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IE 453 – Energy Systems Planning

“A stochastic model for a macroscale hybrid renewable energy system”

Term Project - Report

Group 15

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1. Brief Introduction to the Paper

1.1 Background

The need for sustainable energy has increased rapidly in the past two decades. The reason for that is, fossil fuels, where they still are the main input of energy production throughout the world, are finite resources and pose great threat to the world in terms of global warming and other environmental concerns. Scholars, starting from 1980s, have been studying this problem and propose economically feasible, implementable and eco-friendly frameworks for energy operations. Our paper is one of the work of those scholars, where it recognizes the fossil fuel use for energy consumption as a threat to environment and develops a logical framework for energy supply within the context of renewable sources. In the paper, underdeveloped parts of India, where poor electricity supply constitutes a huge problem for societal-economic progress, is studied as a case study, and the models proposed in the paper have been tested on that region. This is a sound approach because India is very rich in terms of renewable energy potential. Monsoon rains in summer, Himalayan ranges with great hydropower potential and high solar irradiance levels are examples of India's rich renewable sources.

1.2 Ultimate Goal of the Paper

In the paper, hybrid energy generation and allocation system consisting of three different sources of energy is modeled. Energy sources consist of one dispatchable fossil fuel (diesel generator) and two renewable sources (solar energy and hydropower). We know that renewable energy sources comes with two major problems, intermittency of the generation potential and high initial investment costs for the equipment. This paper shows us how combining multiple renewable sources can help reduce the intermittency to increase the reliability the energy supply. Main component of the proposed system is a solar farm, where the solar generation is backed up by a conventional hydropower station and diesel generator to meet the demand. The water stored in the reservoirs of hydropower station serves as a backup to mitigate the volatility in the solar radiation, where the diesel generator serves as the last (also expensive) option in order to meet the demand, when others fall behind the demand. It can be said that this paper aims to help infrastucture planners as it's main purpose is to develop a economically feasible and environmentally energy infrastructure system. Ultimate goal of this paper is to present a model that optimizes the capacities of renewable energy infrastructure (size of the reservoir & capacity of solar farm) in order to manage supply and demand in the most cost effective way possible.

2. Problem Definition

As it was mentioned in the previous section, this paper's goal is to come up with a hybrid energy generation and allocation system consisting of different energy sources. The paper proposes a mathematical model that will help infrastructure planners identify optimal capacity for solar farm, optimal size of the reservoir of hydropower station, optimal basin to build the hydropower station on it and optimal sizes for generator and transmission equipment while accounting for variability and intermittency issues in both the generation of hybrid system and the demand at the same time, in order to manage the supply and demand of electricity. The objective of the proposed model is to minimize the sum of the investment costs and expected penalty cost (cost of using dispatchable source in our case) for the unmet demand, while balancing the supply and demand. The model is a cost minimization model subject to linear set of constraints.

2.1 Input to the Model

- Streamflow data for each candidate basin (water inflow forecast by a large scale hydrological model, "Variable Infiltration Capacity")
- Solar radiation data (direct irradiance measured by U.S. National Renewable Energy Laboratory)
- Demand of each demand point (3-hourly aggregated demand for Delhi, India)

2.2 Expected Output

- Optimal reservoir capacities in hydropower stations
- Optimal sizes of solar panels
- Optimal generator sizes for each hydropower station
- Maximum energy that can be transmitted from a hydropower station to a demand point

3. Methodology

To find optimal sizes for solar farm, reservoirs of the hydrostations along with optimal basins, a linear programming model is to be set up. The model, where we present it in the next section, consists of fairly simple constraints. In addition to that, the linear programming model also involves different scenarios, where in each of them different set of conditions (different streamflow, solar irradiance, etc.) are considered, making the model a stochastic model, more formally a two-stage stochastic program where the first stage is to decide for the optimal sizing and the second stage is to account for the scenario-based operational decisions.

- Main structure of the linear programming model.:
    - Mass-balance equations
    - Demand constraint
    - Technical & logical constraints regarding the electricity generation
    - Total cost incurred from different sources of energy is minimized
    - Costs of all kinds of infrastructure are annualized by proper discount factors.
- We are familiar with the model from our class discussions.

3.1 Problem Formulation

$S_i^{\omega t}$: water stored in the reservoir in hydropower station i at the end of period t in scenario ω

$Z_j^{\omega t}$: mismatched demand (diesel usage) in demand point j in period t in scenario ω

$T_{ij}^{\omega t}$: electricity sent from hydropower station i to demand point j in period t in scenario ω

$L_i^{\omega t}$: water spilled from the reservoir in hydropower station i in period t in scenario ω

$R_i^{\omega t}$: water released from the reservoir in hydropower station i in period t in scenario ω

$Smax_i$: active upper reservoir capacity in hydropower station i

M_j : size of solar panels at demand point j

$PGmax_i$: generator size in hydropower station i

$Tmax_{ij}$: maximum energy transmitted from hydropower station i to demand point j

State variables

i: hydropower station 1,…,I, with a total of I locations

j: demand (solar power station) point 1,…,J, with a total of J points

t: time period 1,…,T, with a total of T periods

ω: scenarios 1,…, Ω, with a total of Ω scenarios

Indices

n: length of time periods

d_h: dimensionless annualization parameter for hydropower stations

d_s: dimensionless annualization parameter for solar power stations

d_t: dimensionless annualization parameter for transmission lines

l_{ij}: percentage of power loss while transmitting electricity from hydropower generation point i to demand point j.

g: standard acceleration due to gravity (~ 9.8 m/s^2)

h_i: height of the reservoir in hydropower generation point i

α: efficiency of hydropower stations

γ: efficiency of solar panels

C_{Si}: unit cost of reservoir capacity in hydropower generation point i

C_{PGi}: unit cost of generator capacity in hydropower generation point i

C_{Mj}: unit cost of solar array in demand point j

C_{Tij}: unit cost of transmission line capacity between hydropower generation point i and demand point j

μ_j: unit cost of generating electricity using diesel generator (i.e. penalty for mismatched demand in demand point j)

p_ω : weight of scenario ω, where $\sum_{\omega=1}^{\Omega} p_\omega = 1$ and $p_\omega \geq 0$

Parameters

i. Cost of Reservoirs:

$$C_1 = \sum_i C_{Si} * Smax_i$$

ii. Cost of Hydropower Generators:

$$C_2 = \sum_i C_{PGi} * PGmax_i$$

iii. Cost of Solar Power Stations:

$$C_3 = \sum_j C_{Mj} * M_j$$

iv. Cost of Transmission Lines:

$$C_4 = \sum_i \sum_j C_{Tij} * Tmax_{ij}$$

v. Expected Cost of Mismatched Demand:

$$C_5 = \sum_{jt\omega} p_\omega * Z_j^{\omega t} * \mu_j$$

Objective function can be stated as:

$$\min(C_1 + C_2) * d_h + C_3 * d_s + C_4 * d_t + C_5$$

Components of the objective function

Objective function consists of the components that are products of sizes and the unit costs for respective sizes. Only in the fifth component (C_5) we are not be taking different scenarios into account. We simplified the model and ignored different scenarios, which means the model is now reduced to a non-stochastic (deterministic) linear programming model. We believe that adding an index for scenarios (w) would complicate things further, so we decided to consider only one scenario as a simplification.

$$
\left.\begin{array}{lr}
S_i^{\omega t} \le \mathrm{Smax}_i \quad \forall i,t,\omega & (1) \\
S_i^{\omega t} = S_i^{\omega(t-1)} + W_i^{\omega t} - R_i^{\omega t} - L_i^{\omega t} \quad \forall i,t : t>1,\omega & (2) \\
S_i^{\omega 1} = \mathrm{Smax}_i + W_i^{\omega 1} - R_i^{\omega 1} - L_i^{\omega 1} \quad \forall i,\ \omega & (3) \\
S_i^{\omega T} = \mathrm{Smax}_i \quad \forall i,\ \omega & (4) \\
f_{Gi}(R_i^{\omega t}) \le PG\mathrm{max}_i * n \quad \forall i,t,\omega & (5) \\
\sum_j T_{ij}^{\omega t} = f_{Gi}(R_i^{\omega t}) \quad \forall i,t,\omega & (6) \\
T_{ij}^{\omega t} \le \mathrm{Tmax}_{ij} * n \quad \forall i,j,t,\omega & (7) \\
D_j^{\omega t} \le Z_j^{\omega t} + f_{Sj}(M_j) + \sum_i T_{ij}^{\omega t} * (1 - l_{ij}) \quad \forall j,t,\omega & (8) \\
S_i^{\omega t}, Smax_i, PGmax_i, R_i^{\omega t}, L_i^{\omega t}, M_j,\ T_{ij}^{\omega t}, Tmax_{ij}, Z_j^{\omega t} \ge 0 \quad \forall i,j,t,\omega & (9)
\end{array}\right\} \ \boxed{\text{Constraints}}
$$

W_it: water inflow to basin i at time t.

N_jt: solar radiation in point j at time t.

D_jt: demand at point j at time t where (w) represents different scenarios with different occurrence probabilities.

Explanation of constraints;

1) Amount of water in the reservoir cannot exceed the capacity
2) Mass-balance equation
3) Initiating the reservoir
4) At time T (end) the reservoir will be full
5) f: (R x g x h x α) indicates total amount of energy generated at time t
6) Generated electricity is limited by the transmission capacity
7) Amount of energy transmitted at time t cannot exceed the transmission capacity
8) Demand constraint
9) All variables are non-negative

4. Strengths and Weaknesses of the Paper

4.1 Strengths

✓ It demonstrates that different renewable energy sources can be combined and used effectively.

- ✓ Shows how to achieve cost-effective way of determining capacities of hydropower and solar power stations to meet energy demand in an over-populous country like India where energy supply might be a problem.
- ✓ It shows both analytically and numerically how it would be beneficial for basins to be connected with each other rather than being independent from each other.
- ✓ Sensitivity analysis section presents a nice glimpse of what would have happened if different unit cost parameters are taken into account. It allows the reader to observe the tradeoffs within the whole system.

4.2 Weaknesses

1) Grid option was not considered in the system. When renewables fall behind the demand, the only option to fulfill the mismatched demand is a fossil fueled (diesel) generator. Probably pulling electricity from the grid (centralized network) would be much more cheaper in practice.
2) Height of the dam is taken as constant, where in real life the height decreases as the water is withdrawn from the dam. This certainly affects the electricity conversion efficiency because height and the angular speed of turbines are more or less proportional to each other. We ignore this relation by taking height as constant.
3) Ecological and agricultural impacts of building a hydropower station are not considered in this paper, but this is not a big problem since ecological impacts are extremely hard to quantify.
4) In the paper, it is assumed that the cost of generator size or unit cost of the reservoir increases in a linear fashion. In practice, we expect cost curves to be concave.
5) Expensive dispatchable source (diesel generator) comes only with operational cost. The paper does not consider the setup cost for the generator.
6) The effect of the length/thickness of the wires on the power loss is ignored.

5. Our Application of the Same Model

We firstly generated random input data (daily) for solar radiation, demand and streamflow because we neither could find the data used in the paper nor any other proper real data from any source. Websites mostly generates uninterpretable (or incorrect) data sheets. We set the unit of demand as GWh and the unit of the solar radiation as GWh/km^2. The paper informs the reader that the streamflow varied between 3 km^3 and 14 km^3 between 1951 and 2003. Therefore, while creating the daily streamflow data, we created a random value between these two values and divided by 365. While generating the data for demand and solar radiation, we have used a sample data. We assumed the data as normal distribution according to Central Limit Theorem and calculated mean and variance values using excel formulas. Mean of the demand is found to be 12.51 and standard deviation is 1.155 (We have used the excel formula

=RANDBETWEEN(1251-115.5*RAND(),1251+115.5*RAND())/100 to generate random demand data). Solar radiation mean is found as 0.531 GWh/km^2 and standard deviation is 0.7241. Since standard deviation is more than the the mean, we have created an if formula to eliminate nonnegativity. Below is a snapshot of the time series data we have generated.

Random dema	Random Solar Radiation	Nonnegative Random So	Random Streamflow(km^3)
12.9200	1.1600	1.16	0.0301
12.0300	0.6400	0.64	0.0082
12.5500	0.1500	0.15	0.0110

We created the model with 10 demand points and 7 basins as proposed in the paper and reproduced the data for each demand point and basins using the above procedure. Lastly, as we have mentioned previously, our objective function has also five components but we did not include scenario in the fifth component, and in general we reduced model to a non-stochastic version.

Below are our assumptions when implementing the model on IBM ILOG CPLEX;

- We formulated the problem as a one-stage program and ignored different scenarios.
- We set generator's lifetime same as the lifetime of the hydropower station.
- We took unit cost of transmission as 0.01 $/kWh.
- Power loss parameter is set as 0.2 (20%) for all distances. The effect of the length/thickness of the wires on the power loss is ignored.

As we have stated in our presentation on 4th of May, we had plenty of zeros in solar panel size array. We first suspected that there was a problem with our code or the model's structure, however, we failed to detect any problem. We concluded that this result is a natural consequence of the cost parameters we set or insufficient solar radiation. At the end of the presentation, Selin Hoca informed us that, with the data she used in the past, solar panels are supposed to supply 30% of the total supply, and she recommended us decreasing the unit cost of the solar panels as well as multiplying time series of the solar irradiance by ten. In section 4.2, we presented the weaknesses of the paper. We did a brainstorm on how we can enhance the model to mitigate those weakness. We slightly changed the model's dynamics based on our ideas. The following are the parts we changed/added to the original model:

- To mitigate weakness (1), we added a grid option to our model. We basically switched diesel component in the model to grid. We set its cost as 0.05$ per KWh. Now, the model has the flexibility of pulling electricity from the grid (centralized network), where the cost is much cheaper than the diesel generator. Our motivation is that we think diesel generator is not the suitable device for this system, which will serve as the supplier of electricity to a entire city or a region. We found that diesel generators are mostly used for private houses, residential buildings, or neighborhoods' electricity supply. There is diesel generator in the world to supply energy at gigawatt levels. That's why we changed diesel component to the grid. We did not consider the setup cost for the grid as it’s not a part of our system. We assume that the centralized network was built independently from our system. We basically outsource electricity when our own system’s generation fails to meet the current demand. For this reason, we don’t have to consider its initial investment cost, we only take its operational cost, which is the cost of electricity per KWh. This modification also mitigates the weakness (5) at the same time.

Another candidate approach to mitigate weakness (5) might be to add a binary variable (say P_t) that indicates whether the diesel generator is on or not at time t, along with adding a term like [max(P_t) * (Cost of the generator)] to the objective function to account for the setup cost of the diesel generator. Above procedure would fix this issue as max(P_t) would be 1 (even if it is used in only one day) and the objective function will incur that initial investment cost needed to purchase the generator. However, there is one major disadvantage we face with this approach. The term “max(P_t)” introduces non-linearity to the model, and makes it difficult (almost impossible) for CPLEX to solve the model in reasonable amount of time. Unfortunately, we failed to find an efficient linearizing technique that will resolve this problem. We believe that this is not a big problem for us since (as we state in the previous paragraph), using diesel generator (instead of outsourcing from the pre-installed grid) for electricity supply of a city or region is not a wise approach.

- For the weaknesses (2) and (4);

We believe that resolution of the (2) and (4) is beyond our knowledge.

- For the weakness (3);

We are not able to quantify the environmental damage of building a hydropower dam, it does not fall into our area of expertise.

- For the weakness (6);

Selin Hoca informed us that the effect of length/thickness of the wires on the power loss is really something negligible. So we don’t go into this further.

The following is the list of our modifications (to account for the weaknesses) on the initial model we have developed;

- Diesel component switched to grid (centralized network) where the unit cost is set $0.05 (one fifth of the cost of diesel),
- Time series data of solar irradiance is multiplied by ten,
- Unit cost of the solar panel is reduced to $160 from $200.

In Appendix A and Appendix B, one may find the OPL code (.mod and .dat files, respectively) we have wrote for the updated model. Results are available in Appendix C and Appendix D. We used CPLEX 12.10 and the model was solved with the machine: 64-Bit Windows OS with Intel i7 7500U (2.7 Ghz) (quadcore) Processor with 8 GB RAM where computation time is 00:00:14:16.

6. Results and Conclusion

In Appendix C and D we present the results we obtained by solving the model. With the help of Selin Hoca's advices on playing with the parameters of the model, we could solve the problem with those zeros in solar panel sizes and managed to obtain logical results. The problem related to those zeros were possibly high unit cost of a solar panel combined with the insufficient solar radiation levels. The model optimized the sizing of the necessary infrastructure and with the proposed model 22.78% of the demand is met by solar panels, 75.78% of the demand is met by hydropower stations, where the rest (1.44%) is supplied from the centralized grid as an outsource option. In the system, the total cost we incur is 706,368.

Appendix A – OPL Code Written for CPLEX

①

```
//Setting Parameters

int length_of_time_periods = ...;
                                  // 24h-data
float Discount_factor_for_hydropower = ...;
float Discount_factor_for_solarpower = ...;
float Discount_factor_for_transmission = ...;
float Gravity = ...;
                                                         // m/s^2
float Efficiency_of_hydros = ...;
float Efficiency_of_solar = ...;
float Unit_cost_of_reservior = ...;
                                  // $/m^3
float Unit_cost_of_generator_capacity = ...;
              // $/kW
float Unit_cost_of_solar = ...;
                                           // $/m^2
float Unit_cost_of_transmission = ...;
                                  // $/kWh
float Unit_cost_of_grid= ...;
                                           // $/kWh
float Power_loss= ...;

range demand = 1..10;
range reservoir = 1..7;
range time = 1..365;
range time2 = 0..365;

float Water_inflow[reservoir][time] = ...;
float Solar_radiation[demand][time]= ...;
float Demand[demand][time] = ...;

float Height_of_reservoir[reservoir]= ...;

//Setting Decision Variables

dvar float Size_of_the_Reservoir[reservoir] ;
dvar float Size_of_the_SolarPanel[demand] ;
dvar float Size_of_the_Generator[reservoir] ;
dvar float Maximum_Energy_Transmission[reservoir][demand] ;
dvar float Water_Size[reservoir][time2] ;
dvar float Grid_Usage[demand][time]  ;
dvar float Electricity_Sent[reservoir][demand][time] ;
dvar float Water_Spilled[reservoir][time]  ;
dvar float Water_Released[reservoir][time] ;
//dvar boolean binary_var[time];


// Objective function

dexpr float Cost_of_Reservoir =  sum(i in reservoir)
(Unit_cost_of_reservior * Size_of_the_Reservoir[i]) ;

dexpr float Cost_of_Hydropower_Generators = ( sum(i in reservoir)
Unit_cost_of_generator_capacity * Size_of_the_Generator[i] );

dexpr float Cost_of_Solar = ( sum(j in demand)
Unit_cost_of_solar * Size_of_the_SolarPanel[j] );

dexpr float Cost_of_Transmission_Line = ( sum(i in reservoir, j
in demand)  Unit_cost_of_transmission *
Maximum_Energy_Transmission[i][j] );

dexpr float Cost_of_Mismatched_Demand = ( sum(j in demand, t in
time) Unit_cost_of_grid * Grid_Usage[j][t] );

//dexpr int setup_cost = max(t in time)binary_var[t];

minimize ((Cost_of_Reservoir + Cost_of_Hydropower_Generators) *
(Discount_factor_for_hydropower)) + (Cost_of_Solar *
Discount_factor_for_solarpower) + (Cost_of_Transmission_Line *
Discount_factor_for_transmission) + (Cost_of_Mismatched_Demand);

// Constraints

subject to{

         forall (i in reservoir , t in time )
                  Water_Size[i][t] <= Size_of_the_Reservoir[i];
```

②

```
         forall (i in reservoir , t in time )
                  Mass_balance:
                           Water_Size[i][t] ==  Water_Size[i][t-
1] + Water_inflow[i][t] - Water_Released[i][t] -
Water_Spilled[i][t];

         forall (i in reservoir)
           Water_Size[i][0] == (Size_of_the_Reservoir[i]) ;

     forall (i in reservoir )
       Initiating_the_reservoir:
         Water_Size[i][1] == Size_of_the_Reservoir[i] +
Water_inflow[i][1] - Water_Released[i][1] - Water_Spilled[i][1] ;


    forall (i in reservoir)
                  At_time_T_end_the_reservoir_will_be_full:
                           Water_Size[i][365] ==
Size_of_the_Reservoir[i] ;

         forall (i in reservoir , t in time )

f_Rxgxhxa_indicates_total_amount_of_energy_generated_at_time_t:
                  Water_Released[i][t] * Efficiency_of_hydros *
Gravity * Height_of_reservoir[i] <= Size_of_the_Generator[i] *
length_of_time_periods;

         forall (i in reservoir , t in time )

         Generated_electricity_is_limited_by_the_transmission_cap
acity:
                           sum(j in demand)
Electricity_Sent[i][j][t] ==
Water_Released[i][t]*Efficiency_of_hydros*Gravity*Height_of_reser
voir[i];

         forall (i in reservoir , j in demand, t in time )

         Amount_of_energy_transmitted_at_time_t_cannot_exceed_the
_transmission_capacity:
                     Electricity_Sent[i][j][t] <=
Maximum_Energy_Transmission[i][j] * length_of_time_periods;

         forall (j in demand, t in time )
            Demand_constraint:
                  Demand[j][t] <= Grid_Usage[j][t] +
(Solar_radiation[j][t]*Size_of_the_SolarPanel[j] *
Efficiency_of_solar) + (sum(i in reservoir)
(Electricity_Sent[i][j][t]) * (1 - Power_loss));

         forall(i in reservoir, t in time)
                  Water_Size[i][t] >= 0;

         forall(i in reservoir)
                  Size_of_the_Reservoir[i] >= 0;

         forall(i in reservoir)
                  Size_of_the_Generator[i] >= 0;

         forall(i in reservoir, t in time)
                  Water_Released[i][t] >= 0;

         forall(j in demand, t in time)
                  Grid_Usage[j][t] >= 0 ;

         forall(i in reservoir, j in demand)
                  Maximum_Energy_Transmission[i][j] >= 0;

         forall(i in reservoir, j in demand, t in time)
                  Electricity_Sent[i][j][t] >= 0;

         forall(j in demand)
                  Size_of_the_SolarPanel[j] >= 0;

         forall(i in reservoir, t in time)
                  Water_Spilled[i][t] >= 0;

}
```

Appendix B – OPL Code written for CPLEX (.dat)

```
// Parameters

length_of_time_periods = 24;
                      // 24h-data
Discount_factor_for_hydropower = 0.0528;
Discount_factor_for_solarpower = 0.0651;
Discount_factor_for_transmission = 0.0582;
Gravity = 9.8;
                                            //
m/s^2
Efficiency_of_hydros = 0.88;
Efficiency_of_solar = 0.12;
Unit_cost_of_reservior = 3;
                             // $/m^3
Unit_cost_of_generator_capacity = 500;
                      // $/kW
Unit_cost_of_solar = 160;
                             // $/m^2
Unit_cost_of_transmission = 0.01;
                      // $/kWh
Unit_cost_of_grid = 0.05;
                             // $/kWh
Power_loss= 0.2;
Height_of_reservoir = [80,100,60,70,90,80,75];


// Time Series Data

SheetConnection my_sheet("Random_Data_12.xlsx");

Demand from SheetRead(my_sheet,"RandData!C3:NC12");
Solar_radiation from
SheetRead(my_sheet,"RandData!C44:NC53");
Water_inflow from
SheetRead(my_sheet,"RandData!C31:NC37");

// writing results to an excel file

SheetConnection
excelresult("C:\\Users\\asus\\opl\\proje12\\results
.xlsx");

Grid_Usage to SheetWrite(excelresult,
"Sheet2!A2:OK20");
Maximum_Energy_Transmission to
SheetWrite(excelresult, "Sheet1!A2:OK20");
```

Appendix C – Results

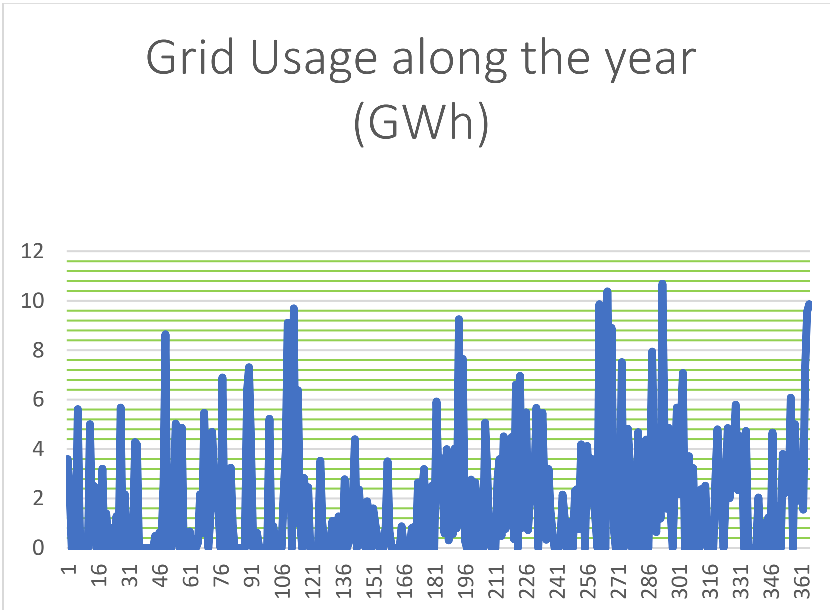

Figure 1: Grid usage along the year

max energy transmitted from basin 1:	1.019378	GWh
max energy transmitted from basin 2:	1.154942	GWh
max energy transmitted from basin 3:	0.782537	GWh
max energy transmitted from basin 4:	0.85651	GWh
max energy transmitted from basin 5:	1.01848	GWh
max energy transmitted from basin 6:	0.944772	GWh
max energy transmitted from basin 7:	0.914266	GWh
total:	6.690886	GWh

Figure 2: Maximum amount of energy transmitted from basins to demand points

Appendix D – Optimal Sizes

Optimal sizes of generators

basin	GW
1	0.71972
2	0.95431
3	0.50064
4	0.62022
5	0.787
6	0.70902
7	0.65236

Optimal sizes of reservoirs

basin	m^3
1	111,918.51
2	83,398.54
3	81,001.09
4	104,109.59
5	137,630.94
6	79,307.58
7	217,463.69

Optimal sizes of solar panels

demand points	km^2
1	0
2	9.166667
3	0
4	8.649425
5	8.050909
6	7.69385
7	9.698276
8	0
9	0
10	8.768437

Figure 3: Optimal sizes

References

Ayse Selin Kocaman, Carlos Abad, Tara J. Troy, Woonghee Tim Huh, Vijay Modi, A stochastic model for a macroscale hybrid renewable energy system, Renewable and Sustainable Energy Reviews, Volume 54, 2016, Pages 688-703.

- ➔ Link: https://www.sciencedirect.com/science/article/pii/S1364032115010795