Smart Grid Fundamentals

MEEC

Assignment VI: Flexibility Management

Authors:

Rodrigo Contreiras (90183) rodrigo.contreiras@tecnico.ulisboa.pt
Gonçalo Aniceto (96218) goncalo.aniceto@tecnico.ulisboa.pt

2022/2023 – 1st Semester, P2

Contents

1 Objectives

For this assignment we had to work with the *GAMS Studio 41* program to optimize a given problem.

The problems to optimize are related to the power consumption of a household with 5 loads and a set of flexibilities during a 24 hours period. The power for the loads can be provided, either through the Energy Grid, through a Photovoltaic System, from know on referred as **PV system** or through a Battery Energy Storage system, from know on referred as **Energy system or storage**.

Problem 1 considers that only the loads, the PV system and the Energy Grid are connected. Problem 2, adds an extra connection to the Energy system. To make more accurate and vast observations, we divide the Problem 2 in two other. Problem 2.1 assumes that the Energy Storage can only provide power to the loads, while Problem 2.2, assumes that besides interacting with the household, the Energy system can also interact with the Energy grid. Lastly Problem 3 adds a constraint for a reduction of the power consumption. Therefore, will test this added constraint with the assumptions made for the previous Problems 1 and 2.2

2 Problems

In this section we answer to the three problems presented in the assignment. To do so we need to take in account the tables for the power demand and the demand flexibility of the loads, the PV system Generation power, the cost in kWh and the scalars, presented in figure 1 to 5, respectively:

** Node demand in m^3/h
Table Pd(i,t) "Power demand (kW)"

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	144.0	145.8	147.6	140.4	133.2	117.0	100.8	91.8	82.8	75.6	69.6	63.6	57.6	55.8	54.0	61.2	68.4	80.4	92.4	104.4	115.2	126.0	136.8	147.6
2	219.6	223.2	226.8	217.8	208.8	180.0	151.2	136.8	122.4	111.6	104.4	97.2	90.0	84.6	79.2	90.0	100.8	118.8	136.8	154.8	174.6	194.4	214.2	234.0
3	219.6	223.2	226.8	217.8	208.8	180.0	151.2	136.8	122.4	111.6	104.4	97.2	90.0	84.6	79.2	90.0	100.8	118.8	136.8	154.8	174.6	194.4	214.2	234.0
4	194.4	198.0	201.6	190.8	180.0	158.4	136.8	122.4	108.0	100.8	93.6	86.4	79.2	75.6	72.0	81.0	90.0	106.8	123.6	140.4	154.8	169.2	183.6	198.0
5	64.8	64.8	64.8	61.2	57.6	50.4	43.2	37.8	32.4	28.8	27.6	26.4	25.2	25.2	25.2	27.0	28.8	32.4	36.0	39.6	47.7	55.8	63.9	72.0

Figure 1: Power demand for each load during 24h period.

Table DeltaP(i,t) "Demand Flexibility (%)"

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.05	0.1	0.1	0.1	0.1	0.1
2	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
3	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
5	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3

;

Figure 2: Demand flexibility for each load during 24h period.

Table PV(i,t) "PV Generation (kW)"

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	0	0	0	0	0	20	80	300	800	1250	1600	1800	2000	1800	1700	1400	950	500	150	30	0	0	0	0

;

Figure 3: Power production of the PV system during 24h period.

```
** cost in ? KWH per hour
Parameter
 cost(t)
/ 1 0.1, 2 0.1, 3 0.1, 4 0.1, 5 0.1, 6 0.1, 7 0.1, 8 0.2,
  9 0.2, 10 0.2, 11 0.2, 12 0.2, 13 0.2, 14 0.2, 15 0.2, 16 0.2,
 17 0.2, 18 0.2, 19 0.2, 20 0.2, 21 0.2, 22 0.2, 23 0.1, 24 0.1/;
```

Figure 4: Cost per Kwh during 24h period.

```
Scalar
         Pmax       "kW"              / 850  /
         E_Stor     "kWh"             / 2000 /
         E_Ini      "kWh"             / 1000 /
         P_ch_max   "kW"              / 1500 /
         P_dch_max  "kW"              / 1500 /
         eff        "%"               / 0.98 /
;
```

Figure 5: Scalars that represent fixed variable values.

2.1 Problem 1

To formulate the problem we defined it on figure 6:

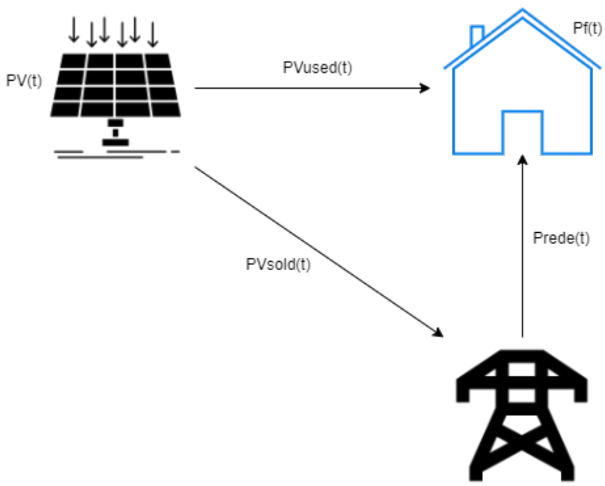

Figure 6: Representation of the connections between the different installations.

As it is visible, the loads, represented on the figure as "Pf(t)" receive power from both the PV system, represented on the figure as "PV(t)", as well as the Energy Grid, represented on the figure as "Rede". Also, the power that is not used from the PV system to power the loads, is then sold to the Energy Grid.

By analysing the figure, as well as the assignment directives, we get to the following representations for the problem definition:

$$P_f(t) = P_{rede}(t) + PV_{used}(t); \tag{1}$$

$$PV(t) = PV_{used}(t) + PV_{sold}(t); \tag{2}$$

$$P_{rede}(t) <= 850; \tag{3}$$

Regarding to the value of the power from the loads, Pf(t), it is calculated based on the power demand and demand flexibility of each load at each hour, represented in figures 1 and 2 respectively. This value, will be the actual power consumed by the loads. All this translates into the following equations in *GAMS studio 41* language:

```
**** General
Flexeq(i,t)..       Pf(i,t)=e=Pd(i,t)+Flex(i,t);
Flexeq2(i,t)..      Flex(i,t)=l=Pd(i,t)*DeltaP(i,t);
Flexeq3(i,t)..      Flex(i,t)=g=-Pd(i,t)*DeltaP(i,t);
MaxConsumption..    sum((i,t), Pf(i,t)) =e= sum((i,t), Pd(i,t));
PfdisplayEq(t)..    Pfdisplay(t) =e= sum(i, Pf(i,t));
**** 1
ConsoMax(t)..       Prede(t)=l=Pmax;
Pf2Eq(t)..          Prede(t) =e= sum(i, Pf(i,t)) - sum(i, PVused(i,t));
PVauxEq(i,t)..      PVused(i,t) =l= PV(i,t);
PVcostEq(i,t)..     PVsold(i,t) =e= PV(i,t) - PVused(i,t);
```

Figure 7: Equations that represent the problem in *GAMS studio 41* language.

Before running the simulation on GAMS to obtain the optimized solution, we made some initial observations and predictions, in order to both analyze if the results we where obtaining made sense and to compare our initial beliefs with the actual results to get to some better conclusions.

Observations:

obs 1: PV(t) is entirely provided to the loads (Pf(t)), when the selling price is zero or less than the buying price over the Energy Grid, and only uses the Prede(t) when necessary;

obs 2: When the selling price on the Energy Grid is equal to the buying price, it doesn't matter whether the PV(t) is supplied to the loads or sold to the Energy Grid;

obs 3: When the selling price is higher than the purchasing price over the Energy Grid, PV(i,t) is completely sold over the Energy Grid and Prede(t) is used to supply electricity to the loads (Pf(i,t));

Predictions:

a): In accordance with **obs 2**, we will encounter one of the following three scenarios:

situation 1: It will happen as stated on **obs 1**;

situation 2: It will happen as stated on **obs 2**;

situation 3: It will happen as stated on **obs 3**;

Theoretically, due to a probabilistic character, situation 2, is the one that is most likely to occur because there are a far higher number of distinct solutions than there are for situations 1 and 3, which are unique.

b):
It will happen as stated on **obs 1**.

c):
It will happen as stated on **obs 3**.

d):
In this case, since maximizing personal consumption is the goal, the maximum amount of PV(t) energy consumption will be attempted. In this way, the PVused(t) will be as high as it can be and only the excess that isn't used to power the loads will be sold.

We can start answering the assignment questions.

2.1.1 Problem 1.a)

On this problem, we want the minimum cost knowing that the buying price from the Energy Grid to the Loads is the same as the selling price, from the PV system to the Energy Grid. This is represented in the following equation:

$$cost = \sum_t P_{rede}(t) * cost(t) - \sum_t PV_{sold}(t) * cost(t); \tag{4}$$

Which translates to the *GAMS studio 41* language:

```
** a)
costs..          z =e= sum(t, Prede(t)*cost(t)) - sum((i,t), PVsold(i,t)*cost(t));
```

Figure 8: Cost equation in *GAMS studio 41* language.

After running the program we got to the following result for the minimal cost:

```
220 VARIABLE z.L                         =      -793.886  total costs during the day
```

Figure 9: Minimal cost achieved.

This was achieved by having the following powers for the variables used:

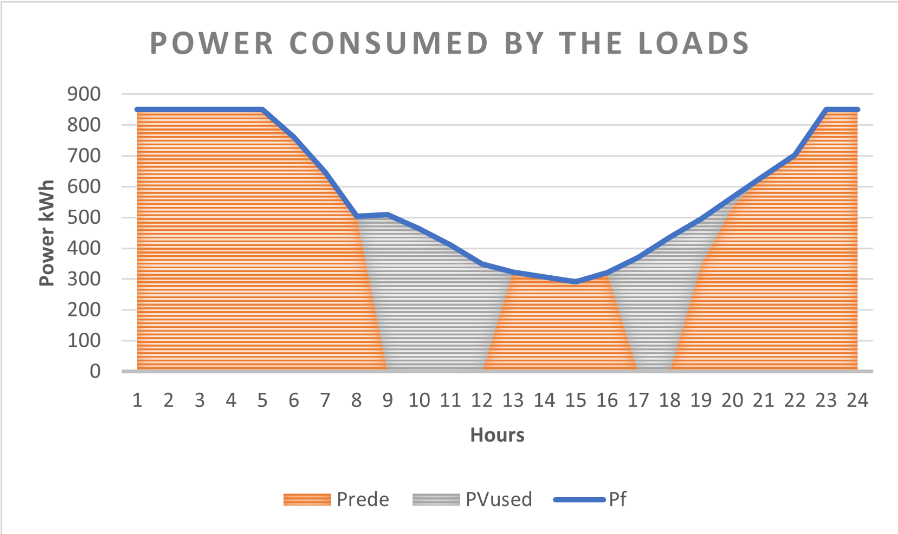

Figure 10: Power consumed by the loads.

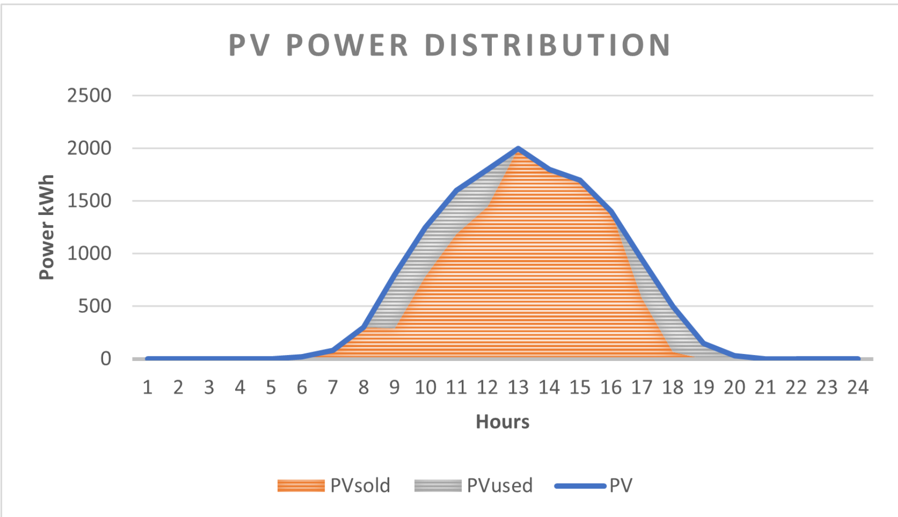

Figure 11: PV power distribution.

As we can see by looking at figures 10 and 11 and at the tables from Appendix A.1, is clearly visible that all the constraints set for this problem where met. On figure 10 the Prede(t) and PVused(t) are stacked together, for us to have the sum of them, which is equal to the Power consumed by the loads (Pf(t)) and on figure 11 Psold(t) and PVused(t) are also stacked and equal to the total PV(t) production.

To note, that our prediction for this exercise was correct. The PVused(t) and Prede(t) are used by the loads in a random way, as long as they comply with the minimum cost value for Pf(t).

2.1.2 Problem 1.b)

On this problem, we want the minimum cost knowing that the selling price, from the PV system to the Energy Grid is zero. This is represented in the following equation:

$$cost = \sum_t P_{rede}(t) * cost(t); \tag{5}$$

Which translates to the *GAMS studio 41* language:

```
** b)
costs..               z =e= sum(t, Prede(t)*cost(t));
```

Figure 12: Cost equation in *GAMS studio 41* language.

After running the program we got to the following result for the minimal cost:

```
220 VARIABLE z.L                    =      1143.792  total costs during the day
```

Figure 13: Minimal cost achieved.

This was achieved by having the following powers for the variables used:

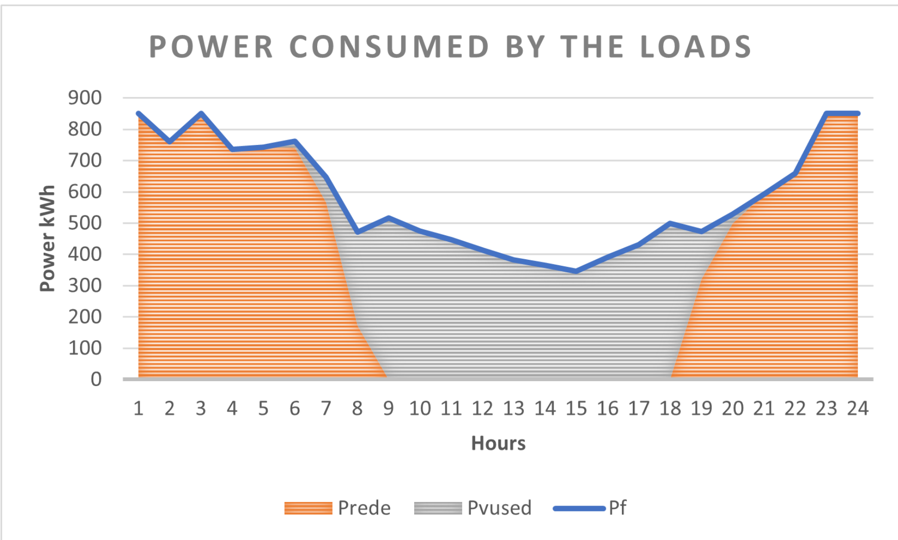

Figure 14: Power consumed by the loads.

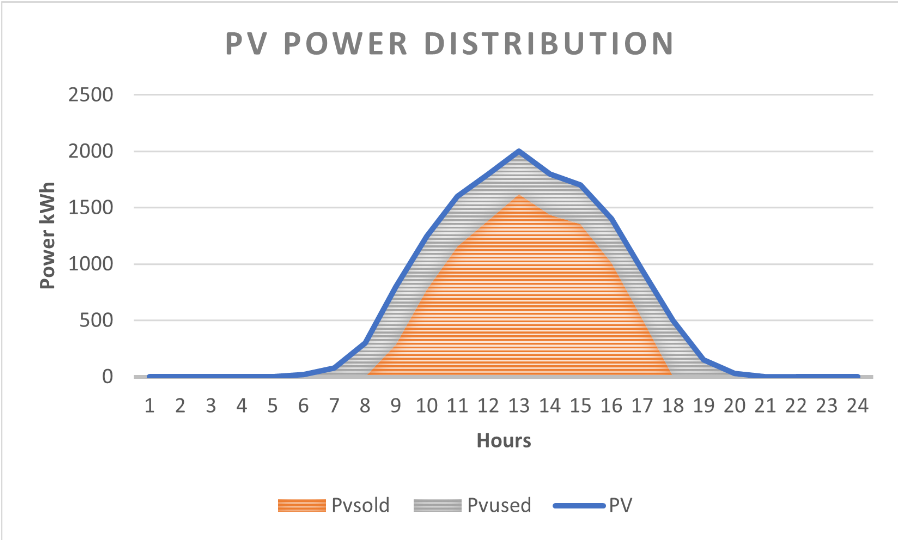

Figure 15: PV power distribution.

As we can see by looking at figures 14 and 15 and at the tables from Appendix A.2, is clearly visible that all the constraints set for this problem where met.

To note, that our prediction for this exercise was correct. As soon as the PV(t) is different than zero, it is used to power the loads and, every time it is capable to power them by it self it thus, as it is visible from the 9h to 17h. This happens, because by powering the loads, the installation needs to buy less power from the Energy Grid, thus reducing the total cost.

2.1.3 Problem 1.c)

On this problem, we want the minimum cost knowing that the buying price from the Energy Grid to the Loads is 20% lower than the selling price, from the PV system to the Energy Grid. This is represented in the following equation:

$$cost = \sum_t P_{rede}(t) * cost(t) - \sum_t PV_{sold}(t) * cost(t) * 1.2; \tag{6}$$

Which translates to the *GAMS studio 41* language:

```
** c)
costs..          z =e= sum(t, Prede(t)*cost(t)) - sum((i,t), PVsold(i,t)*cost(t)*1.20);
```

Figure 16: Cost equation in *GAMS studio 41* language.

After running the program we got to the following result for the minimal cost:

```
 220 VARIABLE z.L                    =     -1367.086  total costs during the day
```

Figure 17: Minimal cost achieved.

This was achieved by having the following powers for the variables used:

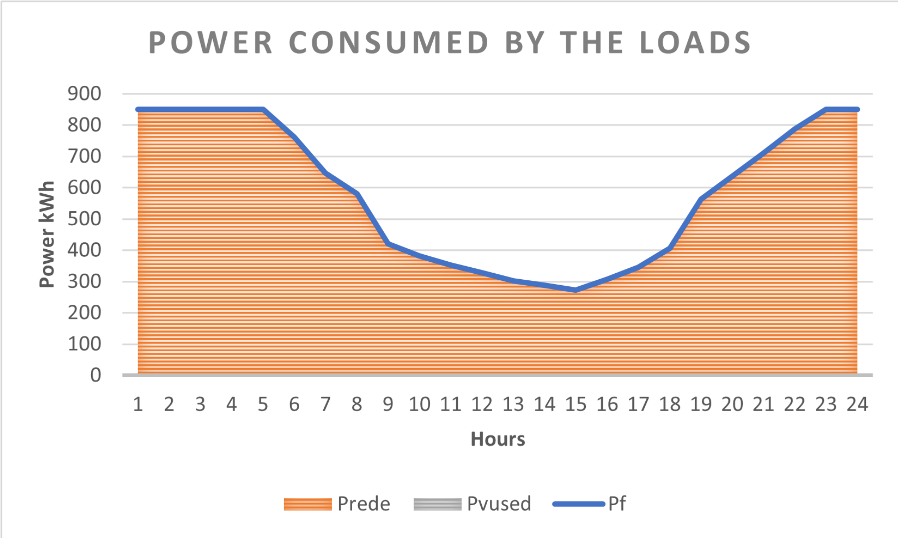

Figure 18: Power consumed by the loads.

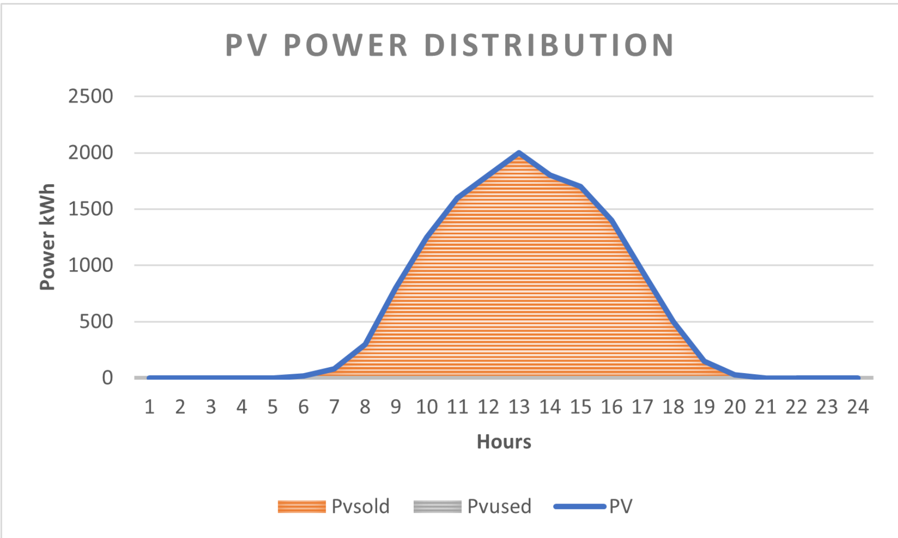

Figure 19: PV power distribution.

As we can see by looking at figures 18 and 19 and at the tables from Appendix A.3, is clearly visible that all the constraints set for this problem where met.

To note, that our prediction for this exercise was again correct. All the PV(t) was sold to the Energy Grid and the loads where all powered by the said Grid. This is shown by the fact that in both figures PVused(t) is set to zero in all hours.

2.1.4 Problem 1.d)

On this problem, we intend to maximize the self-consumption. This is represented in the following equation:

$$cost = \sum_t P_{rede}(t) - \sum_t PV_{used}(t); \tag{7}$$

We decided to make this way, because on GAMS, we decided to leave the solve function as a minimization instead of changing it to a maximization. This way by minimizing that function we are making the PVused(t) the bigger it can be. Which translates to the *GAMS studio 41* language:

```
** d)
costs..          z =e= sum(t, Prede(t)) - sum((i,t), PVused(i,t));
```

Figure 20: Cost equation in *GAMS studio 41* language.

After running the program we got to the following result for the maximum cost:

```
 218 VARIABLE z2.L                    =    -4345.920  total costs during the day
```

Figure 21: Maximum cost achieved.

This was achieved by having the following powers for the variables used:

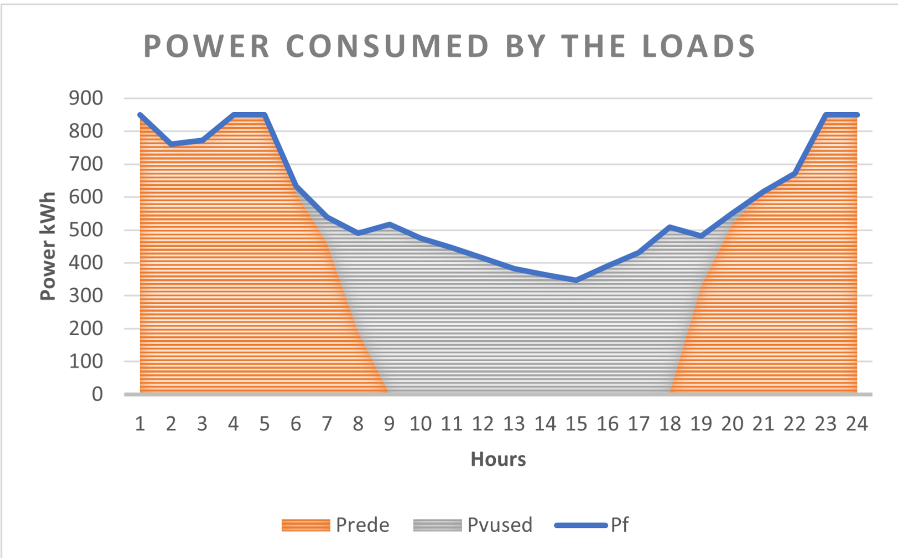

Figure 22: Power consumed by the loads.

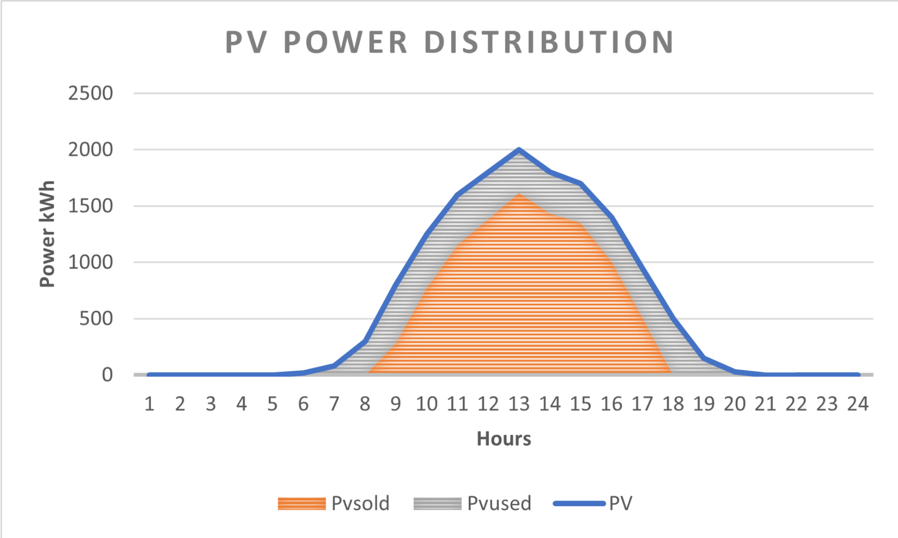

Figure 23: PV power distribution.

As we can see by looking at figures 22 and 23 and at the tables from Appendix A.4, is clearly visible that all the constraints set for this problem where met.

To note, that our prediction for this exercise was again correct. The end result is that PV(t) is used in it's entirety (when possible) to power the loads.

2.2 Problem 2.1

To formulate the problem we defined it on figure 24:

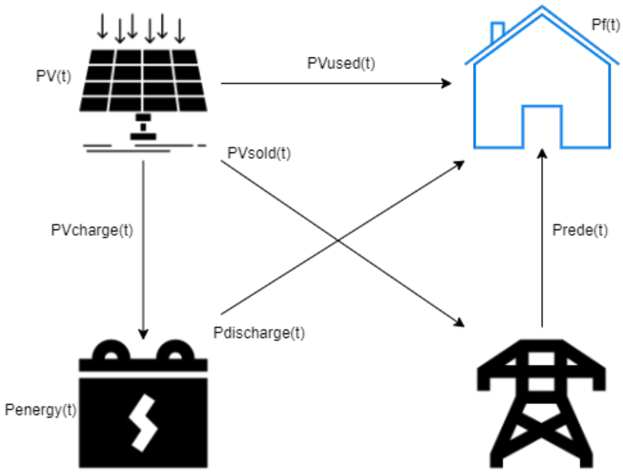

Figure 24: Representation of the connections between the different installations.

As it is visible, the changes made regarding Problem 1, was the introduction of a Energy system. This leads to a new setting, where the Energy System can discharge in order to power the loads and be charged by the PV system.

By analysing the figure, as well as the assignment directives and the Scalar values from figure 5, we get to the following representations for the problem definition:

$$P_f(t) = P_{rede}(t) + PV_{used}(t) + P_{discharge}(t); \tag{8}$$

$$PV(t) = PV_{used}(t) + PV_{sold}(t) + P_{charge}(t); \tag{9}$$

$$P_{rede}(t) <= 850; \tag{10}$$

$$P_{charge}(t) <= P_{ch\_max}; \tag{11}$$

$$P_{discharge}(t) <= P_{dch\_max}; \tag{12}$$

$$Energy(t) <= E_{Stor}; \tag{13}$$

$$Energy(t) = Energy(t-1) + P_{charge} \times eff - \frac{P_{discharge}}{eff}; \tag{14}$$

All this translates into the following equations in *GAMS studio 41* language:

```
**** 2.1 - without Pdischarge selling to Energy Grid from Storage
ConsoMax(t)..                Prede(t)=l=Pmax;
PchargeEq(t)..               Pcharge(t) =l= P_ch_max*X(t);
PdischargeEq(t)..            Pdischarge(t) =l= P_dch_max*(1-X(t));
EnergyEq(t)..                Energy(t) =l= E_Stor;
EnergyEq2(t)$(ord(t)=1)..    Energy(t) =e= E_Ini + Pcharge(t)*eff - Pdischarge(t)/eff;
EnergyEq3(t)$(ord(t)>1)..    Energy(t) =e= Energy(t-1) + Pcharge(t)*eff - Pdischarge(t)/eff;
PVcostEq2(t)..               PVsold2(t) =e= sum(i, PV(i,t)) - PVused2(t) - Pcharge(t);
Pf2Eq(t)..                   Prede(t) =e= sum(i, Pf(i,t)) - PVused2(t) - Pdischarge(t);
```

Figure 25: Equations that represent the problem in *GAMS studio 41* language.

Before running the simulation on GAMS to obtain the optimized solution, we made, again, some initial observations and predictions.

Observations:

obs 4: Energy Storage must be charged at separate times than it must be discharged;

obs 5: PV(t) and Pdischarge(t) are entirely provided to the loads (Pf(t)) when the selling price is zero or less than the buying price through the Energy Grid. Prede(t) is only used when necessary. Pcharge(t) will be used to charge the battery if the initial energy stored is insufficient to power the loads (Pf(t));

obs 6: When the selling price is equal to the buying price on the Energy Grid, it doesn't matter whether the PV(t) is supplied to the loads or sold on the Grid. Pcharge(t) will be zero, due to its efficiency being less than 100%. Pdischarge(t), will be completely provided to the loads;

obs 7: PV(t) is entirely sold across the Energy Grid when the selling price is higher than the buying price, and only the Prede(t) and Pdischarge(t) are used to supply energy to the loads (Pf(t)). Pcharge(t) will be zero because its efficiency is less than zero;

Predictions:

a): In accordance with **obs 6**, we will encounter one of the following two scenarios:

situation 1: It will happen as stated on **obs 6**;

situation 2: It will happen as stated on **obs 7**;

Theoretically, due to a probabilistic character, situation 6, is the one that is most likely to occur because there are a far higher number of distinct solutions than there are for situation 7, which is unique.

b):
It will happen as stated on **obs 5**.

c):
It will happen as stated on **obs 7**.

d):

In this case, since maximizing personal consumption is the goal, the maximum amount of PV(t) and Energy(t) power consumption will be attempted. In this way, the PVused(t) and Pdischarge(t) will be as high as it can be and only the excess that isn't used to power the loads will be sold.

We can start answering the assignment questions.

2.2.1 Problem 2.1.a)

On this problem, the cost is the same as in Problem 1, a), and therefore its' equation is the same as equation (4) and in *GAMS Studio 41* language, the same as figure 8. After running the program we got to the following result for the minimal cost:

```
 221 VARIABLE z.L                    =      -999.094  total costs during the day
```

Figure 26: Minimal cost achieved.

This was achieved by having the following powers for the variables used:

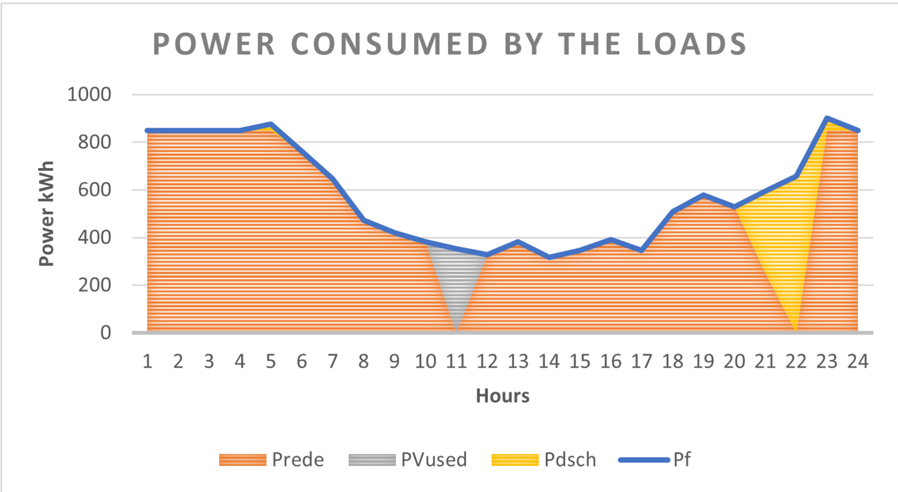

Figure 27: Power consumed by the loads.

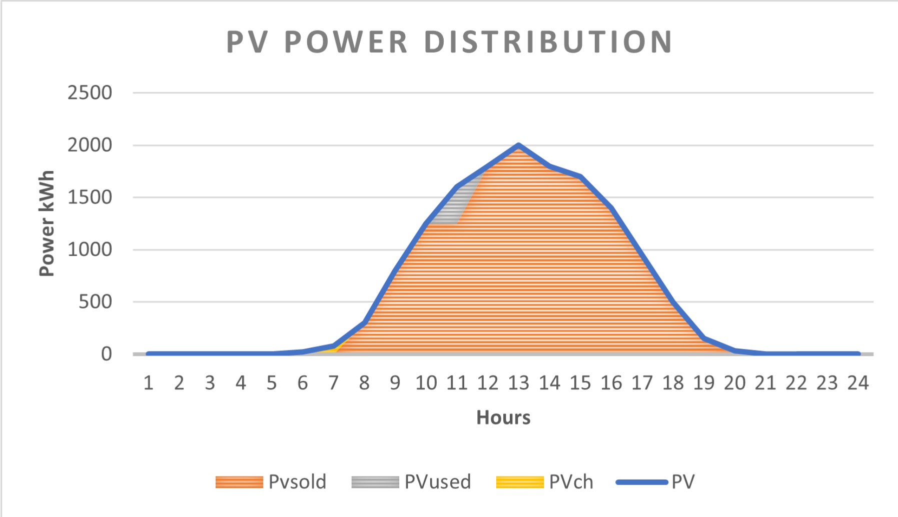

Figure 28: PV power distribution.

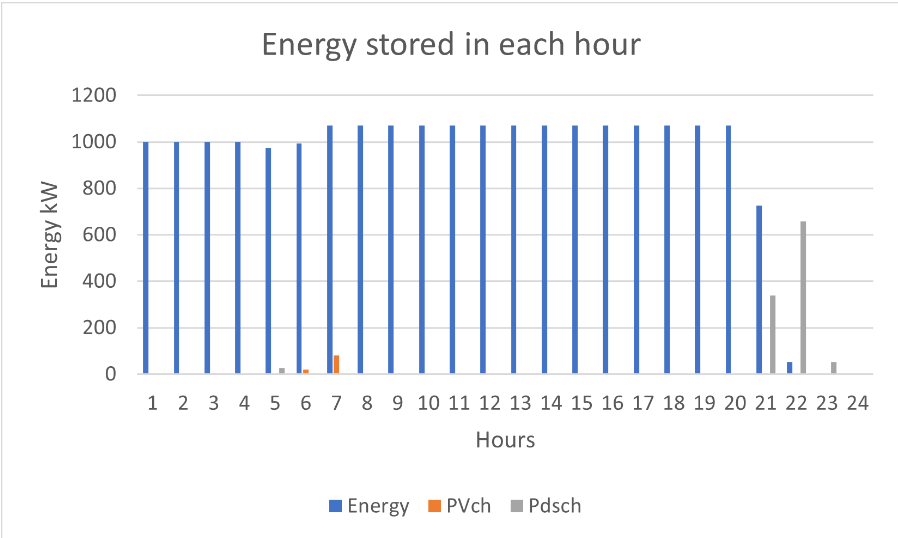

Figure 29: Energy stored in each hour.

As we can see by looking at figures 27, 28 and 29 and at the tables from Appendix B.1, is clearly visible that all the constraints set for this problem where met.

Most of our predictions where correct. Pdischarge(t), as seen by analysing figure 29 depleted the entire Energy(t) stored to power the loads and both the PV(t), as well as the Prede(t) where used as expected in a random way. Regarding the Pcharge(t), was where we got wrong. Although it was minor, in the 6h and 7h, a power surge occurred. This had probably to do with the demand flexibilities of the loads. This tells us that the percentage of power that we lost due to the efficiency of the Energy storage transaction, is still more efficient than to use that said power to sell it to the grid or to use to power the loads.

2.2.2 Problem 2.1.b)

On this problem, the cost is the same as in Problem 1, b), and therefore its' equation is the same as equation (5) and in *GAMS Studio 41* language, the same as figure 12. After running the program we got to the following result for the minimal cost:

```
221 VARIABLE z.L                    =       636.632  total costs during the day
```

Figure 30: Minimal cost achieved.

This was achieved by having the following powers for the variables used:

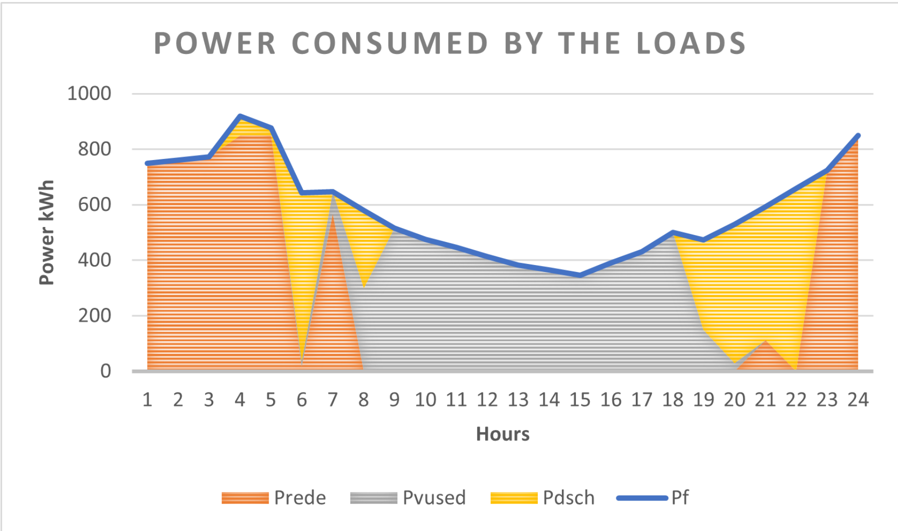

Figure 31: Power consumed by the loads.

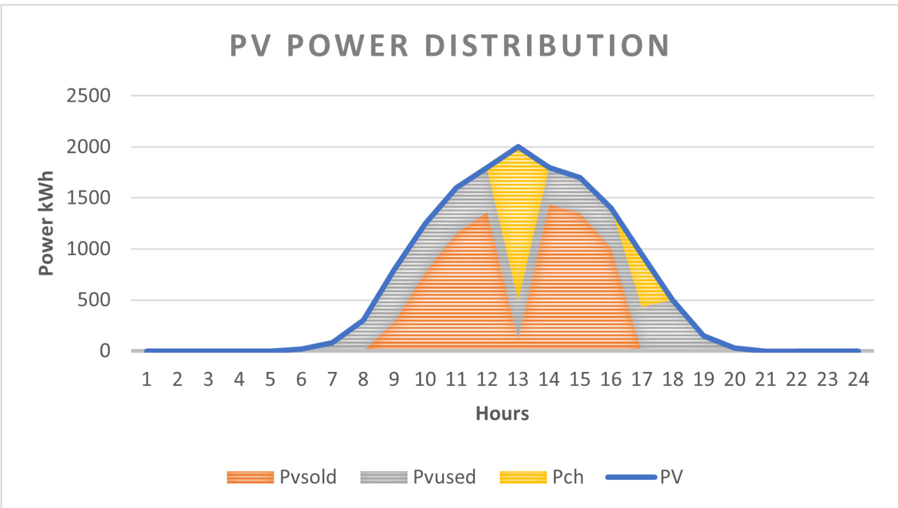

Figure 32: PV power distribution.

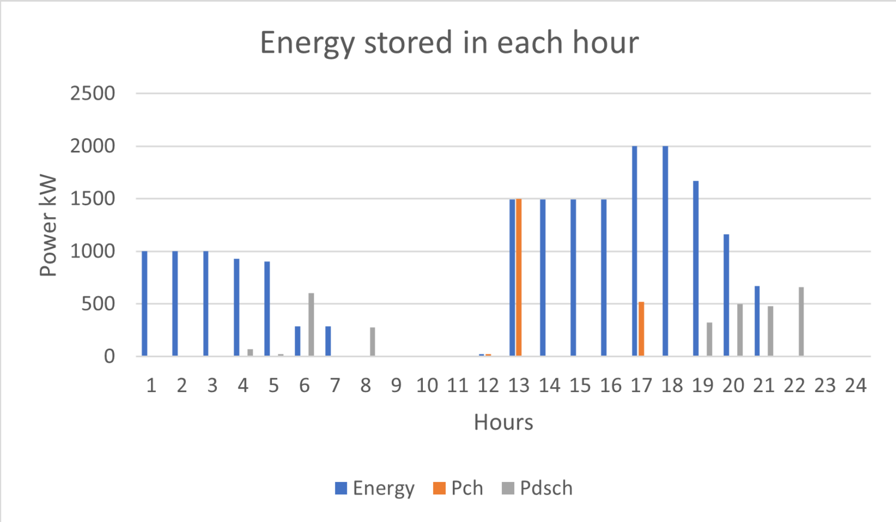

Figure 33: Energy stored in each hour.

As we can see by looking at figures 31, 32 and 33 and at the tables from Appendix B.2, is clearly visible that all the constraints set for this problem where met.

Our predictions where correct. Pdischarge(t), is used right in the beginning to power the loads, and the Prede(t), is only used when absolutely necessary. We can see, in figure 33 that the Energy stored is depleted in 9h and as soon as there is enough PV(t), it is used to power both the loads and to charge the Energy storage to its' maximum, as we can see on the 17h. The Pdischarge(t) is then used to power the loads, pretty much by itself from the 19h to the 22h, until is completely depleted again. It is safe to say that the power from the Energy storage was stored, until there wasn't enough power being produced on the PV system, to power the loads.

2.2.3 Problem 2.1.c)

On this problem, the cost is the same as in Problem 1, c), and therefore its' equation is the same as equation (6) and in *GAMS Studio 41* language, the same as figure 16. After running the program we got to the following result for the minimal cost:

```
221 VARIABLE z.L                    =     -1570.294  total costs during the day
```

Figure 34: Minimal cost achieved.

This was achieved by having the following powers for the variables used:

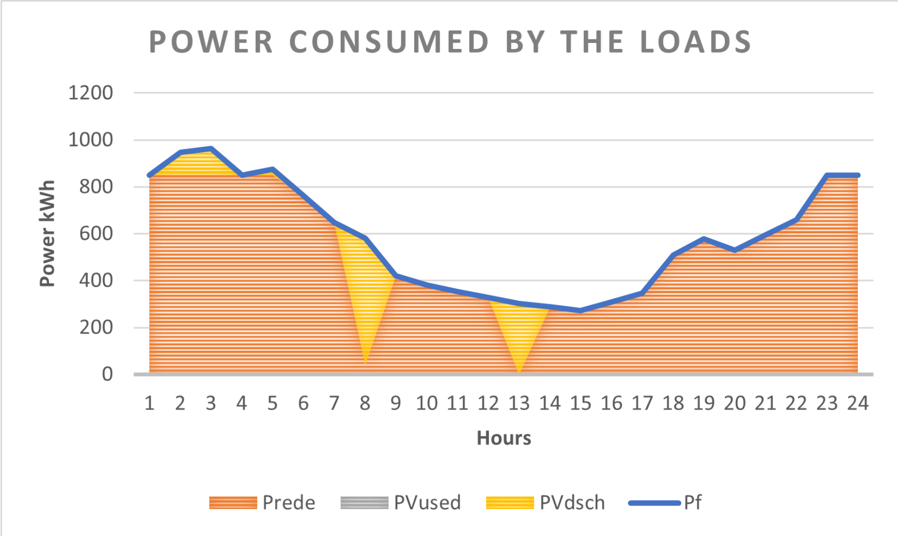

Figure 35: Power consumed by the loads.

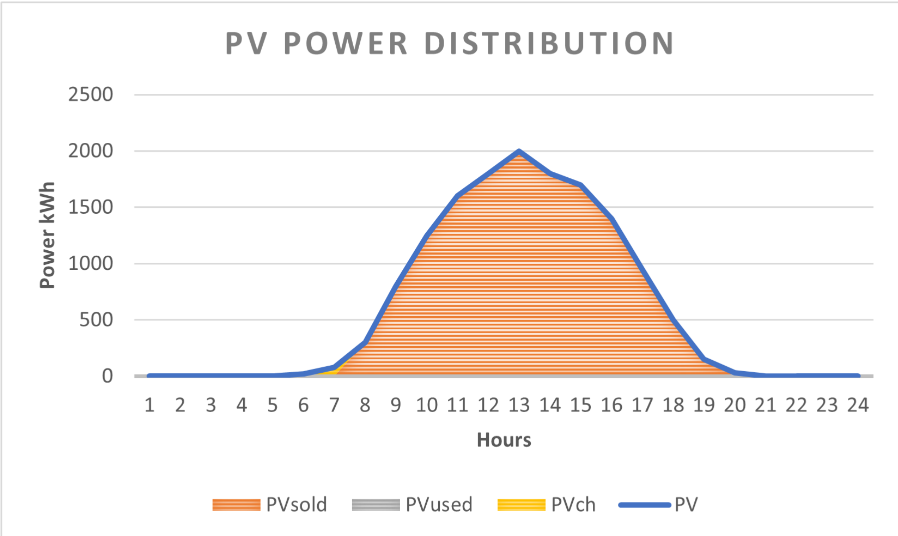

Figure 36: PV power distribution.

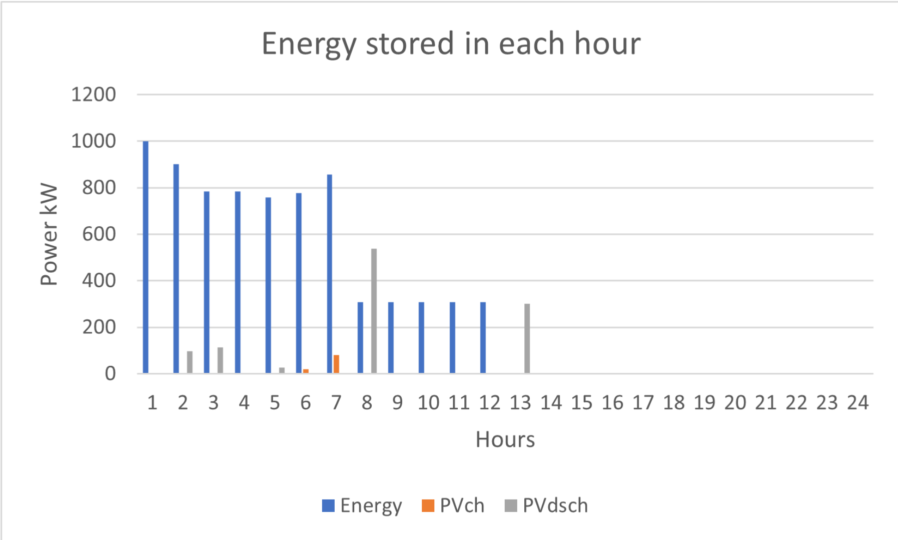

Figure 37: Energy stored in each hour.

As we can see by looking at figures 35, 36 and 37 and at the tables from Appendix B.3, is clearly visible that all the constraints set for this problem where met.

Our predictions where again mostly correct. None power of the PV(t) was used to power the loads, most of it was used to be sold to the Energy Grid, and the loads where powered by the Prede(t) and by the Pdischarge(t), or better, the Energy that was stored previously on the Energy storage. Again the only mistake made was with the Pcharge(t), that was different than zero, althought it was very small. It happen once more over the 6h and 7h, as in Problem 2.1 a), which leads to belief that it really happens becouse of the demand flexibilities used.

2.2.4 Problem 2.1.d)

On this problem, we intend to maximize the self-consumption. This is represented in the following equation:

$$cost = \sum_t P_{rede}(t) - \sum_t PV_{used}(t) - \sum_t P_{discharge}(t); \tag{15}$$

We decided to make this way, because on GAMS, we decided to leave the solve function as a minimization instead of changing it to a maximization. This way by minimizing that function we are making the PVused(t) and Pdischarge(t) the bigger it can be. Which translates to the *GAMS studio 41* language:

```
** d)
costs..          z =e= sum(t, Prede(t)) - sum(t, PVused2(t)) - sum(t, Pdischarge(t));
```

Figure 38: Cost equation in *GAMS studio 41* language.

After running the program we got to the following result for the maximum cost:

```
222 VARIABLE z2.L                    =      1534.080  total costs during the day
```

Figure 39: Maximum cost achieved.

This was achieved by having the following powers for the variables used:

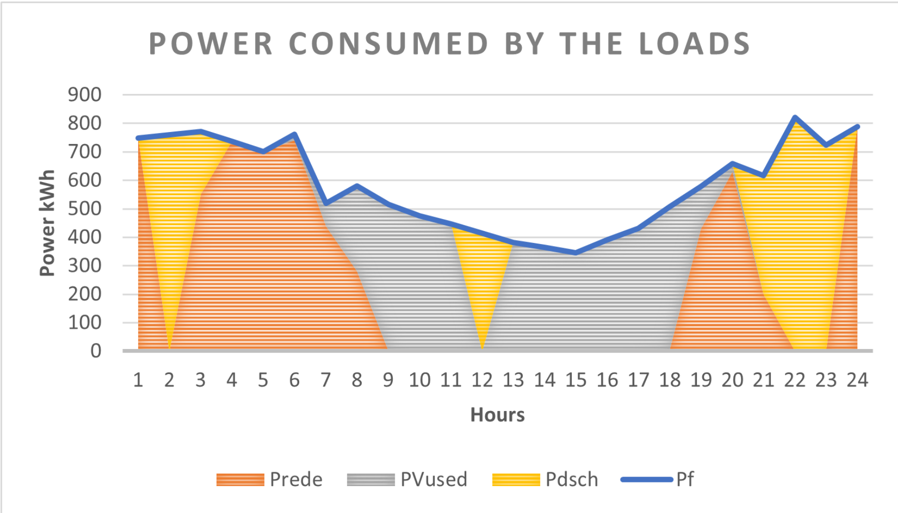

Figure 40: Power consumed by the loads.

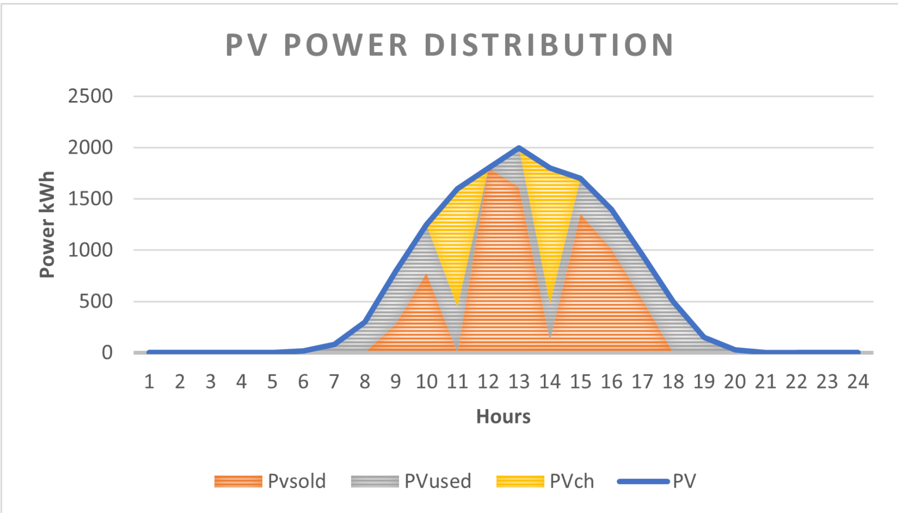

Figure 41: PV power distribution.

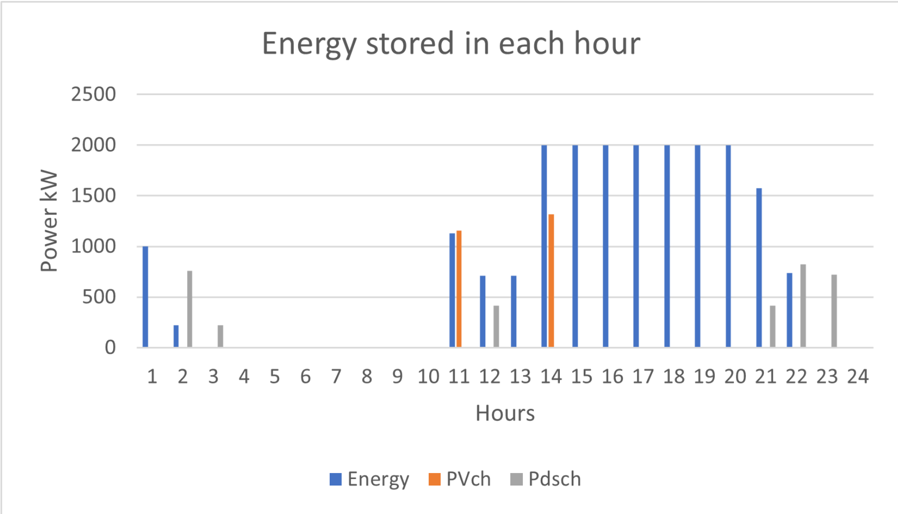

Figure 42: Energy stored in each hour.

As we can see by looking at figures 40, 41 and 42 and at the tables from Appendix B.4, is clearly visible that all the constraints set for this problem where met.

The results obtained where once again similar to our prediction. We can see that in order to have a bigger self-consumption, we need to have a higher interaction with our storage system. It is also visible that the Pdischarge(t) in most off the times is only used when there is no PV power being produced. The only case that it didn't happen was on the 12h, because if there is enough power on the following hours to power the loads and recharge the Energy storage, it doesn't matter if the energy is sold to the Energy Grid or not. Moreover, the cost as nothing to do with our maximization function. If we wanted to give more importance to the self-consumption, while still trying to get the minimum costs, we could introduce the cost on the maximization problem, but with a smaller weight.

2.3 Problem 2.2

To formulate the problem we defined it on figure 43:

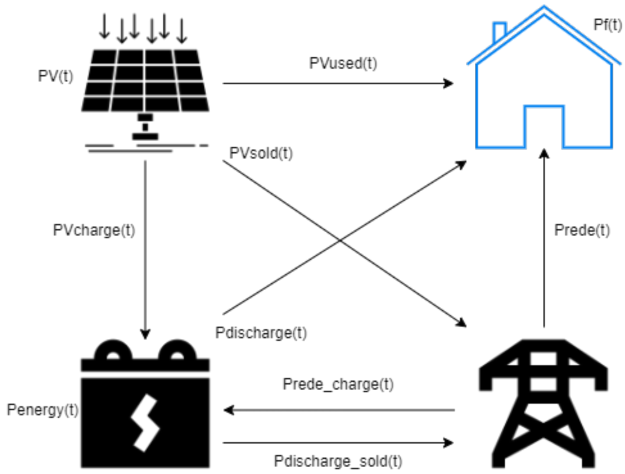

Figure 43: Representation of the connections between the different installations.

As it is visible, the changes made regarding Problem 2, was the introduction of a interaction between the Energy storage, with the Energy Grid, by allowing it to discharge and be charge by it.

By analysing the figure, as well as the assignment directives and the Scalar values from figure 5, we get to the following representations for the problem definition:

$$P_f(t) = P_{rede}(t) + PV_{used}(t) + P_{discharge}(t); \tag{16}$$

$$PV(t) = PV_{used}(t) + PV_{sold}(t) + P_{charge}(t); \tag{17}$$

$$P_{rede}(t) + P_{rede\_charge}(t) <= 850; \tag{18}$$

$$P_{charge}(t) + P_{rede\_charge}(t) <= P_{ch\_max}; \tag{19}$$

$$P_{discharge}(t) + P_{discharge\_sold}(t) <= P_{dch\_max}; \tag{20}$$

$$Energy(t) <= E_{Stor}; \tag{21}$$

$$Energy(t) = Energy(t-1) + (P_{charge} + P_{rede\_charge}(t)) \times eff - \frac{P_{discharge} + P_{discharge\_sold}(t)}{eff}; \tag{22}$$

All this translates into the following equations in *GAMS studio 41* language:

```
**** 2.2 - with Pdischarge selling to Energy Grid from Storage
ConsoMax(t)..               (Prede(t)+Prede_charge(t))=l=Pmax;
PchargeEq(t)..              (Pcharge(t)+Prede_charge(t)) =l= P_ch_max*X(t);
PdischargeEq(t)..           (Pdischarge(t)+Pdischarge_sold(t)) =l= P_dch_max*(1-X(t));
EnergyEq(t)..               Energy(t) =l= E_Stor;
EnergyEq2(t)$(ord(t)=1)..   Energy(t) =e= E_Ini + (Pcharge(t) + Prede_charge(t))*eff - (Pdischarge(t) + Pdischarge_sold(t))/eff;
EnergyEq3(t)$(ord(t)>1)..   Energy(t) =e= Energy(t-1) + (Pcharge(t) + Prede_charge(t))*eff - (Pdischarge(t) + Pdischarge_sold(t))/eff;
*PVauxEq2(t)..               PVused2(t) =l= sum(i, PV(i,t))-Pcharge(t);
PVcostEq2(t)..              PVsold2(t) =e= sum(i, PV(i,t)) - PVused2(t) - Pcharge(t);
Pf2Eq(t)..                  Prede(t) =e= sum(i, Pf(i,t)) - PVused2(t) - Pdischarge(t);
```

Figure 44: Equations that represent the problem in *GAMS studio 41* language.

Before running the simulation on GAMS to obtain the optimized solution, we made, again, some initial observations and predictions.

Observations:

obs 8: PVsold(t) and Pdischarge_sold(t) are sold to the Energy Grid at the same price, and Prede(t) and Prede_charge(t) power is purchased at the same price, as well;

obs 9: PV(t) and Pdischarge(t) are entirely provided to the loads (Pf(t)) when the selling price is zero or less than the buying price, through the Energy Grid. Prede(t) is only used when necessary. Pcharge(t) will be used to charge the battery if the initial energy stored is insufficient to power the loads (Pf(t)). The Energy Storage won't interact with the Energy Grid;

obs 10: When the selling price is equal to the buying price on the Energy Grid, it doesn't matter whether the PV(t) is supplied to the loads or sold on the Grid. Pcharge(t) will be zero, due to its efficiency being less than 100%. Pdischarge(t), will be completely provided to the loads. The Energy Storage won't interact with the Energy Grid;

obs 11: PV(t) and the energy stored on the Energy system is entirely sold across the Energy Grid when the selling price is higher than the buying price, and only the Prede(t) is used to supply energy to the loads (Pf(t)). Pcharge(t) will be zero because its efficiency is less than zero. Will also see cicles of the Energy Storage being charged by the Energy Grid, through Prede_charge(t), followed by discharges through the Pdischarge_sold(t);

Predictions:

a):
It will happen as stated on **obs 10**.

b):
It will happen as stated on **obs 9**.

c):
It will happen as stated on **obs 11**.

d):
In this case, since maximizing personal consumption is the goal, the maximum amount of PV(t) and Energy(t) power consumption will be attempted. In this way, the PVused(t) and Pdischarge(t) will be as high as it can be and only the excess that isn't used to power the loads

will be sold. There will also be interaction between the Energy Grid and the Energy storage, in order for it to be charged, and posteriorly used to power the loads.

We can start answering the assignment questions.

2.3.1 Problem 2.2.a)

On this problem, we want the minimum cost knowing that the buying price from the Energy Grid to the Loads is the same as the selling price. This is represented in the following equation:

$$cost = \sum_t (P_{rede}(t) + P_{rede\_charge}(t)) * cost(t) - \sum_t (PV_{sold}(t) + P_{discharge\_sold}(t)) * cost(t); \quad (23)$$

Which translates to the *GAMS studio 41* language:

```
** a)
costs..  z =e= sum(t, Prede(t)*cost(t)) + sum(t, Prede_charge(t)*cost(t)) - sum(t, PVsold2(t)*cost(t)) - sum(t, Pdischarge_sold(t)*cost(t));
```

Figure 45: Cost equation in *GAMS studio 41* language.

After running the program we got to the following result for the minimal cost:

```
222 VARIABLE z.L                    =     -1025.902   total costs during the day
```

Figure 46: Minimal cost achieved.

This was achieved by having the following powers for the variables used:

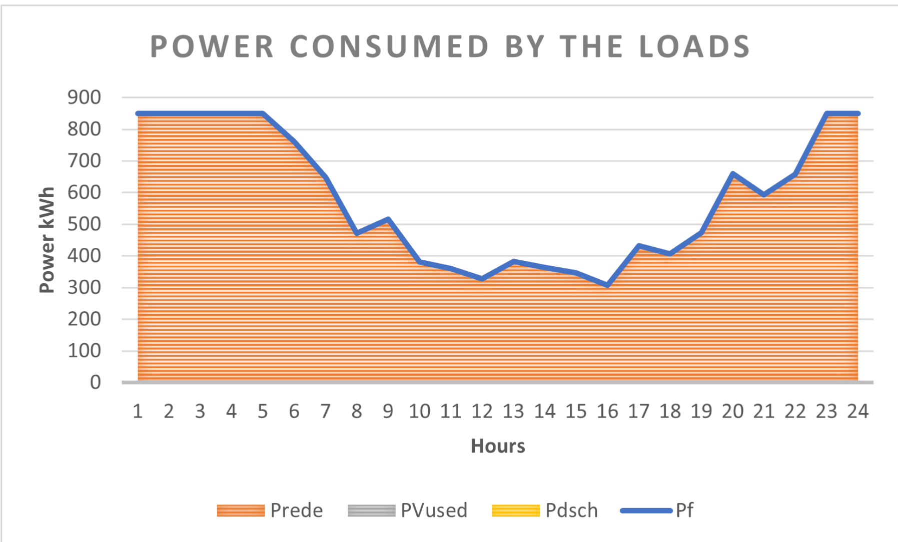

Figure 47: Power consumed by the loads.

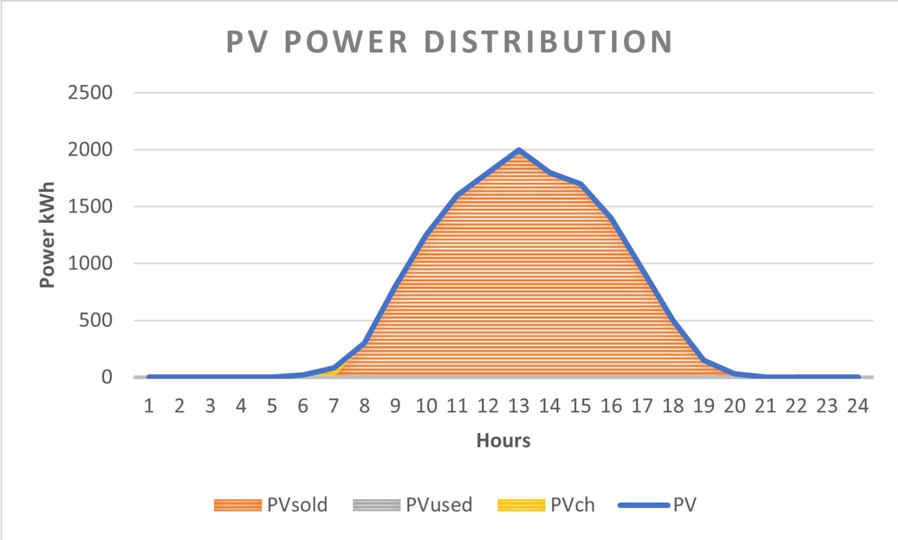

Figure 48: PV power distribution.

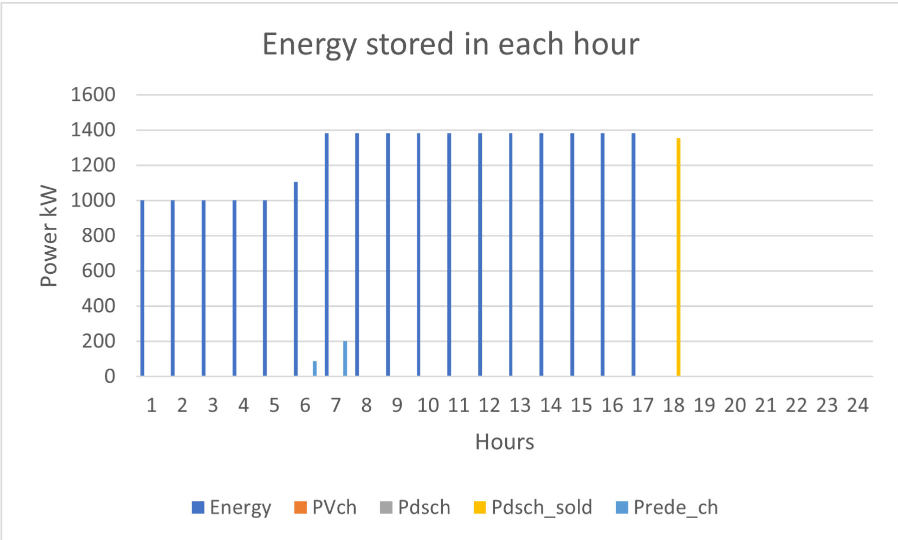

Figure 49: Energy stored in each hour.

As we can see by looking at figures 47, 48 and 49 and at the tables from Appendix C.1, is clearly visible that all the constraints set for this problem where met.

The results where somewhat close to what we expected, but with some twists. Regarding the PV system and the Prede(t) power, they occurred as expected, and according to some previous conclusions. It was with the relation from the Energy storage, with the Energy Grid where we got wrong. We first predicted that they wouldn't interact, but they actually do. This happens, because now the Energy Storage has the capability of buying energy in the hours where the cost is cheaper, store it and then sell it back with profit, or use it to power the loads, instead of having to buy the energy from the grid in those expensive hours. We can get to these conclusions by looking at figure 49, and seeing that the Energy Storage is charged by the

Grid on the 6h and 7h, and discharges it all back at 18h. The Energy storage doesn't charge to its maximum value, because the system operator limited the maximum power, supplied by Prede(t).

2.3.2 Problem 2.2.b)

On this problem, we want the minimum cost knowing that the selling price is zero. This is represented in the following equation:

$$cost = \sum_{t}(P_{rede}(t) + P_{rede\_charge}(t)) * cost(t); \tag{24}$$

Which translates to the *GAMS studio 41* language:

```
** b)
costs..          z =e= sum(t, Prede(t)*cost(t))+ sum(t, Prede_charge(t)*cost(t));
```

Figure 50: Cost equation in *GAMS studio 41* language.

After running the program we got to the following result for the minimal cost:

```
222 VARIABLE z.L                    =       636.632  total costs during the day
```

Figure 51: Minimal cost achieved.

This was achieved by having the following powers for the variables used:

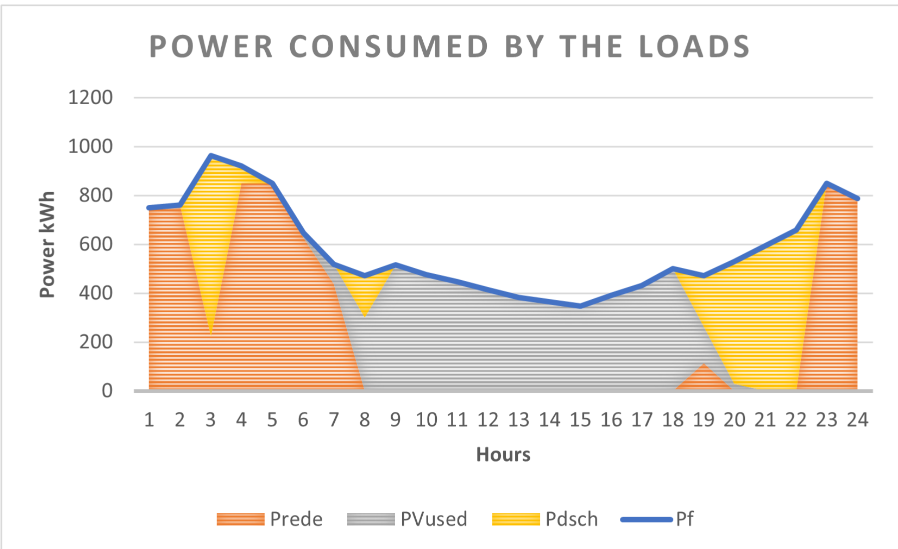

Figure 52: Power consumed by the loads.

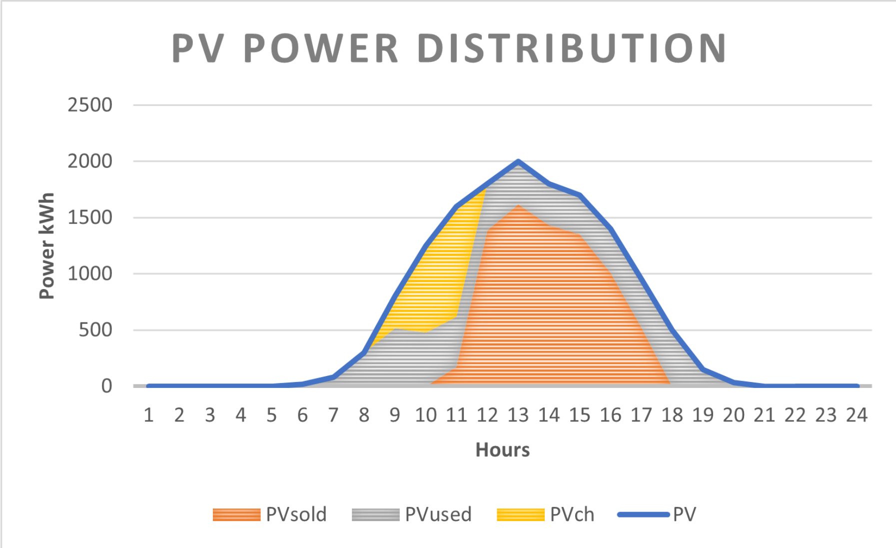

Figure 53: PV power distribution.

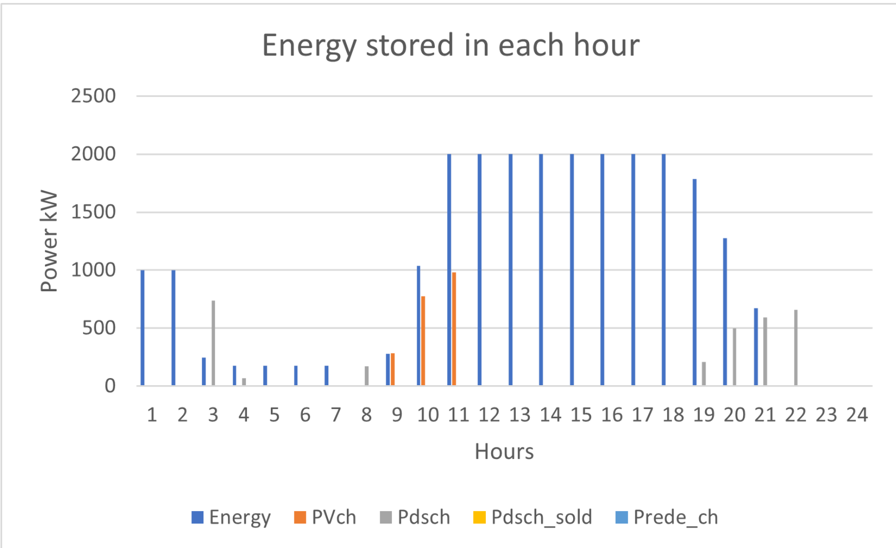

Figure 54: Energy stored in each hour.

As we can see by looking at figures 52, 53 and 54 and at the tables from Appendix C.2, is clearly visible that all the constraints set for this problem where met.

In this case it went exactly as we predicted and our previous conclusions. If the selling price is zero, then the Energy Storage has no benefit in interacting with the Energy Grid, because it doesn't benefit from buying cheaper to sell it afterwards. This will lead us to the same solution as in Problem 2.1 b).

2.3.3 Problem 2.2.c)

On this problem, we want the minimum cost knowing that the buying price is 20% lower than the selling price. This is represented in the following equation:

$$cost = \sum_{t}(P_{rede}(t)+P_{rede\_charge}(t))*cost(t)-\sum_{t}(PV_{sold}(t)+P_{discharge\_sold}(t))*cost(t)*1.2; \quad (25)$$

Which translates to the *GAMS studio 41* language:

```
** c)
costs..        z =e= sum(t, Prede(t)*cost(t)) + sum(t, Prede_charge(t)*cost(t)) - sum(t, PVsold2(t)*cost(t)*1.2) - sum(t, Pdischarge_sold(t)*cost(t)*1.2);
```

Figure 55: Cost equation in *GAMS studio 41* language.

After running the program we got to the following result for the minimal cost:

```
222 VARIABLE z.L                    =     -1798.802  total costs during the day
```

Figure 56: Minimal cost achieved.

This was achieved by having the following powers for the variables used:

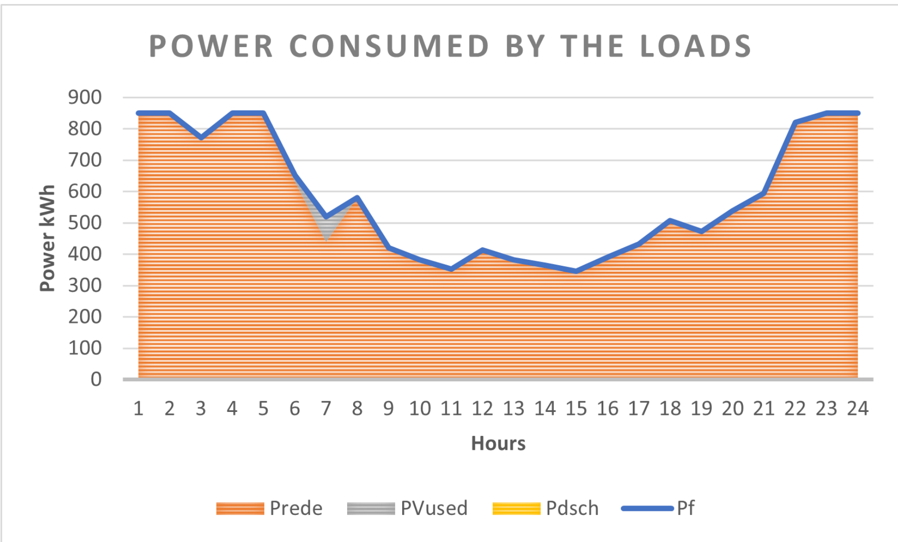

Figure 57: Power consumed by the loads.

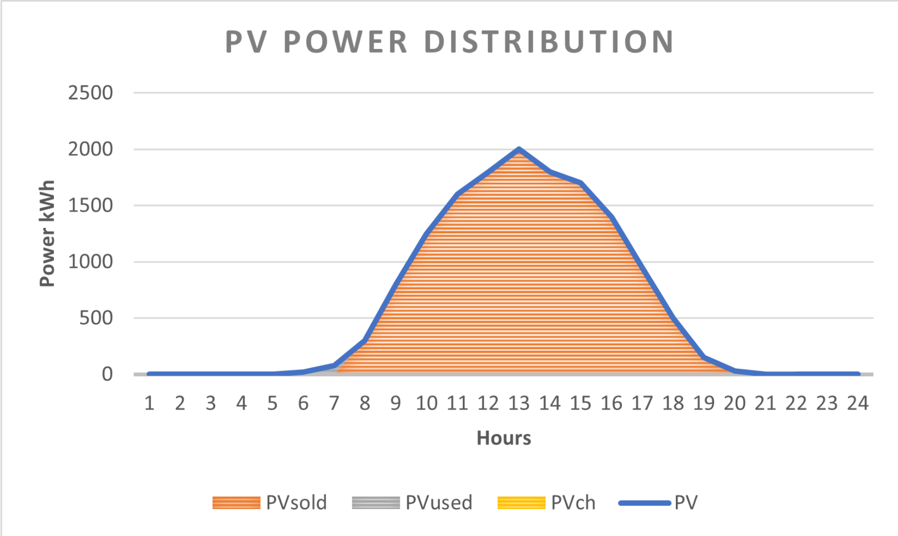

Figure 58: PV power distribution.

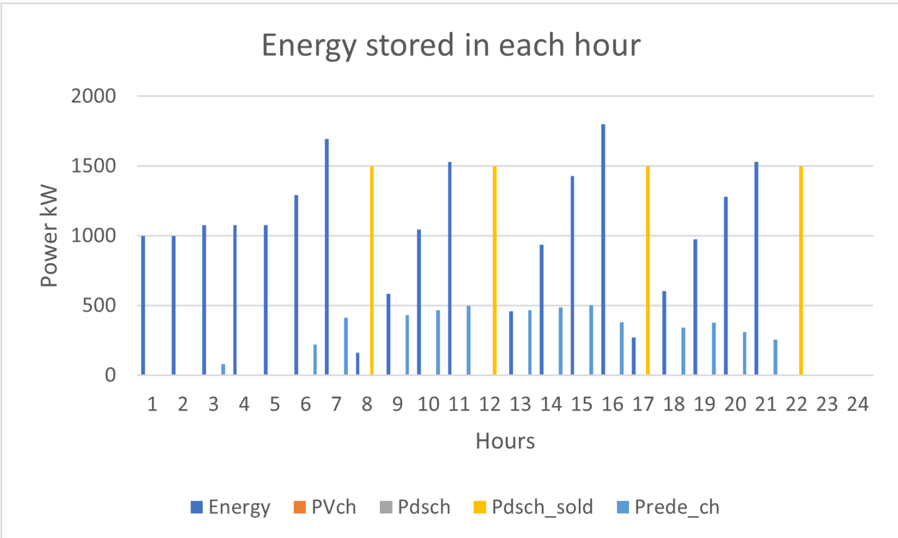

Figure 59: Energy stored in each hour.

As we can see by looking at figures 57, 58 and 59 and at the tables from Appendix C.3, is clearly visible that all the constraints set for this problem where met.

In this case it went exactly as we predicted and our previous conclusions. To take advantage from the selling price being lower than the buying price, the Energy store is charged by the grid in cycles. Being limited by the maximum constraints defined with the Scalars. The PV is also sold almost in its entirety, only being used when the demand flexibilities don't allow the Prede(t) to power the loads by itself.

2.3.4 Problem 2.2.d)

On this problem, we intend to maximize the self-consumption. This is represented using the same cost as in Problem 2.1d), represented in equation (15) and Figure 38.

After running the program we got to the following result for the maximum cost:

```
222 VARIABLE z2.L                    =      4005.936  total costs during the day
```

Figure 60: Maximum cost achieved.

This was achieved by having the following powers for the variables used:

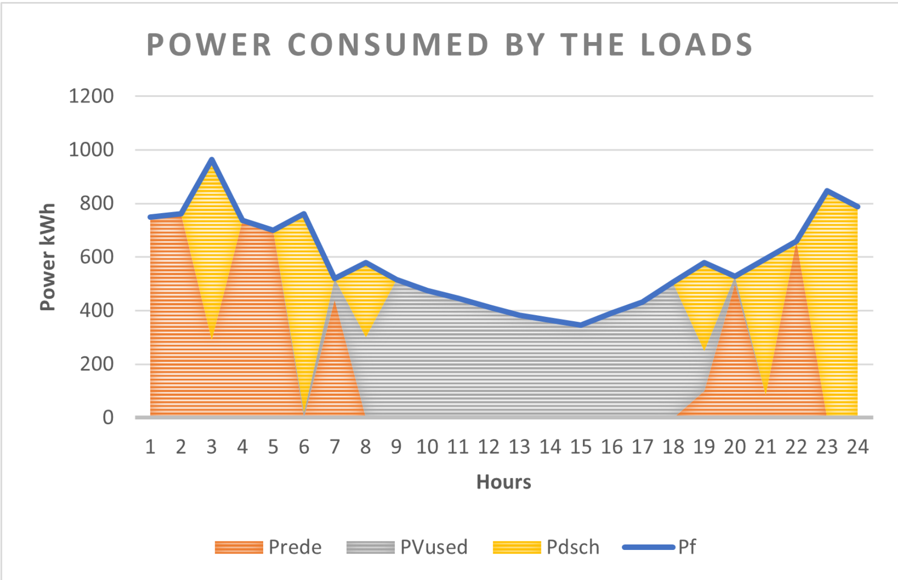

Figure 61: Power consumed by the loads.

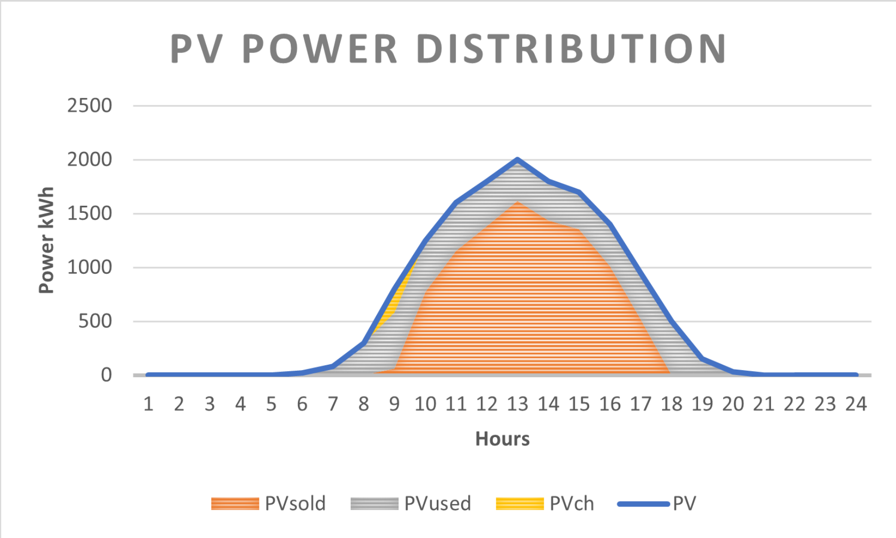

Figure 62: PV power distribution.

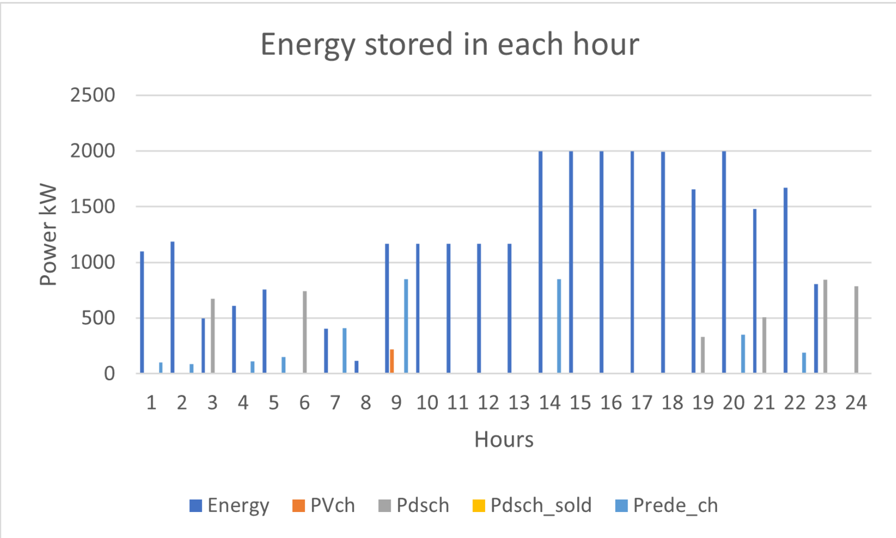

Figure 63: Energy stored in each hour.

As we can see by looking at figures 61, 62 and 63 and at the tables from Appendix C.4, is clearly visible that all the constraints set for this problem where met.

Again it went exactly as we predicted and with our previous conclusions. This shows that by connecting our Energy Storage to the Energy Grid, we can gain greater control over our self-consumption. By storing Energy in advance, we can then safely power our own installation even if by any chance occurs a problem with the Energy Grid supply.

2.4 Problem 3

On Problem 3 we added a new constraint defined by the system operator, where they request a reduction of the power consumption during the periods 19h to 24h, imposing a maximum limit of 700 kW. This was implemented on *GAMS Studio 41* language as defined by figure 64:

```
**** 3 - comment "ConsoMax(t)" and "costs" from previous exercises and uncomment the rest
ConsoMax(t)$(ord(t)>18)..    Prede(t)=l=700;
ConsoMax2(t)$(ord(t)<=18)..  Prede(t)=l=850;
```

Figure 64: Equations that represent the problem in GAMS studio 41 language.

This problem was already studied on the previous Assignment V. It was intended to show the limitations that are faced, when an installation solely relies on a system operator and in return, the problems that come with the non compliance with the constraints imposed by them.

Some conclusions where also retrieved from the data obtained on the previous assignment. This where that the same interpretations can be used even if we used different Problems to define the baseline constraints. Therefore we decided to only use Problem 1 and 2.2 and skipped Problem 2.1.

Problem 1 is a representation of an infeasible solution, as we can see from the following figure 65:

```
Iteration log . . .
Iteration:     1    Infeasibility =           360.700000

--- LP status (3): infeasible.
--- Cplex Time: 0.00sec (det. 0.63 ticks)


Model has been proven infeasible
```

Figure 65: Solution for Problem 3 with constraints from Problem 1.

This occurs, because even by having a PV system to support self-consumption, its functioning relies on the time of the day. On the the hours where it isn't producing any power, if the power consumed by the loads can't meet the system operator requests, it will face the same problems seen on the previous Assignment V. Since we know that the constraints set can't be met for the 23h and 24h and the PV doesn't produce any amount of power after 20h, then the problem as we can see becomes infeasible. This Problem will not be the aim of our focus, because it was already thoroughly studied previously on Assignment V.

Problem 2.2 on the other hand is a representation of a feasible solution as we will see. Since it employs an Energy Storage, it will be able to store energy and, to some extent, circumvent the impositions set by the system operator. Will focus on this Problem from now on.

Predictions:

Our predictions for all the next exercises will be the same for each one, as before on Problem 2, but with slightly worst results for our optimization functions. As we also saw on the previous assignment, the more constraints we add, that limit the flexibility of the Problem, the less optimal it will be.

2.4.1 Problem 2.2 a)

After running the program we got to the following result for the minimal cost:

```
204 VARIABLE z.L                    =     -995.902  total costs during the day
```

Figure 66: Minimal cost achieved.

This was achieved by having the following powers for the variables used:

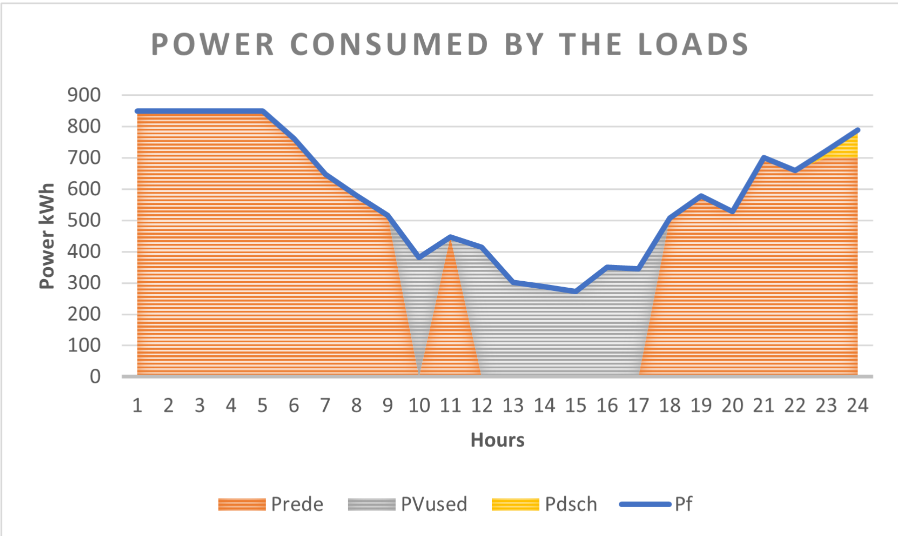

Figure 67: Power consumed by the loads.

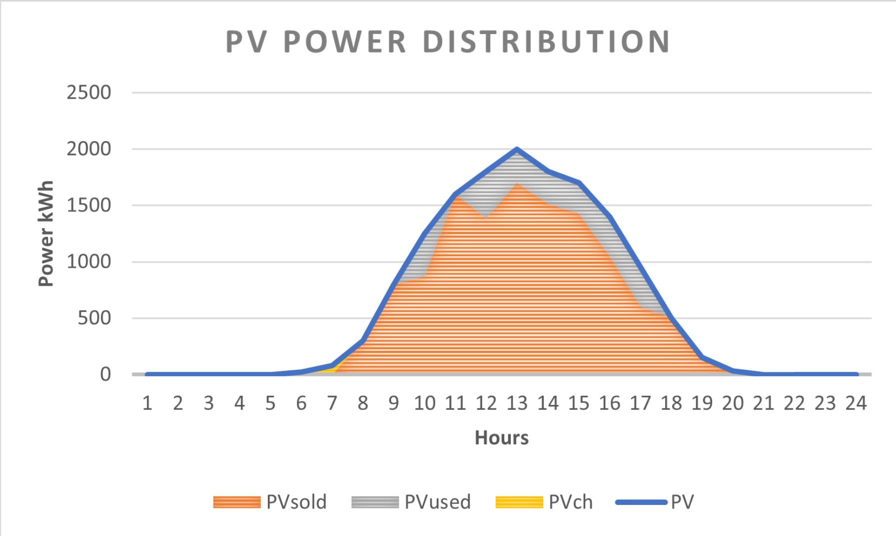

Figure 68: PV power distribution.

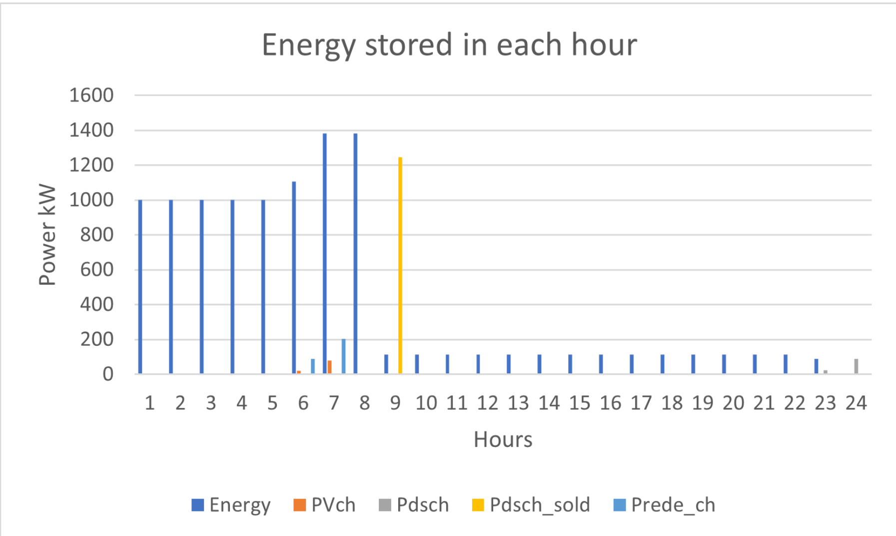

Figure 69: Energy stored in each hour.

As expected, the results went according with the predictions made and the overall cost for this problem was worst than the one obtained in Problem 2, proving once more our constraints limitation that we discovered in Assignment V. This also proves that the infeasibility is overcome.

2.4.2 Problem 2.2 b)

After running the program we got to the following result for the minimal cost:

```
204 VARIABLE z.L                    =       647.760  total costs during the day
```

Figure 70: Minimal cost achieved.

This was achieved by having the following powers for the variables used:

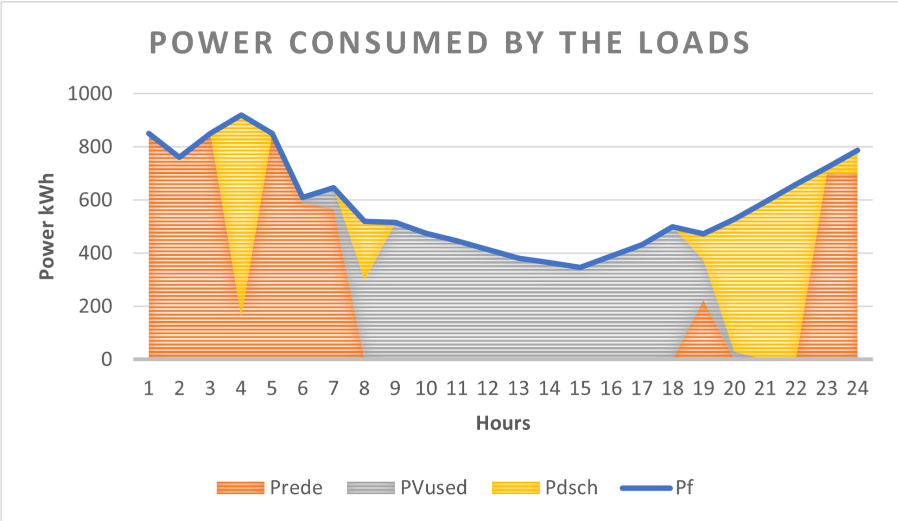

Figure 71: Power consumed by the loads.

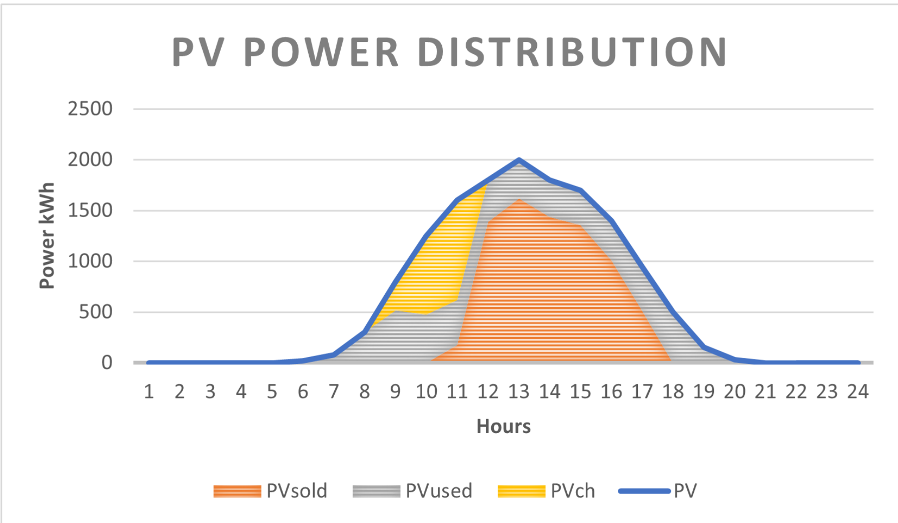

Figure 72: PV power distribution.

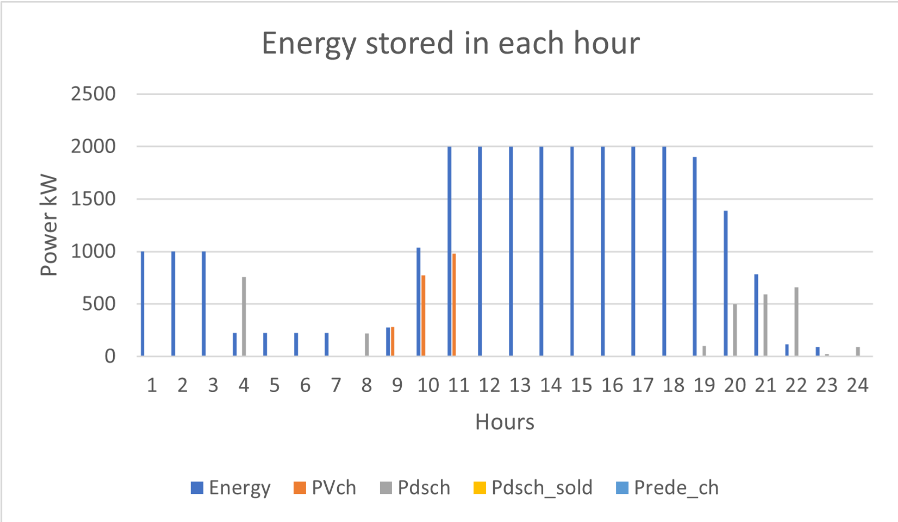

Figure 73: Energy stored in each hour.

As expected, the results went according with the predictions made and the overall cost for this problem was worst than the one obtained in Problem 2, proving once more our constraints limitation that we discovered in Assignment V. This also proves that the infeasibility is overcome.

2.4.3 Problem 2.2 c)

After running the program we got to the following result for the minimal cost:

```
204 VARIABLE z.L                    =     -1744.950  total costs during the day
```

Figure 74: Minimal cost achieved.

This was achieved by having the following powers for the variables used:

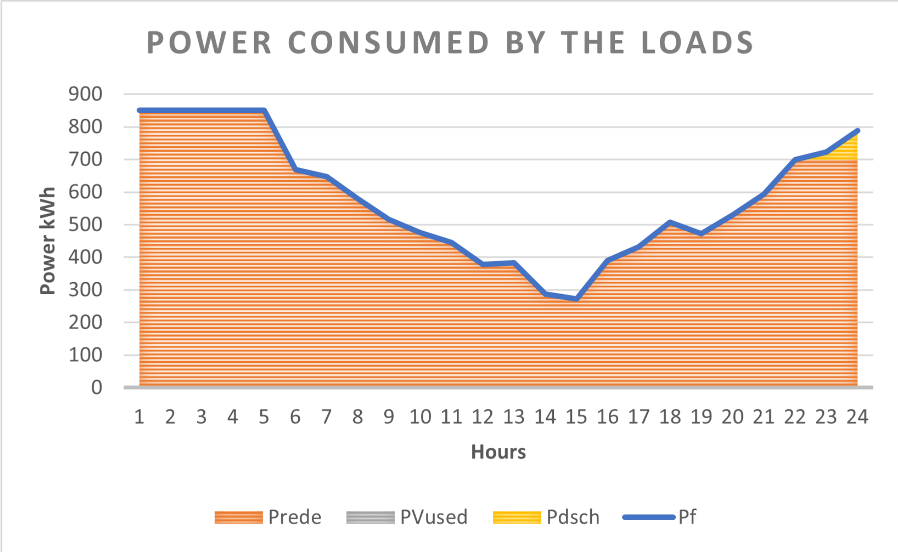

Figure 75: Power consumed by the loads.

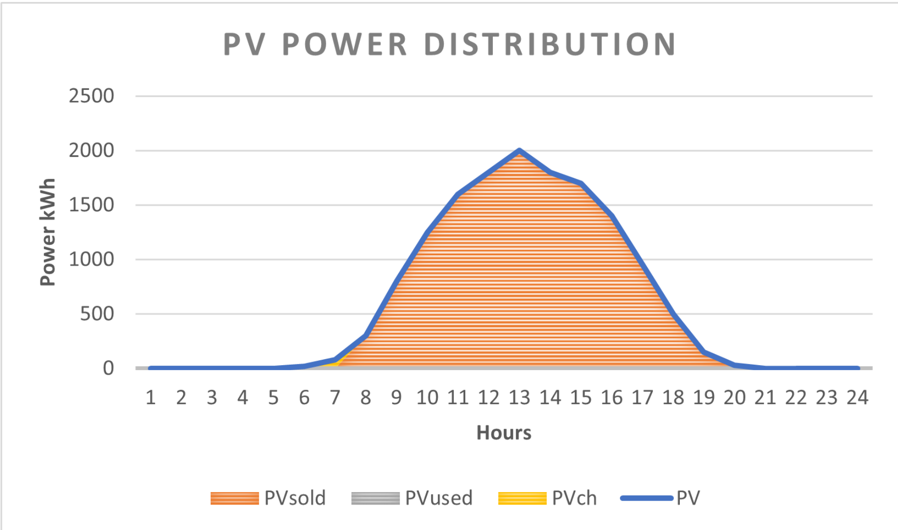

Figure 76: PV power distribution.

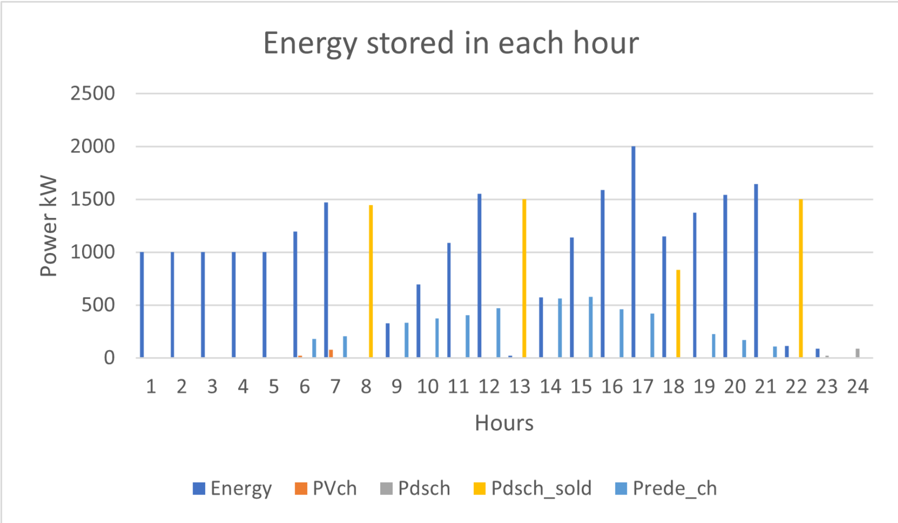

Figure 77: Energy stored in each hour.

As expected, the results went according with the predictions made and the overall cost for this problem was worst than the one obtained in Problem 2, proving once more our constraints limitation that we discovered in Assignment V. This also proves that the infeasibility is overcome.

2.4.4 Problem 2.2 d)

After running the program we got to the following result for the minimal cost:

```
204 VARIABLE z2.L                    =      3633.992  total costs during the day
```

Figure 78: Minimal cost achieved.

This was achieved by having the following powers for the variables used:

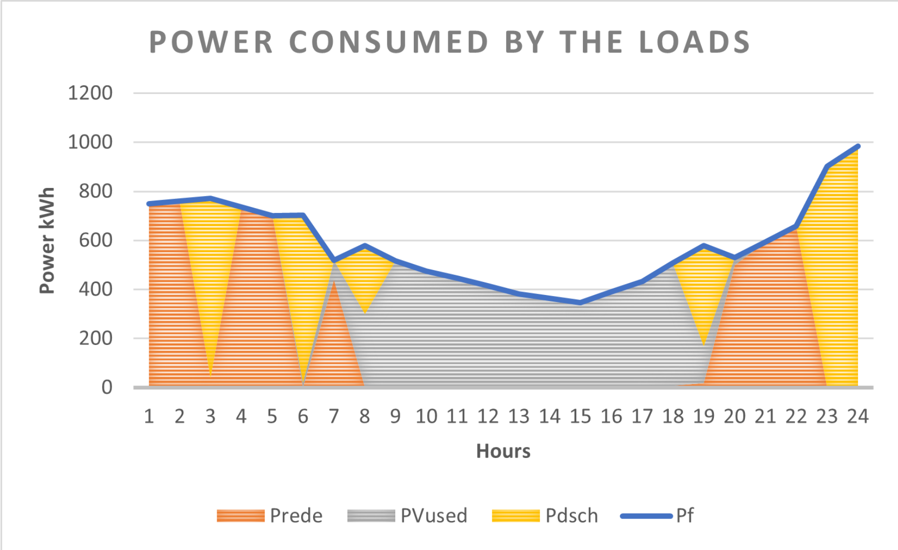

Figure 79: Power consumed by the loads.

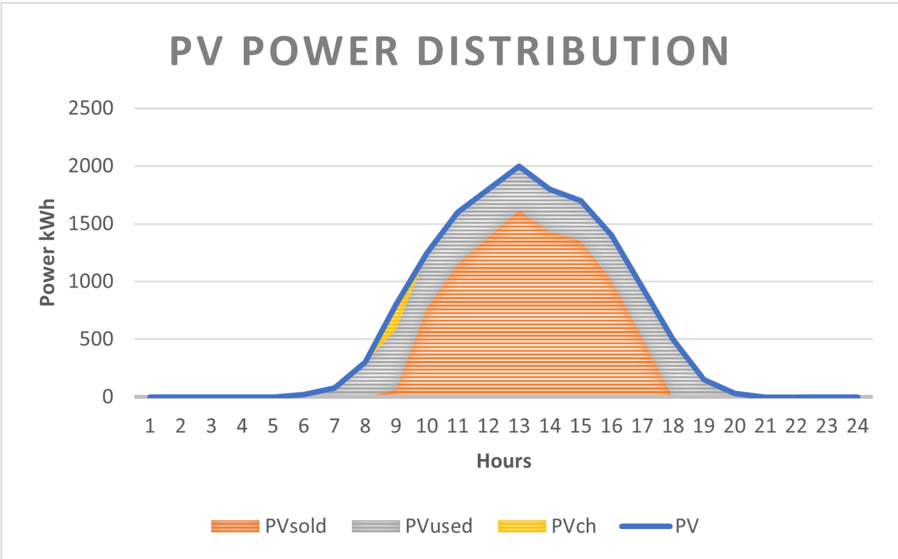

Figure 80: PV power distribution.

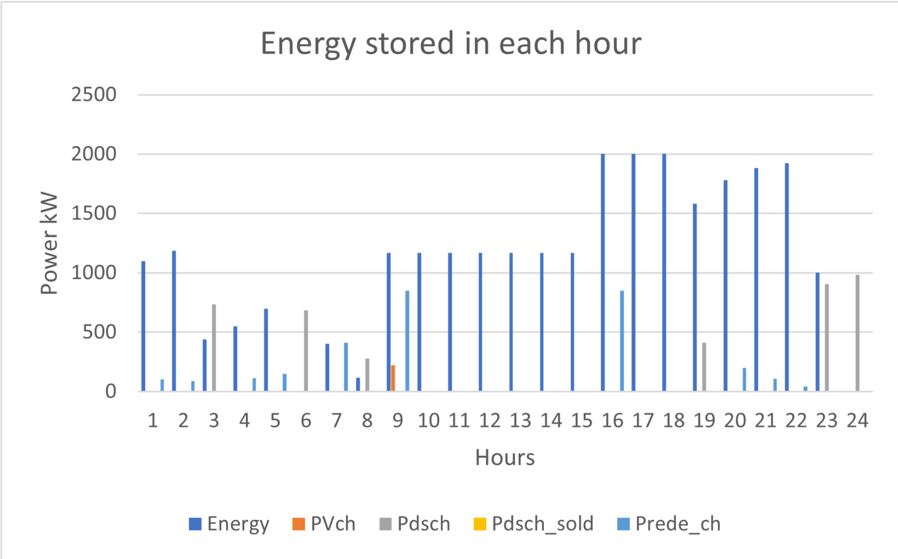

Figure 81: Energy stored in each hour.

As expected, the results went according with the predictions made and the overall cost for this problem was worst than the one obtained in Problem 2, proving once more our constraints limitation that we discovered in Assignment V. This also proves that the infeasibility is overcome.

3 Conclusions

By the end of this assignment, we believe we where able to retrieve crucial information about the constraints used, as well as with the overall problem definition.

We decided to do these three different scenarios, so that we could analyze the benefits of having a more decentralized energy network, composed not only by a Energy Grid controlled by a system operator, but also with a self-consumption energy system (PV system) that allowed a private entity to produce and store its own energy.

With **Problem 1**, we where able to understand some fundamentals about the energy market. On a simple scenario where the private installation could either use the power produced by its own self-consumption system, or sell it to the Energy Grid, the results obtained from the multiple experiments where pretty straight forward. When the selling price is higher than the buying price, the self-consumption energy is sold in its entirety and the energy necessary to power the loads will by bought at a cheaper price from the Energy Grid. When the selling price is lower than the buying price, or if self-consumption is to be maximized, the self-consumption energy is used in its entirety to power the loads and will only use the energy from the Energy Grid, if necessary.

Although it seems an improvement to have such a system, after careful analysis it's still possible to say that is flawed, because the private entity is still extremely dependent on the system operator and its own power consumption and production. Most sustainable energy production systems nowadays are very dependent on factors that can't be controlled and that are not constant, as in this case, the power production of the PV system varied a lot with the time of the day. Therefore, if the installation isn't consuming any energy, on the times that it is producing or if it is consuming on the times that isn't producing, then it needs to rely completely on the system operator.

With **Problem 2** we found a way to overcome the previous concerns by using a Energy storage system. With this system, the private entity is capable of storing energy, so that it can better manage its power consumption and production, while creating one more protective barrier between themselves and the system operator providers. As we saw in both exercises, the same fundamentals about the energy markets, where still applied in both **Problem 2.1 and 2.2**.

On **Problem 2.1**, we saw an improvement in the results obtained for our Optimization Functions, only by introducing a connection between our PV system and the Energy Storage system, because now, the self-consumption energy, didn't need to be either sold or used, but could be stored. This helped to fade the inconstant and uncontrollable factors, created by the sustainable self-production systems, allowing for their energy to be mostly used on the best scenarios. Whether they are to sell the energy to the system operators for a profit, or use it to power the installation.

However it was with **Problem 2.2**, that we saw the best results. This was a full connection scenario, where the Energy Storage was also connected with the Energy Grid. The main conclusions that we retrieved from here was that first, by the Energy Storage being able to be charged by the Energy Grid, it wasn't completely vulnerable to the self-consumption system, which gave the entire installation, a better management of its on power consumption, while limiting the influence of the system operator from the Energy Grid. Another interesting conclusion was that the Energy Storage system, could take advantage of the prices set by the Energy Grid provider at each hour, to both improve its overall profit and restrict energy purchase to the cheaper periods, and then supply it to the installation, when the loads need it.

From this assignment we can finally conclude that a more decentralized energy network, that uses both production and storage systems, is the future, and beneficial to both the private consumers as well as energy producers. Although for this to happen, some crucial constraints need to be well defined, so that neither one as an advantage over the other, as it happened, on **Problem 2.2 c)**, by allowing for the private consumer to buy and sell energy from the Grid, for profit, without any barrier.

References

1)SGF lecture notes
2)Provided code examples

Appendix

A Problem 1

A.1 a)

A.1.1 Power consumed by the loads

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**TOTAL**
Pf	850	850	850	850	850	761,58	647,28	503,64	509,76	463,68	411,26	349,8	322,2	306,9	291,6	320,22	369,54	434,76	495,36	565,2	634,14	703,08	850	850	**14040**
Prede	850	850	850	850	850	761,58	647,28	503,64	0	0	0	0	322,2	306,9	291,6	320,22	0	0	345,36	535,2	634,14	703,08	850	850	**11321,2**
PVused	0	0	0	0	0	0	0	0	509,76	463,68	411,26	349,8	0	0	0	0	369,54	434,76	150	30	0	0	0	0	**2718,8**

A.1.2 PV power distribution

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**TOTAL**
PV	0	0	0	0	0	20	80	300	800	1250	1600	1800	2000	1800	1700	1400	950	500	150	30	0	0	0	0	**14380**
PVsold	0	0	0	0	0	20	80	300	290,24	786,32	1188,74	1450,2	2000	1800	1700	1400	580,46	65,24	0	0	0	0	0	0	**11661,2**
PVused	0	0	0	0	0	0	0	0	509,76	463,68	411,26	349,8	0	0	0	0	369,54	434,76	150	30	0	0	0	0	**2718,8**

A.2 b)

A.2.1 Power consumed by the loads

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**TOTAL**
Pf	850	760,5	850	736,38	742,26	761,58	647,28	471,6	516,24	475,2	446,16	414,24	382,32	364,32	346,32	390,42	431,82	500	472,44	528,84	593,64	658,44	850	850	**14040**
Prede	850	760,5	850	736,38	742,26	741,58	567,28	171,6	0	0	0	0	0	0	0	0	0	0	322,44	498,84	593,64	658,44	850	850	**9192,96**
Pvused	0	0	0	0	0	20	80	300	516,24	475,2	446,16	414,24	382,32	364,32	346,32	390,42	431,82	500	150	30	0	0	0	0	**4847,04**

A.2.2 PV power distribution

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**TOTAL**
PV	0	0	0	0	0	20	80	300	800	1250	1600	1800	2000	1800	1700	1400	950	500	150	30	0	0	0	0	**14380**
Pvsold	0	0	0	0	0	0	0	0	283,76	774,8	1153,84	1385,76	1617,68	1435,68	1353,68	1009,58	518,18	0	0	0	0	0	0	0	**9532,96**
Pvused	0	0	0	0	0	20	80	300	516,24	475,2	446,16	414,24	382,32	364,32	346,32	390,42	431,82	500	150	30	0	0	0	0	**4847,04**

A.3 c)

A.3.1 Power consumed by the loads

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**TOTAL**
Pf	850	850	850	850	850	761,58	647,28	579,6	419,76	381,6	353,04	327,36	301,68	287,28	272,88	307,98	345,78	406,8	562,76	635,4	711,54	787,68	850	850	**14040**
Prede	850	850	850	850	850	761,58	647,28	579,6	419,76	381,6	353,04	327,36	301,68	287,28	272,88	307,98	345,78	406,8	562,76	635,4	711,54	787,68	850	850	**14040**
Pvused	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**

A.3.2 PV power distribution

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**TOTAL**
PV	0	0	0	0	0	20	80	300	800	1250	1600	1800	2000	1800	1700	1400	950	500	150	30	0	0	0	0	**14380**
Pvsold	0	0	0	0	0	20	80	300	800	1250	1600	1800	2000	1800	1700	1400	950	500	150	30	0	0	0	0	**14380**
Pvused	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**

A.4 d)

A.4.1 Power consumed by the loads

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**TOTAL**
Pf	850	760,5	771,84	850	850	633,42	539,28	489,96	516,24	475,2	446,16	414,24	382,32	364,32	346,32	390,42	431,82	507,6	481,68	549,72	616,68	672,28	850	850	**14040**
Prede	850	760,5	771,84	850	850	613,42	459,28	189,96	0	0	0	0	0	0	0	0	0	7,6	331,68	519,72	616,68	672,28	850	850	**9192,96**
Pvused	0	0	0	0	0	20	80	300	516,24	475,2	446,16	414,24	382,32	364,32	346,32	390,42	431,82	500	150	30	0	0	0	0	**4847,04**

A.4.2 PV power distribution

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**TOTAL**
PV	0	0	0	0	0	20	80	300	800	1250	1600	1800	2000	1800	1700	1400	950	500	150	30	0	0	0	0	**14380**
Pvsold	0	0	0	0	0	0	0	0	283,76	774,8	1153,84	1385,76	1617,68	1435,68	1353,68	1009,58	518,18	0	0	0	0	0	0	0	**9532,96**
Pvused	0	0	0	0	0	20	80	300	516,24	475,2	446,16	414,24	382,32	364,32	346,32	390,42	431,82	500	150	30	0	0	0	0	**4847,04**

B Problem 2.1

B.1 a)

B.1.1 Power consumed by the loads

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	TOTAL
Pf	850	850	850	850	875,88	761,58	647,28	471,6	419,76	381,6	353,04	327,36	382,32	317,62	346,32	390,42	345,78	507,6	578,76	528,84	593,64	658,44	902,16	850	**14040**
Prede	850	850	850	850	850	761,58	647,28	471,6	419,76	381,6	0	327,36	382,32	317,62	346,32	390,42	345,78	507,6	578,76	528,84	254,08	0	850	850	**12610,92**
PVused	0	0	0	0	0	0	0	0	0	0	353,04	0	0	0	0	0	0	0	0	0	0	0	0	0	**353,04**
Pdsch	0	0	0	0	25,88	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	339,56	658,44	52,16	0	**1076,04**

B.1.2 PV power distribution

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	TOTAL
PV	0	0	0	0	0	20	80	300	800	1250	1600	1800	2000	1800	1700	1400	950	500	150	30	0	0	0	0	**14380**
Pvsold	0	0	0	0	0	0	0	300	800	1250	1246,96	1800	2000	1800	1700	1400	950	500	150	30	0	0	0	0	**13926,96**
PVused	0	0	0	0	0	0	0	0	0	0	353,04	0	0	0	0	0	0	0	0	0	0	0	0	0	**353,04**
PVch	0	0	0	0	0	20	80	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**100**

B.1.3 Energy stored in each hour

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Energy	1000	1000	1000	1000	973,5918	993,1918	1071,592	1071,592	1071,592	1071,592	1071,592	1071,592	1071,592	1071,592	1071,592	1071,592	1071,592	1071,592	1071,592	1071,592	725,102	53,22449	0	0
PVch	0	0	0	0	0	20	80	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pdsch	0	0	0	0	25,88	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	339,56	658,44	52,16	0

B.2 b)

B.2.1 Power consumed by the loads

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	TOTAL
Pf	749,16	760,5	771,84	919,62	875,88	642,48	647,28	579,6	516,24	475,2	446,16	414,24	382,32	364,32	346,32	390,42	431,82	500	472,44	528,84	593,64	658,44	723,24	850	**14040**
Prede	749,16	760,5	771,84	850	850	17,58	567,28	0	0	0	0	0	0	0	0	0	0	0	0	0	113,36	0	723,24	850	**6252,96**
Pvused	0	0	0	0	0	20	80	300	516,24	475,2	446,16	414,24	382,32	364,32	346,32	390,42	431,82	500	150	30	0	0	0	0	**4847,04**
Pdsch	0	0	0	69,62	25,88	604,9	0	279,6	0	0	0	0	0	0	0	0	0	0	322,44	498,84	480,28	658,44	0	0	**2940**

B.2.2 PV power distribution

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	TOTAL
PV	0	0	0	0	0	20	80	300	800	1250	1600	1800	2000	1800	1700	1400	950	500	150	30	0	0	0	0	**14380**
Pvsold	0	0	0	0	0	0	0	0	283,76	774,8	1153,84	1363,124	117,68	1435,68	1353,68	1009,58	0	0	0	0	0	0	0	0	**7492,144**
Pvused	0	0	0	0	0	20	80	300	516,24	475,2	446,16	414,24	382,32	364,32	346,32	390,42	431,82	500	150	30	0	0	0	0	**4847,04**
Pch	0	0	0	0	0	0	0	0	0	0	0	22,63633	1500	0	0	0	518,18	0	0	0	0	0	0	0	**2040,816**

B.2.3 Energy stored in each hour

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Energy	1000	1000	1000	928,9592	902,551	285,3061	285,3061	0	0	0	0	22,1836	1492,184	1492,184	1492,184	1492,184	2000	2000	1670,98	1161,959	671,8776	0	0	0
Pch	0	0	0	0	0	0	0	0	0	0	0	22,63633	1500	0	0	0	518,18	0	0	0	0	0	0	0
Pdsch	0	0	0	69,62	25,88	604,9	0	279,6	0	0	0	0	0	0	0	0	0	0	322,44	498,84	480,28	658,44	0	0

B.3 c)

B.3.1 Power consumed by the loads

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	TOTAL
Pf	850	947,66	963,36	850	875,88	761,58	647,28	579,6	419,76	381,6	353,04	327,36	301,68	287,28	272,88	307,98	345,78	507,6	578,76	528,84	593,64	658,44	850	850	**14040**
Prede	850	850	850	850	850	761,58	647,28	42,14	419,76	381,6	353,04	327,36	0	287,28	272,88	307,98	345,78	507,6	578,76	528,84	593,64	658,44	850	850	**12963,96**
PVused	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**
PVdsch	0	97,66	113,36	0	25,88	0	0	537,46	0	0	0	0	301,68	0	0	0	0	0	0	0	0	0	0	0	**1076,04**

B.3.2 PV power distribution

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	TOTAL
PV	0	0	0	0	0	20	80	300	800	1250	1600	1800	2000	1800	1700	1400	950	500	150	30	0	0	0	0	**14380**
PVsold	0	0	0	0	0	0	0	300	800	1250	1600	1800	2000	1800	1700	1400	950	500	150	30	0	0	0	0	**14280**
PVused	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**
PVch	0	0	0	0	0	20	80	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**100**

B.3.3 Energy stored in each hour

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Energy	1000	900,3469	784,6735	784,6735	758,2653	777,8653	856,2653	307,8367	307,8367	307,8367	307,8367	307,8367	0	0	0	0	0	0	0	0	0	0	0	0
PVch	0	0	0	0	0	20	80	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PVdsch	0	97,66	113,36	0	25,88	0	0	537,46	0	0	0	0	301,68	0	0	0	0	0	0	0	0	0	0	0

B.4 d)

B.4.1 Power consumed by the loads

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	TOTAL
Pf	749,16	760,5	771,84	736,38	700,92	761,58	519,12	579,6	516,24	475,2	446,16	414,24	382,32	364,32	346,32	390,42	431,82	507,6	578,76	659,16	615,9	821,16	723,24	788,04	**14040**
Prede	749,16	0	552,34	736,38	700,92	741,58	439,12	279,6	0	0	0	0	0	0	0	0	0	7,6	428,76	629,16	200,3	0	0	788,04	**6252,96**
PVused	0	0	0	0	0	20	80	300	516,24	475,2	446,16	0	382,32	364,32	346,32	390,42	431,82	500	150	30	0	0	0	0	**4432,8**
Pdsch	0	760,5	219,5	0	0	0	0	0	0	0	0	414,24	0	0	0	0	0	0	0	0	415,6	821,16	723,24	0	**3354,24**

B.4.2 PV power distribution

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	TOTAL
PV	0	0	0	0	0	20	80	300	800	1250	1600	1800	2000	1800	1700	1400	950	500	150	30	0	0	0	0	**14380**
Pvsold	0	0	0	0	0	0	0	0	283,76	774,8	0	1800	1617,68	117,3834	1353,68	1009,58	518,18	0	0	0	0	0	0	0	**7475,063**
PVused	0	0	0	0	0	20	80	300	516,24	475,2	446,16	0	382,32	364,32	346,32	390,42	431,82	500	150	30	0	0	0	0	**4432,8**
PVch	0	0	0	0	0	0	0	0	0	0	1153,84	0	0	1318,297	0	0	0	0	0	0	0	0	0	0	**2472,137**

B.4.3 Energy stored in each hour

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Energy	1000	223,9796	0	0	0	0	0	0	0	0	1130,763	708,0693	708,0693	2000	2000	2000	2000	2000	2000	2000	1575,918	738	0	0
PVch	0	0	0	0	0	0	0	0	0	0	1153,84	0	0	1318,297	0	0	0	0	0	0	0	0	0	0
Pdsch	0	760,5	219,5	0	0	0	0	0	0	0	0	414,24	0	0	0	0	0	0	0	0	415,6	821,16	723,24	0

C Problem 2.2

C.1 a)

C.1.1 Power consumed by the loads

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	TOTAL
Pf	850	850	850	850	850	761,58	647,28	471,6	516,24	381,6	361,1	327,36	382,32	364,32	346,32	307,98	431,82	406,8	472,44	659,16	593,64	658,44	850	850	**14040**
Prede	850	850	850	850	850	761,58	647,28	471,6	516,24	381,6	361,1	327,36	382,32	364,32	346,32	307,98	431,82	406,8	472,44	659,16	593,64	658,44	850	850	**14040**
PVused	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**
Pdsch	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**

C.1.2 PV power distribution

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	TOTAL
PV	0	0	0	0	0	20	80	300	800	1250	1600	1800	2000	1800	1700	1400	950	500	150	30	0	0	0	0	**14380**
PVsold	0	0	0	0	0	0	0	300	800	1250	1600	1800	2000	1800	1700	1400	950	500	150	30	0	0	0	0	**14280**
PVused	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**
PVch	0	0	0	0	0	20	80	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**100**

C.1.3 Energy stored in each hour

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Energy	1000	1000	1000	1000	1000	1106,252	1383,317	1383,317	1383,317	1383,317	1383,317	1383,317	1383,317	1383,317	1383,317	1383,317	1383,317	0	0	0	0	0	0	0
PVch	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pdsch	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pdsch_sold	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1355,651	0	0	0	0	0	0
Prede_ch	0	0	0	0	0	88,42	202,72	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

C.2 b)

C.2.1 Power consumed by the loads

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	TOTAL
Pf	749,16	760,5	963,36	919,62	850	648,2	519,12	471,6	516,24	475,2	446,16	414,24	382,32	364,32	346,32	390,42	431,82	500	472,44	528,84	593,64	658,44	850	788,04	**14040**
Prede	749,16	760,5	224,58	850	850	628,2	439,12	0	0	0	0	0	0	0	0	0	0	0	113,36	0	0	0	850	788,04	**6252,96**
PVused	0	0	0	0	0	20	80	300	516,24	475,2	446,16	414,24	382,32	364,32	346,32	390,42	431,82	500	150	30	0	0	0	0	**4847,04**
Pdsch	0	0	738,78	69,62	0	0	0	171,6	0	0	0	0	0	0	0	0	0	0	209,08	498,84	593,64	658,44	0	0	**2940**

C.2.2 PV power distribution

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	TOTAL
PV	0	0	0	0	0	20	80	300	800	1250	1600	1800	2000	1800	1700	1400	950	500	150	30	0	0	0	0	**14380**
PVsold	0	0	0	0	0	0	0	0	0	0	171,5837	1385,76	1617,68	1435,68	1353,68	1009,58	518,18	0	0	0	0	0	0	0	**7492,144**
PVused	0	0	0	0	0	20	80	300	516,24	475,2	446,16	414,24	382,32	364,32	346,32	390,42	431,82	500	150	30	0	0	0	0	**4847,04**
PVch	0	0	0	0	0	0	0	0	283,76	774,8	982,2563	0	0	0	0	0	0	0	0	0	0	0	0	0	**2040,816**

C.2.3 Energy stored in each hour

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Energy	1000	1000	246,1429	175,102	175,102	175,102	175,102	0	278,0848	1037,389	2000	2000	2000	2000	2000	2000	2000	2000	1786,653	1277,633	671,8776	0	0	0
PVch	0	0	0	0	0	0	0	0	283,76	774,8	982,2563	0	0	0	0	0	0	0	0	0	0	0	0	0
Pdsch	0	0	738,78	69,62	0	0	0	171,6	0	0	0	0	0	0	0	0	0	0	209,08	498,84	593,64	658,44	0	0
Pdsch_sold	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Prede_ch	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

C.3 c)

C.3.1 Power consumed by the loads

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**TOTAL**
Pf	850	850	771,84	850	850	651,3497	519,12	579,6	419,76	381,6	353,04	414,24	382,32	364,32	346,32	390,42	431,82	507,6	472,44	539,4103	593,64	821,16	850	850	**14040**
Prede	850	850	771,84	850	850	631,3497	439,12	579,6	419,76	381,6	353,04	414,24	382,32	364,32	346,32	390,42	431,82	507,6	472,44	539,4103	593,64	821,16	850	850	**13940**
PVused	0	0	0	0	0	20	80	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**100**
Pdsch	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**

C.3.2 PV power distribution

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**TOTAL**
PV	0	0	0	0	0	20	80	300	800	1250	1600	1800	2000	1800	1700	1400	950	500	150	30	0	0	0	0	**14380**
PVsold	0	0	0	0	0	0	0	300	800	1250	1600	1800	2000	1800	1700	1400	950	500	150	30	0	0	0	0	**14280**
PVused	0	0	0	0	0	20	80	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**100**
PVch	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**

C.3.3 Energy stored in each hour

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Energy	1000	1000	1076,597	1076,597	1076,597	1290,874	1693,536	162,9242	584,5594	1043,591	1530,612	0	458,3264	934,2928	1427,899	1800,053	269,4407	604,9927	975,0015	1279,379	1530,612	0	0	0
PVch	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pdsch	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pdsch_sold	0	0	0	0	0	0	0	1500	0	0	0	1500	0	0	0	0	1500	0	0	0	0	1500	0	0
Prede_ch	0	0	78,16	0	0	218,6503	410,88	0	430,24	468,4	496,96	0	467,68	485,68	503,68	379,7488	0	342,4	377,56	310,5897	256,36	0	0	0

C.4 d)

C.4.1 Power consumed by the loads

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**TOTAL**
Pf	749,16	760,5	963,36	736,38	700,92	761,58	519,12	579,6	516,24	475,2	446,16	414,24	382,32	364,32	346,32	390,42	431,82	507,6	578,76	528,84	593,64	658,44	847,02	788,04	**14040**
Prede	749,16	760,5	289,8404	736,38	700,92	0	439,12	0	0	0	0	0	0	0	0	0	0	0	99,10594	498,84	84,72578	658,44	0	0	**5017,032**
PVused	0	0	0	0	0	20	80	300	516,24	475,2	446,16	414,24	382,32	364,32	346,32	390,42	431,82	500	150	30	0	0	0	0	**4847,04**
Pdsch	1,05E-11	2,27E-13	673,5196	0	6,82E-13	741,58	0	279,6	0	0	0	0	0	0	0	0	0	7,6	329,6541	0	508,9142	1,14E-12	847,02	788,04	**4175,928**

C.4.2 PV power distribution

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**TOTAL**
PV	0	0	0	0	0	20	80	300	800	1250	1600	1800	2000	1800	1700	1400	950	500	150	30	0	0	0	0	**14380**
PVsold	0	0	0	0	0	0	0	0	62,69498	774,8	1153,84	1385,76	1617,68	1435,68	1353,68	1009,58	518,18	0	0	0	0	0	0	0	**9311,895**
PVused	0	0	0	0	0	20	80	300	516,24	475,2	446,16	414,24	382,32	364,32	346,32	390,42	431,82	500	150	30	0	0	0	0	**4847,04**
PVch	0	0	0	0	0	0	0	0	221,065	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**221,065**

C.4.3 Energy stored in each hour

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Energy	1098,823	1186,533	499,2683	610,6159	756,7143	0	402,6624	117,3563	1167	1167	1167	1167	1167	2000	2000	2000	2000	1992,245	1655,863	2000	1480,7	1668,429	804,1224	0
PVch	0	0	0	0	0	0	0	0	221,065	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pdsch	1,05E-11	2,27E-13	673,5196	0	6,82E-13	741,58	0	0	0	0	0	0	0	0	0	0	0	7,6	329,6541	0	508,9142	1,14E-12	847,02	788,04
Pdsch_sold	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Prede_ch	100,84	89,5	0	113,62	149,08	0	410,88	0	850	0	0	0	0	850	0	0	0	0	0	351,16	0	191,56	0	0

D Problem 3

D.1 Problem 2.2 a)

D.1.1 Power consumed by the loads

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**TOTAL**
Pf	850	850	850	850	850	761,58	647,28	579,6	516,24	381,6	446,16	414,24	301,68	287,28	272,88	350,76	345,78	507,6	578,76	528,84	700	658,44	723,24	788,04	**14040**
Prede	850	850	850	850	850	761,58	647,28	579,6	516,24	0	446,16	0	0	0	0	0	0	507,6	578,76	528,84	700	658,44	700	700	**11574,5**
PVused	0	0	0	0	0	0	0	0	0	381,6	0	414,24	301,68	287,28	272,88	350,76	345,78	0	0	0	0	0	0	0	**2354,22**
Pdsch	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	23,24	88,04	111,28

D.1.2 PV power distribution

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**TOTAL**
PV	0	0	0	0	0	20	80	300	800	1250	1600	1800	2000	1800	1700	1400	950	500	150	30	0	0	0	0	**14380**
PVsold	0	0	0	0	0	0	0	300	800	868,4	1600	1385,76	1698,32	1512,72	1427,12	1049,24	604,22	500	150	30	0	0	0	0	**11925,78**
PVused	0	0	0	0	0	0	0	0	0	381,6	0	414,24	301,68	287,28	272,88	350,76	345,78	0	0	0	0	0	0	0	**2354,22**
PVch	0	0	0	0	0	20	80	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100

D.1.3 Energy stored in each hour

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Energy	1000	1000	1000	1000	1000	1106,252	1383,317	1383,317	113,551	113,551	113,551	113,551	113,551	113,551	113,551	113,551	113,551	113,551	113,551	113,551	113,551	113,551	89,83673	0
PVch	0	0	0	0	0	20	80	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pdsch	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	23,24	88,04
Pdsch_sold	0	0	0	0	0	0	0	0	1244,371	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Prede_ch	0	0	0	0	0	88,42	202,72	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

D.2 Problem 2.2 b)

D.2.1 Power consumed by the loads

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**TOTAL**
Pf	850	760,5	850	919,62	850	610,02	647,28	520,9	516,24	475,2	446,16	414,24	382,32	364,32	346,32	390,42	431,82	500	472,44	528,84	593,64	658,44	723,24	788,04	**14040**
Prede	850	760,5	850	160,52	850	590,02	567,28	0	0	0	0	0	0	0	0	0	0	0	224,64	0	0	0	700	700	**6252,96**
PVused	0	0	0	0	0	20	80	300	516,24	475,2	446,16	414,24	382,32	364,32	346,32	390,42	431,82	500	150	30	0	0	0	0	**4847,04**
Pdsch	0	0	0	759,1	0	0	0	220,9	0	0	0	0	0	0	0	0	0	0	97,8	498,84	593,64	658,44	23,24	88,04	2940

D.2.2 PV power distribution

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**TOTAL**
PV	0	0	0	0	0	20	80	300	800	1250	1600	1800	2000	1800	1700	1400	950	500	150	30	0	0	0	0	**14380**
PVsold	0	0	0	0	0	0	0	0	0	0	171,5837	1385,76	1617,68	1435,68	1353,68	1009,58	518,18	0	0	0	0	0	0	0	**7492,144**
PVused	0	0	0	0	0	20	80	300	516,24	475,2	446,16	414,24	382,32	364,32	346,32	390,42	431,82	500	150	30	0	0	0	0	**4847,04**
PVch	0	0	0	0	0	0	0	0	283,76	774,8	982,2563	0	0	0	0	0	0	0	0	0	0	0	0	0	2040,816

D.2.3 Energy stored in each hour

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Energy	1000	1000	1000	225,4082	225,4082	225,4082	225,4082	0	278,0848	1037,389	2000	2000	2000	2000	2000	2000	2000	2000	1900,204	1391,184	785,4286	113,551	89,83673	0
PVch	0	0	0	0	0	0	0	0	283,76	774,8	982,2563	0	0	0	0	0	0	0	0	0	0	0	0	0
Pdsch	0	0	0	759,1	0	0	0	220,9	0	0	0	0	0	0	0	0	0	0	97,8	498,84	593,64	658,44	23,24	88,04
Pdsch_sold	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Prede_ch	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

D.3 Problem 2.2 c)

D.3.1 Power consumed by the loads

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**TOTAL**
Pf	850	850	850	850	850	669,6656	647,28	579,6	516,24	475,2	446,16	377,3344	382,32	287,28	272,88	390,42	431,82	507,6	472,44	528,84	593,64	700	723,24	788,04	**14040**
Prede	850	850	850	850	850	669,6656	647,28	579,6	516,24	475,2	446,16	377,3344	382,32	287,28	272,88	390,42	431,82	507,6	472,44	528,84	593,64	700	700	700	**13928,72**
PVused	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**
Pdsch	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	23,24	88,04	111,28

D.3.2 PV power distribution

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**TOTAL**
PV	0	0	0	0	0	20	80	300	800	1250	1600	1800	2000	1800	1700	1400	950	500	150	30	0	0	0	0	**14380**
PVsold	0	0	0	0	0	0	0	300	800	1250	1600	1800	2000	1800	1700	1400	950	500	150	30	0	0	0	0	**14280**
PVused	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**
PVch	0	0	0	0	0	20	80	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100

D.3.3 Energy stored in each hour

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Energy	1000	1000	1000	1000	1000	1196,328	1473,393	0	327,0848	694,3888	1090,152	1553,364	22,752	574,2176	1139,795	1590,184	2000	1149,185	1372,194	1539,93	1644,163	113,551	89,83673	0
PVch	0	0	0	0	0	20	80	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pdsch	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	23,24	88,04
Pdsch_sold	0	0	0	0	0	0	0	1443,925	0	0	0	0	1500	0	0	0	0	833,7988	0	0	0	1500	0	0
Prede_ch	0	0	0	0	0	180,3344	202,72	0	333,76	374,8	403,84	472,6656	0	562,72	577,12	459,58	418,18	0	227,56	171,16	106,36	0	0	0

D.4 Problem 2.2 d)

D.4.1 Power consumed by the loads

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	TOTAL
Pf	749,16	760,5	771,84	736,38	700,92	702,84	519,12	579,6	516,24	475,2	446,16	414,24	382,32	364,32	346,32	390,42	431,82	507,6	578,76	528,84	593,64	658,44	902,16	983,16	14040
Prede	749,16	760,5	39,58038	736,38	700,92	0	439,12	0	0	0	0	0	0	0	0	0	0	7,6	18,82357	498,84	593,64	658,44	0	0	5203,004
PVused	0	0	0	0	0	20	80	300	516,24	475,2	446,16	414,24	382,32	364,32	346,32	390,42	431,82	500	150	30	0	0	0	0	4847,04
Pdsch	0	0	732,2596	0	0	682,84	0	279,6	0	0	0	0	0	0	0	0	0	0	409,9364	0	0	0	902,16	983,16	3989,956
Prede_ch	0	0	0	0	0	180,3344	202,72	0	333,76	374,8	403,84	472,6656	0	562,72	577,12	459,58	418,18	0	227,56	171,16	106,36	0	0	0	

D.4.2 PV power distribution

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	TOTAL
PV	0	0	0	0	0	20	80	300	800	1250	1600	1800	2000	1800	1700	1400	950	500	150	30	0	0	0	0	14380
PVsold	0	0	0	0	0	0	0	0	62,69498	774,8	1153,84	1385,76	1617,68	1435,68	1353,68	1009,58	518,18	0	0	0	0	0	0	0	9311,895
PVused	0	0	0	0	0	20	80	300	516,24	475,2	446,16	414,24	382,32	364,32	346,32	390,42	431,82	500	150	30	0	0	0	0	4847,04
PVch	0	0	0	0	0	0	0	0	221,065	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	221,065
Prede_ch	0	0	0	0	0	180,3344	202,72	0	333,76	374,8	403,84	472,6656	0	562,72	577,12	459,58	418,18	0	227,56	171,16	106,36	0	0	0	

D.4.3 Energy stored in each hour

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Energy	1098,823	1186,533	439,3295	550,6771	696,7755	0	402,6624	117,3563	1167	1167	1167	1167	1167	1167	1167	2000	2000	2000	1581,698	1778,834	1883,067	1923,796	1003,224	0
PVch	0	0	0	0	0	0	0	0	221,065	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pdsch	0	0	732,2596	0	0	682,84	0	279,6	0	0	0	0	0	0	0	0	0	0	409,9364	0	0	0	902,16	983,16
Pdsch_sold	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Prede_ch	100,84	89,5	0	113,62	149,08	0	410,88	0	850	0	0	0	0	0	0	850	0	0	0	201,16	106,36	41,56	0	0