and concerned about privacy and risk than we thought.
- Shifting Energy Use
    - People are willinging to shift their usage, between 50%-75% are willing to shift. In order of willingness: dishwasher, clothing machine and dryer, A/C, EV.
    - Work scheduling conflicts are tougher, use IoT devices to help.
    - EV's have the potential to destroy and make the pricing situation a lot worse. However, if the programs are implemented well, EV's can be a great incentive for enrolling people in TOU.
- Solar
    - Adoption remains low, especially considering our education and age demographics. Willingness to wait for the investment is low.
    - No surprise, solar needs federal and state tax incentives
- Savings Calculations
    - A lot of potential for savings for idle reduction.

    - ○ Dangers regarding RTP spikes, TOU might be a better alternative for the general public. RTP is like the stock market and credit cards.

## 5.2 Time of Use Pricing

Given the challenges that we explored that come with enrolling people in RTP, our alternative proposal for the general public is Time of Use. For people with high risk tolerance, RTP can be an appealing option. For the general public, that wants to reap the benefits of lower electricity rates when they shift their appliances and more importantly electric vehicles, Time of the Use is an appealing option. Time of Use will also become crucial as electric vehicle adoption continues to increase. As estimated in Appendix H, charging an electric vehicle at home will result in an average 61.2% increase to the average monthly MA resident electricity consumption. And while for the owners of electric vehicles, the average fixed rate is not a bad deal and will still work out to be less expensive than fueling a gas vehicle, the 61.2% increase can be detrimental to the electric grid. As shown in Figure 5.1, the biggest increase in price is correlated to the biggest demand spike right around 5-7pm when most people return from traditional 9-5 jobs. It is a fair assumption that the owners of the electric vehicles, upon returning home, will plug in their vehicles to charge from the main power grid, making the 5-7pm spike much worse. Therefore, we urge the states to consider implementing a Time of Use option and especially encouraging that option for electric vehicle owners. Our group believes that the regulations that the states put forth regarding different electricity pricing plans over the next decade can either continue to overload the grid and drive the prices upwards, or create an excellent monetary incentive to pay more attention to their overall electricity consumption, while receiving benefits of the lower rates.

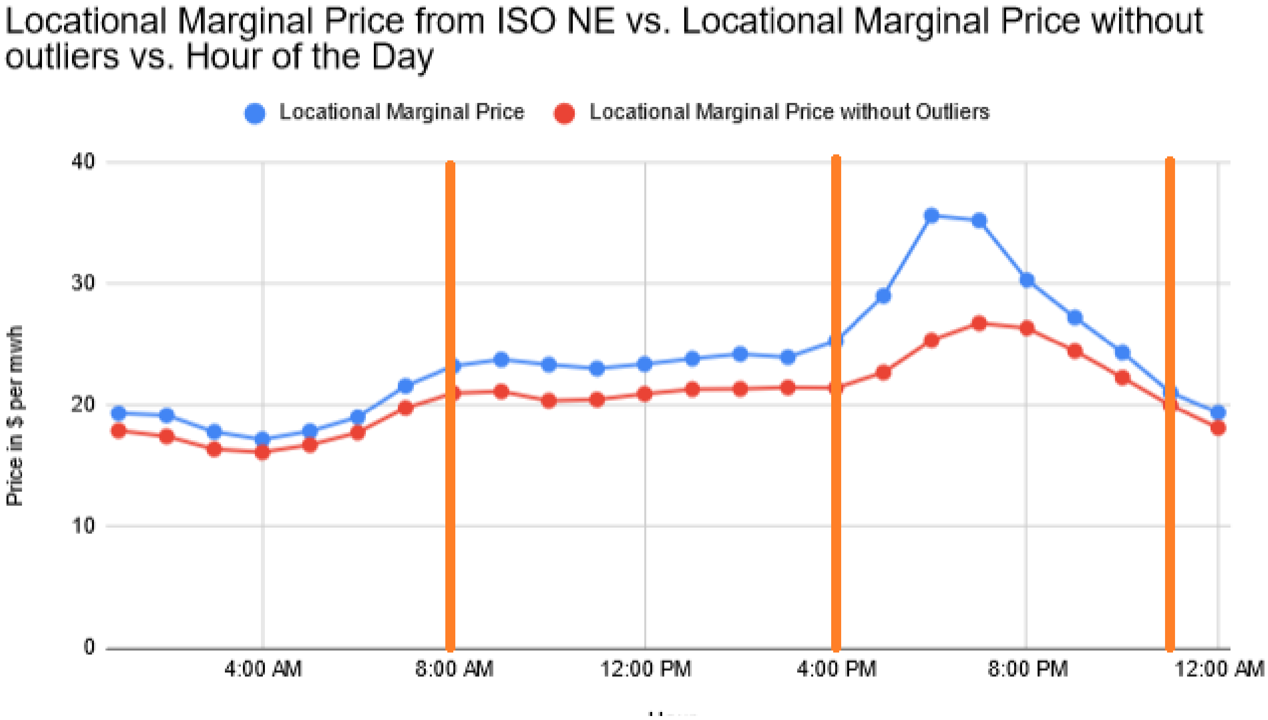

Figure 5.1 Locational Marginal Price from ISO NE vs. Locational Marginal Price without outliers vs. Hour of the Day with proposed time of use intervals.

Therefore, we encourage the states to consider a Time of Use option where residents get charged two or three different rates depending on the hours of the day. Figure 5.1 shows one potential rate scheme, with different prices at 10pm-8am, 8am-4pm and 4pm-10pm to encourage the reduction of the energy consumed during the 4pm-10pm period and shift the load to the 10pm-8am period. In terms of the price suggestion, we encourage the states to consider slightly raising the rates from 21.92 cents per kwh for the 4pm-10pm period or keeping it the same in order to make sure this plan is not punishing lower income residents, those that do not have the option or technological aptitude to shift and non-electric vehicles owners. Instead, we encourage the states to offer lower rates around 16-18 cents per kWh for the 10pm-4am period, in order to really incentivize shifting heavy appliances and electric vehicle load.

## 5.3 Behavioral Recommendations

Participants from our survey showed a notable willingness to experiment with RTP and other alternative pricing schemes as well as a willingness to shift their consumption to at least degree. Considering the comparative ease of use of Time of Use versus RTP, this could mean even smoother sailing towards the above mentioned suggestions for Time of Use plans. RTP would have to be micromanaged by the customer, in a way similar to that of “churning” credit cards by constantly keeping track of what times, programs, and purchases will maximize their savings. Yet for the customer who wants to save money, save the grid, and save the environment without going too mad, the aforementioned several-hour long segments of time for pricing in Time of Use offer a more directly understandable relationship between time and price while still encouraging—and in  cases mandating—load shifting. Furthermore, as prior research has indicated, complications in changing habits or otherwise introducing new behaviours often fails; to a large extent the extra money spent on simpler programs is simply seen as a convenience fee to be happily paid!

As with different spending patterns for cash vs. credit cards, delayed feedback for monthly billing inhibits direct feedback to improve consumer behavior. After all, without a readout of charges that is both immediate and comprehensive, a consumer will not really know to pay attention until well into any given cycle. A recommendation to improve mindfulness of both the cost to the consumer as well as their load on the grid is simple: weekly, digital updates on their electricity use via some sort of mobile phone application or even email. Further, to make the information more easily digestible, it ought to be broken out much like a typical electric bill. Specifically, it should contain heavy, quantitative data in smaller tables should the recipient wish to see them, but a focus on graphs and other visuals to immediately communicate both the usage and changes in customer behavior.

Beyond that, one of the most notable motivating factors for people was having the agency to know they are in charge of the changes in their own behaviour. Naturally, many people are motivated either by the hope to do good for the world and save energy or do well for themselves and save money. Our survey, prior research, and even interviews all emphasize the same common thread: the consumer needs to feel both like it was their own idea and interest that sparked the change, and their own power that caused it. These preferences affect both the education outreach as well as the process that should be used to implement the switch to RTP. To reach people, they will want it to feel like a pricing scheme they heard about themselves, such as through their electric bill. For the actual change in electricity delivery, a truly overwhelming preference for opt-in was shown, and really must be recommended for any dramatic change such as this since it will likely reduce the feeling of being "forced" into it. While examples we had been given of former attempts at load shifting often involved utility providers controlling the time of use to  extent, modern technology like IoT devices simultaneously automate the process as well as give consumers a sense of control over it, even if it does not become an active part of their lives.

Impressively, our survey showed both a decent understanding of RTP as well as a willingness to learn more about it before rejecting it and alternative pricing outright. This means we can recommend a slightly more quantitative approach to education outreach. People will likely respond better when they feel they have been fully informed of all the ins and outs of a new pricing scheme. Similarly, because so many were willing to shift their usage of major appliances, that could be a particularly direct way of approaching the matter: explicitly stating the savings we have researched and calculated elsewhere in this paper. Along the same lines, with many being willing to do things such as install solar panels with either long term or even no financial payoff whatsoever, it is recommended to emphasize education towards how RTP, load shifting, and the like benefits the grid, the environment, and other such factors that are often also the motivation to be willing to take what is only on paper a loss like the solar panels for a less personal yet larger in overall scope benefit.

To accompany both the appeal to humanity and load shifting overall, as well as aid in making RTP or Time of Use more tangible as a time-based activity, we also recommend the utilization of public spaces for electricity use when possible. For example, using cafes or other productivity spaces for "away from office" work (especially as work from home may be extended indefinitely for some industries post-covid) or spending an evening in a library with children to do homework when electricity use on the grid is at its most strained, will take a significant load away from the grid. The better utilization of public spaces can both spawn a greater sense of community for the “solar panel minded” consumer. Just as well, it can provide both cost and energy use savings to both them and the grid itself, as these locations naturally often provide use of their electricity for free (with some other purchase) and the distribution of energy is less widespread when more people end up using the already high-capacity businesses. These businesses may also already have increased capacity through increased space and funding for solar panels, additional on-site generators, and other such special connections meant to ensure remaining open and operational during emergencies. Furthermore, consumers being out of the home for use of public spaces can have the additional byproduct of arriving home later for use of at-home electronics, another especially important facet in offsetting the worst peaks in the early evening—in particular as EVs become more common!

## 5.4 Smart Home Technology

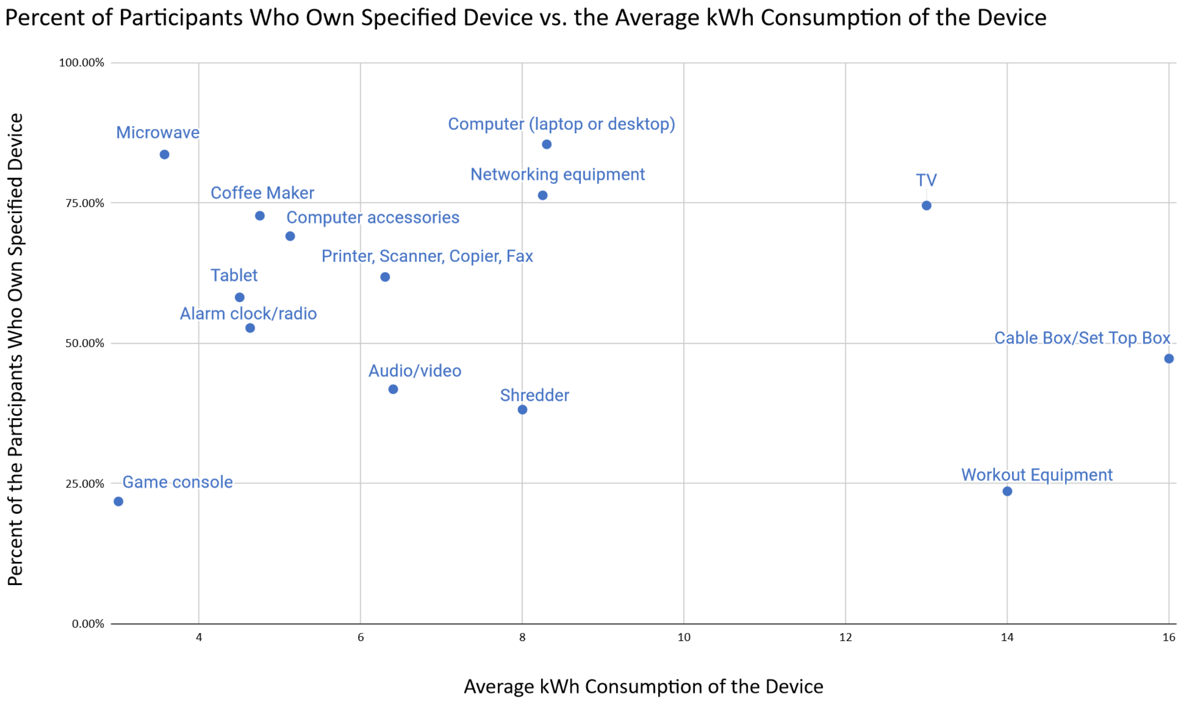

Figure 5.2. Percent of Participants Who Own Specified Device vs. Average kwh Consumption of the Device.

The surveyed participants were asked about fourteen specific idle devices. As shown in Figure 5.2 and estimates in our calculations in Chapter 4.5.1, the average participant is estimated to spend $191.10 on idle energy alone. In order to reduce the amount of idle energy consumption and draw more attention to the problem, the following section explores potential IoT devices as a solution.

Several smart home technologies exist and can also be used to assist with real time pricing and help limit electricity waste. An automatic timer plug will use a simple clock to switch on-and-off the flow of electricity to a device. Users may be able to install these devices to cut-off electricity to their power-hungry entertainment systems at times when they are asleep or not home. A motion-sensing power strip contains a simple circuit to sense the movement of people and provide electricity to devices when a person is present. A user could connect devices of their home office to a motion-sensing power strip - which would provide electricity to these devices when the user is present and turn-off the devices shortly after the user leaves.

Internet-connected smart home technology which can control power to these devices functions as an always-on microcomputer that draws electricity[12] and runs a local server. Given the amount of idle energy that these smart home devices can potentially consume, putting certain devices such as an alarm clock, microwave, or coffee maker on one of these Internet-connected devices for the purpose of limiting energy waste may be counterproductive and actually consume more energy than it would be saved. However, if a user puts multiple devices on a power-strip and then efficiently controls the electricity usage of all the devices on that strip with Internet-connected technology, they would potentially be able to reduce the amount of idle power consumed.

Many of the survey participants indicated that they would be interested in shifting the times that they ran high-energy-usage appliances.  Devices such as an air conditioner or electric vehicle charger, can be connected to a smart home plug or power strip that is configured to provide power at times when electricity pricing is known to be low (though users may want to confirm that the smart home plug they use can safely transfer the amount of power that these appliances need). Other appliances including washing machines and dishwashers usually can not be easily triggered by providing power (depending on the specific model). These appliances would likely require a more sophisticated version, such as a smart-dishwasher, for the average user to use technology to automatically turn-on the appliance.

By using more sophisticated smart home technology that connects to the Internet and runs its own analyses, a user could possibly program their devices to automatically monitor the pricing of electricity and use power at those times. Such a setup is not standardized with a product and would need to be constructed by a knowledgeable programmer. An automated setup would also require much caution as the usage of pricing would be controlled by code – not the customer paying for the electricity.

Smart home devices can be useful for both minimizing electricity waste and taking advantage of real time pricing. Internet-connected smart home devices also pose a great potential risk to the users – many of whom do not understand what the technology really is or its potential danger. Internet-connected circuit breakers pose an even greater risk, given the large amounts of electricity they control. Our first and most important recommendation for managing devices is to encourage users to understand the technology. Those who do not understand smart home technology, especially the elderly or those with less education, should take extra care to thoroughly research devices before they purchase and install them. A simple way to stay protected from the dangers of smart home devices is to limit their usage whenever possible. Users should only install a device if they truly believe it will be beneficial. As a general

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[12] The amount of electricity that each smart home device draws, varies extremely between device manufacturers. Our group assumed that at a minimum, it would consume as much power as a Raspberry Pi which draws 144 wh in a day which is 51.1 kwh.

rule-of-thumb it is recommended that they install less-complicated devices to minimize security events. For example, a timer is far less likely to break or cause harm than an Internet-connected plug. Unless they are familiar with the technology and comfortable with computers, users should be discouraged from using Internet-connected or micro-computer technology to control their electricity. If users do install micro-computer IoT technology, they should configure the devices to limit the amount of data that is collected. Users should also make a point to constantly look for updates to their device – security updates can be easily missed and not all manufacturers send notifications for new updates. Users should also get rid of their IoT device if the manufacturer goes out of business or otherwise stops providing updates for their device. IoT devices are accessible over the Internet and the authentication system should be as secure as possible to prevent unauthorized use. The authentication system should be secured using a unique password and multiple forms of authentication if possible.

At the time of conducting this research in September 2020-March 2021, the IoT products we recommend below were considered by our group to be good potential options in terms of cost, security, and ease of use. However, given how rapidly changing the security landscape is for IoT devices, the recommendations that follow might not be best in a few months or years. Use the examples of specific products as guidelines and please conduct your own research on the modern reviews and suggestions for any IoT device. The BN-LINK 7 Day Heavy Duty Digital Programmable Timer is a well-rated timer that can be used to turn the flow of electricity on or off at specific times. The motion of a person can be detected by the Tricklestar 7 Outlet Advanced PowerStrip which then provides electricity to the connected outlets as specified by the user. The Gosund Mini Wifi Outlet Smart Plug and the Smart Power Strip are Internet-connected devices which have been found to be relatively secure.

## 5.5 Future Data Collection and Survey Improvement

Our team has future recommendations for IQPs, MQPs or other levels of study trying to repeat or expand on this research. For making more robust quantitative analysis precise numerical data is required. This means instead of asking questions like their age range we would ask their age or if we wanted more precision their date of birth as this allows us to calculate age down to the day. This also means if we wanted to perform quantitative analysis on levels of education we should ask for years of education and not degree of education. This is because we would have to estimate years of education from degree of education. If a range is given as an answer we would need to know the distribution of that range or we would have to make assumptions about how the range is distributed. (An example of where we did this was asking fall, winter, spring, and summer electricity spending and not just average monthly spending or just a range of spending.) Error and variance propagation is important in testing claims based on the data.

Other recommendations we have for collecting data is making sure selectable response options cannot have contradicting interpretations. For example “I have no expectation of ‘x ‘.” could mean “I expect not ‘x’” or “I have no expectations one way or another”.

# 6. Conclusion

Despite barriers imposed by COVID-19 and the relatively small sample size of our survey, our results are still promising in showing interest and openness to alternative electricity pricing schemes such as RTP or TOU. Our group believes there is a need to re-evaluate how people consume electricity, encourage electricity consumption reduction, switch to more renewable sources and keep in mind the constraints on the grid. Given how receptive our survey participants are to alternative electricity pricing methods in order to save money, reduce their environmental impact and to help the grid, our group is optimistic about alternative pricing methods that encourage lower electricity consumption and encourages time of use programs that shift load heavy devices to off peak hours such as between 11pm and 6am using smart home technologies. Given that California is pioneering environmental initiatives such as rolling out time of use programs and banning gas vehicle purchases by 2035, it is our expectation that MA and other states will follow suit, especially given that on January 5th, Governor Baker of Massachusetts joined California's initiative to ban sales of new gas cars by 2035 as well it would not be surprising if the state also started to re-evaluate their electricity policies given that MA as of 2020 stands as the 44th highest average electricity usage state and 3rd highest average rate in terms of electricity ("Electricity Rates in Massachusetts").

However, given the price spikes in Real Time LMP rates, it still largely remains a complicated and risky option to recommend to an average resident. As part of our project, we had the pleasure of speaking with Barbara Kates Garnick, Professor of Practice at Tufts and she was quick to point out during our initial conversation that discussion around RTP is complicated, especially when it comes to thinking about extending the option to the consumers. Specifically, she was concerned with points like those represented in Figure 4.17 where the price is 250 $ per mwh. When Griddy, one of the companies doing RTP in Texas, advertises their program, they highlight the low and even negative electricity prices, but fail to warn consumers about those price spikes. During the initial phase of our research in September 2020 we referenced several incidents that Griddy experienced during heat waves of the summer of 2019. Griddy has received several warnings about their failure to properly educate their consumers about the pitfalls of wholesale prices. More information can be found in Appendix B. As we got closer to the conclusion of the project, Texas experienced unprecedented electricity problems in February of 2021 due to the winter storms. In March, 2021 our group found out that the Texas Attorney General sued Griddy, claiming they misled customers. "Texas Attorney General Ken Paxton is suing Griddy, saying the electricity provider passed along massive increases during winter storms, leaving customers to face up to $5,000 in power bills. Paxton's lawsuit says Griddy deceived customers when it promised low "wholesale" energy prices" (Chappell, 2019). The state has received more than 400 complaints about Griddy in less than two weeks. One woman in particular was charged $4,677 for one week of electricity for an 800 square foot apartment (Chappell, 2019). The lawsuit also cites Better Business Bureau alert from 2019, which "said

Griddy should not promise wholesale prices to consumers because it doesn't directly own or control a facility that primarily sells to retailers" (Chappell, 2019). Griddy's is an extreme example of how RTP can hurt customers. There are other programs, in Illinois specifically, where RTP has worked well, but mostly due to strict supervision from the state. Griddy's continuous problems with customers and the law is largely due to the unregulated Texas electricity market. But in the end Texas winter storms of 2021 and Griddy's largely unregulated existence only serves to highlight that privatization of electricity is a dangerous path to be on, especially if the prices are not capped. Barbara Kates Garnick was especially aware of pitfalls such as failure to properly inform the consumer, and told us early in the project, if we were to make any recommendation regarding RTP and the general public, we had to be careful.

Our group proposes an analogy between RTP and stock trading or credit card rotation. Residents that have a tolerance for risk that do invest in individual stocks can benefit from enrolling into RTP, doing their research and carefully monitoring price spikes and drops in order to benefit financially. Those that have lower risk tolerance or lack the desire to continuously monitor price fluctuations, but still want to derive the financial benefits are like individuals investing in mutual funds and those individuals can derive the biggest benefit from participation in TOU. In that scheme, individuals participation in mutual funds still are a part of the system and derive the long term benefit, less than the people actively monitoring the electricity prices/stocks, but with a greater peace of mind.

# Appendix A. Types of Electricity Price Models

The definitions are established by Schneider and Sunstein on page 3 (Schneider & Sunstein, 2016, p.3)

1. **Fixed Price (FP):** The electricity price is constant over all hours in the month, for a fixed period of time. It may be reassessed, for instance, every three months or every six months, to allow for seasonal and long-term changes in energy costs. An example customer on a fixed price could pay $.08 / kWh for the energy portion of all energy consumed in a given month.
2. **Time-of-Use Price (TOU):** The electricity price varies according to a set daily schedule. An example customer on a TOU rate could pay $.06 / kWh during off-peak hours, and $.15 / kWh during peak hours, for instance set as 3 p.m. to 9 p.m. on weekdays.
3. **Critical-Peak Price (CPP):** The electricity price increases during declared critical-peak hours, decided by the utility with a required notice period, e.g. 6 hours or the previous business day. An example customer on a CPP rate could pay $.07 / kWh during off-peak hours, and $.25 / kWh during the declared critical-peak hours.
4. **Time-of-Use with Critical Peaks (TOU + CPP):** This rate has the features of both TOU and CPP rates. For example, a customer could pay $.06 / kWh during off-peak hours, $.15 / kWh during scheduled peak hours, and $.25 / kWh during the declared critical-peak hours.
5. **Real-Time Price (RTP):** This rate tracks the wholesale spot price of electricity for each hour in which electricity is consumed. For example, a customer could pay $.038 / kWh from 1 p.m. - 2 p.m. on Tuesday, $.042 / kWh from 2 p.m. - 3 p.m., and $.095 / kWh from 4 p.m - 5 p.m.

TOU, CPP, TOU + CPP and RTP pricing models are all forms of time varying prices (TVPs) and several studies refer to them by this umbrella term. The following paper however will be examinining RTP models specifically.

The models listed above are applicable to the energy charges, but do not include the fees that the consumers are charged for the distribution of electricity. Most electricity companies will charge their consumers fees on a kW basis to offset the costs of delivering electricity to the consumers. A lot of the fees the customers are charged in the United States depend on the state that they live in. An example of of the fees that Massachusetts residents might be charged include: Distribution Charge, Transmission Charge, Renewable Energy Charge and more. A customer can find out more about their charges by going to their electricity provider, such as Eversource (“Understanding My Electric Bill”) or National Grid (“Basic Bill”).

# Appendix B. Detailed research about existing real time pricing or time of use models

Griddy in Texas

Griddy will arguably be the most interesting company on this list. Griddy is a company in Houston, Texas that operates exclusively under the RTP model. Griddy provides a lot of FAQ and press materials explaining their pricing model and the business model in detail. There are a lot of lessons to be learned from Griddy's success and failures, which we will examine more closely.

Griddy works on a subscription model in which users pay $9.99 a month and have access to real time prices (Griddy FAQ), plus the delivery fees required by the state of texas and a hidden fee which we will cover below. According to Griddy's calculations, that $9.99 fee is still low enough to make the program beneficial for the consumers, even those that do not have solar panels or batteries to store excess electricity (Griddy FAQ).

First, an item worth pointing out is that unlike other electricity companies, Griddy works based on the "pay-as-you-go-billing" which has inconvenienced and angered their consumers on multiple occasions. To open an account with Griddy, a customer has to charge their account with $49. When their account reaches below $25, the account will be automatically recharged using a customized amount from $49 to $500 that can be set by the customer. Pay as you go billing is not inherently good or bad, however many lower income members of the program mentioned that their accounts were wiped during the heat of August 2019 when the electricity prices were at an all time high. For those of the low income,  did not have enough money in the account to begin with but were charged several hundred dollars if they did not have a good home automation system set up. This also means that customers weren't eligible upfront for COVID-19 Electricity Relief Programs in 2020, when many consumers were staying in their homes more than usual and running their A/C. Although Griddy does offer one, a customer has to sign up and be approved for the program (Griddy FAQ). While they are waiting to be approved for the program, they will still be charged the usual rates. The benefit of the pay at the end of the month programs like National Grid or Eversource is that consumers can get in touch with the company and request assistance on their bill so their account cannot be charged at any time. This is one good lesson to learn, and it will be our recommendation for utility companies using RTP to collect the data during the month, but charge at the end.

In terms of the monthly bill that their consumers can expect to see, Griddy charges for wholesale electricity, delivery charges, membership fee, taxes and merchants services fee, which is the most surprising. Merchant services is the fee Griddy charges the consumer for using credit or debit cards. According to Griddy, they charge up to 2.5% of the bill plus $0.25 per transaction (Griddy FAQ). Most electric companies absorb the cost of credit card fees or give their users an option to pay via a check, like Eversource. Griddy does mention this fee in their policy in the fine print, however doesn't advertise this fee. Depending on the cost of the consumer bill, this can charge the cost-benefit analysis since in addition to the membership fee, consumers will have to pay an additional 2.5% percent of the whole bill.

The existence of Griddy and their wide customer base signifies a shift in consumers' energy needs and it is good to have competition on the market. However, the biggest takeaway to learn from Griddy is the importance of consumer education, since RTP model is only beneficial to the consumers if they take proper steps to avoid consuming electricity at peak prices, and are aware of the membership fees and hidden merchants fees. As we will cover in more detail in Section 2.4, RTP model comes with risks and if a utility or a company doesn't emphasize those risks they can end up with a dissatisfied consumer base.

### Hourly Pricing in Illinois

Another interesting state to examine for their use of RTP rates is Illinois, which is the only state we have been able to find that requires RTP as an option. Residents in Illinois have the option to pay for their electricity based on the RTP rates, as mandated by the Public Utilities Act passed by the Illinois General Assembly. While there are no standalone RTP companies, there are two programs Hourly Pricing for ComEd customers and Power Smart Pricing for Ameren customers that offer RTP rate (Jones, 2019).

Illinois Commerce Commision which oversees the implementation and compliance with the Public Utilities act also mandates that the utilities file annual reports showing how their real time pricing programs performed. In 2018, "Next to ComEd's standard fixed rate, Hourly Pricing participants saved an average of 10.4 percent on their supply, or $75 on average, for a combined total of $1,947,768. And compared to Ameren's standard fixed rate, Power Smart Pricing participants saved an average of 7.9 percent on their supply, or $58.10 on average, for a combined total of $681,971. Looking at the last four years, Hourly Pricing and Power Smart Pricing participants have respectively saved 15 percent and 10 percent on the supply portion of their bills" (Jones, 2019). These are the averages for both, people who implemented smart home technology and monitored their prices and those who did not. "Of 5,029 Hourly Pricing customers surveyed in 2018, 40 percent said that they do not check prices. And of 2,469 Power Smart Pricing customers, 55 percent said that they don't check either" (Jones, 2019). This also implies that the customers who did not check their rates have even more potential for savings if they monitored rates more actively, preferable through the use of a smart home system. It is also important to note that not all of the savings resulted from the RTP model alone. On average, customers in both programs reduced their annual electricity use by 732 kwH which contributed to their savings. Both of these findings influence our set of recommendations and our approach in the methodology.

Lastly, an important element to this conversation are electric vehicle owners. In 2018, there were 2,208 self reported electric vehicle owners (a 58% increase from previous year) and CUB found that customers under the hourly pricing model could save 52-59% on their energy costs (Jones, 2019).

### Time of Use Rate in California

California is an example of a state that began transitioning to Time of Use rates. Over the years, California has tested "over 300 time varying rates in 62 pilots" and has determined that consumers can understand and respond to those rates" (Trabish, 2018). In 2015, the California Public Utilities Commission (CPUC) ordered the state's three investor-owned utilities (IOUs) to transition to default rates by 2019, requiring customers pay TOU rates unless they opt out" (Trabish, 2018). While the order mandates time of use pricing, it is not the same as real time pricing. TOU pricing in California is designed to shift the consumer's peak usage away from high priced time periods by reflecting the peak demand in the TOU, but it will not be completely reflective of real time prices. However, the hope is that real time pricing will be the next step. In November 2018, a petition was filed by several energy players to consider allowing optional residential real time pricing and many residents have indicated interest in RTP models, especially those with electric vehicles (Trabish, 2018).

### Real Time Pricing in Massachusetts

Unfortunately there is no law in Massachusetts requiring the suppliers to provide access to RTP and according to our research there are no companies offering RTP.

In 2013, Eversource conducted a study in Massachusetts with dynamic pricing. They found that although the interest was high, it was hard to enroll customers in the program. Out of 53,000 customers contacted, only 1,549 were enrolled at the end of 2013 (Investigation into Grid Modernization). In general, during 2015's investigation into grid modernization in New Hampshire court, Eversource claimed that they do not believe smart meters will help grid modernization and that the costs of the installing the meters will far outweigh the benefit so it is not surprising that TOU adoption by Eversource is limited (Investigation into Grid Modernization). Although they do have a Time of Day Rate and Variable Peak Pricing rate in Connecticut (Time of Use Pricing 7) (Variable Peak Pricing FAQ), they do not have any in Massachusetts.

Notably, National Grid launched the first TOU pilot program in 2015 with 15,000 residents in Worcester, Massachusetts using smart meters called "Smart Energy Solutions". Although 15,000 residents were offered to join, everyone could opt out. Ed White, the vice president of customer strategy and environment noted that he believes more people opted to sign on due to the rising electricity rates (Corcoran, 2015). This program was not a RTP model, but rather a "smart rewards pricing plan that gives customers lower rates than the current basic service rate for 335 days/year and offers savings for shifting energy-intensive activities to 8:00 PM-8:00 AM" (*National Grid to pilot smart grid in Worcester)*. The other 30 days are expected to be peak days and the customers were encouraged to conserve their energy. Under the Smart Rewards plan, White estimated in 25015 that a household that uses 500 kwH per month could save $16 per month, or $192 yearly, however this does assume that the customers will change their consumption patterns (Newsham, 2015).

In September 2016, National Grid announced that they will be extending their program by two more years, and received approval from the Department of Public utilities to extend until December 2018. The decision to extend the timeline was driven by the increase in customer satisfaction and positive feedback. “In its first year, SES achieved a 98% retention rate, 72% customer satisfaction rate and helped customers save $1.25 million on their electricity bills. The programme was estimated to have allowed consumers lower power usage by 4% during peak periods in 2015” (Theron-Ord, 2016).

Unfortunately, the program is no longer available to Massachusetts residents.

# Appendix C. Detailed Calculations for Cost-Benefit Analysis of Solar

We used the information from Energy Sage, a great resource that helps individuals figure out their potential costs and take all of the different factors into the consideration to come up and a few other outside sources to come up with a sample cost-benefit analysis of solar to determine whether this is something we recommend. For the following analysis we will assume the resident lives in Massachusetts and their average monthly bill is **607 kwH ("Average Electric Bill", 2020).**

**Step 1: Figure out the average electricity use in dollars/month or kwH per month to determine the system size**

First, we need to figure out the size of the solar system. In order to do that we can either take the average monthly customer bill and divide by 21 cents, which is the average electricity rate in Massachusetts to estimate their kwH use per month or if we know the average monthly usage in kwH hours go to the next step ("True Cost of Solar for Massachusetts").

*(Optional) Average monthly electricity bill =* ***$127.47***
*(Optional) Average monthly energy consumption = average monthly electricity bill / 0.21 cents/kwH = 607 kwH/month.*

*kwH requirements for the system per year = average monthly kwH use * 12 = 607 kwH/month =* ***7,284 kwH/year.***

**Step 2: Figure out the size of the system needed**

Next, we need to know the production ratio, which stands for how much sun the solar panels will get in a given set up and state. This number varies greatly depending on the customer location and orientation of the roof, however for the purposes of this calculation we will assume the production ratio is 1.15 which is the average for MA customers ("True Cost of Solar for Massachusetts").

*System size needed = annual electricity use / 1.15 = 7,284 kwH / 1.15 =* ***6,334 watts.***

**Step 3: Figure out the net cost to install the system**

Average price per watt for solar in Massachusetts in 2020 for homeowners is 3.22 cents/watt ("True Cost of Solar for Massachusetts").

*Net cost = System size needed * cost per watt = 6,334 watts x 3.22 =* ***$20,395***

**Step 4: Subtract federal tax credits**

Next, it is important to consider the federal and state tax credits as incentives given to the customers. In the United States, between 2016-2019 federal solar tax credit stood at 30% of the cost of the system. In 2020, the tax dropped down to 26%. In 2021 the tax is expected to drop to 22% and expected to go away completely for residential customers in 2022 and drop to 10% for commercial energy systems ("Investment tax credit for solar power"). For our purposes we will take the 26% tax credit as it stands in 2020. If the credit does decrease significantly this will affect the cost-benefit analysis for consumers, however it is also possible that the government will step in and raise tha tax.

*Federal tax incentive = total system cost * 0.26 =* ***$20,395 * 0.26 = $5,303***
*Net cost after federal incentive = $20,395 - $5,303 = $15,092*

**Step 5: Consider Solar Panel Life and Degradation**

It is also important to consider solar panel degradation. Average solar panel has a warranty of 20 to 30 years. The degradation numbers vary greatly, from 0.3% to 0.8% per year depending on the quality of the solar panels (Richardson, 2020). The most comprehensive study found an average 0.5% rate and 0.8% median rate degradation (Jordan, 2012). We will use 0.8% per year degradation for our calculations (Austin, 2016). Note that because 0.8% is a relatively small degradation rate, most basic calculations don't factor it in, however we wanted to be as precise as possible. Below is the table that shows the output numbers with the degradation rate factored in.

| Year | % Remaining of the Original Capacity | Yearly Output (kWh) | Sum of Output | Yearly Bill ($) | Sum of Bills ($) |
|---|---|---|---|---|---|
| 0 | 100 | 7284 | 7,284.00 | $1,529.64 | $1,529.64 |
| 1 | 99.2 | 7225.7 | 14,509.73 | $1,517.40 | $3,047.04 |
| 2 | 98.4 | 7167.5 | 21,677.18 | $1,505.17 | $4,552.21 |
| 3 | 97.6 | 7109.2 | 28,786.37 | $1,492.93 | $6,045.14 |
| 4 | 96.8 | 7050.9 | 35,837.28 | $1,480.69 | $7,525.83 |
| 5 | 96 | 6992.6 | 42,829.92 | $1,468.45 | $8,994.28 |
| 6 | 95.2 | 6934.4 | 49,764.29 | $1,456.22 | $10,450.50 |
| 7 | 94.4 | 6876.1 | 56,640.38 | $1,443.98 | $11,894.48 |
| 8 | 93.6 | 6817.8 | 63,458.21 | $1,431.74 | $13,326.22 |
| 9 | 92.8 | 6759.6 | **70,217.76** | $1,419.51 | **$14,745.73** |
| 10 | 92 | 6701.3 | 76,919.04 | $1,407.27 | $16,153.00 |
| 11 | 91.2 | 6643 | 83,562.05 | $1,395.03 | $17,548.03 |

| | | | | | |
|---:|---:|---:|---:|---:|---:|
| 12 | 90.4 | 6584.7 | 90,146.78 | $1,382.79 | $18,930.82 |
| 13 | 89.6 | 6526.5 | 96,673.25 | $1,370.56 | $20,301.38 |
| 14 | 88.8 | 6468.2 | 103,141.44 | $1,358.32 | $21,659.70 |
| 15 | 88 | 6409.9 | 109,551.36 | $1,346.08 | $23,005.79 |
| 16 | 87.2 | 6351.6 | 115,903.01 | $1,333.85 | $24,339.63 |
| 17 | 86.4 | 6293.4 | 122,196.38 | $1,321.61 | $25,661.24 |
| 18 | 85.6 | 6235.1 | 128,431.49 | $1,309.37 | $26,970.61 |
| 19 | 84.8 | 6176.8 | 134,608.32 | $1,297.13 | $28,267.75 |
| 20 | 84 | 6118.6 | 140,726.88 | $1,284.90 | $29,552.64 |
| 21 | 83.2 | 6060.3 | 146,787.17 | $1,272.66 | $30,825.31 |
| 22 | 82.4 | 6002 | 152,789.18 | $1,260.42 | $32,085.73 |
| 23 | 81.6 | 5943.7 | 158,732.93 | $1,248.19 | $33,333.91 |
| 24 | 80.8 | 5885.5 | **164,618.40** | $1,235.95 | **$34,569.86** |
| 25 | 80 | 5827.2 | 170,445.60 | $1,223.71 | $35,793.58 |
| 26 | 79.2 | 5768.9 | 176,214.53 | $1,211.47 | $37,005.05 |
| 27 | 78.4 | 5710.7 | 181,925.18 | $1,199.24 | $38,204.29 |
| 28 | 77.6 | 5652.4 | 187,577.57 | $1,187.00 | $39,391.29 |
| 29 | 76.8 | 5594.1 | 193,171.68 | $1,174.76 | $40,566.05 |
| 30 | 76 | 5535.8 | 198,707.52 | $1,162.53 | $41,728.58 |

**Step 6: Subtract state SREC/Smart Home Credits**

There are also a few local and state tax incentives for solar. These incentives are more confusing, hence they are often left out of the calculations, however they can significantly add up over time. Massachusetts offers two programs, SREC (I) and Smart Home Program (Thoubboron, 2020).

In 2016, people installing solar in Massachusetts were eligible for the Solar Renewable Energy Certifications (SREC) program. The program was popular and reached a capacity in 2016. Given the popularity of the program and state's interest in supporting renewable energy, in 2018 MA began offering the SMART program. "With SMART, solar energy system owners receive a payment from the state for their solar production at a fixed rate per kilowatt-hour (kWh) of solar energy produced. The compensation is calculated by subtracting the value of the energy (determined by electricity rates) from the total incentive amount" (Thoubboron, 2020).

How much you'll earn through the SMART program depends on your utility company, the block you're eligible for, how much solar energy you produce, and the type and size of your solar panel installation. You can view the full block structure in the Energy Sage article, however we are interested in the first block. Most of the residential solar projects are less than 25 kW. The SMART Home program rewards residents for 10 years, based on a pre-set rate 0.34 cents/kwH for Eversource and 0.31 cents/kwH for National Grid (Thoubboron, 2020).

Assuming that the owner of the panels is the customer of Eversource and has a 6,333 kWh solar system that produces 7,284 kwH/year, they will be eligible for 0.31 cents/kwH. At the start of the program, Eversource determines the value of energy is 0.20 cents/kwH. So the calculation is as follows:

*Added incentive rate = (baseline incentive rate - value the energy) = 0.34 - 0.20 = 0.14 cents*
*Yearly savings from Smart Home = added incentive rate * solar system output per year*
*0.14 ** 7,284 *= $1,019.8 saved per year*

*10 Year Savings from Smart Home adjusted with production numbers from the 0.8% degradation = added incentive rate * solar system output per 10 years*
*10 Year Savings = 0.14 * 70,217.8 =* ***$9,830.5 saved in 10 years.***

Because of the complex math and variables, most solar panels providers round and include a $1000/year state incentive in their solar quote. It is worth noting that there are also other bonuses offered by the SMART program, such as adding solar canopy, using energy storage, or building a system on a landfill (Thoubboron, 2020).

**Step 7: Subtract Residential Renewable Energy Income Tax Credit**

Massachusetts also allows a one time credit of 15%, up to $1000 against the state income tax credit against the net cost (including installation cost) of renewable energy systems (“Residential Renewable Energy Income Tax Credit”, 2020) (“Massachusetts’ solar rebates and incentives”).

*Residential Renewable Energy Income Tax Credit = Net Cost * 0.15 = Total cost - federal cost * 0.15*
***$20,395 - $5,303 = 15,092 * 0.15 = 2,263.8 > $1,000 → eligible for $1,000***

**Step 8: Consider monthly savings**

Assuming that a customer chooses a system that fully covers their electricity needs ( do choose a system that covers 80% due to roof and cost limitations), we also have to consider yearly savings.
*Money saved in the first year = previous monthly bills * 12 month = $127.47 * 12 = $1,529.6*
*Money saved in the first 10 years adjusted with 0.8% degradation rate = $14,745.73*

*Money saved during the 25 years adjusted with 0.8% degradation rate = $34,569.86*

**Step 9: Total 10 year savings**

*Total system cost - federal incentive - state incentive - residential renewable energy income tax credit - money saved on the electricity bills in 10 years*

***$20,395 - $5,303 - $9,830.5 - $1,000 - $14,745.73 = $10,484.2 saved***

**Step 10: Total 25 year savings**

For a complete analysis it is also important to analyze the total savings over the lifetime of the solar panels. The lifetime of the solar panels varies, most newer solar panels have a warranty of about 25 years, which is the number we will use for our calculation.

After the 10 year period mark, a consumer will no longer be eligible for the SREC, however they will still continue to receive the benefits of the energy that they are not paying for.

*Total system cost - federal incentive - state incentive - residential renewable energy income tax credit - money saved on the electricity bills in 25 years*

***$20,395 - $5,303 - $9,830.5 - $1,000 - $34,569.86 = $30,308.36 saved***

**Step 11: Savings in the lifespan of the battery**

After 25 years, as can be seen in the table, the battery reaches 80% of the original capacity which is the point that manufacturers consider when providing a warranty. With laptop batteries, phone batteries, electric car batteries, and solar panels 80% is used to define the end of warranty and “end of life”. 80% is the point where manufacturers believe the capacity will start affecting how you use the product. However, this applies much more to the phone, laptop or even car batteries, however when it comes to expense products such as solar panels or home storage battery solutions it is important to acknowledge that it is unlikely that a consumer will get rid of their panels at 80% and they don’t have any reason to do so. So in reality while we are conducting our analysis for the 10 and 25 year mark, the solar panels will likely last much longer and continue giving a greater return on investment.

**Step 12: Increased property value**

Another factor worth considering is that properties with solar panels see about a 3%-4% increase in property value (“Solar panels increase property values”, 2020), which is especially significant for Massachusetts. The median home price in Massachusetts is around $352,700 (the number varies significantly depending on the region of MA). 3% from the median home value is **$10,581 which is no small number.**

**Step 13: Massachusetts Solar Sales and Solar Property Tax Exemptions**

There are also two other major tax exemptions for solar homeowners in MA: the sales tax and the property tax incentives. **Solar sales tax** exempts customers from the sales tax on the cost of solar installation. **Solar property tax** exempts the homeowners from the added tax bill amount that they would have to pay if the value of their solar systems was added to the tax basis for their home (Zientara, 2020). All this means is that solar adds value to your home, like discussed in step 12 on average between 3-4% and the exemption makes sure the owners don't pay extra taxes on that value. In Massachusetts, the owners are 100% exempt from the solar sales tax and are 100% exempt for 20 years from the solar property tax (Zientara, 2020).

### Step 14: Environmental Benefit

While it is hard to quantify what is the environmental benefit of solar, especially considering that more and more residents get part of their electricity generated from renewable sources already so not all of their electricity is coal powered. However, for the purposes of demonstrating a sample environmental benefit calculation, we will assume that a resident receives 100% coal powered non-renewable energy and switches to solar panels that are able to meet all of their demands.

There are a lot of varied numbers out there in terms of how much $CO_2$ consumers are able to save by installing solar. One estimate is that a 5 kW system, which will produce roughly 150,000 kWh of emission free electricity is able to save 103 metric tonnes of $CO_2$ ("Carbon offsets vs. rooftop solar", 2019). 103 metric tonnes is equivalent to 113.5 tons of $CO_2$ or 227,000 pounds of $CO_2$, which means that for every kW, residents can save around 45,400 pounds of $CO_2$. Other, more conservative estimates range from 30,000 pounds of $CO_2$ per kW to 35,000 pounds of $CO_2$ per kW. For our system, this means residents can save from 198,000 to 299,640 pounds of $CO_2$ over 25 years. This is a wide range and not a lot of studies have been done specifically looking into kWh and saved $CO_2$, so the numbers above are estimates. Nevertheless as the concern for the environment grows, the ability to save $CO_2$ will likely be a more important factor for the future residents.

# Appendix D. Detailed Calculations for Cost-Benefit Analysis of Lithium Ion Batteries

First, the report from 2020 which performed throughout analysis claimed that a lithium ion battery has a total cycle life of about 1,000 (Koethe et al., 2020, p.41) however we have not been able to find a source to back up that claim. The source referenced in the paper notes that nickel-cadmium batteries last for 1,000 cycles before self discharge starts interfering with performance, however makes no claim about the cycle life about lithium ion batteries (Koethe et. al., 2020, p.41). Modeling the number of cycles that a battery can last is a complicated process and the best resource we have been able to find conducted an entire study to attempt to model lithium ion battery degradation (Oudalov, 2016). They proposed the model shown in FIgure 7.1.

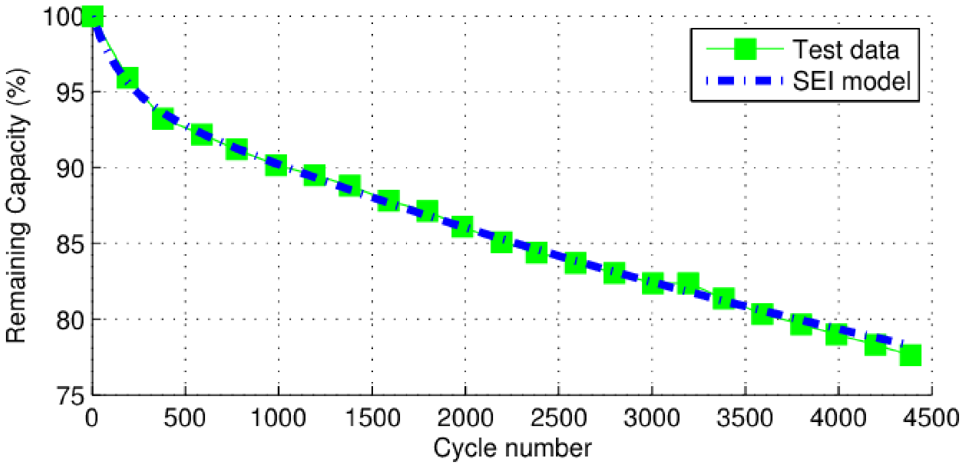


Figure 7.1. A proposed SEI model to model the cycle number of lithium ion battery vs. remaining capacity (Oudalov, 2016).

Using 80% as the marker, since “battery end of life is typically defined as the point at which the battery only provides 80% of its rated maximum capacity” (Oudalov, 2016), we can see that an estimated number of cycles that a lithium ion battery can withstand is closer to 3500. Using the figure from above, we came up with an average equation that models the loss of the battery capacity in terms of cycle number.

The second work, an IQP from 2017, titled “Equalizing Energy Use in Homes” performed an analysis on the Tesla Wall battery to find out whether it was economical (Xu et. al, 2017, p. 34). Their model was simpler and they made several assumptions, which we will have to examine closely.

One of them was a claim that the battery can hold 1000-1500 cycles and referenced Tesla's Powerwall site. This was the hardest assumption to check and back up with evidence. The Tesla Powerwall site gives no indication that the number is correct and after thorough research, we believe the group used incorrect numbers from a third party site to come up with that number from a source which confused Tesla Powerwall and Tesla Powerpack. Powerpack which was designed as a backup power option functions similarly to Tesla Model S and model X battery, using nickel-cobalt-aluminum cathode and is expected to last for 1000-1500 cycles, for around 15 years. The Powerwall, which was designed as a daily cycling option, made from nickel-manganese-cobalt is meant to last for 5,000 cycles for 15 years. Powerwall was designed to complement the use with wind and solar energy (Shahan, 2015). Tesla does not specify whether this 5,000 cycles claim is made on 0 to 100% capacity charge and discharge, or it is based on 30-80%. Knowing that the heat, the lithium's ion's worst enemy and constant 0 to 100% cycle accelerates battery's life degradation, we will assume 30-80% cycling.

Their analysis also assumes that after 1500 cycles the battery is completely dead. While this might have been done to simplify their analysis, they did not provide enough information about the workings of a battery. "Battery end of life is typically defined as the point at which the battery only provides 80% of its rated maximum capacity" (Oudalov, 2016). So after a certain amount of cycles, the battery reaches the 80% of the maximum capacity and the equation could be built to reflect that. However, an equation could also be built using even less capacity, if we care about maximizing the cost benefit, the battery can still hold plenty of power even at 80%. In technical terms, the battery is no longer as efficient as it was, but in monetary terms this doesn't mean that an owner should throw out a battery just because it is at 80% capacity.

The group also did not make a distinction between Powerwall 1 vs. Powerwall 2. Powerwall 1 was unveiled in April 2015 and Powerwall 2 was introduced in October 2016. You can any longer purchase Powerwall 1, only Powerwall 2. Powerwall 1 originally had two options, a smaller unit of 7 kwH for $3,000 and a bigger unit of 10 kwH for $3,500 (Anderson, 2015). In reality, the $3,000 unit had actual usable energy of 6.4 kwH (Pyper, 2016).

Powerwall 2 originally cost $5,500 and now costs $6,500. The group in 2017 used $5,500, but in our analysis we will use the most up to date number $6,500. They also assumed the installation cost is $0, which can be understandable and accepted to simplify the analysis, but it is important to note that Tesla estimates that the installation would cost around $4,500 which is no small number. Depending on the state that you live in, there are different tax incentives which can be used to offset  of the cost so analysis could be performed for battery cost alone, battery cost + installation cost or battery cost + installation cost - tax incentives.

The group was also unclear about the battery capacity, in one place in the paper they claimed the battery efficiency is 13.5 kwH, but in another place and in their calculations they assumed it was 14 kwH. While the difference is fairly small, we still think it is important to use the most accurate number. According to Tesla's powerwall specification sheet, the battery has a total energy of 14 kwH and usable energy of 13.5 kwH so we will use 13.5 kwH as our measurement ("Powerwall Specification Sheet").

The group also stated that Tesla claims 92.5% efficiency, and although it is possible that Tesla has updated its numbers since, the current round trip efficiency according to Tesla is 90% ("Powerwall"). Several other sources on the Web also use 92.5% efficiency as the number, however we will go with 90% as Tesla's official specification sheet claims.

of the other assumptions they made were sound, such as the fact that the battery will charge and discharge at lowest and highest costs each day. For the purposes of their work, they were not considering storing excess solar, but only buying from the grid when the prices are lowest and selling when they are highest. For the purposes of our work, we will be assuming that we store excess electricity (so we "buy" for the cost of "0") and sell at an average highest price. Yes, it is not possible to predict ahead of time exactly when the prices will be highest, but there is good data that would allow the user to make an approximate estimate.

The biggest problem with calculations for the Tesla Powerwall however is that Tesla's claim about the battery's ability to last 5,000 cycles before it reaches 80% of the original capacity is contradicted by other research regarding lithium ion battery degradation and our calculations in the previous section.

As the capacity of the battery is dependent on the cycle number an analysis of the cost effectiveness of the battery should take into account the number of cycles or battery percentage a user will keep the battery before throwing it out. Previous analysis used:

*Capacity* (high price * efficiency - low price) - ( Price of battery / cycles covered under warranty)*

*Capacity* (high price * 0.9 - 0) - ( 6500 / 5000)*

Our analysis used:

*Initial capacity* Fraction of retained capacity at time 'a' * (high price * efficiency - low price) - ( Price of battery /* $a_{\text{cycles kept}}$*).*

The graph above is a model of the battery capacity as it relates to cycle numbers. The relationship is roughly linear past cycle number 500, so the model can be expanded to account for days past the 4500 cycles on the graph. The model of the graph is:

S(x) = {1 - .00015x (0,500), .925 - .000057x (500,13737.5).

S(x) is the fraction of remaining capacity as compared to original capacity. This was created by fitting a line to the curve at the first section (0,500) and the second section (500,4000) where the slope of the second section was then calculated when 0 percent capacity was reached. The instantaneous decrease in battery capacity is

- d/dx S(x) = f(x) ={.00015x (0,500),.000057x (500,13737.5).

The mean total loss in battery capacity after ‘a’ days =

$(\int_0^a x * f(x)\, dx)/a$ this is just an application of calculus

Thus the mean battery capacity is 1 - $(\int_0^a x * f(x)\, dx)/a$

As we know f(x) we then have

$1 - [(\int_0^{500} x * f(x)\, dx) + (\int_{500}^a x * f(x)\, dx)]/a$if ‘a’ >500 and

$1 - [(\int_0^a x * f(x)\, dx)]/a$if ‘a’<500

We had to break up the integrand as this is a splice of functions.

$1 - [(\int_0^{500} x * .00015\, dx) + (\int_{500}^a x * .000057\, dx)]/a$ ‘a’ >500

$1 - [(\int_0^a x * f(x)\, dx)\ ]/a$’a’ < 500

This simplifies to the fraction.

$1 - [18.75 + .0000285(a^2 - 500^2)]/a$ ‘a’>500 and ‘a’<13,737.5

$1 - [.000075a]$ for ‘a’ < 500

Fractional capacity ‘a’ = $\text{Frac}_a$ =

$1 - [.000075a]$ a < 500

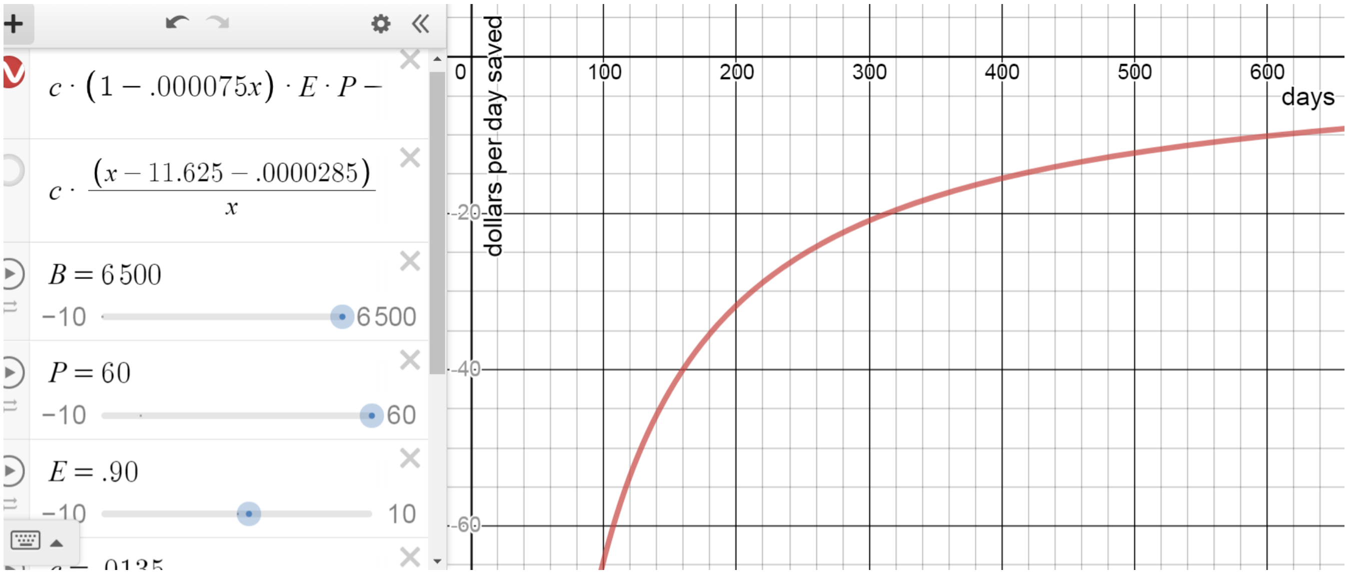
$1 - [11.625 + .0000285(a^2)]/a$ 500<a<13,737.5

This allowed us to determine how much money could be saved per cycle given the user will keep the battery for “a” cycles and is using the battery to store excess solar.

$C_{\text{initial capacity}}$ $\text{Frac}_a$ $P_{\text{high}}$ $e_{\text{efficiency}}$- ( $P_{\text{battery}}$ / $a_{\text{cycles kept}}$)
This becomes

$C_{\text{initial capacity}}$ $\{(1 - [.000075a]((0;500)),1 - [11.625 + .0000285(a^2)]/a\ ((500;13{,}737.5))\}$
$P_{\text{high}}$ $e_{\text{efficiency}}$- ( $P_{\text{battery}}$ / $a_t$)

Using this equation we came up with 2 graphs for the equation:



$c \cdot (1 - .000075x) \cdot E \cdot P -$

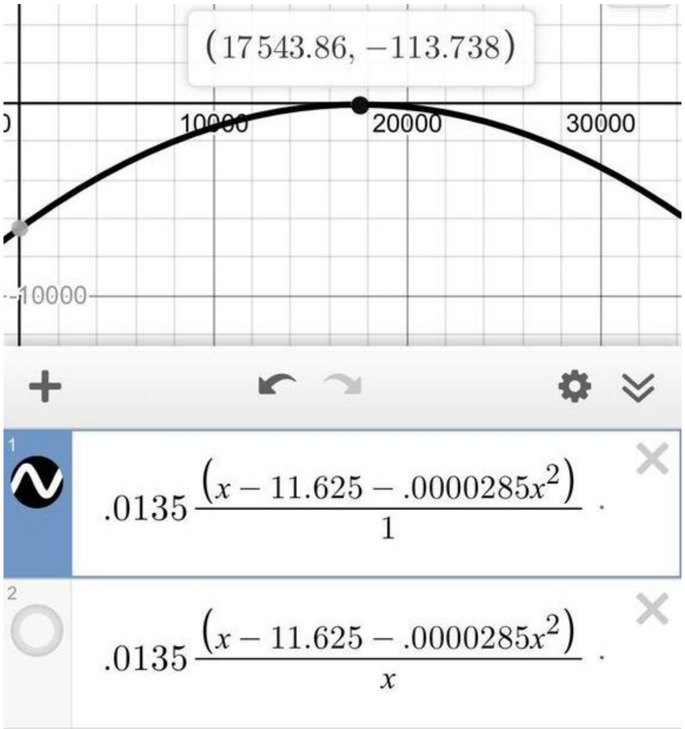
$c \cdot \frac{(x - 11.625 - .0000285)}{x}$

$B = 6500$

$P = 60$

$E = .90$

Figure 7.2. Graph representing how many days does a user have to keep a battery in order to make a certain amount of average dollars per day. This graph is valid only through the first 500 days.



$$.0135\frac{\left(x-11.625-.0000285x^{2}\right)}{1}$$

$$.0135\frac{\left(x-11.625-.0000285x^{2}\right)}{x}$$

Figure 7.3. Graph showing a lack of intersection point number of days that battery has been in use (x axis) and the total dollars saved (on the y-axis) vs.

As shown in Figure 7.3, the calculation does not break even. This graph is valid only on the interval of (500,17543.86]

We used total and not average in the second graph as the average passes -\$.01 the lack of intersection hard to see that way. Graphically it is apparent that this is a bad financial investment. The initial cost is so high that even if one did utilize the full lifetime of the battery they would still be in the red. The group also claimed that lithium ion loses about 10% of its charge in the first 24 hours of charging (Koethe & et al., 2020, p.41), however according to their own source lithium ion only loses about 5% after the first 24 hours and then 1-2% per month which can make a big difference in terms of the calculations (“What Does Elevated Self-Discharge Do?”, 2018).

# Appendix E. Definitions of Behavioral Considerations

Truncated table sourced from Hobman, et al. (2016)

| Behavioral Factor | Description |
|---|---|
| Aversion to complexity/Cognitive and choice overload | Tendency to adopt simpler decision rules (and therefore potentially make worse decisions/choices) as the information and stimuli in one's environment becomes more complex. |
| Trust as a decision heuristic | Tendency to use perceptions of trust as a decision-making 'heuristic' — i.e., a mental shortcut or rule-of-thumb to speed up information processing, problem-solving and decision-making in complex and cognitively demanding situations. |
| Status quo bias | Tendency to resist change and instead favour the status quo or 'default' setting, which oftentimes means not acting (i.e., inertia) or avoiding making a decision altogether. |
| Loss aversion | Tendency to focus more heavily on losses than on comparable gains, and to exert far greater effort in order to avoid a loss as compared to an equivalent-sized gain. |
| Risk aversion | Tendency to prefer certainty over risk, especially when the stakes are high — i.e., people are more willing to choose a certain or guaranteed gain as compared to gamble for an uncertain pay-out. While risk-taking behaviour is more likely in the context of losses, when the stakes are high, again, people are far less likely to take a gamble and will instead prefer a certain or guaranteed loss. |
| Time inconsistency and spatial and temporal discounting | Tendency to be short-sighted on nearby or immediate costs/benefits and farsighted on costs/benefits that are further away or in the future — i.e., people 'discount the future' and prefer smaller immediate rewards (e.g., $5 now) rather than larger future rewards (e.g., $100 next year). |

| | |
|---|---|
| Normative social influence | Tendency to follow the behaviour of others, make social comparisons, and adhere to social norms — i.e. people are heavily influenced by how others think, feel and act; they often care about performance, possessions and wellbeing *relative to other people*, rather than in absolute terms. |
| Perceived fairness/inequality | Tendency to be averse to inequalities and unjust outcomes, and to seek fairness in one’s transactions. |

| Truncated table sourced from Behavioral Economics Review (2014) | |
|---|---|
| Behavioral Factor | Description |
| Effective energy-saving behaviours depend on the degree of cognitive effort required. | Needing to take action or even the anticipation of action discount the reward of doing so in many consumers, with several choosing to not act on them. This leads to better outcomes with “opt-out” systems for desirable behaviours, as consumers rarely put in the effort to do so. |
| Improving the ease with which information is interpreted will drive conservation behaviours | Fluency--high speed, low resource demand, and high accuracy--more effectively calls a consumer to action. By making electricity consumption easy to read and especially through use of visuals, the mental complexity is decreased and consumers become more open to shifting behaviour. |
| The metrics presented to consumers matter in terms of successfully affecting behavioural change. | Not understanding the units used for electricity consumption likely makes changing behaviours on them more difficult. Units that more easily display an expected cost of running a vehicle or appliance are far more effective in both educating and changing behaviour in a consumer. |
| The way energy costs are framed has a large impact on consumer behaviour. | Putting energy costs, even if equivalent, into different contexts will dramatically shift a consumer’s behaviour. For electricity, savings per day would likely be too minimal to cause any change, but per week, month, or even year can. |

| | |
|---|---|
| | Similarly, framing “not saving” the money as “money you have lost” is more effective in instigating loss aversion. |
| Providing individualized and real-time feedback on electricity consumption is an effective way to nudge consumers towards conservation behaviours. | Providing the option for real-time feedback of energy usage is likely to be more impactful in reducing use than a monthly bill statement. These were especially helpful if the feedback was frequent over a long period of time, provided appliance-specific breakdowns, and presented it in a clear and appealing way. |
| Social benchmarking, when implemented correctly, provides a powerful means to nudge consumer behavior. | Energy conservation can be driven by comparing a consumer to the usage of others--and this becomes more effective the more local these “others” are to them. However, this is heavily influenced by pre-existing beliefs; a study found that while this method reduced energy consumption in “green” Democrats, it actually *increased* consumption in “non-green” Republicans. |
| Commitment devices are effective when it comes to keeping consumers on track towards changes in behavior. | By encouraging consumers to actively pledge to a commitment device, such as an agreement to recycle on regular intervals helps prevent procrastination and efforts falling short of intention to consume less energy. |
| Compliance with dynamic pricing models in order to manage peak demand is driven in part by actual and perceived differences in the financial incentives. | Increasing the ratio of prices between peak and off-peak hours helps shift loads and encourage changes in consumption behaviour by making the difference in cost more immediately obvious. Critical Peak Pricing was especially effective in shifting consumption at particularly high-use times. |

# Appendix F. Delforge, 2015 table summary

| **Table F.1. List of Devices That Consume the Most Idle Energy, according to Delforge 2015 study** | | | |
|---|---|---|---|
| Category | Device Name | Average idle power consumed (watts/year) | Pages from the Study |
| Home Equipment | Fishpond equipment | 220 | p.17, p.19 |
| Home Equipment | Fan (ceiling) | 110 | p.19 |
| Home Equipment | Halogen light fixture left 24/7 | 92 | p.30-36 |
| Home Equipment | Hot water recirculation pump | 70 | p.17, p.18, p.19, p.26 |
| Home Equipment | 24/7 lighting | 27 | p.17, p.18, p.19 |
| Home Equipment | Electric Workout Equipment (ex. Treadmill) | 14 | p.30-36 |
| Home Equipment | Furnace | 6.7 | p.20, p.26 |
| Home Equipment | Light motion sensor | 7 | p.30-36 |
| Home Equipment | Power strip/splitter | 5 | p.30-36 |
| Home Equipment | Irrigation system | 3.5 | p.18, p.19 |
| Home Equipment | Pool pump | 5 | p.30-36 |
| Home Equipment | Home automation | 4.83 | p.30-36 |
| Home Equipment | Alarm clock/radio | 4.63 | p.30-36 |
| Home Equipment | Cordless phone | 4.625 | p.30-36 |
| Home Equipment | Always plugged in mobile phone charger | 4 | p.30-36 |
| Home Equipment | Rechargeable vacuum | 3.71 | p.30-36 |
| Home Equipment | EV charger | 3 | p.30-36 |
| Home Equipment | Night light | 2.5 | p.30-36 |
| Home Equipment | Always plugged in Bluetooth headset charger | 2 | p.30-36 |
| TV Equipment | Cable Box/Set Top Box | 16 | p.17, p.18, p.19, p.26 |

| | | | |
|---|---|---|---|
| TV Equipment | TV | 13 | p.17, p.18, p.19, p.26 |
| TV Equipment | Audio/video (surround sound, VCR, amplifier, DVD player, speakers, woofer, subwoofers) | 6.4 | p.30-36 |
| TV Equipment | Game console (ex. Wii) | 3 | p.30-36 |
| TV Equipment | Whole house audio system | 350 | p.20 |
| Workstation/Office Equipment | Computer - desktop | 9.5 | p.17, p.18, p.19, p.26 |
| Workstation/Office Equipment | Computer - laptop | 7.1 | p.18, p.19 |
| Workstation/Office Equipment | Computer accessories (data storage, external disk drive, network disk storage) | 5.25 | p.30-36 |
| Workstation/Office Equipment | Computer peripherals (monitor, mouse, keyboard) | 5 | p.30-36 |
| Workstation/Office Equipment | Tablet | 4.5 | p.30-36 |
| Workstation/Office Equipment | Modem | 11 | p.17, p.18, p.19 |
| Workstation/Office Equipment | Router | 5.5 | p.18, p.19 |
| Workstation/Office Equipment | Networking equipment | 7.466 | p.30-36 |
| Workstation/Office Equipment | Printer | 6.3 | p.18, p.19, p.26 |
| Workstation/Office Equipment | Shredder | 8 | p.30-36 |
| Workstation/Office Equipment | Scanner | 1 | p.30-36 |
| Workstation/Office Equipment | Copier | 6.3 | p.18, p.19 |

| | | | |
|---|---|---|---|
| Workstation/Office Equipment | Fax | 6.3 | p.18, p.19 |
| Kitchen | Coffee Maker | 4.75 | p.30-36 |
| Kitchen | Microwave | 3.57 | p.30-36 |
| Kitchen | Oven | 3.14 | p.30-36 |
| Kitchen | Dishwasher | 2.66 | p.30-36 |
| Kitchen | Stove | 1.5 | p.30-36 |
| Bathroom/Laundry | Rechargeable toothbrush | 2 | p.30-36 |
| Bathroom/Laundry | Water softener | 3.5 | p.30-36 |
| Bathroom/Laundry | Clothes washer | 2.25 | p.30-36 |
| Bathroom/Laundry | Clothes dryer | 3.33 | p.30-36 |
| Bathroom/Laundry | Heated towel rack | 140 | p.20 |

# Appendix G: Full Survey Questions

Survey intro message: The following survey is created by a team of WPI students in order to better study alternative pricing methods for electricity, people's electricity consumption habits, and potential savings on electricity bills by switching to real time pricing, reducing energy consumption, participation in solar and electric vehicle technology. All of the questions in the survey are optional, and provide the option "Prefer Not to Answer" or just skip the question. No data gathered in the survey will be used to identify the participants, and only aggregate statistics will be presented in the final report. Thank you for your participation.

**Section 1: Demographics**

Question 1: What state do you currently live in?

Options: Dropdown of 50 states, Prefer Not to Answer

*Reason: cost benefits of RTP, solar panels, electric vehicles and electric vehicles vary state to state so we want to make sure the residents are in Massachusetts in order to make our best estimate for their potential savings.*

Question 2: What age range do you fall into?

______Options: Under 18, 18-20, 21-29, 30-39, 40-49, 50-59, 60-69, 70 or older, Prefer Not to Answer

*Reason: Ideally in our survey we want to target older audiences of 20+ that might own or rent their residence and have options regarding their electricity provider and energy usage. However, we also want to know if people under 20 or under 18 take this survey since those people are likely to be involved in high schools or colleges and are the best audience for participation in new and innovative programs so we want to know how much they might know about RTP and smart home devices.*

Question 3: Indicate the highest level of education you have received:

Options: Less than high school, High school graduate, college, 2 year degree, 4 year degree, Professional degree, Doctorate, Prefer Not to Answer

*Reason: This is important to assess for of the more complicated technologies such as smart home technologies and real time pricing. one with a PhD degree is much more likely to be able to set up a good RTP system with smart home technology and solar integrations so we are trying to assess the demographics of those taking the survey in order to determine how complicated of a technology they can handle.*

Question 4: Do you own or rent your property?

Options: Own, Rent, Other ____, Prefer Not to Answer

*Reason: this in order to determine whether participants might be eligible for solar panels.*

**Section 2: Electricity Provider and Consumption**

Question 1: Who is your current electricity provider?

Options: Eversource/formerly NSTAR, National Grid, Other ____ (specify), Don't Know, Prefer Not to Answer

*Reason: We are mostly familiar with the policies, pricing mechanisms and incentives of Everource and National Grid. It would be the easiest to estimate savings for customers of those utility companies hence we want to see what is the % of customers in MA who have either one of these providers and make sure there are no other providers we are unaware of.*

Question 2: How much month to month on average are you **expecting/budget** to spend on electricity (in dollars per month)? Number: ______.

2a. How much is your typical bill in the Summer? (dollars per month or a range)

2b. How much is your typical bill in the Fall? (dollars per month or a range)

2c. How much is your typical bill in the Winter? (dollars per month or a range)

2d. How much is your typical bill in the Spring? (dollars per month or a range)

Options: Number $___, Prefer Not to Answer

*Reason: The purpose of this question is to determine what people are currently spending on electricity month-month, how much it varies depending on the season. This will give us base numbers to know how much people are spending and how much electricity they are consuming, in order to estimate how much they might pay under RTP scheme.*

Question 3: Would you be willing/are you able to spend more on your electricity bill in the Summer if it meant your overall bill for the year was reduced?

Options: Yes, No, Depends on the numbers (specify how much range you could tolerate), Prefer Not to Answer

*Reason: to assess the risk tolerance of our survey participants. In order to benefit the most from RTP, participants should be willing and/or be able to spend more in the summer months, while reducing their overall bill.*

Question 4: Has COVID-19 affected your typical bill?

Options: Yes, No, Prefer Not to Answer

4a. If yes, did it increase your bill or decrease?

Options: Increased, Decreased, Prefer Not to Answer

*Reason: the purpose of this question is to study how COVID-19 affected an individual's consumption and make projections about how much more/less they might spend if more people are working from home.*

Question 5: Are you aware of any alternative electricity pricing schemes as opposed to your current plan?

Options: Yes, No, Prefer Not to Answer

5a. Check off any of the terms you are familiar with:

Options: Real Time Electricity Pricing, Time of Use Pricing, Fixed Rate Pricing, None

*Reason: to assess the awareness about RTP before informing the participants what it is to gather what is the general knowledge about this subject.*

**Below is the table describing differences between fixed rate pricing vs. real time pricing for electricity. Please familiarize yourself with the table below and then answer the next set of questions.**

| **Fixed Rate Pricing** | **Real Time Pricing** |
|---|---|
| ● Standard plan<br>● Pay a fixed amount per unit of energy (kWh) regardless of the time you are using electricity<br>● More suitable for those that prefer to avoid large fluctuations in their month to month bill (ex.do not have the budget to pay more in the summer) or tend to use a lot of electricity during the day<br>● Can put more strain onto the electrical grid during peak demand hours creating the need for more use from non-renewable sources | ● Alternative plan<br>● Pay a varied rate depending on the hour and demand (ex. pay more during afternoon, but less during evening/night hours)<br>● Can pay more in the summer, but can save overall during the year if you shift usage to night hours<br>● Can pay even less if you have a smart home system setup that helps adjust electricity usage<br>● Reduce peak load on the grid and help the environment |

Question 6: Would you be willing to consider implementing RTP in the future?

Options: Yes, No, Don’t Know/Not sure/Need More information, Prefer Not to Answer

*Reason: to help us make recommendations to assess whether people are actually willing to switch.*

6a. If yes, what factors would affect your decision whether or not to participate in RTP?

Options: Benefits to the Environment (reducing how much non-renewable generators have to operate during the peak demand), Money Savings (saving money by shifting your electricity usage), Both, Neither, Other, Prefer not to Answer

*Reason: for recommendations, to determine what is the best approach for encouraging participation.*

Question 7: Which of the following factors would increase the likelihood of you switching to RTP?

Options (checklist): if a utility company such as Eversource or National Grid reached out to you, if a community program you are involved in reached out, your family (relatives, children) telling you about the program, college/university/research institution reaching out to you, your neighbors telling you about the program, your own interest in the program.

*Reason: like question 6, to determine what is the best approach for encouraging participation.*

Question 8: If your electricity provider offered you to change your pricing program, would you prefer the option was opt-in or opt out? (Note: opt in = when you have to specifically ask to be enrolled into the program, opt-out = when you are automatically enrolled, and can call to disenroll from the program)

Options: Opt in, opt out, No preference, Prefer Not to Answer

*Reason: for recommendation, to determine whether to recommend opt in our opt out.*

**Section 3: Device and Appliance Assessment**

Question 1: Check off any of the devices you have in your home and indicate a number of devices owned:

Options:

- Clothing washing machine
- Clothing dryer machine
- Dishwasher
- In wall A/C
- Window A/C
- Portable A/C
- Fan (ceiling or desk)
- Non-LED Light Bulbs
- Electric Workout Equipment (Treadmill, rowing machine)
- Alarm clock/radio
- Cable Box/Set Top Box
- TV
- Audio/video (surround sound, VCR, amplifier, DVD player, speakers, woofer, subwoofers)
- Game console (ex. Wii)
- Computer (laptop or desktop)
- Tablet
- Computer accessories and peripherals (monitor, mouse, data storage, external disk drive, network disk storage)
- Networking equipment (modem, router)
- Printer/Scanner/Copier/Fax

- Shredder
- Coffee Maker
- Microwave

Question 2: Which of the following smart home technology devices do you currently have in your home?

Options: Smart thermostat (ex. Google Nest, Ecobee, etc), Smart Power Plug or a Smart Power Strip, Smart Circuit Breaker

*Reason: establish the level of barrier to entry for smart home device implementation. If a large percent of the population already owns certain devices, it is going to be easier to recommend smart home technology.*

Question 3: Check off any device that you would be unwilling to have in your home? For each of the devices you check off, indicate a reason why.

Options: Smart Thermostat - privacy concerns, cost, technology barrier, other, Smart Power Plug - security/privacy concerns, cost, technology barrier, other, Smart Power Strip - privacy concerns, cost, technology barrier, other, Smart Circuit Breaker

*Reason: to establish whether there are any barriers to participation in smart home automation which is crucial to RTP and determine what they are if there are any.*

Question 4: Do you use a password manager? (ex. LastPass, Dashlane, Nord Password Manager e.t.c)

Options: Yes, No, Prefer Not to Answer

Question 5: How often do you check for updates to your devices? (ex. mobile phone, computer, smart home devices)

Options: Weekly, Monthly, Every 3 Months, Every 6 Months, Never.

Reason:

Question 6: Do you employ any techniques to limit the ability of companies to track you online? (ex. limit software permissions, using privacy extensions or an ad blocker, refraining from using a service)

Options: Yes, No, Prefer not to Answer

*Reason:*

Question 7: Do you own or lease solar panels?

Options: Yes own, Yes lease, No, Prefer not to answer, Other (specify)

*Reason: establish how many of our survey participants already participate in solar.*

7a.If not, have you considered solar panels in the past?

Options: Yes, No, Prefer not to answer

7b. If yes (aka you have considered panels), what were the barriers preventing you from getting solar panels?

Options: Have no access to the roof space (either because of the type of building you live in or because you rent), Roof not suitable for solar (either because of the year it was built, not enough space, faces the wrong direction (North), and e.t.c), Not sure about the options on the market and process of obtaining, Upfront costs, Other (specify)

*Reason: establish the biggest barriers for participation in solar in order to make the best recommendations.*

Question 8: Are you aware of/have you taken advantage of the federal and/or state tax incentives for solar?

Options: Yes, No, Prefer Not to Answer

*Reason: applicable both to those that already have panels and those that do not, the purpose of this is to understand the awareness about these programs. These programs are an important incentive and if awareness is low, recommendations need to be made for increasing awareness.*

Question 9: What is the longest amount of time you would be willing to wait for your solar panel energy savings to pay back the costs of installation?

Options: 1-5 years, 5-10 years, 10-15 years, 15-20 years, 20-25 years, 25-30 years, I have no expectation of it paying for itself, Other (specify), Prefer not to Answer

*Reason: assess how much people are willing to wait until they see significant return on investment.*

Question 10: Do you own an electric vehicle or a plug in hybrid?

Options: Checklist, own an electric vehicle, own a hybrid, own both, own neither

*Reason: assess whether they will be charging it at home and can repeat the benefits of RTP + vehicle charging incentives.*

10a. If yes, specify the make, model and year of the vehicle.

Options: Make ____ (free form) Model _____ (free form), Year (free form), Prefer Not to Answer

*Reason: we care about the battery capacity of the car to determine how much it costs to charge it, this varies from model to model.*

10b. Do you have an electric vehicle charger in your home?

Options: Yes, No, Prefer Not to Answer

*Reason: to assess whether this will play a role in electricity consumption. EV battery takes a lot of energy to charge up and if they are charging their battery several times a week, the costs will add up. If so, participants are more likely to consider RTP programs where they pay a lot less during off peak hours to charge the vehicle.*

10c. If yes, at what times do you usually charge your electric vehicle/plug in hybrid?

Options 1am-5am, 6am-9am, 9am-12pm, 12pm-5pm, 5pm-9pm and 10pm-12am

*Reason: assess the potential for savings if participation in off hours charging programs.*

10d. Do you use charging stations provided at grocery stores, colleges, and other community spaces?

Options: Yes, No, Prefer Not to Answer

*Reason: important answer for establishing to what extent customers will be charging their vehicles at home vs. at other locations.*

9e. If you do not own an electric vehicle, what is the barrier for you to access it?

Options: Don't have interest/don't want to switch my current vehicle, Upfront Cost, Not sure about existing options and models on the market, Range concerns/time it takes to charge (how many miles the vehicle can drive before it needs to be charged again), Other concerns (specify)

*Reason: assess what are the biggest barriers to propose recommendations for solving and mitigating the problems.*

Question 10: What is the longest amount of time you would be willing to wait for your electric vehicle to pay for itself?

Options: 1-5 years, 5-10 years, 10-15 years, 15-20 years, 20-25 years, 25-30 years, I have no expectation of it paying for itself, Other (specify), Prefer not to Answer

*Reason: assess how much people are willing to wait until they see significant return on investment.*

**Section 4: Behavior**

Question 1: Would you be willing to shift your **dishwasher** time of use to a different part of the day like at night (if it was automatically done for you with technology) if it could save you money on your **electricity bill** or **help the electrical grid and the environment?**

Options:

a. Would it for both cases
b. Would do it to save money
c. Depends on the amount of money you would save on your electric bill
    i. Indicate the smallest number (in dollars) that would make you shift you usage
d. Would do it to help the electrical grid and/or environment
e. Wouldn't do it in either case

*Reason: assess the potential savings on electric bills by switching use times and determining what are the most influential factors.*

Question 2: Would you be willing to shift your **washing machine for clothing** time of use to a different part of the day like at night (if it was automatically done for you with technology) if it could save you money on your **electricity bill** or **help the electrical grid and the environment?**

Options:

f. Would it for both cases
g. Would do it to save money
h. Depends on the amount of money you would save

        i. Indicate the smallest number (in dollars) that would make you shift you usage
    i. Would do it to help the electrical grid and/or environment
    j. Wouldn’t do it in either case

*Reason: Same as 1.*

Question 3: Would you be willing to **run A/C in the morning** to pre cool your home instead of running it during the day if it could save you money on your **electricity bill** or **help the electrical grid and the environment?**

Options:

    k. Would it for both cases
    l. Would do it to save money
    m. Depends on the amount of money you would save
        i. Indicate the smallest number (in dollars) that would make you shift you usage
    n. Would do it to help the environment
    o. Wouldn’t do it in either case

*Reason: Same as 1.*

Question 4: Would you be willing to **charge your electric vehicle** at night if it could save you money on your **electricity bill** or **help the electrical grid and the environment?**

Options:

    p. Would it for both cases
    q. Would do it to save money
    r. Depends on the amount of money you would save
        i. Indicate the smallest number (in dollars) that would make you shift you usage
    s. Would do it to help the environment
    t. Wouldn’t do it in either case
    u. *Reason: Same as 1.*

Question 5: Are there any lifestyle barriers that would prevent you from making changes as listed in questions 1-4.

Options: Yes, No, Not Sure, Prefer Not to Answer

5a. If yes, which of the following barriers apply?

Options: Abnormal behavioral, work scheduling conflict, distrust in the effectiveness, resistance to change, other (specify).

# Appendix H: Electric Vehicle Battery Capacity

In order to get an estimate for kWh that an electric vehicle might consume per year, we researched the most popular electric vehicles as of 2020 on the US market, looked up their battery capacity numbers and estimated mileage. We also made assumptions about the average number of miles that a person would drive per year to give a monetary value in terms of cost to charge the electric vehicle throughout the year. Note, that while the numbers were researched to the best of our ability, the battery capacity and especially estimated mileages vary significantly between vehicle models and year to year, so the data is an estimate.

First, we researched the most popular vehicles and came up with a listing of 8 most popular EV models in the US as of the end of 2020 shown in the table below (McCarthy, 2020). For every car referenced, we researched and found an estimate regarding the battery capacity and an estimated mileage. Note again that both of those are not the most precise numbers, the battery capacity is usually more accurate given that it is provided by the manufacturer while estimated miles are an estimate and a calculation partially based on the battery capacity.

Table H.1. Most Popular Electric Vehicles as of June 2020, Batteries, Range and Prices

| Make | Model | Year Referenced | Battery (kWh) | Estimated Range (miles) | Price to charge the battery once | Average Yearly kWh Consumption[13] | Price to charge per year at home [14] |
|---|---|---|---|---|---|---|---|
| Tesla | Model 3 (Long Range) | 2020 | 79[15] | 353 | $17.32 | 3021.25 | $661.96 |
| Tesla | Model Y (Long Range) | 2020 | 72.5[16] | 264 | $15.89 | 3707.39 | $812.29 |
| Tesla | Model X (Long Range) | 2020 | 100[17] | 325 | $21.92 | 4153.85 | $910.11 |
| Chevy | Bolt | 2019 | 60[18] | 238 | $13.15 | 3403.36 | $745.68 |
| Tesla | Model S (Long | 2019 | 100[19] | 348 | $21.92 | 3879.31 | $849.96 |

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[13] Based on the assumed 13,500 miles per year of driving
[14] Based on the 21.92 cents per kWh MA average rate
[15] Source: Kane, 2020
[16] Source: *Tesla Model Y Long Range Dual Motor*. (n.d.).
[17] Source: *Tesla Model X*. (n.d.).
[18] Source: *2019 Chevrolet Bolt EV Specifications*. (n.d.).

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Range) | | | | | | |
| Nissan | LEAF | 2017 | 40[20] | 151 | $8.77 | 3576.16 | $783.54 |
| Audi | e-tron | 2018 | 95[21] | 222 | $20.82 | 5777.03 | $1,265.75 |
| Porsche | Taycan | 2019 | 93.4[22] | 203 | $20.47 | 6211.33 | $1,360.90 |

In order to calculate the annual costs that would be associated with charging each EV at home, we found the average number of miles that a person in the US drives per year, which seems to stand at 13,500 miles as of 2020 (Dewitt, 2020).
The average yearly annual consumption in kWh was calculated as follows:
*(13,500 miles/estimated range (miles)) * Battery (kwh)*
The price to charge the vehicle per year at home was calculated as follows:
*(13,500 miles/estimated range (miles)) * Battery (kwh) * 21.91 cents/kwh / 100 = dollars to charge specified EV model at home per year*

Therefore we estimate that on average the most popular EV vehicle models released in the last couple of years would on average consume from 3,021 kWh to 6211 kWh, and if they were charged using the fixed rate price for MA as of 2020 it would cost anywhere from $661 to $1360.

In terms of comparison between the electric vehicles and gas vehicles, we estimated the price difference. "The average car sold in the United States gets an average of around 25 miles per gallon (MPG)" (John, 2019). However, it is important to keep in mind that the fuel efficiency has been steadily increasing in recent years, and the actual average MPG for vehicles in the US is lower than 25 MPG given that many people don't own newer vehicles. Regardless if we stick with the 25 MPG, keeping in mind that the actual number is what lower we can make an estimated comparison between a gas vehicle vs. an EV.

*The price to fuel a vehicle per year was calculated as follows:*
*Average number of miles a person drives in the US/estimated MPG that a vehicle gets * average gasoline cost*
*(13,500 miles[23]/25 MPG[24]) * 2.423 $/gallon[25]* = $1,308.42

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[19] Source: *The Longest-Range Electric Vehicle Now Goes Even Farther, 2019*
[20] Source: *Nissan Leaf.* (n.d.).
[21] Source: *Audi e-tron (2018). (n.d.).*
[22] Source: *Porsche Taycan Battery*. (n.d.).
[23] Source: Dewitt, 2020.
[24] Source: John, 2019.
[25] Source: "*National average gas prices*"

Note that two highest numbers for price to charge per year at home for EV are $1360.9 and $1,265.7 for Porsche and Audi respectively, however the other six models cost significantly less per year to fuel. Especially striking is the Tesla Model 3 which stands at $661.96.

Of course, there are plenty of other concerns regarding EV's that don't have to do with the cost to fuel, as far as we know it is not generally disputed that people are able to save on the fueling costs if they opt in to get an electric vehicle. However, upfront cost and range concerns still remain a problem. Even a Tesla Model 3 that we estimate would take $661.96 to fuel as opposed to $1,308.42 for a gas vehicle, is not nearly enough to pay for itself during the allotted time span for the vehicle.

More importantly for our project regarding the electricity consumption, the average household in MA consumes 574 kWh of electricity per month. The average battery capacity of the models we examined is 79.9 kwH, with an average of 263 miles of estimated range.

*Average number of miles an American person drives per year / 12 = average number of miles an American person drives per month = 13,500 miles / 12 = 1,125 miles per month*

*Average yearly kwh consumption for the EV / 12 = average monthly kwh consumption for EV 4216.21 / 12 = 351.35 kwh per month*

If the average MA household consumes 574 kWh, then the additional added 351.35 kwh would result in an extra 61.2% increase, which means a significant additional load on the grid.

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