Report

Question 1

Appliances:

- Washing Machine
- EV
- Dishwasher

Time-of-use pricing scheme: 1NOK/kWh between 5:00 pm - 8:00 pm

0.5NOK/kwh for off-peak hours (everything else).

Optimization problem to obtain minimum energy cost:

$$\min \sum_{i=1}^{3} \sum_{t \in S_i} P_i \cdot C(t)$$

where:

- SUM of x1,x2,x3: Start times for the **dishwasher, washing machine, and EV charging**.
- Pi: Power consumption per hour for each appliance i.
- C(t): Cost per kWh at a given time slot t, which can be:
  - **1 NOK/kWh** during peak hours.
  - **0.5 NOK/kWh** during off-peak hours.
- Si represents the set of time slots when appliance i is running.

Constrains

1. Energy requirements:
   a. Dishwasher: 1.44 kWh total.
   b. Washing machine: 1.94 kWh total
   c. EV: 9.9 kWh total

2. Time slot availability:
    a. Each appliance should complete its operation within 24 hours
    b. No overlapping constraints since shiftable appliances can run in parallel

Strategy

Trying to avoid peak hours (5 pm to 8 pm)

Mathematically it would make sense to just run the appliances at the same time in off-peak hours such as 2:00 am since the only goal is to minimize the cost, but in practical that could cause load on the power system causing it to turn off.

Therefore a more optimal approach would be to schedule the appliances to start after each other without entering the peak hours spot in the day.

How long these 3 appliances run for where not mentioned in the assignment description therefore the only thing that's left to do is just estimate.

These are the estimations:

EV charging: 9 hours

Dishwasher: 1 hour 30 minutes

Washing machine: 1 hour 30 minutes

Scheduling plan:

- **EV Charging**: 9.9 kWh → **12:00 AM - 9:00 AM**
- **Dishwasher**: 1.44 kWh → **9:00 AM - 10:30 AM**
- **Washing Machine**: 1.94 kWh → **11:00 AM - 12:30 PM**

Calculation:

Since all appliances are scheduled outside **5 PM - 8 PM**, they all run at **0.5 NOK/kWh**.

$$\text{Total Cost} = (9.9 + 1.44 + 1.94) \times 0.5 = 6.64\,\text{NOK}$$

Question 2

Formulation as a linear programing optimization problem.

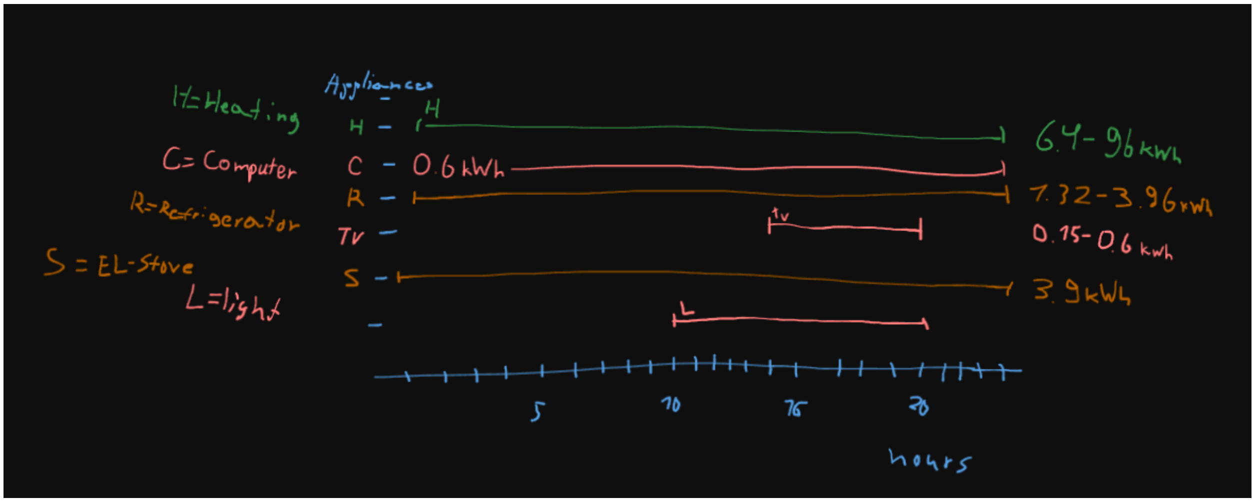
$$\text{Minimize} \quad \sum_{i=1}^{N} \sum_{t=1}^{24} x_{i,t} \cdot P_i \cdot C_t$$

where:

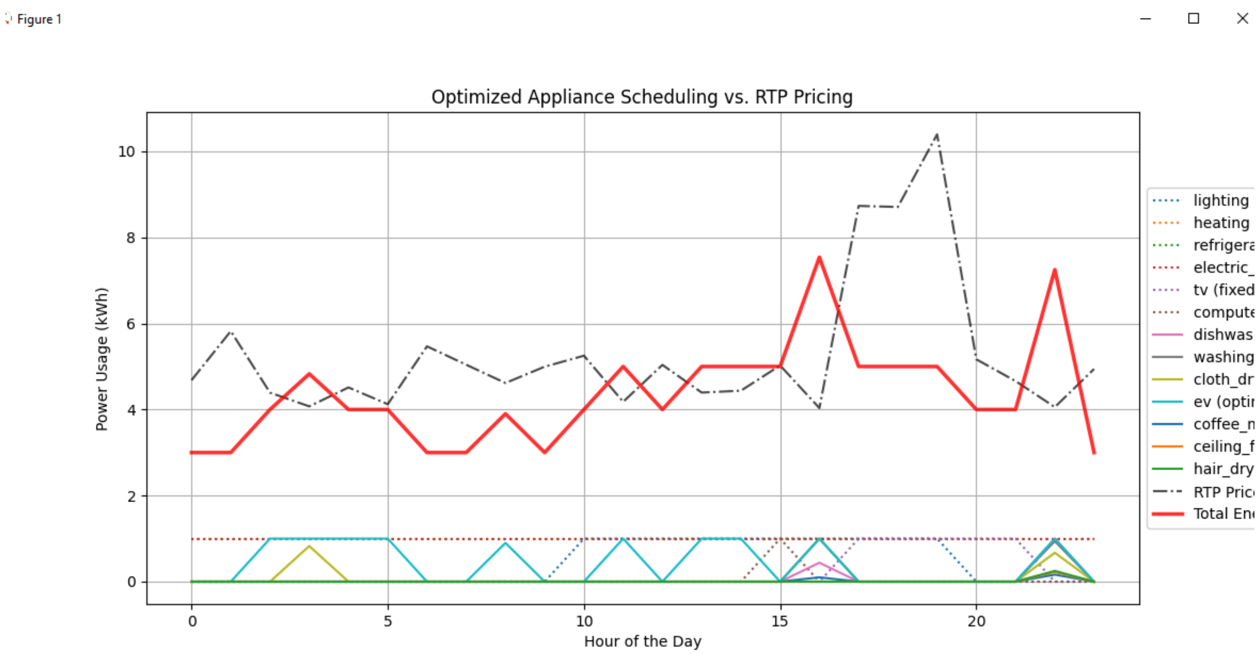
- xi,t is a binary decision variable: **1 if appliance i is ON at hour t, 0 otherwise**.
- Pi is the **power consumption (kWh)** of appliance i.
- Ct is the **electricity price (NOK/kWh) at hour t, determined by real-time pricing (RTP)**.
- N is the **total number of appliances**.

Constrains:

1. Each appliance must consume its required daily energy
2. Each appliance operates between it's operating window
3. The total power used in any hour must not exceed a given threshold



This illustrates the range that each appliance will be active on.



plot of house appliances, if for example ev is 1 it means they're turned on, the black dashed line is the RTP price and the red line is the total energy consumed per hour. As you can notice the algorithm tries to prioritize minimum RTP cost, so it schedules the appliances in the most cost effective territory and doesn't try to run them in peak hours.

The problem is solved by applying a linprog function where the the max power constrains are between appliances * num_hours and max_power_per_hours. These constrains are appended into lists and are converted to numpy arrays.

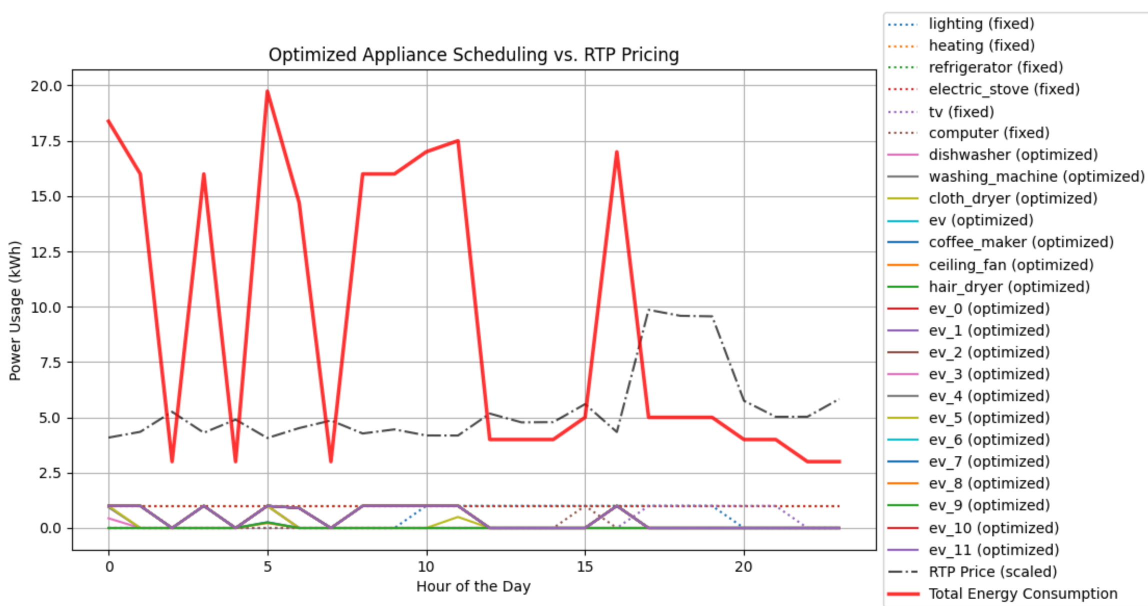
The result is returned along with the shiftable appliances list and is then plotted.

Question 3

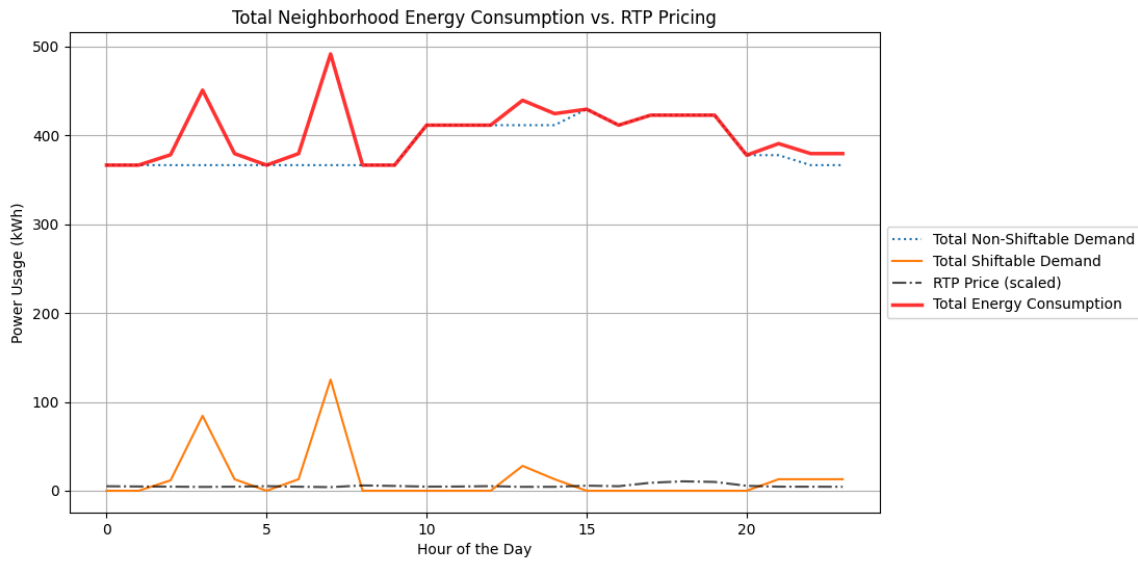
In this problem we have to optimize the scheduling of appliances in a neighborhood. The amount of households is set to 30 and each household can have both non-shiftable and shiftable appliances. The goal is to minimize the total energy cost the neighborhood considering the real-time pricing that is randomly generated.

Problem overview

1. Appliance categories:
    - Non-shiftable appliances: fixed operational times
    - Shiftable appliances: these appliances can be rescheduled to minimize power consumption during peak hours
2. RTP curve: Electricity price varies by the time of day, higher prices during peak hours eg 17-19. Goal is to schedule the shiftable appliances in a way to minimize the cost, avoiding peak-hour usage as much as possible.
3. optimization problem:
    - for each household and each shiftable appliance, decide which hour of the day it should be turned on
    - minimize total cost for all households in the neighborhood based on the RTP curve
    - Constrains:
        - Each shiftable appliance must consume its energy within its available time window
        - Non-shiftable appliances have fixed operation time



above is a figure that illustrates a since appliance energy consumption



above is a figure that illustrates the total energy consumption of the neighborhood

The problem is solved by building a cost vector penalizing peak hour usage, if the time of day the shiftable appliance is running is in peak hours, they will get a penalty of 100. Then there's a equality constraints meaning that each appliance should run for it's required energy level and at what time they're allowed to run.

The inequality constraints is max power limit per hour, this is something that is used in question 4 and therefore is set to a very high number in question 3 to see how the optimization function reacts differently.

At the end there's a function to calculate total energy cost for the entire neighborhood, this is done by running optimize schedule for each number of households and then returning the total cost. This is the total energy cost for the neighborhood. It is then plotted using the plot_schedule() function.

Run oblig1.3.py

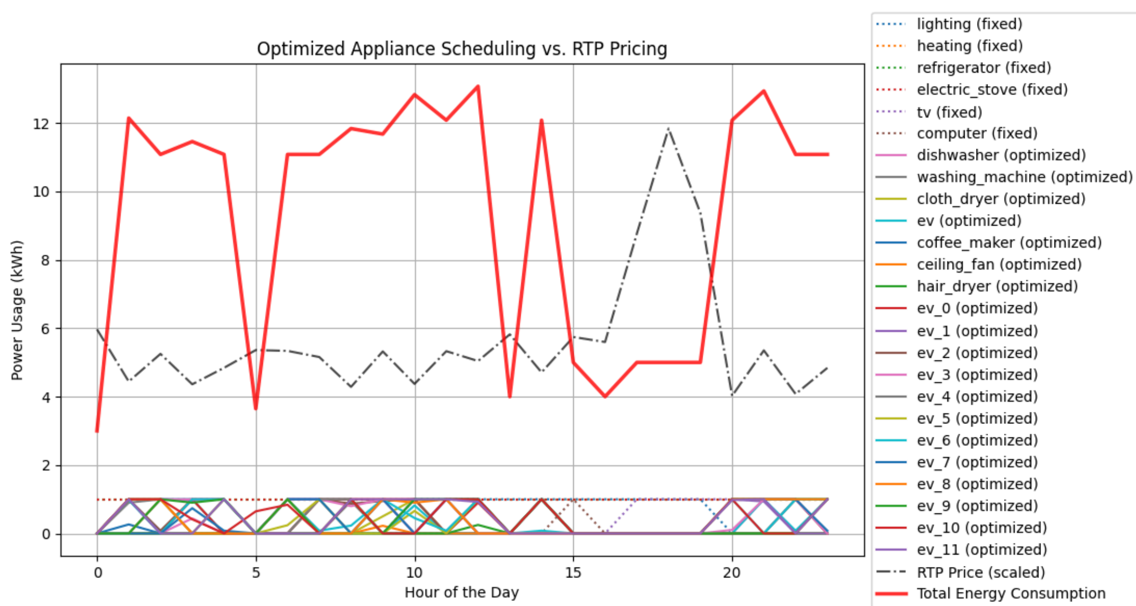
required libs:

numpy, matplotlib and scipy

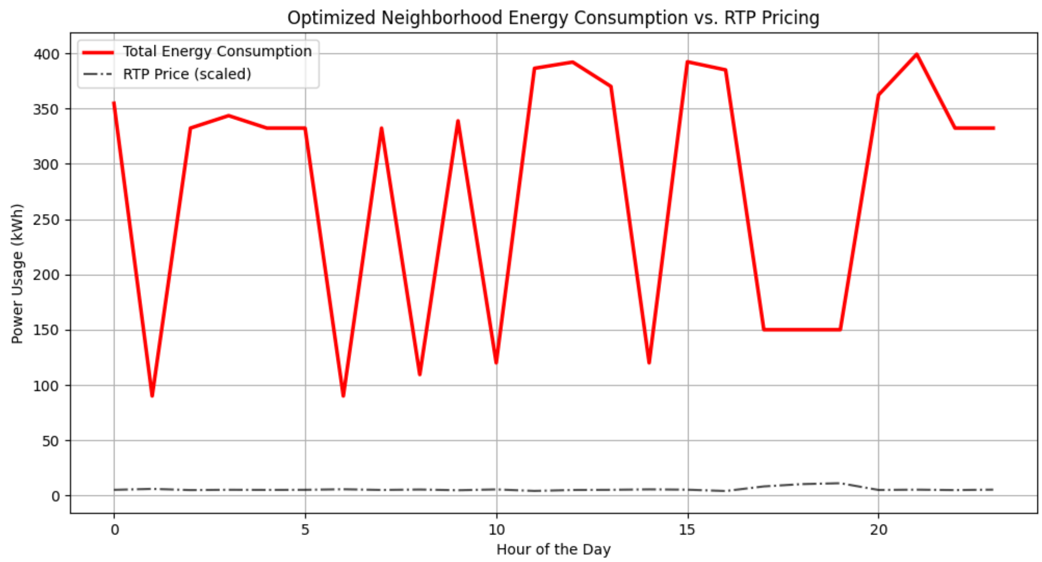
how to install: pip install *needed package*

Question 4

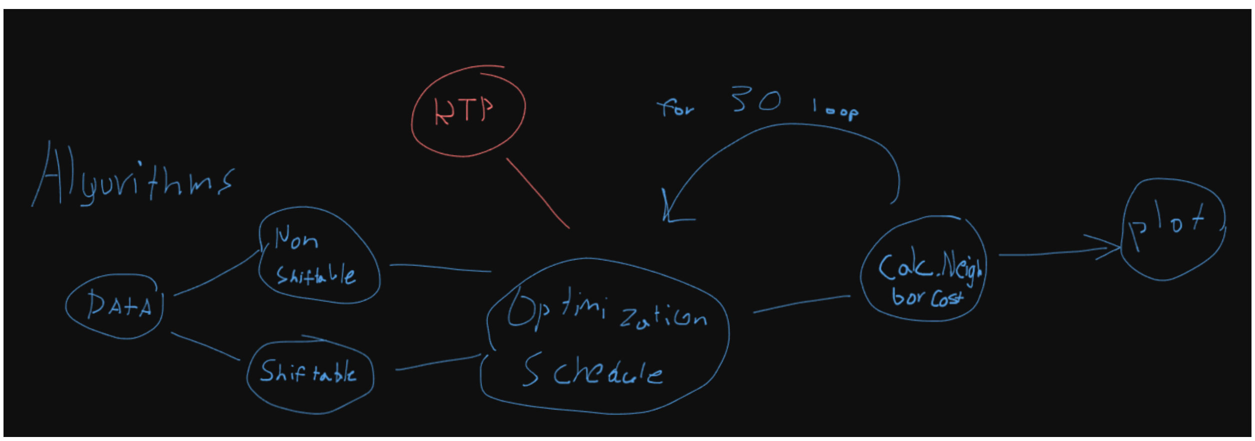
To improve this I tried to set the max power per hour to 80. The main difference in theory is that it should eliminate or chip away the peaks to be instead evenly distributed. However the result came out rather flocculating. This can be explained by the algorithm prioritizing the areas with as less rtp price as possible.



this shows a figure of a single house power usage



shows a figure of a neighborhood power usage



A flowchart explaining how algorithms are called

Analysis of ToU and RTP

ToU (time of use) offers a constant more predictable pricing model, where the rates are predetermined based on time. Just as RTP it increases on peak hours and is inherently made to shift demand from peak to off peak times. ToU mostly gets its price predetermined and does not fluctuantly change like RTP. RTP is a more dynamic approach and the prices floctuate based on the real time market. Hence also (real time pricing), it seems to me that RTP is much more complex as a price rate calculator and it can also offer much more flexibility if the energy usage changes in real time.

I do want to point out that if you look at it from a long-term vs short-term perspective TOU can be much better for long term optimization strategy meanwhile RTP works best with short-term optimization

RTP can also react to real time market changes, such as fuel cost, weather, renewable energy availability etc meanwhile TOU has a much more stable and predictable price line and it means that users may not benefit from the fluctuations that RTP can provide during periods of high renewable energy generation.