HW1, EE 552, Energy System Planning
January 25, 2024, Dr. McCalley, Due Thursday, February 15, 2024, 11:59 pm

Assignment:

1. Answer the following questions. I suggest you either use the resource identified in the question or use the data in the class notes. If, for a particular data item, there is not a resource identified, and if you cannot find it in my notes, then provide your own estimate (i.e., search for it or guess). Identify the source of your information. I suggest that you do a "first-pass" on this, answering all questions, in a very limited amount of time. Then perform the reading assignment below to refine these data. Try to obtain answers to these questions that characterize 2022; if you cannot find it for 2022 but can for another previous year, then use it but then give a projection to 2022 and provide the reasoning you used to make that projection.
    a. Existing annual US electric generation capacity (see Tables 4.2A and 4.2B of the most recent [2022] EIA Electric Power Annual Report, located at www.eia.gov/electricity/annual/pdf/epa.pdf):
        i. What is total electric generation **capacity** (in GW) in the US?

        ii. Compute the percent each existing generation technology contributes to the total US electric generation **capacity**.

        iii. Estimate a reasonable upper bound number for 2022 "North American summer peak demand." To make this estimation, use data provided in the NERC 2022 summer reliability assessment found at www.nerc.com/pa/RAPA/ra/Reliability%20Assessments%20DL/NERC_SRA_2022.pdf to complete

Table 1 below. The 50/50 demand is the MW level for which the probability that summer peak demand will exceed is 50% (this is also called “summer net internal demand”); the 90/10 demand is the MW level for which the probability that summer peak demand will exceed is 10% (this is also called “extreme summer peak demand”). Justify that your answer is an “upper bound,” but “reasonable” (not too high). Exclude struckthrough Canadian regions.

Table 1: Summary of US noncoincident summer peak demand (Canadian regions are struckthrough)

Region	50/50 demand	90/10 demand
MISO		
~~MRO-Manitoba Hydro~~		
~~MRO-SaskPower~~		
~~NPCC-Maritimes~~		
NPCC-New England		
NPCC-New York		
~~NPCC-Ontario~~		
PJM		
SERC-East		
SERC-Central		
SERC-Southeast		
SERC-Florida Peninsula		
SPP		
TOTAL, US Eastern Interconnection		
TOTAL, RE-ERCOT		
~~WECC-NWPP-AB~~		
~~WECC-NWPP-BC~~		
WECC-CA/MX		
WECC-NWPP-US		
WECC-SRSG		
TOTAL-US WECC		

b. Total annual 2022 US electric energy production:

   i. What is total annual 2022 US electric energy production (energy)? Use Tables 3.1A and 3.1B of www.eia.gov/electricity/annual/pdf/epa.pdf.

   ii. What percent does each existing generation technology contribute to the annual electric energy production?

c. What are the major differences between the percentages given in (a) for capacity and the percentages given in (b) for energy? Give a reason for your observations:

d. Use https://flowcharts.llnl.gov/commodities/carbon to answer the following questions about 2022 US Anthropogenic (human-caused) CO_2 emissions:

   i. What is the total annual CO_2 emissions from all sources?

   ii. What percent of total CO_2 emissions is from electric energy production?

   iii. What percent is from transportation?

    iv. What percent of total CO_2 emissions from electricity production is from each of the following generation fuels: Coal, natural gas, petroleum.

e. What are typical efficiencies for pulverized coal-fired units, combustion turbines, combined cycle units, and nuclear plants?

f. Use the EIA data at www.eia.gov/outlooks/aeo/assumptions/pdf/elec_cost_perf.pdf and the NREL data at https://atb.nrel.gov/electricity/2023/technologies to identify reasonable assumptions regarding generation technology data, in terms of investment cost (also known as CAPEX) ($/MW), O&M cost ($/MWhr), emissions per unit energy ($MMTCO_2e$/MWhr), efficiency, and capacity factor for each of the following generation technologies:
    i. Ultracritical pulverized coal with & without carbon capture & sequestration (CCS)
    ii. Natural gas combined cycle with and without CCS
    iii. Combustion turbines
    iv. Conventional nuclear (O&M should include waste storage)
    v. Nuclear - Small modular reactors
    vi. Onshore wind
    vii. Offshore wind
    viii. Solar PV with tracking

g. Make an assumption regarding a carbon tax level, in $/$MMTCO_2e$ that will be implemented. Assume this tax level is implemented beginning 2024. State your assumption.

h. Demand Growth, Generation Retirements, and Generation Investments Needs:
    i. What is a reasonable assumption for annual US growth in peak load over the next 40 years, from 2025 to 2050?

    ii. Make reasonable assumptions on expected life for each generation technology, and on the age-portfolio of the existing generation fleet, and from this, what percent of each type of the existing generation fleet will need to be retired between 2025 and 2050, and when it will be retired.

    iii. Develop a plot against time, 2025 to 2050, of annual peak load, and total capacity of each type of the existing generation resource. The capacity plots SHOULD NOT include new capacity, i.e., the capacity plots should show declining capacity of each type according to your retirement assumptions.

iv. Based on the plots developed in the previous step, determine the total generation capacity investment required for each successive 5-year interval (i.e., 2025, 2030, 2035, 2040, 2045, 2050). Assume total capacity must be at least 1.15 times peak load in each interval. Capacity contribution for wind and solar should be credited at a reduced level, e.g., 50% of nameplate for solar and 15.5% for wind per the MISO document at https://cdn.misoenergy.org/2022%20Wind%20and%20Solar%20Capacity%20Credit%20Report618340.pdf. (Note that these numbers, 0.5 and 0.155, are *capacity credits*, which are not the same as *capacity factors*). We use capacity credit to assess expected capacity relative to peak. We use capacity factors to assess expected energy production over a time period such as a year.

i. Energy growth:

   i. What is a reasonable assumption for annual US growth in electric energy produced over the next 25 years, from 2025 to 2003?

   ii. Develop a plot against time, 2025 to 2050, of total annual energy produced, and total energy produced by each type of existing generation resource. These plots SHOULD NOT include energy produced by new capacity, i.e., the production plots should show declining energy of each type according to your retirement assumptions. You will need to use estimated capacity factors to develop these plots.

j. Make an assumption regarding the real discount rate.

2. After obtaining, or estimating, all of the above data, review the following. The information need not be read in detail – some parts of each document may be skipped or very quickly scanned. There are two things to look for in performing this reading. First, look for refinements on the data you provided in responding to question 1 above. Second, look for description on the study approach that was used or is being proposed (this last effort is mainly applicable to items h-j below).
   a. Data at the US DOE Energy Information Administration (EIA) website http://www.eia.gov/, on electricity, at http://www.eia.gov/electricity/.
   b. US Department of Energy, Energy Information Administration, website on environment: https://www.eia.gov/environment/data.php#summary
   c. US Environmental Protection Agency website: www.epa.gov/energy/about-us-electricity-system-and-its-impact-environment.
   d. Lazard's cost of energy analysis, https://www.lazard.com/research-insights/2023-levelized-cost-of-energyplus/
   e. Sargent and Lundy Capital Cost Summary, www.eia.gov/analysis/studies/powerplants/capitalcost/pdf/capital_cost_AEO2020.pdf.

f. NERC Long-Term Reliability Assessments, www.nerc.com/pa/RAPA/ra/Pages/default.aspx.
g. MTEP2023 (and previous) Midcontinent ISO (MISO) Transmission Expansion Plans, www.misoenergy.org/planning/transmission-planning/mtep/#t=10&p=0&s=&sd=
h. Public Service Company of New Mexico Integrated Resource Plan, https://www.pnmforwardtogether.com/assets/uploads/PNM-2023-IRP-Report-corrected-2023-12-18.pdf

3. Develop a spreadsheet calculation that provides the total emissions together with the present worth on total cost (investment and O&M) for a US generation portfolio from 2025 to 2050. You should be able to represent the portfolio in terms of the existing generation fleet (a fixed input) together with input data that can be easily changed that characterizes retirements and additional investments. Use the spreadsheet calculator to identify and recommend a generation investment strategy that most effectively achieves emissions reduction at least cost.

➔The calculation spreadsheet provides the recommended generation portfolio built from the beginning of 2025 to the beginning of 2050— a 25-year period, considering the generation capacity requirement (1.15 peak load), the existing generation fleet, and the lifetime for different type of generation plants. The associated cost and emissions are also calculated. Here are some comments.

• This is a two-objective optimization problem—the minimization of cost and emissions. If emissions are expressed into cost using carbon tax, it becomes a single-objective optimization problem, which can be solved using optimization softwares such as Cplex and Matlab. However, this is not the focus of this assignment. We can benefit more through the process of manually adjusting the generation portfolio to satisfy the peak load while considering the cost and emissions based on the knowledge learned in the class. The proposed generation portfolio may not be the "optimal" one in a mathematical sense, but it represents a good estimation of the most effective way to achieve emissions reduction at least cost.

• The total cost for a plant over its **lifetime** is equal to the present worth of the investment plus the present worth of the production cost at each year.

• The time step is five years. Within each time step, assume all the numbers remain constant. For example, the fuel price and generation capacity will not change ***within*** each 5-year period. In addition, the same amount of money has the same value within each time step. The discount rate is assumed to be (1.08^5 -1) per time step.

• The "Composite O&M Costs" of Table 1 can be used to compute production costs. This is the variable O&M plus (fuel price)*heat rate (resulting in \$/MWhr).

• The recommended investment is found by manually adjusting the ratio of each type of generation capacity to satisfy 1.15 times peak load. The basic idea is to design an evolving portfolio of generation resources that "greens" the electric power sector in a reasonably-economically attractive way that accounts for grid needs. For example, although the wind and solar are clean and cheap, some fossil-fueled resources will be needed to provide grid flexibility. In addition, wind and solar must be increased gradually (over the entire planning horizon) rather than suddenly (i.e., in just one year). Considering almost all the hydro resources have been exploited today, new hydro plants will not be built until old ones retire. In other words, an upper bound is set for the cumulative hydro generation capacity. As for coal plants, having too much coal without carbon capture and sequestration will be difficult to justify, yet PC with CCS are expensive. It is unlikely that anyone will ever build subcritical coal plants again due to their lower efficiencies. Even supercritical coals plants might be hard to justify. Although ultracritical coal plants look better from an emissions point of view, they are pretty expensive.

4. Develop a plot against time, 2025 to 2050, of annual peak load, and total capacity of each type of generation resource (capacity for wind and solar should be multiplied by capacity credit). The capacity plots should include both old and new capacity, accounting for retirements and investments, and total generation capacity should

exceed peak load by about 15% (less is bad for reliability and more is too expensive). The below is an example of the capacity plots (peak load is not shown).

5. Develop a plot against time, 2025 to 2050, of total annual electric by each type of generation resource. These energy plots should include energy produced by both old and new resources, accounting for retirements and investments. You will need to use your estimated capacity factors to develop these plots. The below is an example of the energy plot.

6. What to turn in (by e-mail):
    a. A summary of all data (1a)-(1j) and information and the corresponding sources.
    b. A copy of your spreadsheet calculator.
    c. The plots developed in items (4) and (5) above.
    d. A discussion of why you are recommending the generation expansion approach implemented.
    e. You have now developed a generation expansion model, and you have completed your first generation expansion study ☺. Provide some brief comments on how your analysis should be improved; in developing this response, consider material on the study approach in the reports that you read in above step 2.