IN5410
Energy Informatics

ASSIGNMENT 1:
HOME ENERGY MANAGEMENT

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Abstract

Home energy management will become increasingly more important in the future, because of all the new and smarter electric devices that continuously appear on the market. The current power grid is not capable of meeting the power demand in the near future, a problem we already see with the increasing number of electric vehicles (EV). A promising demand response is to implement dynamic pricing schemes that allow power consumers to manage their own consumption by shifting non-essential electric appliances to hours with lower power demand and lower pricing rates. In this assignment we have investigated the use of Time-of-Use (ToU) and Real-Time-Pricing (RTP) schemes for households of residential customers, using linear programming optimization to minimize energy cost. The use of the ToU method is a (long-term) stable pricing scheme that allows power consumers to predictably use appliances during off-peak hours and gain a lower power bill. The RTP method is a bit more unpredictable, with rates and peak-hours changing with the power market, but may result in a higher financial gain compared to the ToU method. We managed to reduce energy cost for all households, by using linear optimization to distribute the consumption at favorable times. A large portion of the gain is from moving charging of electric vehicles to nighttime, and avoid cooking and laundry in the highest peak-hours.

Contents

1 Introduction

In today's western society, most of us are totally dependent on the access of electricity in the everyday life. We use the power to heat up our houses, watch TV, charge our cellphones, taking a warm shower, making dinner, and so on. Some of us even use the power to charge up our electric vehicles. In other words, without a constant and predictable power supply, the everyday life as we know it would cease to exist.

Some of the appliances we use depend on a constant access to electricity during the day, while others can be used a couple of hours when it suits us. If many people use a large amount of appliances at the same time, this will cause peak demands, which in turn may cause the pricing rates to increase over time. Customers are of course interested in getting favorable pricing rates, while the power suppliers are interested in reducing peak loads on the grid. It's important to reduce power peaks so that the power companies are able to meet the power demand at all times, as well as reducing the chance of overloading the grid. This can be handled by implementing demand response in combination with smart grids, smart meters and dynamic pricing.

A negative side of smart grids worth mentioning, although not a part of this assignment, is that data flow from smart-meters can raise privacy problems if not handled right. One issue is that the data contains information about the household consumption that can indicate routines for when people are home or on vacation. Some customers mean this is a violation of their privacy. Also, if this sensitive information leaked out to third-parties, or the system is targeted by a cyber attack, the customers could risk being victims of burglary or other undesirable situations. Therefore, creating a secure system and gaining the customers trust, is a major concern and priority for the suppliers.

In this assignment, we'll look into how customers can introduce home energy management into their daily life, in order to achieve the lowest possible power bill. The strategy is to distribute appliances to low-rate hours during the day. We will investigate three different cases; a simple household consisting of three shiftable appliances, a household with both shiftable and non-shiftable appliances, and a whole neighborhood where the households have a different amount of randomly selected shiftable appliances in addition to the non-shiftable. We'll implement two different pricing schemes, known as Time of Use (ToU) and Real-Time Pricing (RTP), and briefly discuss their impact on the energy cost.

2 Background information & code

2.1 Energy cost minimization

Linear programming (LP) is an optimization problem where both the target function and the constraints consists of linear expressions. The target function could either be maximized or minimized depending on the problem we want to solve. In this assignment we want to minimize the energy cost for one or multiple households according to their energy consumption, using different pricing schemes.

To solve this problem, we chose to implement the built-in function **scipy.optimize. linprog** in Python [7], with *method='inter-point'* and default lb and ub. A brief description of all parameters provided to the linprog function is given in table 1. Specifically for this assignment, a more detailed parameter description is provided in table 2. For a more thoroughly description of the parameters and the usage of linprog, see the documentation provided by www.scipy.org.

So, lets take a closer look at the theory behind this function. Mathematically speaking, we want to find a vector (x) of decision variables, that minimizes the function

$$\min_{\mathbf{x}} \left\{ c^T x \right\}$$

such that

$$\begin{aligned} A_{ub}x &\leq b_{ub} \\ A_{eq}X &= b_{eq} \\ lb \leq x &\leq ub \end{aligned}$$

When providing the function with time boundaries, and power use per day (time), the program will optimize when each appliance will run, based on the lowest energy price. The program returns the optimized result, where the return *fun* is the optimal value of the objective function $c^T x$. This is the minimized cost we'll present later in the report for the different households.

Table 1: Parameter description for the linprog function [7].

Parameter	Description	Type
c	The coefficients of the linear function to be minimized	1D array
A_{ub}	The inequality constraint matrix	2D array
b_{ub}	The inequality constraint vector	1D array
A_{eq}	The equality constraint matrix	2D array
b_{eq}	The equality constraint vector	1D array
lb, ub	Lower and upper bounds. Default = (0,None)	Sequence

Table 2: Description of the parameters we used in the linprog function. h=24 (hours)

Parameter	Description	Shape
c	Pricing scheme	(n_{app}*h,)
A_{ub}	Consists of two matrices, X and Y, concatenated together to Z. X has shape (h, n_{app}*h), where we add a '1' in each row, one column at a time. (Like a identity matrix with truncated representation). Y is an identity matrix, shape (n_{app}*h, n_{app}*h)	(n_{app}*h, n_{app}*h)
b_{ub}	Power use (PU) for all appliances [PU_{app1}*h + PU_{app2}*h +...+ ($Tot\_PU_{\text{all apps}}$)*h]	(n_{app}*h+1*h,)
A_{eq}	Matrix with pre-filled time intervals for all appliances E.g. if we have 2 applications, with a 24-hour interval. 1's is within the time boundaries, where the app. can run. Shape/Output: [[0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.1.1.1.1. 0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.] [0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0. 0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.1.1.1.1.1.1.1.0.]]	(n_{app}, n_{app}*h)
b_{eq}	Daily Use [kWh] for all appliances. [Daily use_{app1}, Daily use_{app2}, ...]	(n_{app},)

The individual time-intervals are generated by creating a zeros-list with h entries. We then replace all 0's with 1's within the allowed run-time, set by the start-up and deadline parameters. The run-time can therefor consist of fare more available time slots than the actual needed time for the appliance. This availability makes it possible for **linprog** to place a certain appliance in the most cost efficient time-slot.

2.2 Appliances

We have to keep track of the daily consumption of the households, and the easiest way to do this is to divide the consumption into a 24-hour time frame, where each time frame corresponds to a one hour period. This means the shortest time an appliance can be used, is for one hour, and 24 hours at the most. This corresponds to the **Time**-column (power use per day [h]), which states how long each appliance have to run. The **Power use**-column is the average power consumption of the device, and the **Daily use**-column is calculated by

$$\text{Daily use [kWh]} = \text{Power Use [kW]} * \text{Power use per day (Time) [h]} \tag{1}$$

We have to distinguish between non-shiftable and shiftable appliances. Non-shiftable appliances are appliances with strict consumption scheduling in a household, while shiftable appliances are appliances that can be used at various times. For instance they can be used when the pricing rate is low.

In table 3, we have the consumption of all non-shiftable appliances for the household. Lighting with standard bulbs, heating includes floor heating, two refrigerator-freezer combination, each using 1.32 kWh and two computers/laptops using 0.6 kWh per day per computer. In table 4 we have the consumption of all mandatory shiftable appliances for the household.

Table 3: Consumption of non-shiftable, strict consumption scheduling, appliances.

Appliances	Daily use [kWh]	Power use [kWh]	Time [h]	Start-up α [h]	Deadline β [h]
Lighting	1.50	0.15	10	10:00	20:00
Heating	8.00	0.33	24	00:00	23:00
Refrigerator (2)	2.64	0.11	24	00:00	00:00
Electric stove	3.90	3.90	1	16:00	18:00
TV	0.50	0.10	5	18:00	23:00
Computer (2)	1.20	0.30	4	16:00	23:00

Table 4: Consumption of shiftable appliances.

Appliances	Daily use [kWh]	Power use [kW]	Time [h]	Start-up α [h]	Deadline β [h]
Dishwasher	1.44	0.72	2	20:00	23:00
Laundry machine	1.94	0.97	2	15:00	21:00
Cloth dryer	2.50	2.50	1	20:00	23:00
Electric Vehicle	9.90	3.30	3	00:00	06:00

In addition to the appliances in table 3 and 4, we made a selection of optional shiftable appliances, listed in table 5. The typical energy consumption values for the appliances is gathered from the site *Energy Use Calculator* [1]. This site offers calculators for various electric appliances found in a normal household.

Table 5: Consumption of optional shiftable appliances.

Appliances	Daily use [kWh]	Power use [kW]	Time [h]	Start-up α [h]	Deadline β [h]
Coffee maker	0.240	0.240	1	06:00	08:00
Hair dryer	0.220	0.220	1	06:00	08:00
Microwave	0.600	0.600	1	16:00	22:00
Cellphone charger	0.015	0.005	3	00:00	23:00
Game console	0.270	0.090	3	18:00	23:00
Router	0.144	0.006	24	00:00	23:00

Note that all appliances is kept in an excel sheet, that easily can be imported to Python using a Pandas DataFrame [4].

2.3 Running the Python code

Running the code: **project1.py -T -X -W**

Give one of the arguments for "-T": -1, -2, -3 (Task 1, Task 2, Task 3)
The optional argument -X will create, save and show plots for the task.
The optional argument -W will print out possible warnings that occurred.

You might need to install: **conda install python-graphviz** and **pip install excel2img**

2.4 Flowchart - Python algorithm

In figure 1 we have illustrated the Python algorithm used for calculating the minimized cost in a flowchart. When running the program, the user have to provide which task to run, and can provide an optional argument if plots are desired. The program starts by importing the Excel file containing the data from table 3, 4 and 5. The program will then collect the appliance data needed for the task, before generating a pricing scheme. Then the time-intervals are generated for each appliance, filling in which hours the appliance can run based on the set-up and deadline parameters. The next step is to generate all the parameters used in the **linprog** function described in section 2.1. Finally, the program prints out selected return-information from the **linprog** function, like energy consumption and minimized energy cost. Plots histograms if selected.

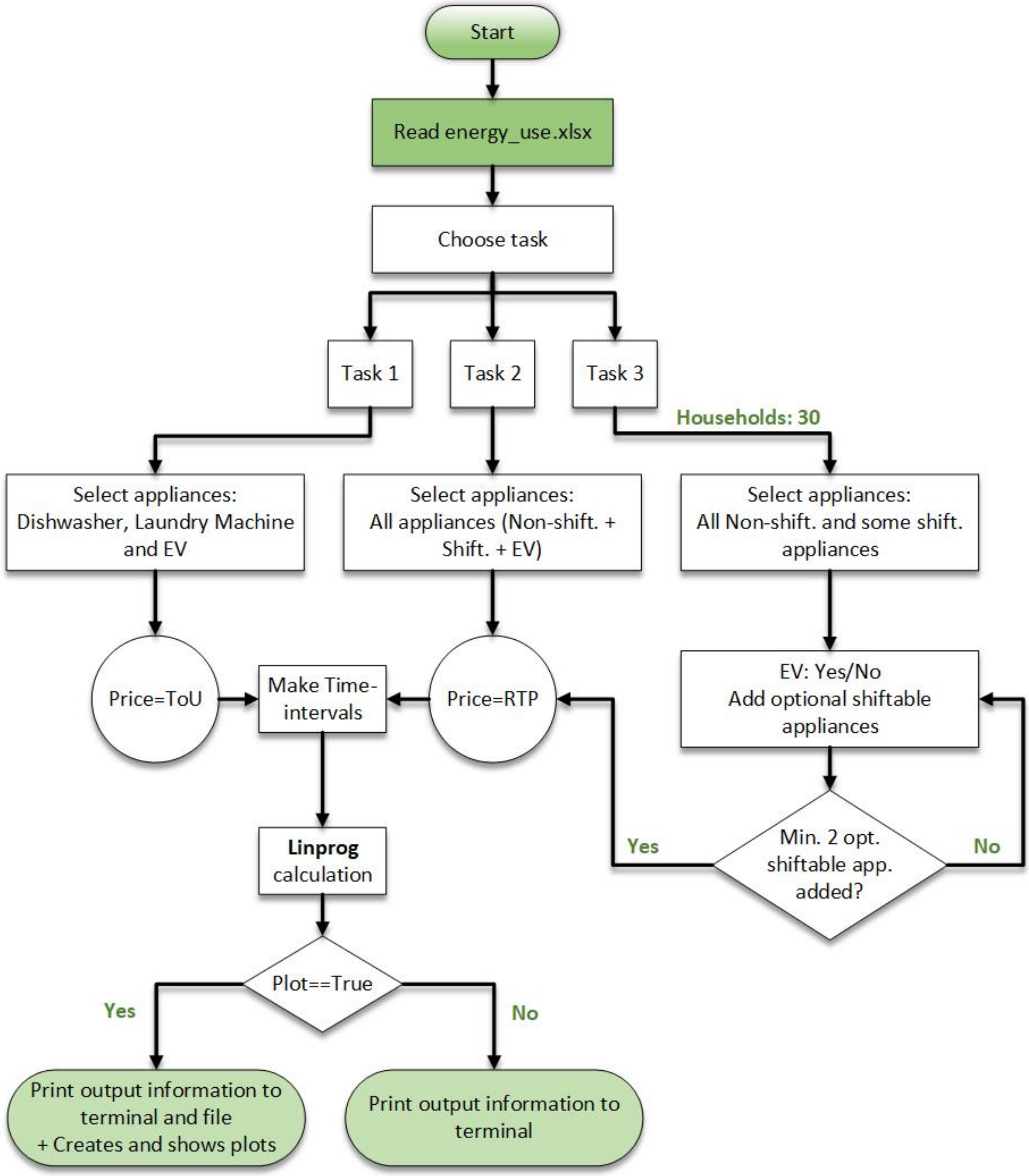

Figure 1: A basic flowchart of the Python algorithm used for calculating the minimized cost for the 3 households/tasks as described in section 3, using a ToU or RTP pricing scheme.

3 Households

The main power consumers can be divided into tree users, the residential users, commercial users and industrial users. We are only focusing on the typical power demand of residential households, during a day. In this section we have a basic overview of the household-combinations we explore in this assignment. We state which pricing scheme the different households use, as well as the selection of appliances.

3.1 Simple household | ToU

We are first exploring a strategy to achieve a minimum energy cost, where a simple household holds three appliances. A laundry machine, an EV and a dishwasher. We assume the ToU pricing scheme, as explained in section 4.1.

The main strategy to minimize energy cost includes not using the appliances during peak hours, as well as not using the appliances simultaneously. This is to reduce the all-over energy peak, although the daily energy cost wont be affected.

3.2 Complex household | RTP

In a complex household we are using all non-shiftable appliances from table 3 and all shiftable appliances from table 4. In addition, we have a selection of optional shitftable appliances, table 5, where we in this complex household use all of them. In total this gives 16 appliances to be used at various times and duration through a single day. The power demand will then naturally vary widely during the day. This power variation combined with a RTP scheme creates a complex problem when solving the energy cost minimization problem.

The strategy used to minimize energy cost were by approaching the problem as a linear programming optimization problem. We then used **linprog**, as described in section 2.1.

3.3 Neighborhood | RTP

The small neighborhood consists of 30 complex households, as described in section 3.2. But we are making a few changes to make the neighborhood more realistic. This means that each household use all non-shiftable appliances and all three first shiftable appliances from table 4. In a realistic neighborhood, not all households would own an EV, so EVs were randomly selected for a fraction of the households. In addition, the household only use 2-6 of the optional shiftable appliances, table 5, during the day.

When writing a program for minimizing the energy cost for the neighborhood, we reused the code from section 3.2. The main difference where to make a loop that made the calculations for all 30 households, and made sure we summed up the total cost and consumption for the neighborhood.

4 Pricing schemes

In this assignment we are using two non-static pricing schemes, the Time-of-Use and the Real-Time-Pricing scheme. We will use rates that are electricity prices per unit consumption (NOK/kWh).

4.1 Time-of-Use | ToU

The Time-of-Use tariff are a predefined pricing scheme, and can vary on a daily, weekly or seasonal base. This means it won't reflect the true changes in the electricity market, but tries to predict the plausible power demand, and sets the rates accordingly. The residential power demand is highly dependent on the geographical location, time-of-year and the, as well as differences between weekdays, weekends and holidays. When considering an ordinary day, the power demand is lower at night and mid-day, when a large portion of the population are asleep or away from home. The demand is much higher at times like morning before work, and afternoon. These time periods/hours are known as "peak" hours, because the residential users are consuming a large amount of power on applications like heating, lighting and electronic devices.

The ToU have higher pricing rates during peak hours, and a more pleasing rate during off-peak hours. The advantage of the ToU pricing scheme is that residential users can distribute shiftable appliances to off-peak hours to save money, and also help balancing the demand [3]. This is a huge help for the power grid, as peak hour demand are increasing in a rate unmanageable for the power companies.

We will use a simple ToU pricing scheme, that have one peak-hour period from 17:00 to 20:00 UTC. The rest of the day are off-peak hours. The rate for the peak hour is 1NOK/KWh and 0.5NOK/KWh for off-peak hours. This pricing scheme is used in the case with a simple household, explained in 3.1.

4.2 Real-Time-Pricing | RTP

The Real-Time-Pricing scheme are dynamic prices generated as a reflection of the power market. Meaning the pricing rate usually varies during different intervals of the day, often on an hourly base. This is a consequence of the constant fluctuations in the market. The rates will usually be released to customers a day to one hour beforehand [5]. This is in contrast to ToU, where the rates are provided to customers far in advance, and stays stable for a long period of time.

The RTP model comes with advantages for the customers, most important that the customers are free to make real-time adjustments to their power consumption based on the dynamic pricing rates, giving them the opportunity to reduce their power bill.

We will use the RTP model for the situations with a complex household (3.2) and a neighborhood (3.3). Our model will include two main peak-hour periods. The first peak-hour period is in the morning between 06:00 and 08:00 UTC. The last peak-hour period occurs in the afternoon, from 16:00 to 19:00 UTC, and has a generally higher rate than the first peak-hour. To simulate RTP, we used a function that causes small disturbances in the pricing rate, by randomly increasing or decreasing the rate within a given range. At night, from 00:00 to 06:00 UTC, we have set the random variations to be very small. At daytime during off-peak hours, we have a slightly wider range of random variations than during nighttime. During the peak-hours in the morning and afternoon, we set the random variations to be even higher.

5 Results & Discussion

For all households we have explored strategies to schedule the use of the appliances in order to minimize energy cost.

5.1 Time-of-Use pricing scheme

The ToU pricing scheme used for the simple household is illustrated in figure 2, where we can see that we only have one peak-hour period. The price is stable at 0.5 NOK/kWh at off-peak hours, and 1.0 NOK/kWh at peak hours.

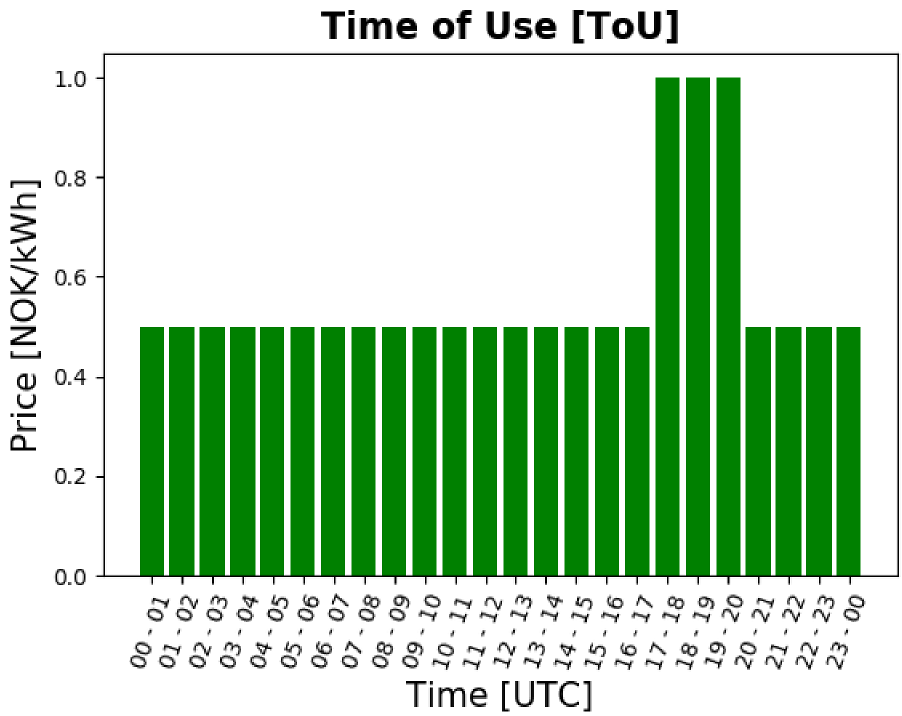

Figure 2: The price variations (ToU) during the day.

5.2 Simple household | ToU

All our appliances (EV, dishwasher and laundry machine) is shiftable, meaning we can choose which time we want the appliances to run. Not surprisingly, we will have the lowest energy cost if we use the appliances outside the peak-hours, as seen in figure 2. However, we should consider if it's reasonable that the appliances can be used in the off-peak hours. Starting with the EV, it seems reasonable that this could be charged up during the night when we often do not need the car anyways. We would then benefit from the low price rate during nighttime, and we would have a fully charged EV ready in the morning. This would also be a benefit to the grid, as the power peaks are relatively small during night. For the dishwasher and washing machine, these are appliances we often would want to use at daytime when we are home. If the washing machine could be turned on and be finished before the peak-hours begin, this would be a reasonable time to wash our cloths. If we have to wait until after peak-hour, it's often to late to do this chore. A dishwasher is something we would probably want to turn on after we are finished eating dinner. If we finish dinner before peak-hours ends, we should wait to turn it on until the peak-hours are over and the pricing rate is low, in this case at 8 pm.

The total cost will be the same if we run the appliances at different times, or at the same time, during off-peak hours. However, we should consider the effects of using all the appliances simultaneously. This will cause a higher consumption, causing a higher power demand. This will cause a higher load on the power grid, which may affect the development of the pricing scheme in the future, as well as the power companies may feel the need to raise the network tariff. It is therefore more reasonable to distribute the energy load more equally during the timeline.

The one day household consumption we found to be realistic, and cost effective, is illustrated in figure 3. The EV is charged during night, the laundry machine is started after work, and the dishwasher is turned on in the evening. The calculated lowest energy cost using our algorithm is 6.64 NOK. This can easily be checked analytically,

$$c_{min} = (1.44 + 1.94 + 9.90)_{app}\ \mathrm{kWh} * 0.5\frac{\mathrm{NOK}}{\mathrm{kWh}} = 13.28\ \mathrm{kWh} * 0.5\frac{\mathrm{NOK}}{\mathrm{kWh}} = \underline{6.64\ \mathrm{NOK}}$$

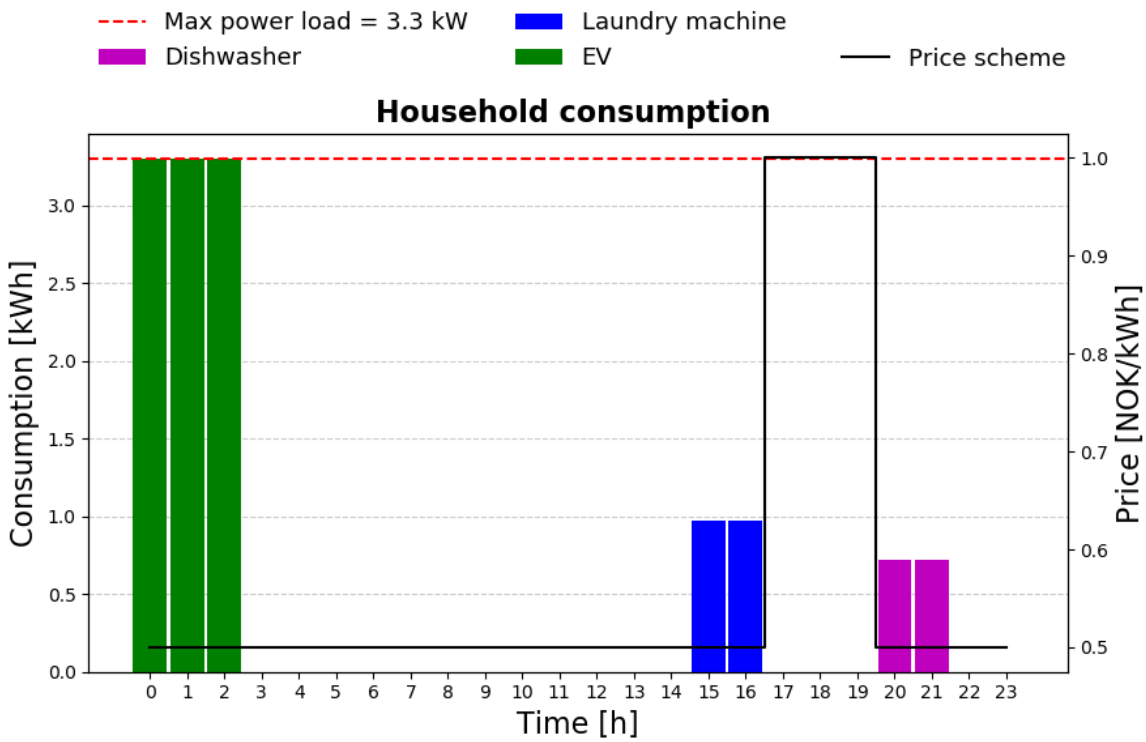

Figure 3: The energy consumption of the household during a day.

In figure 3, we also observe that the EV causes a higher energy peak during night time. The total energy required to charge the EV each day could be distributed over a couple of more hours, then the hourly demand would be reduced.

5.3 Real-Time-Pricing scheme

The RTP scheme used for the complex household and the neighborhood is illustrated in figure 4. We have to assume that this is created before the day starts, so that our program knows for which time-slots to assign the different appliances to minimize the energy cost. The figure also illustrates the two peak-hours we added to our calculations, one during the morning, and one during the afternoon, as described in section 4.2.

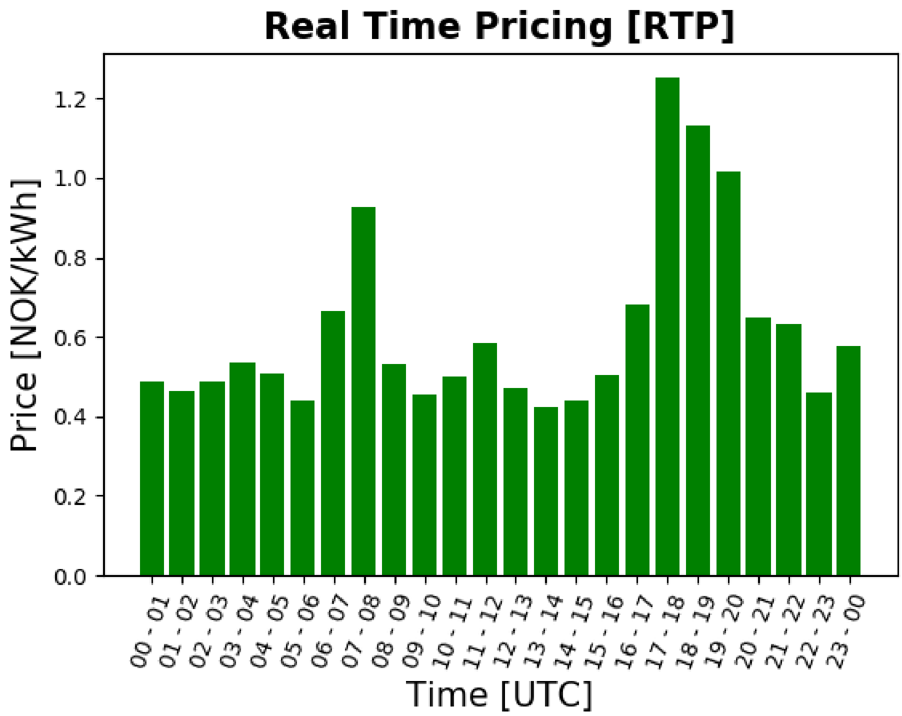

Figure 4: The price variations (RTP) during the day.

5.4 Complex household | RTP

In figure 5 we can see how the different appliances is distributed at different hours to minimize the energy cost. We observe that the non-shiftable appliances, for instance heating and lightning, are turned on at the given times whether its peak-hour or not. This is according to our expectations, since we have determined that these appliances must be kept on, because of the necessity to use these appliances at the given times.

When it comes to the shiftable appliances, it seems like our algorithm successfully manage to distribute the shiftable appliances at reasonably hours given the timing constraints and the higher price during the peak-hours. We see that the shiftable appliances is placed outside the peak-hour, resulting in lower cost. Table 6 provides the consumption and minimized cost for the household.

Table 6: Consumption and minimized cost for the complex household.

Non-shiftable consumption [kWh]	Shiftable consumption [kWh]	Opt. shiftable consumption [kWh]	Total appliance consumption [kWh]	Minimized cost [NOK]
17.7	15.8	1.5	35.0	19.1

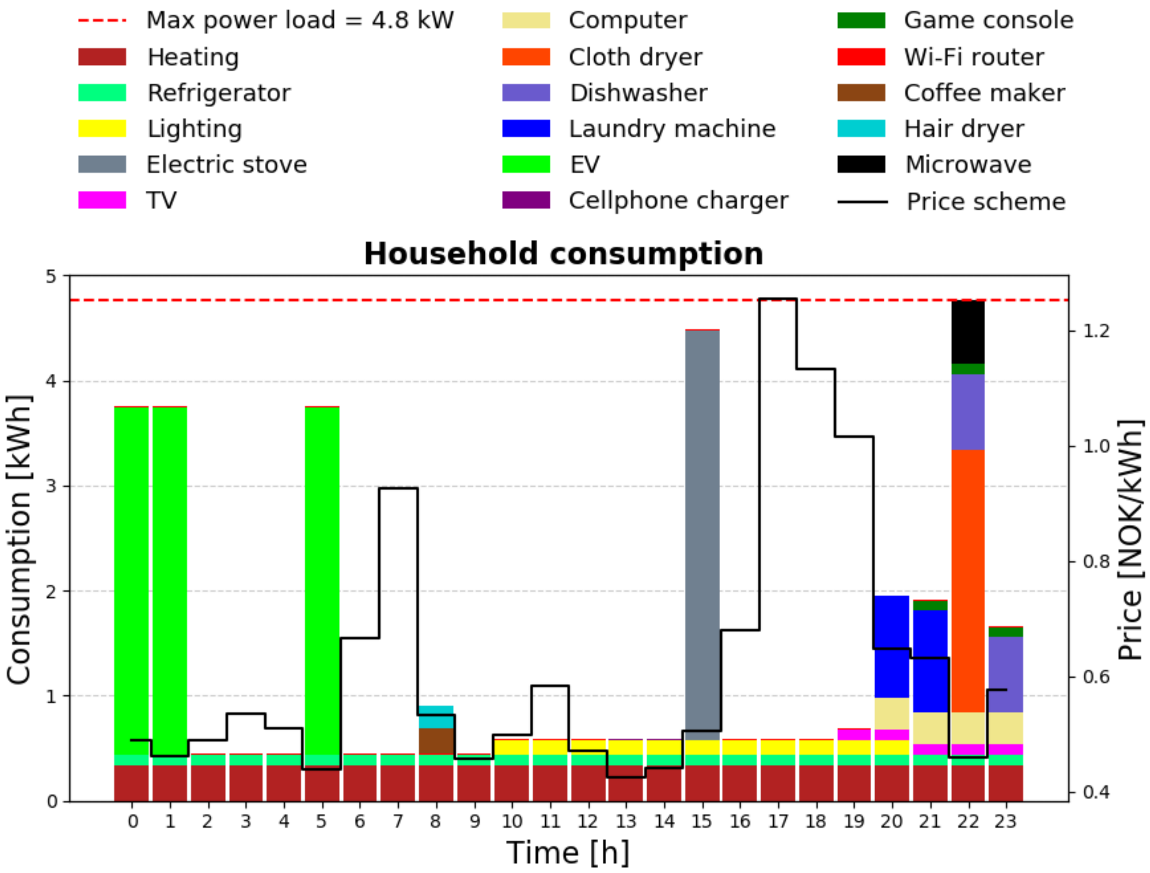

Figure 5: The energy consumption for the household's appliances during one day.

For the EV (which can be charged between 00:00-06:00, but only needs 3 hours to charge up) we see that our program splits up the charging to minimize the energy cost. To split up the charging for an EV to benefit from the low cost, is probably an easy and realistic thing to accomplish in real-life, using for instance a timer or the app that most car manufacturers provides to their EV. However, for some of the other devices, splitting up the usage could be more problematic. For instance, a laundry machine which takes 2 hours to finish, may not work properly if the power is cut off right in the middle of the program!

To summarize, figure 5 provides a good reminder of the importance of having some knowledge about price variations, appliances and consumption. If the consumer is aware of when peak-hours usually occur and keeps track of the electricity market, the consumer will have the ability to gain a lot economically. However, this also requires that the user has some knowledge of the different appliances, and their power consumption. For instance, the figure illustrates how some shiftable appliances (like the EV discussed above) consume a lot of kWh in a short period of time. Being aware of these things, the user may adjust his/hers habits of using the appliances, to achieve a lower cost.

5.5 Neighborhood | RTP

In figure 6 we have the total energy consumption for the neighborhood for a day, with RTP. The graph is split into consumption for non-shiftable and shiftable appliances, to get an overview where the main energy consumption is used during the day. We can see that 17 households owns an EV, which are all charged during the three hours with the lowest rate, from midnight to 2:00 and 5:00-6:00 UTC. The main goal of the assignment were to use linear (programming) optimization to minimize the energy cost, by relocate the high power demand during peak-hours to hours with a desirable pricing rate. We can see from the graph that this have been achieved, as the shiftable appliances are used at a minimum during the time frame from 16:00-21:00 UTC.

The total power consumption used by the neighborhood is listed in table 7. We can see that the non-shiftable appliances contributes to the largest part, mostly because of the electric stove used at 15:00 UTC. The table also shows the total minimized cost of 502.6 NOK.

From the figure we also observe high peak loads at 15:00 and 22:00 UTC. This is because all the households are provided the same timing constraints for the same appliances. This is an unrealistic scenario, because in real life not everyone returns home to cook dinner at 15:00, or use the cloth dryer at 22:00. To achieve a more realistic result, we could for instance assign different timing constraints for the appliances for each household. This can be done by changing the α and β parameters in the input excel-file, or by adding a slightly random variation to these parameters in the program. Making this change would spread the consumption of the shiftable appliances over a wider time, better reflecting a neighborhood consisting of individual households.

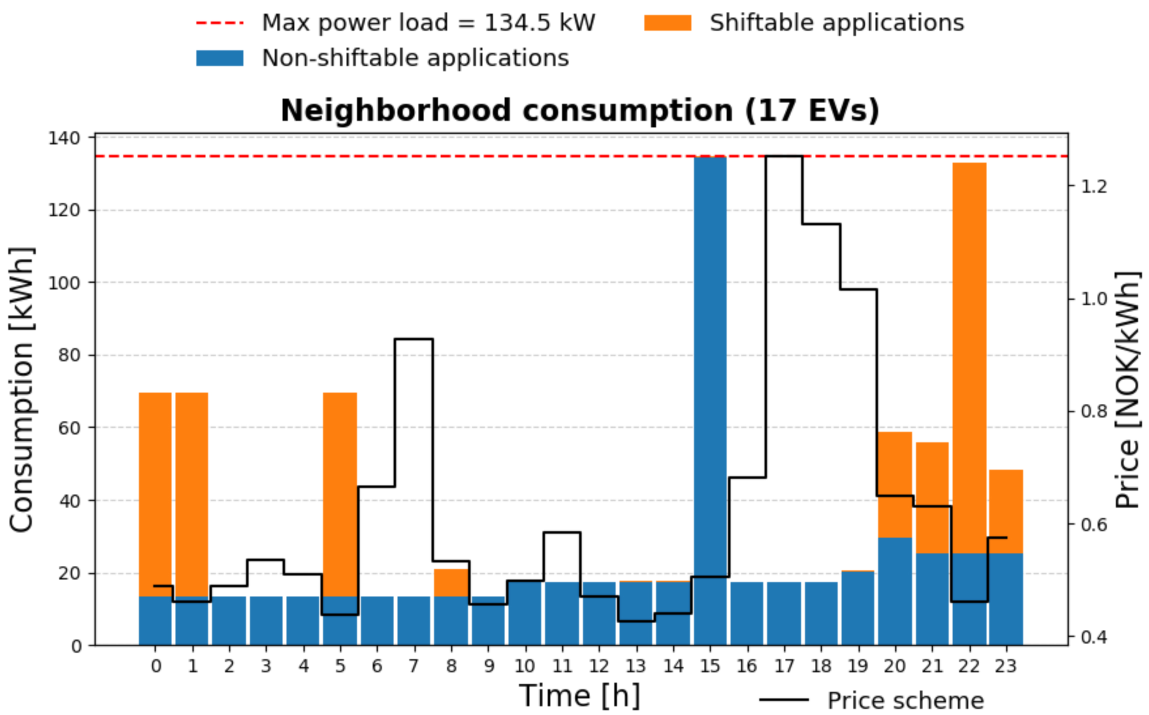

Figure 6: Energy consumption for a neighborhood consisting of 30 households.

Table 7: Consumption and minimized cost for the neighborhood.

Non-shiftable consumption [kWh]	Shiftable consumption [kWh]	Total appliance consumption [kWh]	Total minimized cost [NOK]	Number of EVs
532.2	368.4	900.6	502.6	17

In table 8 we have various information about the individual households in the neighborhood. The optional shiftable appliances where randomly selected by our Python program, where each house had to have between 2 and 6 optional appliances.

CC - Cellphone charger, GC - Game console, WiFi - Wi-Fi router, CM - Coffee maker, HD - Hair dryer and MW - Microwave.

Table 8: All 30 houses in the neighborhood

House	Non-shift. [kWh]	Shift. [kWh]	Total [kWh]	EV	Optional application	Min. Cost [NOK]
1	17.74	6.94	24.68	No	CM, HD, MW	14.3
2	17.74	6.04	23.78	No	CC, WiFi	13.8
3	17.74	6.26	24.00	No	WiFi, CM	14.0
4	17.74	6.54	24.29	No	CC, GC, WiFi, CM	14.1
5	17.74	16.30	34.05	Yes	CC, GC, CM	18.6
6	17.74	7.37	25.11	No	CC, GC, WiFi, CM, HD, MW	14.5
7	17.74	16.39	34.14	Yes	CC, WiFi, CM, HD	18.7
8	17.74	17.25	34.99	Yes	GC, WiFi, CM, HD, MW	19.1
9	17.74	16.79	34.53	Yes	GC, WiFi, MW	18.8
10	17.74	16.86	34.59	Yes	CC, CM, HD, MW	18.9
11	17.74	6.13	23.88	No	CC, CM	13.9
12	17.74	16.84	34.58	Yes	CM, HD, MW	18.9
13	17.74	6.28	24.02	No	CC, WiFi, CM	14.0
14	17.74	16.16	33.90	Yes	CC, WiFi, HD	18.5
15	17.74	16.18	33.92	Yes	CC, WiFi, CM	18.6
16	17.74	6.88	24.62	No	CC, WiFi, CM, MW	14.2
17	17.74	16.04	33.78	Yes	CC, CM	18.5
18	17.74	17.05	34.79	Yes	CC, GC, WiFi, CM, MW	19.0
19	17.74	7.14	24.89	No	CC, GC, WiFi, CM, MW	14.4
20	17.74	17.12	34.87	Yes	CC, GC, CM, HD, MW	19.0
21	17.74	6.50	24.24	No	CC, MW	14.0
22	17.74	16.76	34.50	Yes	CC, WiFi, HD, MW	18.8
23	17.74	6.04	23.78	No	CC, WiFi	13.8
24	17.74	16.91	34.65	Yes	CC, GC, CM, MW	18.9
25	17.74	17.03	34.77	Yes	GC, WiFi, CM, MW	19.0
26	17.74	16.16	33.90	Yes	CC, WiFi, HD	18.5
27	17.74	16.19	33.93	Yes	GC, WiFi	18.6
28	17.74	7.12	24.87	No	CC, GC, WiFi, HD, MW	14.4
29	17.74	6.72	24.46	No	CM, MW	14.2
30	17.74	16.43	34.17	Yes	CC, GC, WiFi, HD	18.7

5.6 ToU and RTP impact on the energy cost

The future of a well functioning smart grid systems will be dependent on direct and intelligent load control [2]. The direct control should be dependent on smart-appliances in the household, where the power suppliers can remotely control non-essential appliances during high power demand periods. The intelligent control is based on pricing, and can be done by the customers, both to reduce the power bill, but also help the suppliers to reduce power peaks. Both the ToU and RTP models are ideal for this.

As we recall from earlier, when using the ToU pricing scheme, the consumer is informed about the price well in advance. This gives them an overview of the exact rates during the day in the future to come. This means that ToU allows the user to set routines for when certain appliances should be used and gain a good control of the costs. This is especially useful for charging an EV, or deciding when to do laundry. So, compared to a static pricing scheme where the price is equal the entire day, it can definitely be money to save using ToU.

The RTP pricing scheme is even more advanced, containing constant variations in the hourly price. Since RTP follows the current situation in the power market, this pricing scheme will naturally be of higher risk for the consumer, but can also gain a higher reward than other pricing schemes. Comparing RTP with a flat-rate pricing scheme, studies show that the consumers would benefit from using RTP. For instance, the American paper **The cost and benefits of Real-Time-Pricing. An empirical investigation into consumer bills using hourly energy data and prices** [9], states that : *"The cost of average, flat-rate supply service for individual consumers was significantly higher than the hourly market price in 2016. ComEd customers on the utility's default, flat-rate supply price as a whole paid, on average, over 13 percent more than they would have on real-time pricing"*. Another interesting thing their analysis showed, is that 97 % of the ComEd customers would benefit from RTP, even without changing their behavior.

New appliances are continuously made smarter, so they can have a two-way communication with the smart grid, and be connected to the internet. This makes it possible to turn on or off appliances even though you are away from home, e.g. the laundry machine can be turned on two hours before you return from work. But by making customers more aware of the high pricing rates during peak-hours, it's easy to reduce cost even without smart-appliances. In a pilot study with Malvik Everk, **Demand response from household customers: experiences from a pilot study in Norway** [6], customers were provided stickers to apply on appliances. These just stated which hour are peak-hours, so they were easy to avoid. The study concluded that *"..load shifting from peak periods to off-peak periods. This resulted in an economic benefit for the customers due to moving loads from hours with high prices to hours with lower prices"*.

Comparing ToU and RTP, we think most people would find ToU to be useful, and well worth the effort to move some appliances around to gain a lower energy cost. Some people are still skeptical to the use of smart-meters and RTP, but if power companies continue to create better solutions, without necessarily a hands-on user participation, we think this is the stepping stone for the future of home energy management. Already today there are for instance apps, like **Tibber - Smartere strøm** [8], that helps the customer gain control over the power consumption of the household. One of the advantages with Tibber is that the app is connected to the smart-meter and smart-appliances, taking care of smart-heating, EV charging and more.

6 Conclusion

We can conclude that introducing residential power consumers to non-static pricing schemes like ToU and RTP will have a positive outcome, especially if their appliances are handled right. This means, the consumers should manage their appliances intelligently in order to minimize energy cost. The ToU method is predetermined for each time period, making it easy for consumers to make a predefined cost efficient plan for when appliances should be used. Different from the ToU method, is the RTP method where the hourly rates are dynamically changed based on a reflection of the power market. Although the rates should be provided at least a day in advance, it would be necessary to have smart-appliances to get the best utilization of the system.

When analyzing home energy management and/or demand response situations, it is often a complex problem consisting of many factors that must be taken into consideration. Some factors even depend on unpredictable events, like the cost of producing electricity may change according to weather conditions. During our analysis, we detected several changes that could have been made to reflect more realistic scenarios. For instance, implementing different timing constraints for each household in the neighborhood would have provided a more realistic picture of the power demand. We have also seen that "smarter" appliances in combination with a smart-grid could be beneficial to further reduce the energy cost, as well as reducing peak loads on the power grid.

The trending in the power market indicates that our societies need for electricity will continue to increase in the future. The current power grids are not able to handle this change, and expanding the existing grid comes with a high cost, although probably inevitable. By introducing smart grids, smart meters and tariffs that follows a dynamic pricing based on the market, the highest power peaks can be reduced, as well as reducing the energy cost for both power companies and power consumers. Luckily, technology is constantly evolving, providing us with energy-efficient appliances and better solutions for the future.

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