**Department of Electrical, Computer, & Energy Engineering**
**University of Colorado - Boulder**

**ECEN 5427**
**Power System Planning & Operations**
**Spring 2023**

**Assignment 3:** Capacity Expansion Modeling in GAMS
**Due:** 3:30 pm February 16th
**Total points:** 100 points

You are an integrated resource planner for ERCOT, and you've been asked to perform an analysis on the optimal mix of generation capacity for the system. This is intended to be an initial screening analysis before doing a more detailed study and does not need to consider existing power plants[1] or transmission constraints.

The analysis should focus on how much capacity is needed to meet system load, focusing on five generation technologies: coal, combined cycle natural gas, nuclear, wind, or solar. You can build as much generating capacity of each technology as you would like, but you incur investment cost and fixed operations and maintenance costs for each unit of capacity that is built. Each type of plant also has its own variable operation and maintenance costs, fuel costs, and emissions rates.

To provide power to your customers you must ensure that you have sufficient generating capacity available for each hour of the year. You have at your disposal data on the historical energy consumption of your customers in every hour. While the generation of all types of plants is dependent on the total installed capacity, wind and solar plants are also limited by their resource availability, and a timeseries of the capacity factor (i.e., fraction of installed capacity available) is provided.

Part I: Problem formulation **[50 points]**

1. Define (using words or mathematical notation) any sets and parameters needed for this capacity expansion problem.

[1] This is known as a "greenfield" capacity expansion problem. A separate but related problem involves considering an initial mix of power plants, with the ability both to invest in new plants and to retire existing plants. The second problem is referred to as a "brownfield" capacity expansion problem.

2. What is (are) the decision variable(s) of the problem?

3. Formulate an equation representing the objective function.

4. Define any constraints of the problem.

Part II: Implementation **[50 points]**

5. Using your problem formulation from Part I and the provided data sets, implement the problem in GAMS. See the appendix below for details on the data and how to load into GAMS. Submit your GAMS code with this assignment.

    a. Run the code. What is the value of the objective function? What does this represent?

    b. How much of each technology is built in the optimal outcome? Why do you think this is the case?

6. Your supervisor just informed you that ERCOT is implementing a $CO_2$ emissions constraint of 100 million metric tonnes per year on each utility.

    a. State any new parameters and constraints needed to capture this emissions limit.

    b. Rerun your model with this emissions constraint included. What happens to the system cost and the amount of capacity for each technology?

7. Interpret and discuss your findings from the GAMS analysis. Why do you think the models builds the capacity it builds? Did any of the results surprise you? What additional constraints do you think would make this analysis more realistic?

Appendix – Overview of data sets

Plant performance data: `plant_characterics.csv`

- Data based on emissions, heat rate, and capital and operating costs based loosely on information in the 2021 NREL Annual Technology Baseline (ATB).
- Fuel cost information based on information in the 2021 EIA Annual Energy Outlook (AEO) (see Table 3 – Energy Prices by Sector and Source, Reference Case).
- Units:
    - Capital and FOM costs: $ per kW installed capacity
    - VOM and fuel costs: $ per MWh generation
    - Emissions: tonnes CO2 per MWh generation

Timeseries data: `timeseries.csv`

- Load data based on 2021 historical data from ERCOT.
- Solar and wind capacity factors generated using NREL's SAM tool. Data is based on latest recent available weather information for Lubbock, Texas[2].
- Units:
    - Load: MWh in each hour
    - Solar and wind capacity factors: fraction (range 0-1)

Hint! To read in data from a csv directly to GAMS, you can use the following command:

```
table genpar(i,*)
$offlisting
$ondelim
$include plant_characteristics.csv
$offdelim
$onlisting
;
```

Columns can then be referenced directly (e.g., `genpar(i,"cap_cost")` ) in constraints or assigned to other parameters as needed.

[2] In a more detailed study, you would want to ensure that a) the weather and load timeseries were from the same year, and b) solar and wind capacity factors of different locations were matched to the potential plants that would be built.