Electric Power Markets Spring 2023 ENV 717

Nicholas School of the Environment Duke University

Assignment #3

In this assignment, you will use eGrid and EIA data to create a supply curve for electricity in PJM, and PJM demand data to estimate cost of meeting different demand levels.
*Please include all the graphs and tables into the word document your will submit as a solution to this assignment. Also submit a file with your calculations (excel or python) and a few lines inside those files explaining your approach to find the answers.

1. (25%) Download the file eGRID2020.xls from the eGRID website released on 1/27/2022, which contains the most recent data on power generation units for the U.S[1]. Look at the PLNT20 tab and create a subset of power plants that contains only those plants with the following characteristics:
-Column L, Balancing Authority Code, is PJM Interconnection, LLC.
-Column Y, Plant primary fuel category is equal to Coal, Gas, Hydro, or Nuclear.
-Column AA, Plant capacity factor, is 0.1 or greater.
-Column AB, Plant nameplate capacity (MW), is 10 or more.
a. (10%) What is the total installed capacity (in MW) from this subset of plants?

145,756.10 MW
For details, see python code or Excel file in the Github repository of the course.

b. (15%) Assume a competitive electricity market which has, on the supply side, a number of nuclear, coal-fired, natural gas-fired, and hydropower generators as presented in this subset of plants. Use the information given in columns AB, AJ, AN, AV, Plant nameplate capacity (MW), Plant annual heat input (MMBtu), Plant annual net generation (MWh), Plant annual CO_2 equivalent emissions (tons), to build a supply curve or electricity.
Assume the short-run marginal cost of natural-gas-fired and coal-fired generators is the cost of fuel only. Assume the short-run marginal cost of nuclear energy is $9/MWh. Graph the supply curve (aggregated short-run marginal cost) for electricity (at a given hour of the day). Assume the average coal and natural-gas prices for 2021 as reported by EIA in $/MBTU[2].
For this problem assume that there is no tax on CO2 equivalent emissions. This will change in the next assignment. Please copy the graph in your word document and do not forget to insert a title and to label the axes. Please differentiate the nuclear, coal plants, natural gas and hydro plants by graphing them with different colors and markers. Also remember that another way to refer to Million Btu is MMBtu.

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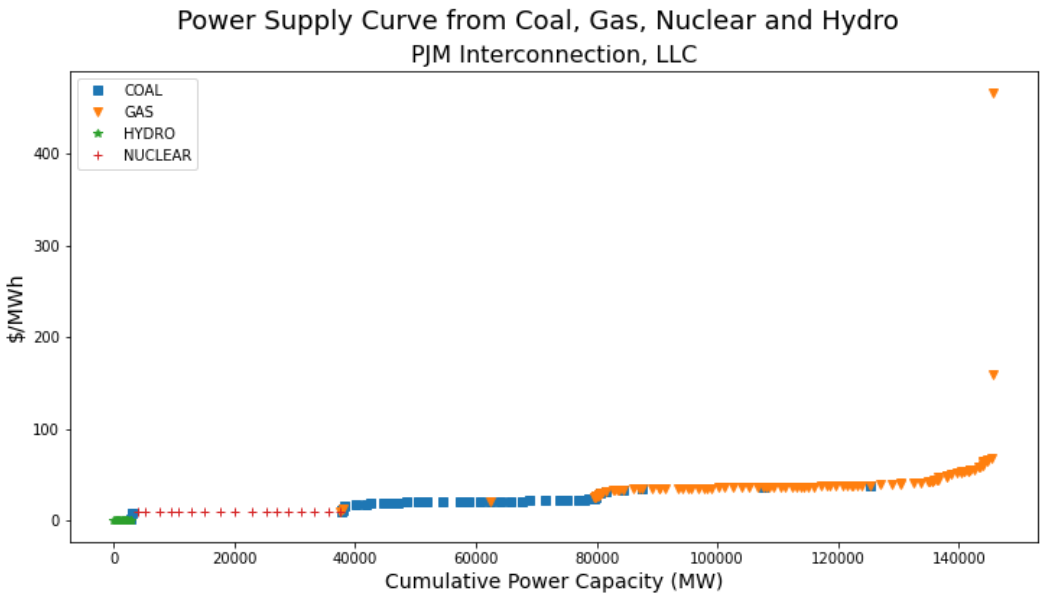
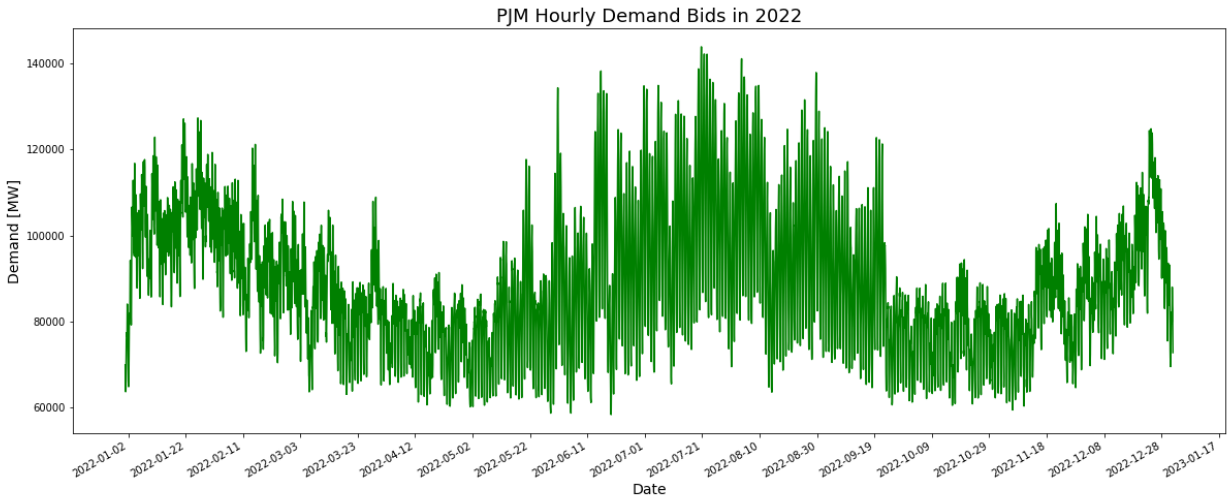
[1] The next release scheduled for 2023 will occur after this assignment is designed.
[2] From the Electric Power Annual With Data for 2021 | Release Date: November 7, 2022 | Next Release Date: October 2023. Table 7.1. Receipts, Average Cost, and Quality of Fossil Fuels for the Electric Power Industry, https://www.eia.gov/electricity/annual/html/epa_07_01.html



For details, see python code or Excel file in the Github repository of the course.

2. (25%) Download year 2022 electricity demand data (bids to buy for the day-ahead market) for PJM from https://dataminer2.pjm.com/feed/hrl_dmd_bids. Make sure you select 1/1/2022 (hour 0:00) as start date and 12/31/2022 (hour 23:59) as end date.
a. (10%) Graph the time-series of hourly demand (Include the graph in your word document, with demand in MW in the vertical axis and date in the horizontal axis. Make sure the axes are properly labeled.



For details, see python code or Excel file in the Github repository of the course.

b. (15%) What was the peak demand (in MW) observed in 2022? When did the next 4 highest demands occur in 2022? Fill out the table below.

Demand	Load (MW)	Date	Time
Highest Peak	143864.0	2022-07-20	16:00
2nd highest	143819.0	2022-07-20	17:00
3rd Highest	142681.0	2022-07-20	15:00
4th highest	142190.0	2022-07-21	16:00
5th highest	142138.0	2022-07-22	16:00

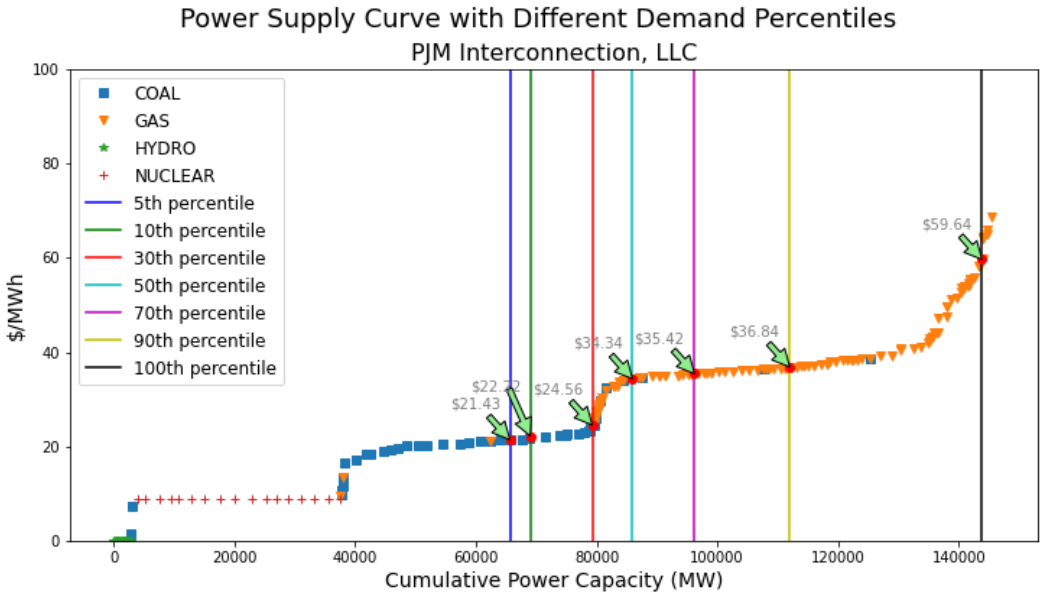
For details, see python code or Excel file in the Github repository of the course.

3. (25%) Clear the market for a few levels of demand.
a) (15%) Use the demand data found in 2. to find the percentiles 1, 5, 10, 30, 50, 70, 90, 100 for total annual demand. Write down those percentiles in the table below. If you are using excel, the function Percentile will be useful. Percentile (Array, 0.9), where array is the matrix containing all the 8760 values of hourly demand in 2019 gives you the percentile 90%.
Using the supply curve found in 2, find the competitive market-clearing price for different load levels corresponding to each percentile. Use these results to fill out the following table:

Demand Percentile	Demand (MW)	Mkt clearing price ($/MWh)
5%	65,632.85	21.43
10%	69,010.10	22.22
30%	79,286.10	24.56
50%	85,960.50	34.34
70%	96,233.80	35.42
90%	112,019.30	36.84
100%	143,864.00	59.64

Calculated percentile using the numpy percentile function.
Observed market clearing price for each demand value in the table. Obtain the marginal cost from the unit that can provide the next MW.

b) (10%) Show graphically, how the market is cleared for an inelastic demand (i.e., in the same graph present both the supply curve and the vertical lines for percentiles of demand 5%, 50%, 90% and 100% in the same graph. Their intersection is the price).



For details, see python code or Excel file in the Github repository of the course.

4. (10%) Problem 3.3 from Kirschen and Strbac.

Southern Antartica electrical energy market.
Assuming that all imbalances are settled at the spot market price, calculate the profit or loss made by each of these participants.

Company	**Contract Type**	**Electricity Purchased (MWh)**	**Electricity Sold (MWh)**	**Price ($/MWh)**	**Expenses ($)**	**Revenue ($)**	**Profit ($)**
Red (1000MW Max Cap Genco)	Long-term contract		600	15		9,000	
Red	Futures		200	14.75		2,950	
Red	Futures		200	16		3,200	
Red	Futures		200	15.50		3,100	
Red	Futures	200		16	3,200		
Red	Put Option		**200*(Does Not Exercise)**	**14.75***			
Red	Option Fee				50		
Red	Generation	800		14	11,200		

Red	Spot Market	200		15.75	3,150		
Red TOTAL		**1,200**	**1,200**		**17,600**	**18,250**	**650**
Green (800MW Max Cap Genco)	Long-term contract (peak)		500	16		8,000	
Green	Futures		250	15.75		3,937.50	
Green	Generation	770		14.25	10,972.50		
Green	Spot Market		20	15.75		315	
Green TOTAL		**770**	**770**		**10,972.50**	**12,252,50**	**1,280**
Blue (1200MW Retailer)	Long-term contract (peak)	700		15.5	10,850		
Blue	Futures	250		15.75	3,937.50		
Blue	Futures	300		15	4,500		
Blue	Futures		50	15.50		775	
Blue	Retail		1250	16.50		20,625	
Blue	Spot Market	50		15.75	787.50		
Blue TOTAL		**1300**	**1300**		**20,075**	**21,400**	**1,325**
Yellow (900MW Retailer)	Long-term contract (peak)	550		16.25	8,937.50		
Yellow	Futures	200		15	3,000		
Yellow	Futures	200		14.75	2,950		
Yellow	Futures	50		14.50	725		
Yellow	Futures		100	14		1,400	
Yellow	Call Option	100		15.50	1,550		
Yellow	Option Fee				25		

Yellow	Retail		850	16.40		13,940	
Yellow	Spot Market		150	15.75		2,362.50	
Yellow TOTAL		**1100**	**1100**		**17,187.50**	**17,702.50**	**515**
Magenta (Trading Co)	Futures	50		14.50	725		
Magenta	Futures	100		15	1,500		
Magenta	Futures		100	15.25		1,525	
Magenta	Futures	50		14.25	712.50		
Magenta	Futures		100	17		1,700	
Magenta TOTAL		**200**	**200**		**2,937.50**	**3,225**	**287.50**
Purple (Trading Co)	Futures		100	14.75		1,475	
Purple	Futures	50		15	750		
Purple	Futures		200	14.50		2,900	
Purple	Futures	250		14	3,500		
Purple TOTAL		**300**	**300**		**4,250**	**4,375**	**125**

Total Profits of each company:

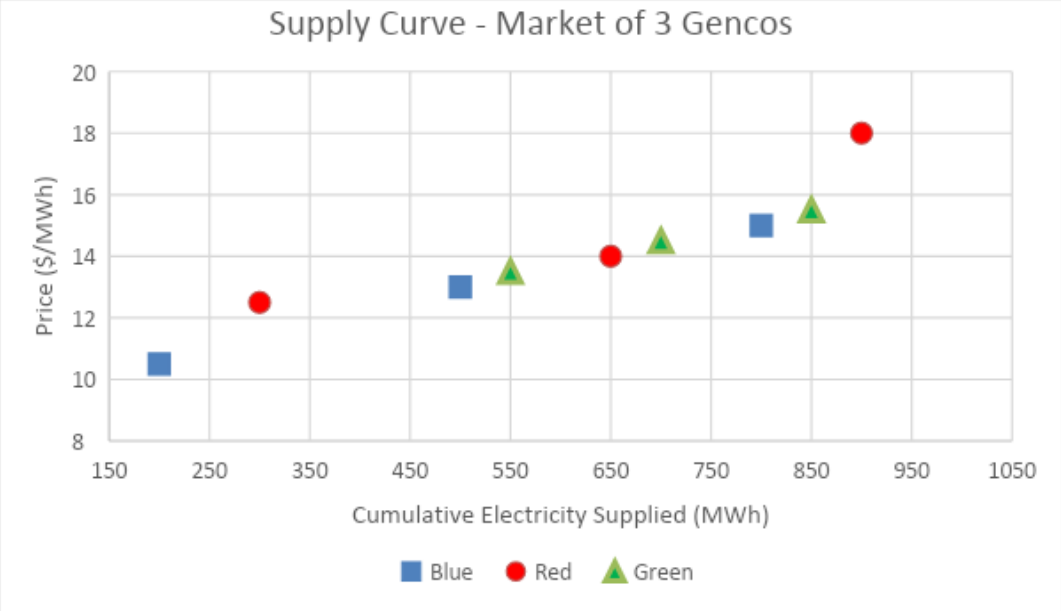
Company	Profit ($)
Red	650
Green	1,280
Blue	1,325
Yellow	515
Magenta	287.50
Purple	125

5. (15%) Problem 3.4 from Kirschen and Strbac.
The operator of a centralized market for electrical energy has received the bids shown in the table below for the supply of electrical energy during a given period.

Problem 3.4a: Supply curve

Building the supply curve requires organizing the generation in merit order (lowest to highest price). The table and the supply curve are presented below.

Company	Amount (MWh)	Cumulative Electricity Supplied (MWh)	Price ($/MWh)
Blue	**200**	**200**	**10.50**
Red	**100**	**300**	**12.50**
Blue	**200**	**500**	**13.00**
Green	**50**	**550**	**13.50**
Red	**100**	**650**	**14.00**
Green	**50**	**700**	**14.50**
Blue	**100**	**800**	**15.00**
Green	**50**	**850**	**15.50**
Red	**50**	**900**	**18.00**



Problem 3.4b:
Assume that this market operates unilaterally, that is, that the demand does not bid and is represented by a forecast. Calculate the market price, the quantity produced by each company and the revenue of each company for each of the following loads: 400MW, 600MW, 875 MW.

Load = 400MW

Company	Amount (MWh)	Price ($/MWh)
Blue	200	10.50
Red	100	12.50
Blue	**200 (100/200 MWh supplied)**	**13.00**
Green	50	13.50
Red	100	14.00
Green	50	14.50
Blue	100	15.00
Green	50	15.50
Red	50	18.00

With a load of 400MW, the **market price is $13/MWh.**

The quantity produced by each company and the revenue of each company:

Company	Quantity Produced (MWh)	Revenue ($13/MWh)
Blue	**300**	**$3,900**
Red	**100**	**$1,300**
Green	**0**	**$0**

Load = 600MW

Company	Amount (MWh)	Price ($/MWh)
Blue	200	10.50
Red	100	12.50
Blue	200	13.00
Green	50	13.50
Red	**100 (50 of 100 MWh supplied)**	**14.00**
Green	50	14.50
Blue	100	15.00
Green	50	15.50
Red	50	18.00

With a load of 600MW, the **market price is $14/MWh.**

Quantity produced by each company and the revenue of each company:

Company	Quantity Produced (MWh)	Revenue ($14/MWh)
Blue	**400**	**$5,600**
Red	**150**	**$2,100**
Green	**50**	**$700**

Load = 875MW

Company	Amount (MWh)	Price ($/MWh)
Blue	200	10.50
Red	100	12.50
Blue	200	13.00
Green	50	13.50
Red	100	14.00
Green	50	14.50
Blue	100	15.00
Green	50	15.50
Red	**50 (25/50 MWh supplied)**	**18.00**

With a load of 875MW, the **market price is $18/MWh.**

Quantity produced by each company and the revenue of each company:

Company	Quantity Produced (MWh)	Revenue ($18/MWh)
Blue	**500**	**$9,000**
Red	**225**	**$4,050**
Green	**150**	**$2,700**

Problem 3.4c:
Suppose that instead of being treated as constant, the load is represented by its inverse demand curve, which is assumed to have the following form:

$$D = L - 4.0 \cdot \pi$$

where D is the demand, L is the forecasted load and π is the price. Calculate the effect that this price sensitivity of demand has on the market price and the quantity traded.

If Load = 400MW, then Demand = 400 – 4 * 13 (see price obtained from previous question)
Demand = 400 – 52 = 348

Demand = 348MW

Company	Amount (MWh)	Price ($/MWh)
Blue	200	10.50
Red	100	12.50
Blue	**200 (48/200 MWh supplied)**	**13.00**
Green	50	13.50
Red	100	14.00
Green	50	14.50
Blue	100	15.00
Green	50	15.50
Red	50	18.00

With a demand of 348MW, the **market price is $13/MWh.**

Quantity produced by each company and the revenue of each company:

Company	Quantity Produced (MWh)	Revenue ($13/MWh)
Blue	**248**	**$3,224**
Red	**100**	**$1,300**
Green	**0**	**$0**

If Load = 600MW, then Demand = 600 – 4 * 14 (see price obtained from previous question)

Demand = 600 – 56 = 544

Demand = 544MW

With a demand of 544MW, given this market supply curve, the **market price is $13.50/MWh.**

Because this is a shift in price from the previous calculation, we recalculate demand based on this new price.

If Load = 600MW, then Demand = 600 – 4 * 13.4
Demand = 600 – 54 = 546

Demand = 546MW

Company	Amount (MWh)	Price ($/MWh)
Blue	200	10.50
Red	100	12.50
Blue	200	13.00
Green	**50 (46/50 MWh supplied)**	**13.50**
Red	100	14.00
Green	50	14.50
Blue	100	15.00
Green	50	15.50
Red	50	18.00

Quantity produced by each company and the revenue of each company:

Company	Quantity Produced (MWh)	Revenue ($13.50/MWh)
Blue	**400**	**$5,400**
Red	**100**	**$1,350**

Green	**46**	**$621**

If Load = 875MW, then Demand = 875 – 4 * 18 (please see price obtained in question 5b)
Demand = 875 – 72 = 803

Demand = 803MW

With a demand of 803MW, given this market supply curve, the **market price is $15.50/MWh.**

Because this is a shift in price from the previous calculation, we recalculate demand based on this new price.

If Load = 875MW, then Demand = 857 – 4 * 15.5
Demand = 875 – 62 = 813

Demand = 813MW

Company	Amount (MWh)	Price ($/MWh)
Blue	200	10.50
Red	100	12.50
Blue	200	13.00
Green	50	13.50
Red	100	14.00
Green	50	14.50
Blue	100	15.00
Green	**50 (13 of 50 MWh supplied)**	**15.50**
Red	50	18.00

With a demand of 803MW, given this market supply curve, the **market price is $15.50/MWh.**

Quantity produced by each company and the revenue of each company:

Company	Quantity Produced (MWh)	Revenue ($15.50/MWh)
Blue	**500**	**$7,750**

Red	**200**	**$3,100**
Green	**113**	**$1,751.50**