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REDUCING THE MONTHLY ELECTRICITY BILL USING REAL-TIME PRICING OPTIMIZATION

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ABSTRACT

The electricity bill is increasing every year. Traditional methods of reducing the cost all involve reducing electricity consumption, which is not always desirable. In this thesis, we develop an optimization model that proposes an alternate solution to rising costs. There are some appliances, such as a dishwasher, that can be run at a different time period. Consumers do not care when these types of appliances are run as long as the tasks are finished before they are needed. The model takes advantage of residential real-time pricing (RRTP) to schedule certain appliances during low-peak periods. But, there are other appliance tasks that cannot be moved. For that type of energy usage, another solution was devised. During high-peak periods, instead of using energy from the grid, energy is drawn from onsite and offsite renewable resources, which can sometimes be cheaper than RRTP. I incorporated all of these ideas into the optimization model. The objective is to minimize the electricity bill. I coded scripts in Python to modify datasets. Other scripts were coded to write the optimization model to a .lp file, which then was read in by CPLEX, a linear program optimizer. The three main components of the optimization model include the objective function, constraints, and bounds.

Results indicate that peak shaving alone can reduce costs by about 5-6%. Drawing from offsite renewable energy to supply nonmovable tasks during high-peak periods save an additional 4% with 2013 solar prices, 16% with 2017 wind prices, and 19% with 2017 hydroelectric prices. Onsite renewable resources are too expensive to justify the cost, but can be at grid parity within a few years.

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Chapter 1

Introduction

Overview

Electricity consumption for households has been steadily increasing. The average US household's square footage has increased by nearly 50% since 1975. The Residential Energy Consumption Survey indicates from 1993 – 2005 that the household consumption of electricity per year has increased. [3].

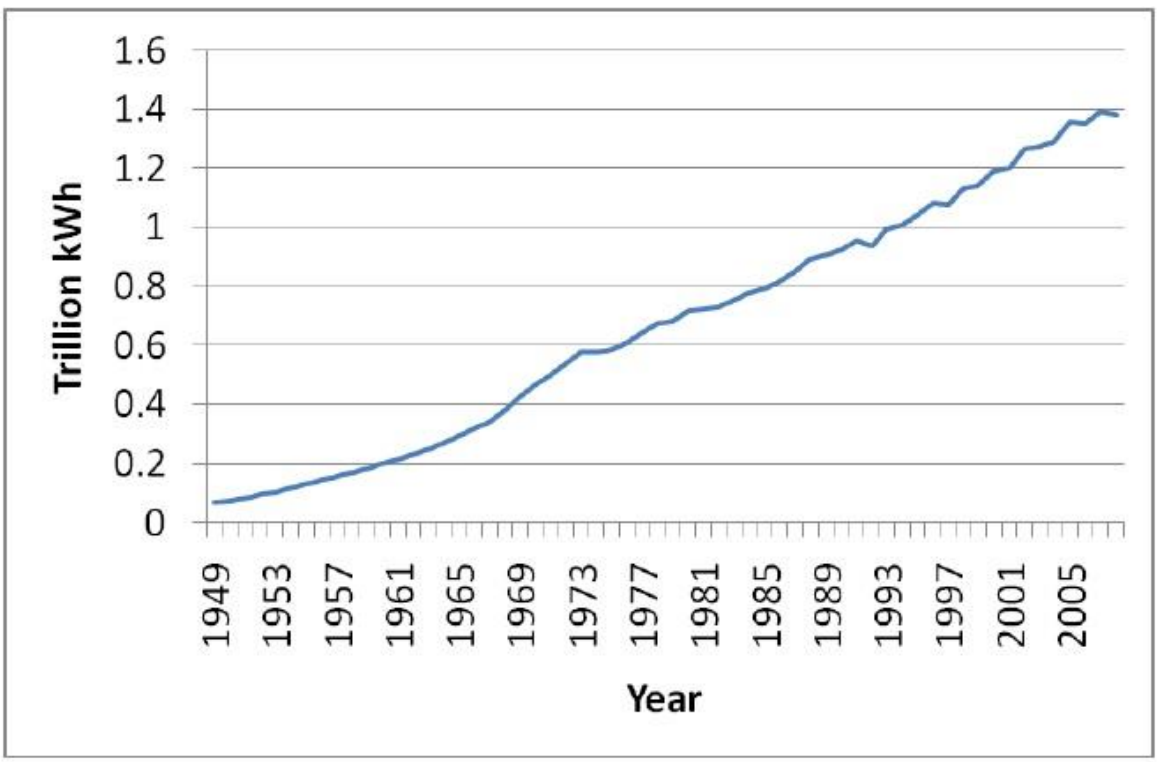

Figure 1-1: The increase of electricity consumption from 1993 - 2005 [3].

For the current system of electricity, most households do not use a time-of-use plan and do not interact at all with the power grid. Electricity mostly comes in the form of offsite nonrenewable resources and not renewable energy. Even though renewable energy, especially wind energy, is becoming cheaper than fossil fuels, 76% of electricity generation is done with nonrenewable resources. [1].

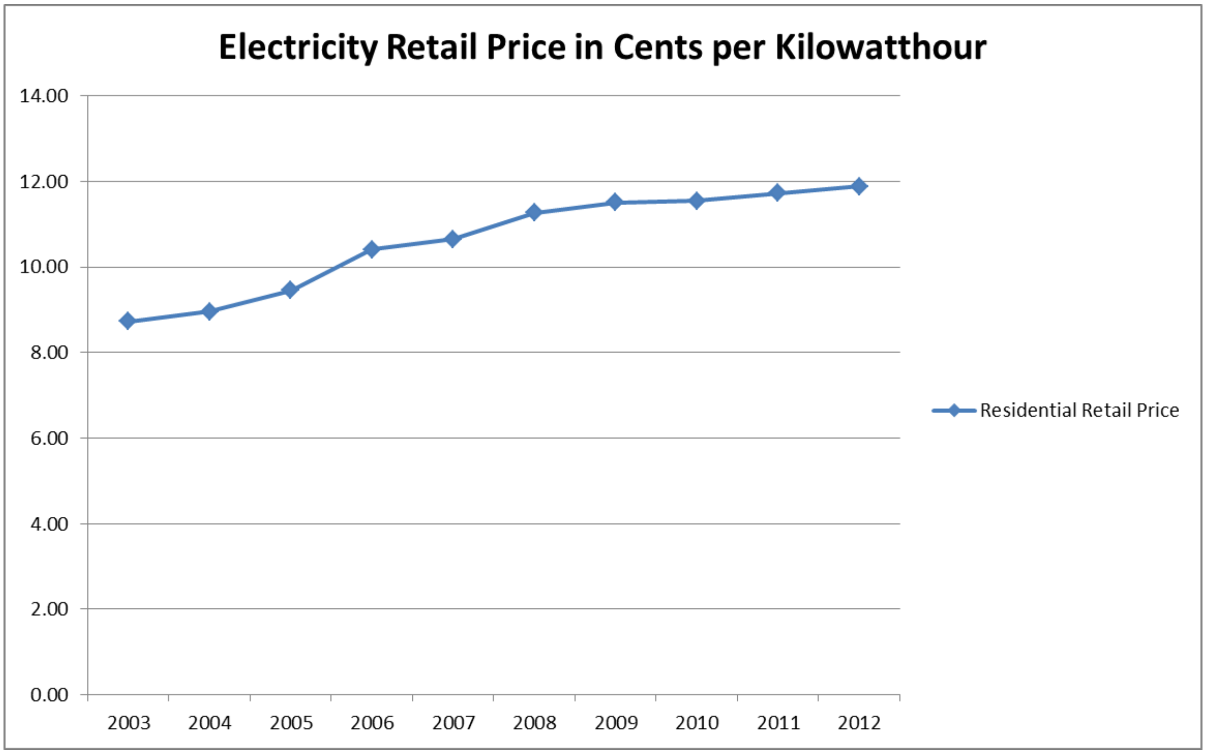

Figure 1-2: Rising Electric Prices in Cents per kWh to Consumers [6].

The current situation introduces the question, “How can we reduce the cost of electricity without impacting the amount of energy we use?” To begin, several key aspects of the electricity distribution system were looked at, from the source to the home. Analyzing each aspect helped determine possible ways on how the cost could be reduced.

Next, a linear program was designed to realistically model the current electricity grid in a simplified form (with the proposed battery and renewable additions). The interactions between each variable had to be carefully considered, and constraints were created so that the components abided by these rules. For example, the power drawn by all of the home’s appliances can’t be greater than what is drawn from the power plants. Data was taken from a variety of sources as inputs, and the program was scripted to be given to CPLEX to solve. The main goal is to minimize the electricity bill. The secondary goal is to use as much renewable energy as possible without increasing the cost by a significant amount. The results show that the savings are very significant. With 2013 and 2017 data, households can save up to 25.6% and 40.1% respectively while partially using renewable energy. This hybrid solution is definitely the recommended solution to rising nonrenewable electricity costs, with an eventual shift to 100% renewable energy as renewable energy becomes cheaper and cheaper.

Real-time Electricity Pricing

When the price of electricity increases, consumers ultimately suffer the most because they are offered fixed prices for purchasing electricity. By offering prices to consumers that rarely change, the electric industry is very inefficient. Real-time pricing (RTP) depends on the time that electricity is being used. Customers pay different prices during peak usage and off-peak usage. Liberalization from flat pricing allows consumers to be more knowledgeable about how much they are paying for their electricity as well as allow them to make better purchase decisions about when to use electricity [5]. During the morning, electricity is actually priced the highest in RTP since most people are awake at that time and a high volume of electricity is being used. The beginning of a day is when electricity is priced the cheapest since people are asleep and appliances are not being used. Even though real-time pricing is possible, consumers are only offered a stagnant flat rate pricing, which only changes from year-to-year and barely from season-to-season.

Real time pricing also is based on trade in spot markets, balancing markets, or other exchanges. Changes happen either hourly or half-hourly and corresponds to changes in real-time or day-ahead energy costs. Customers are usually notified of expected real time prices one day in advance [7].

Traditional Methods of Reducing Electricity Costs

Currently, most households are only offered flat rate pricing for electricity, consumers can still cut costs by managing their use of energy through traditional methods. Households can purchase appliances such as washing machines, TVs, or computer equipment that conserve more electricity. Even though this is available, it might not be desirable because of certain lifestyle changes that consumers might not want. Consumers also can purchase lighting that use less wattage as well as properly insulating and heating their house. When lights are not being used, they can also be turned off. Appliances that are not currently in use can also be unplugged to conserve electricity. Thermostats can also be set lower than usual during the winter and summer. Windows can also be kept open during warmer days instead of using the air conditioner. During colder days, people can wear thicker clothes as an alternative to using the heater.

Even though reducing carbon emissions might be desirable, the primary focus of this project is to reduce the household's monthly electricity bill. The secondary focus is to reduce carbon emissions. Even though households can purchase appliances that are more efficient, it is costly and is not desirable to do so. Assuming that a household has access to real time electricity pricing, it can use computerized scheduling methods that will minimize costs and optimize the household to utilize as renewable energy whenever it is cheapest to do so. During low-peak hours, the computer program will utilize cheap, offsite nonrenewable energy during low-peak hours and also storing some energy into the battery to use during high-peak hours.

The Power Grid

The power grid represents the transfer of electricity to consumers from offsite power plants. Electricity generated from these sources such as coal, oil, natural gas, and nuclear still are the nation's largest source of industrial air pollution and greatly contributes to emissions.

On the other hand, electricity markets do offer cleaner ways to produce power. The EPA reports that on average, replacing each kWh of traditional power with renewable power avoids the emission of more than one pound of carbon dioxide. Renewable energy is also cheaper than nonrenewable energy and also helps reduce the household's carbon footprint. Purchasing renewable energy also provides protection against the volatile prices of nonrenewable resources [4].

Onsite renewable energy includes solar and wind power. Solar panels and windmills have an initial installation cost. This initial cost is factored into the levelized cost of energy (LCOE) for this optimization problem. They can be situated on top of a house or possibly integrated into a building, reducing the costs of shingles. [4]

The house will have a solar panel as well a wind turbine. Even though onsite renewable resources are expensive to install, the government gives tax credits to help reduce the costs [8]. Because of real time electricity pricing, most of the time, the onsite renewable resources will be more expensive, but during high-peak hours, the price of the solar panel and windmill will be less than electricity coming from the power grid. Since the resource is located onsite instead of offsite, the electricity is more efficient since it onsite electricity has small transmissions losses compared to offsite resources. This optimization problem uses the levelized cost of installation factored into every kWh.

Optimization Model Description

The model can also calculate if a household wants to reduce carbon emissions by a certain percentage.

Even though this project encourages the usage of renewable energy, reducing the home's carbon footprint is not the primary goal. Reducing the home's monthly electricity bill is the top priority. Switching to offsite renewable energy can still reduce the monthly electricity bill if it is cheaper than nonrenewable resources.

For this project the house theoretically has access to real time pricing for their electricity as well as a special battery. This battery will be located near the house. During low-peak periods, the battery will store electricity that will be used during higher peak hours. This will help optimize the electricity in the household and reduce the monthly electricity bill.

Chapter 2

The Optimization Problem

Description

After researching the various key aspects of the electricity grid as well as the nontraditional components that will be added in, an optimization model was designed. The objective function was designed to represent all of the costs that the home will incur when using this hybrid energy system. In addition, each component of the model was carefully scrutinized to make sure that its limitations were accounted for in the Constraints section. Some constraints are common sense to humans, but need to be directly specified because CPLEX cannot logically reason. One such constraint is energy drawn must be equal to energy used. In order to realistically model the system, other constraints had to be considered such as the physical limitations of each component. One example is the capacity factor, which says that a renewable resource cannot produce more than a percentage of its maximum rating. A solar panel can produce at most 50% of its maximum energy because the sun only shines during the day. But even then, its capacity factor is only 13% because of inefficiencies and cloudy days. Finally, there are hypothetical constraints such as the CRF that were implemented to test the effects of forced renewable energy usage, even when it is not optimal to do so. These constraints are designed for the purposes of analysis, and are switched on and off as necessary. This rigorous process was needed to ensure the results required for a complete analysis of the entire system. In addition, it also keeps the model as realistic as possible by including all of the physical limitations.

Inputs

This optimization model incorporates offsite nonrenewable and renewable energy sources and onsite renewable energy sources. A house will optimize the use of these resources in order to effectively lower the energy bill. The battery will be used to store energy during low peak periods and used during high peak periods.

Time: Time is denoted as t. The time horizon is represented as T, which is 3 months. Since the home data is limited to only 3 months, the model will also be constrained to 3 months.

Power (home): The power that the home demands at a certain time.

Power (appliances): This includes appliances in which their power usage cannot be changed. These appliances are used One example of this would be a refrigerator; it has to keep running or food will spoil.

Capacity Factor: The capacity factor is the ratio of a specific resource's actual output to its potential output. For this project, assume that the nonrenewable resources from the power grid is unlimited and that the capacity factor of those resources do not need to be considered. All resources are located outside the home. The capacity factor is used when considering renewables primarily because they are never going to be operating at maximum efficiency. This optimization model makes the situation as realistic as possible.

Cost: Cost is the price of electricity. Offsite nonrenewable resources are based on RRTP. Onsite resources are always constant and will always be included in calculations even though energy is wasted. Offsite renewable resources have a constant LCOE but only energy used is calculated.

Carbon Reduction: The optimization model will also consider reducing carbon emissions if desirable.

Location	Name	Description
Both	Time	t: unit of time (half hour)
		T: total number of time units (3 months)
	Power (home)	$P_{t, home}$: power demand of the home at time t (kW)
Internal	Power (appliances)	$P_{t, otherapp}$: power of appliances that can't be changed (ex. refrigerator) (kW)
External	Capacity Factor	$CF_{n, t, onrenew}$: capacity factor of onsite renewable power plants, for each n^{th} onsite renewable resource $CF_{n, t, offrenew}$: capacity factor of offsite renewable power plants, for each n^{th} offsite renewable resource
	Cost	$C_{t, offnon}$: electricity cost based on peak at time t ($/kWh) $C_{n, onrenew}$: onsite renewable cost (flat operating costs), for each n^{th} renewable ($/kWh) $C_{n, t, offrenew}$: offsite renewable cost at time t ($/kWh)
	Carbon Reduction	CRF_{home}: carbon reduction factor for the home ($0 \leq CRF_{home} \leq 1$)

Decision Variables

The appliances in the house determine how much energy is being drawn from offsite and onsite resources as well as when and where the energy is being drawn from.

Power (Appliances): Appliances in the house that represent how much kW each appliance uses. These appliances can be run at any time (unlike a refrigerator) and this project optimizes how and when each appliance draws power. The table shows each of the decision variables and the power drawn by each appliance.

Power: The amount of power that is being drawn from onsite and offsite resources. Onsite renewable resources include the solar panel and windmill and they only generate a limited amount of energy in a certain period of time. Offsite nonrenewable and renewable resources are drawn through the power grid.

Battery: The discharge rate, the recharge rate, and the maximum energy capacity of the battery are denoted by dt (kW), rt (kW), and L (kWh). L is determined by the most common home backup battery used today. Assume that this is the battery that is being used for this optimization model.

Limiting Factor: Restricts the amount of energy that the offsite renewables can generate so it will not be over what the house can consume.

Location	**Name**	**Description**
Internal	Power (appliances)	$P_{t, dish}$: power drawn by the dishwasher at time t (kW) $P_{t, wash}$: power drawn by the washing machine at time t (kW) $P_{t, dryer}$: power drawn by the dryer at time t (kW)
External	Power	$P_{n, onrenew}$: amount of power drawn from onsite renewable sources (kW) $P_{n, t, offrenew}$: amount of power drawn from offsite renewable sources (kW) $P_{t, offnon}$: amount of power drawn from offsite nonrenewable sources (kW) $P_{n, onrenew(max)}$: maximum power that each n^{th} onsite renewable can theoretically produce (kW) $P_{n, offrenew(max)}$: maximum power that each n^{th} offsite renewable can theoretically produce (kW)
	Battery	d_t: discharge rate of battery (kW) r_t: recharge rate of battery (kW) l_t: current charge of battery (kW) L: maximum capacity of the battery (kW)
	Limiting Factor	$LIM_{offrenew}$: the limiting factor that restrict the size of the offsite renewable resources such that the resources will not be "too big" for the home

Objective Function

The overall goal of this optimization model will be to minimize the monthly electricity bill. This is the objective function that will be used in this model:

$$Monthly\ Bill = Minimize[\sum_{t=0}^{T}(Battery\ Running\ Costs + Onsite\ Renewable\ Operating\ Costs$$

$$+ Offsite\ Renewable\ Cost + Offsite\ Nonrenewable\ cost)\ /\ 3]$$

The time resolution for this optimization problem is a half hour. The sum is the battery running costs, onsite renewable operating costs, offsite renewable costs, and offsite nonrenewable costs divided by 3, which is 3 months: May, June, and July.

The table below shows how each of the variables is formulated:

Location	**Name**	**Description**
External	Battery running costs	$C_{t,\ offnon} * r_t$
	Onsite renewable operating costs	$C_{n,\ onrenew} * P_{n,\ onrenew}$
	Offsite renewable operating costs	$C_{n,\ t,\ offrenew} * P_{n,\ t,\ offrenew}$
	Offsite nonrenewable costs	$C_{t,\ offnon} * P_{t,\ offnon}$

Constraints

Home total power: The home's power demand at any point in time must be equal to all the power demands of the appliances in the home. The appliances in the home must be equal to the energy that it draws from all energy sources.

Battery: The battery's current charge level must be equal to the amount discharged subtracted from the previous charge level added to the amount recharged. The battery that will be used will be a 1.5 kW. The battery also cannot have a negative value for its charge, so the power level must always be between zero and the maximum capacity of the battery.

Onsite Renewable: The onsite and offsite renewable resources cannot generate more than the house can consume.

Offsite Nonrenewable: The energy that comes from the power grid also cannot exceed the power demand of the home.

Home Demand: The power demand of the home must be equal to the energy that it draws from all sources, which also is the total energy supplied to the appliances in the home.

Carbon Reduction: The optimization model also considers the desired amount of carbon emissions to reduce.

Location	**Name**	**Description**
Internal	Home Total Power	$P_{t,home} = P_{t,dish} + P_{t,wash} + P_{t,dryer} + P_{t,otherapp}$: the home's power demand at any point in time must be equal to all the power demands of the appliances in the home
	Battery	$l_t = l_{t-1} - d_{t-1} + r_{t-1}$: current charge level is equal to the previous charge level - amount discharged + amount recharged $0 \leq l_t \leq L$: current charge must be between 0 and the maximum charge on the battery

Location	Name	Description
External	Onsite renewable	$\sum_{n=0}^{1} P_{n,onrenew} = \sum_{n=0}^{1} CF_{n,t,onrenew} * P_{n,onrenew(\max)})$: total power of all onsite renewable sources must be between 0 and the sum of all renewable resource maximum power rating limited by a capacity factor $0 \leq CF_{n,t,onrenew} \leq 1$ capacity factor must be between 0 and 1
	Offsite renewable	$0 \leq \sum_{n=0}^{1} P_{n,offrenew} \leq \sum_{n=0}^{1} (CF_{n,t,offrenew} * P_{n,t,offrenew(\max)})$: total power of all offsite renewable sources must be between 0 and the sum of all renewable resource maximum powers limited by a capacity factor $0 \leq CF_{n,t,offrenew} \leq 1$: capacity factor must be between 0 and 1 $0 \leq P_{n,offrenew(\max)} \leq LIM_{offrenew} * \max(P_{t,home})$: the maximum power that is transferred from each n^{th} renewable resource to the home must be limited by some factor of the maximum home power demand; otherwise the power transferred will be too big in comparison to the home $0 \leq LIM_{offrenew} \leq 1$: limiting factor must be between 0 and 1
	Offsite	$0 \leq \sum_{n=0}^{2} (P_{n,t,offrenew}) + P_{t,offnon} \leq P_{peak} \leq \max(P_{t,home})$: the offsite sources must be between 0 and the peak power, which in turn must be less than the maximum home power demand at any point in time

Location	**Name**	**Description**
	Home Demand	$P_{t,home} = \sum_{n=0}^{2}(P_{n,onrenew} + P_{n,t,offrenew}) + P_{t,offnon} + d_t - r_t$: the power demand of the home must be equal to the power drawn from all sources
	Carbon Reduction	$\sum_{t=0}^{T}(P_{t,onrenew} + P_{t,offrenew}) \geq CRF_{home} * \sum_{t=0}^{T}(P_{t,home})$: the total amount of renewable energy consumed must be at least a fraction of the total power over the whole period

Chapter 3

Methodology

Data Preparation

The optimization model is based on data for Home A that was collected in the UMass Smart* Data Set for Sustainability [11]. The home was fitted with sensors in the mains panel. Electricity data was collected every second for the entire home and also for each circuit over a period of three months (May, June, and July). This provided a very detailed dataset for the purposes of optimization. However, the sensors were not able to return a value for every second. I filled in those missing values with the most recent preceding value.

I obtained the real-time nonrenewable energy cost data from ComEd, a company that provides electricity for people living in the Chicago area. All price plans have variable costs of about 3 cents/kWh as well as a fixed cost of about $17.50 per month [12]. The cost data has the same time horizon (May, June, and July) as the electricity data to better match the prices with energy consumption during summer. Furthermore, I used the cost data with no alterations to simulate a real home as much as possible. For onsite and offsite renewable energy resources, levelized costs of energy (LCOE) and capacity factors were collected from a variety of sources.

The optimization model assumes that the home must use all solar and wind energy produced onsite. Offsite renewable and nonrenewable energy are chosen depending on which is cheaper. The battery will charge from offsite nonrenewable energy when appropriate. CPLEX was used to optimize this linear program.

Coding Process and CPLEX

I created Python scripts to prepare the data in usable forms and also create the linear program. The initial UMass dataset had many missing values. Although the electrical sensors attempted to collect data every second, oftentimes it failed to do so. The first script filled in missing values using the most recent previous value. The second script calculated the home's daily kW usage for each day. These values are used in the constraints to signify to CPLEX that the electricity drawn from all sources cannot exceed the daily usage. The third script calculates the nonmovable appliance usage for every half hour. Nonmovable appliances must be used when they are needed. Therefore, this data is used to signify to CPLEX that the electricity drawn for each half-hour must be greater than or equal to the amount needed by these nonmovable appliances. The fourth script generates the actual linear program that is read in by CPLEX. This script also generates additional variations to show if each component of the model is saving money. Each variation removes a part of the optimization model. The original model is generated first, then onsite renewable energy is removed, followed by offsite renewable energy. Then, the script takes the original model and applies the CRF to it, in increments of 10%. In addition to the constraints listed in Chapter 2, the script also adds the constraints described above. Bounds are added for each decision variable so that they cannot have a negative value. Movable appliances are limited by their maximum wattage rating, so these bounds are also limited up to the ratings. Then, the script outputs the linear programs in .lp format, which is recognizable by CPLEX. The programs are run through CPLEX Interactive Optimizer and the results are formatted in Excel for evaluation.

Model Variations

There are four model variations that CPLEX was tasked to optimize. The first variation is the standard model. It allows the usage of all sources and the battery with no carbon emission restrictions. The second variation assumes that the home has no onsite renewable resources. It is commonly known that onsite residential renewable resources are expensive. In addition, wasted energy will also have an impact on the cost. Therefore, it is important to evaluate the effectiveness of onsite sources. For the third variation, only offsite nonrenewable resources and the battery will be used. The fourth variation is based off of the original model, but utilizes the carbon reduction factor (CRF), which dictates how much green power the home must use. This tests how cheap or expensive “going green” actually is. All of these results are also compared to the traditional fixed cost program.

Originally, solar, wind, and hydroelectric energy were all to be used for offsite resources. However, because the LCOE are constant, CPLEX would always choose the lowest-priced source (hydroelectric) and ignore the other two whenever the offsite nonrenewable resource had a higher price. Furthermore, wind and hydroelectric energy were fairly cheap. This could have interfered with the model’s peak shaving feature. The model would choose the renewable energy resource fairly often. As a result, each offsite renewable resource was analyzed separately. Current 2013 solar energy LCOE data was chosen to be the sole offsite renewable resource so that peak shaving effects can be analyzed. Solar energy is expensive enough so it would not override peak shaving, but cheap enough to be used during the highest peak periods. 2017 projections of wind and hydroelectric LCOE were chosen to analyze hybrid solutions in the future.

Chapter 4

Evaluation

Price Analysis of Peak Shaving

To begin the analysis, I looked at the prices of the first, second, and third model variations (Refer to Table A.1 in the Appendix). Most importantly, the prices will reveal which components of the model are useful. The most questionable addition to the model is the onsite renewable energy. Excess wasted energy is very costly and may eliminate any advantages the onsite sources had.

The first model (normal, offsite solar) achieved 17.3% savings over the three months. The average monthly bill is $99.39, while the fixed price bill is $120.19. The second model using (no onsite renewables) using offsite solar energy had even greater savings at 25.7%. The average monthly bill for that model is $89.34. Unfortunately, this shows that onsite renewable resources are not yet viable as a cost reduction technique (disregarding buyback programs). Residential solar panels and wind turbines are expensive because of their small size. However, solar panels will achieve grid parity by 2018 as long as tax credits continue to be awarded [10]. Solar generation cost will decline by about 50% and will continue until 2020 [2].

The third model (no renewables) results indicated that the price increased by about $15, with savings of 21.5% compared to the fixed price bill. ComEd residential real-time pricing (RRTP) participants saved an average of 16% in 2011 [9]. Since I used the same price data for this model, it can be said that the peak shaving method saves 5.5% more than manually trying to get the best price. Although peak shaving alone can cut costs by a decent amount, a combination of peak shaving and renewable energy still provides the highest savings and is the recommended route.

Analysis of Renewable Energy Impact on Price

As stated in the previous section, onsite renewable energy is not cost-efficient at this time due to possible excess energy and expensive installation costs. Offsite renewable energy is not cost-efficient by itself, especially current solar energy. But during high-peak periods, offsite nonrenewable energy can be as expensive as $.15/kWh. This is the time when the home can switch to offsite renewable energy to cut on costs.

In the third model variation, no renewable resources were allowed. For the model that was using offsite solar energy, the price increased by about $15. For the offsite wind and hydroelectric models, the price difference was much greater. This indicates two things. First, these results confirm that offsite renewable energy enhances peak shaving savings. Second, the hybrid solution will become even more effective in the future, until renewable energy prices completely dominate nonrenewable energy prices.

In the fourth model, forcing the home to use renewable energy increases costs, but surprisingly not by an exorbitant amount. Because the optimization model already incorporates renewable energy to reduce cost, CRF restrictions up to 30% barely increase the cost of the monthly bill, which is already great for the environmentally-conscious. In fact, using real-time pricing and peak shaving techniques, a home based on the offsite solar model can be forced to use about 80% renewable energy and still break even with fixed-cost pricing. Annually decreasing renewable energy costs are also a factor.

Chapter 5

Conclusion

I developed an optimization model to reduce energy usage during peak times to cut costs without lowering energy consumption. Peak shaving reduced electricity costs in the home by a substantial amount. By moving the three most energy-consuming appliances to low-peak periods using peak shaving techniques, energy consumption was allowed to remain the same while the monthly bill dropped substantially. In addition, renewable energy not only can cut carbon emissions, but even help cut costs during high-peak periods. However, onsite renewable energy is not viable because of wasted excess energy. In addition, it is more expensive than offsite renewable energy, where the energy can be produced in bulk and more efficiently. For all types of offsite renewables, the home can reduce carbon emissions by up to 30% without incurring a large cost penalty. After that, the cost increases exponentially. I believe this paper is a stepping stone for more advanced research in this area. In addition, this paper gives credence to the hypothesis that RRTP combined with scheduling techniques and renewable energy can have a substantial positive impact on both the monthly electricity bill and the environment.

Future Work

As renewable energy becomes cheaper and cheaper, it becomes even more prudent to consider renewable energy as part of the model. Consequently, research delving deeper into the renewable energy aspects of this project is suggested. Additions to the model such as renewable energy buyback programs may prove that onsite renewable energy can be useful in reducing costs. Another possible topic may look into the usage of real-time electrical prices for renewable energy, if they exist. Finally, future research can be made even more realistic by considering unforeseeable events such as blackouts. Future research can look into the effects of fully switching to battery and renewable energy usage during these periods.

Appendix

Tables and Graphs

Table A.1 – Optimization results for all models.

Fixed amount per month	Prices before fixed charge ($17.50)	Including fixed charge ($17.50)	Percent change (vs. fixed)	Avg. monthly bill
May	100.09	117.59		
June	100.69	118.19		
July	107.28	124.78		
Fixed Total	308.06	360.56		120.1866667
First Model (normal, solar 2013)	245.66	298.16	-0.173064122	99.38666667
First Model (normal, wind 2017)	209.76	262.26	-0.272631462	87.42
First Model (normal, hydroelectric 2017)	203.47	255.97	-0.290076548	85.32333333
Second Model (no onsite renew, solar 2013)	215.51	268.01	-0.256684047	89.33666667
Second Model (no onsite renew, wind 2017)	171.17	223.67	-0.379659419	74.55666667
Second Model (no onsite renew, hydroelectric 2017)	163.19	215.69	-0.401791657	71.89666667
Third Model (no onsite and offsite renew)	230.37	282.87	-0.215470379	94.29
Fourth Model (CRF, solar 2013)				
0.00%	245.66	298.16	-0.173064122	99.38666667
10.00%	247.24	299.74	-0.16868205	99.91333333
20.00%	249.47	301.97	-0.162497227	100.6566667
30.00%	253.96	306.46	-0.150044375	102.1533333
40.00%	260.76	313.26	-0.131184824	104.42
50.00%	269.15	321.65	-0.107915465	107.2166667

60.00%	279.13	331.63	-0.080236299	110.5433333
70.00%	290.63	343.13	-0.048341469	114.3766667
80.00%	304.12	356.62	-0.010927446	118.8733333
90.00%	320.57	373.07	0.034696028	124.3566667
100.00%	350.43	402.93	0.117511649	134.31
Fourth Model (CRF, wind 2017)				
0.00%	209.76	262.26	-0.272631462	87.42
10.00%	211.04	263.54	-0.269081429	87.84666667
20.00%	211.56	264.06	-0.267639228	88.02
30.00%	212.95	265.45	-0.263784114	88.48333333
40.00%	215.36	267.86	-0.257100067	89.28666667
50.00%	218.61	271.11	-0.24808631	90.37
60.00%	222.83	275.33	-0.236382294	91.77666667
70.00%	228.06	280.56	-0.22187708	93.52
80.00%	234.7	287.2	-0.203461282	95.73333333
90.00%	243.13	295.63	-0.180080985	98.54333333
100.00%	256.88	309.38	-0.141945862	103.1266667
Fourth Model (CRF, hydroelectric 2017)				
0.00%	203.47	255.97	-0.290076548	85.32333333
10.00%	204.72	257.22	-0.286609718	85.74
20.00%	205.07	257.57	-0.285639006	85.85666667
30.00%	206.13	258.63	-0.282699135	86.21
40.00%	208.04	260.54	-0.277401819	86.84666667
50.00%	210.72	263.22	-0.269968937	87.74
60.00%	214.32	266.82	-0.259984469	88.94
70.00%	218.85	271.35	-0.247420679	90.45
80.00%	224.72	277.22	-0.231140448	92.40666667
90.00%	232.26	284.76	-0.210228533	94.92
100.00%	244.17	296.67	-0.177196583	98.89

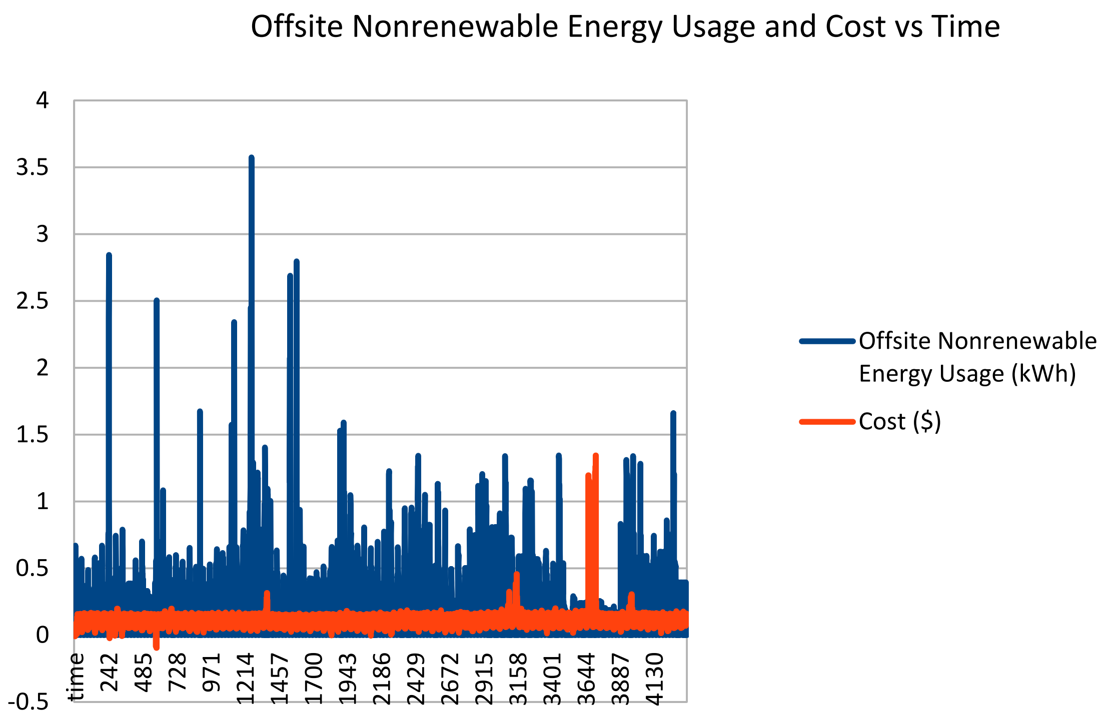

Figure A.2 – Graph of optimized offsite nonrenewable energy usage and cost.

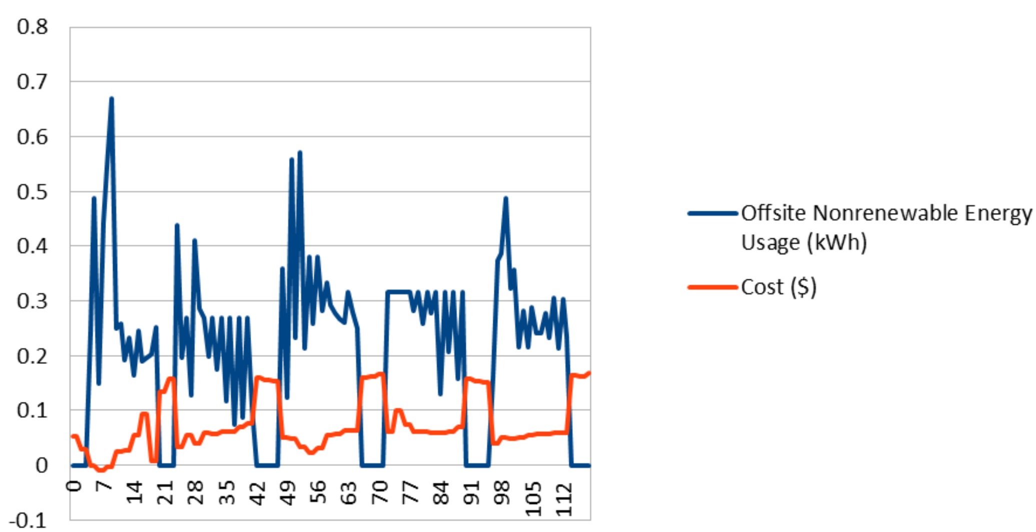

Figure A.2b – Zoomed in graph of Figure A.2 showing the optimization.

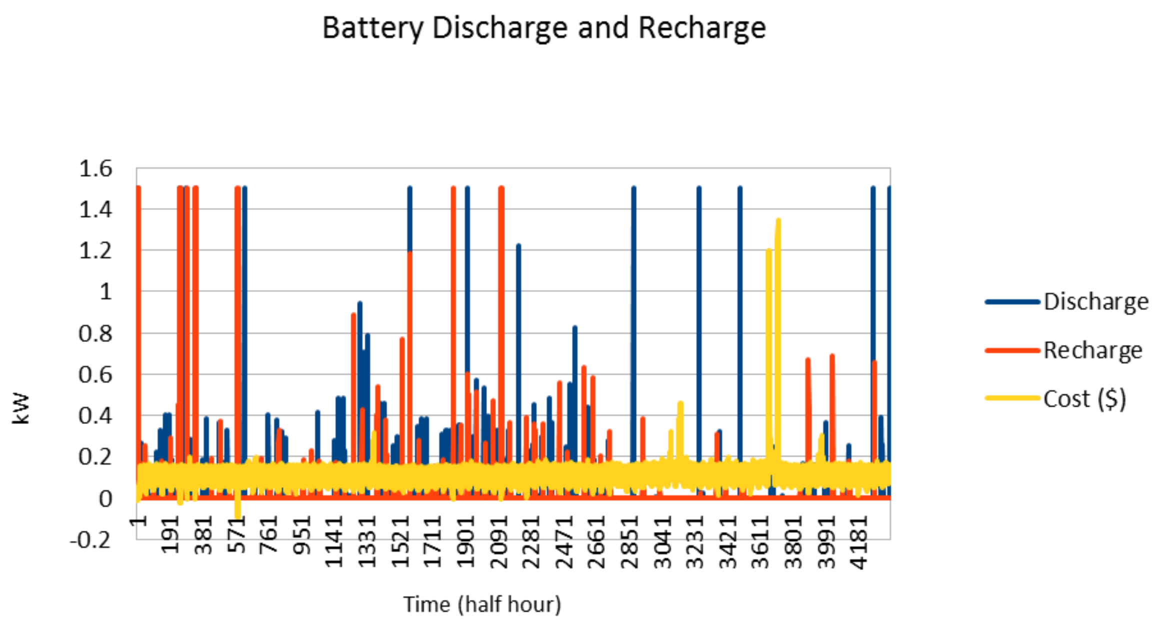

Figure A.3 – Graph of battery recharge and discharge.

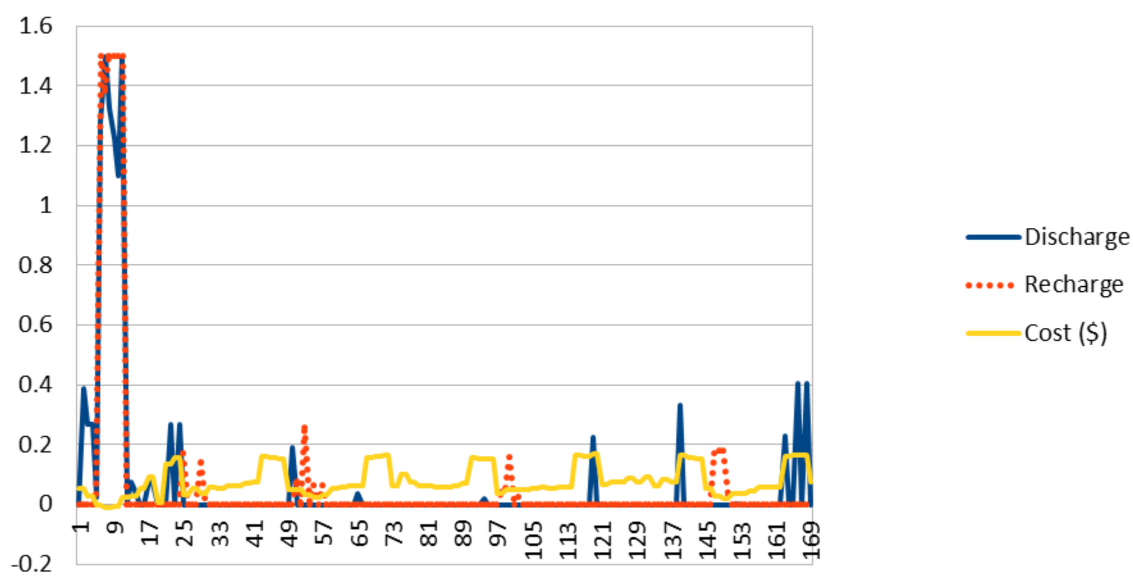

Figure A.3b – Zoomed in graph of Figure A.3 showing the battery recharge and discharge.

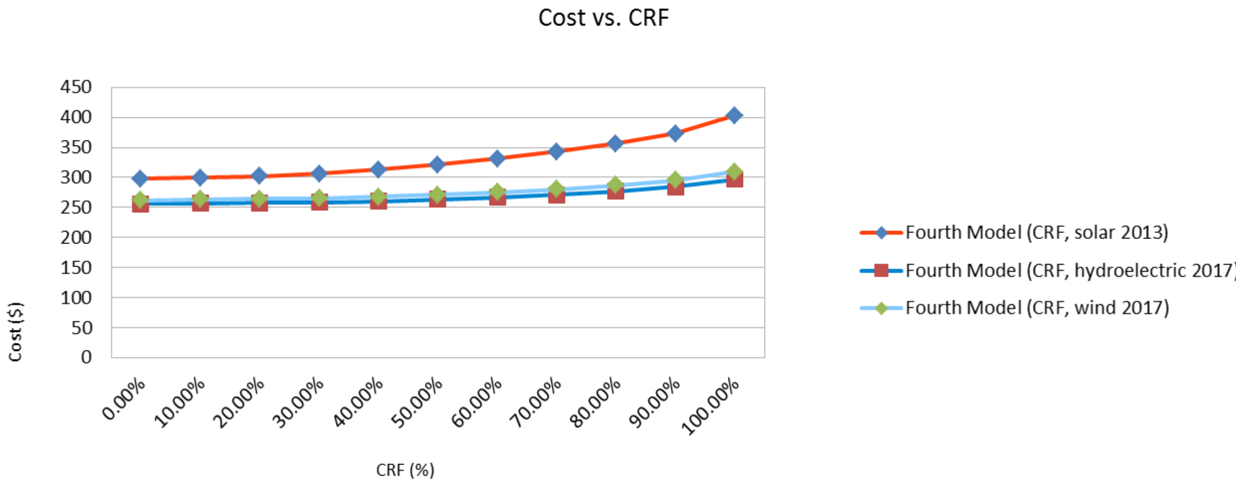

Figure A.4 – Graph of carbon reduction factors and the effect on the monthly bill.

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Honors in Computer Science

Research Experience

- Research Assistant at Penn State, Math Department – Analysis of the Prisoner's Dilemma and players' reactions on various graphs. (Spring 2011-present)
- Research Intern at Lehigh University – Determining loss caused by splitting of fiber optic cables. (6/2007-8/2007)

Work Experience

- Note Taker for Penn State ODS. (Spring 2012-present)
- Developer and administrator of www.jennyskuali.com, a website for a restaurant. (2012-present)
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- Dean's List: Fall 2009 – Spring 2010, Spring 2011-present
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