Homework Problem:

We're going to take the data that we merged and cleaned from the EIA forms and build a simple version of the power plant dispatch problem. The goal of the power plant dispatch problem is to choose the output of each power plant in a generator fleet so that electricity demand is met at the lowest possible cost. In practice, power plant dispatch problems might contain detailed operational information about each generator (e.g. how quickly they can ramp, how long they must be shut down before starting them up again, etc.) and detailed market information (e.g. how much power plant capacity needs to be on reserve), but we will make a much simpler model defined by the following linear program:

$\min K = \sum_g C_g * P_g \;, \; \forall g$ *minimize the sum of (each generator's cost times each generator's output)*

s.t.

$\sum_g P_g \geq D, \; \forall g$ *sum of all generators' power output ≥ Demand*

$\sum_g R_g * P_g \leq E, \; \forall g$ *the sum of (each generator's emissions rate times each generator's output) ≤ Emissions Cap*

$P_g \leq P_{cap}, \; \forall g$ *each generator's output ≤ its capacity*

where

P_g	output of generator *g* (MWh)
P_{cap}	capacity of generator *g* (MW)
C_g	cost to operate generator *g* ($/MWh)
R_g	emissions rate of generator *g* (tons CO_2 / MWh)
D	electricity demand (MWh)
E	emissions cap, or the maximum amount of CO_2 that is allowed to be emitted by the power plants (tons CO_2)

Instructions:

Part 1: Write and solve the linear program defined above.

1. Download the RHODES_JOSHUA_EIA_2016_data_OPTHW.csv from Canvas. You've already made something similar from your own data merging/cleaning, but go ahead and use this file so I know you have the right information.
2. Download the fuel_properties.csv from Canvas. This contains information about the cost and co2 emissions for different fuels.
3. Read these 2 csvs into R.
   Set D (demand) = 550,000.
   Set E (emissions cap) = 350,000
4. We are going to edit the generator data a bit by selecting just a subset of the data and calculating C_g and R_g for each generator.
   a. Select a subset of the generators. We only want to include generators that:
      have a capacity greater than 50

have a heat rate greater than 0
have a heat rate less than 20,000
use one of the following fuel types only:
BIT, BLQ, DFO, LIG, NG, NUC, RC, RFO, SUB, WC, WDS

b. Create a new column that contains C_g for each generator
   hint: how much fuel does the generator consume?
   how much does that fuel cost?
c. Create a new column that contains R_g for each generator
   hint: how much fuel does the generator consume?
   how much CO_2 is emitted when burning that fuel?
d. **Print the head (first 6 rows) of your generator data frame.**
   hint: here is the first row of mine:

	Utility.ID	Plant.Cod	Prime.Mo	Energy.So	Utility.Na	Technolog	Plant.Nam	Nameplat	Operating	Operating	Operating	Net.Gene	Elec.Fuel.	cap_fac	heat_rate	Year	dol_per_MWh	ton_CO2_per_MWh
1	10000	1241	ST	SUB	Kansas Cit	Conventic	La Cygne	1578	1975	1977	1973	7933023	82845470	0.573889	10443.11	2016	15.66467222	1.01507076

   hint: my generator dataframe has 1797 rows

5. Create the linear program model
   hint: What is the objective? What are the constraints? What are the variables? How many constraints and variables will you have?
   hint: Consider using the "set.bounds" command for the generator capacity constraint.
6. Solve the linear program
   a. **Print out the objective**
   b. **Print out the objective divided by the Demand constraint** (this is your average $/MWh cost of meeting demand)
   c. **Print out the constraints** (i.e. "get.constraints")
   d. **Print a Table showing how much energy was generated by each fuel type**
      hint: column 1 is the 11 fuel types we sub-selected on, column 2 is MWh output
      hint: aggregate

Part 2: Solve the linear program multiple times for tighter emissions constraints. Observe how reducing the emissions constraints increases costs and changes the dispatch.

1. Build a for loop that solves the linear program for different values of E_g and stores the solutions
   a. Create an empty results dataframe that will hold the information you want to capture from each solution
   b. Loop through E_g values from 350,000 to 230,000 in steps of 10,000
   c. As you loop through the E_g values:
      i. Update E_g for the linear program
      ii. Solve the linear program
      iii. Add results to the results dataframe
         hint: consider using "rbind"
2. Similar to Part 1, 6, d, build a table showing how much energy was generated by each fuel type
3. Plot some results
   a. Plot a bar chart showing how the energy generated by each fuel type changes between the high emissions (E_g = 350,000) and low emissions (E_g = 230,000) solutions
      i. **Print that chart**

b. Plot a line chart showing how the average cost of meeting demand ($/MWh) changes with the emissions cap (E_g)

    i. **Print that chart**

    hint: see chart solutions at the end of the homework pdf

General Hints:

Pay close attention to units. Heat Rates are in Btu/kWh. Fuel costs are in $/mmBtu. Fuel emissions are in kg CO_2 / mmBtu. 1 mmBtu = 1 million Btu. C_g and R_g should be normalized, i.e. in terms of "per MWh" not in terms of the generators whole capacity.

If you are getting some errors, check for N/A values in your data. Summations, multiplications, etc. cannot be performed on N/A values.

Remember to use the "write.lp" command to see what your linear program looks like. Make sure it aligns with the linear program equations. I would recommend using a subset of the generator data (maybe 10 rows) and a smaller Demand (so that the model can solve) to check what your model looks like before running the full solution.

What to Turn In:

A working R script. When I run the script, it should print out all of the things in **bold** above.

Plot Solutions and Discussion:

When we force the generation fleet to operate under an emissions cap, we shift a lot of energy from BIT, LIG, RC, and SUB (all types of coal) to NG (natural gas) because natural gas is a lower emitting fuel. The consequence is that dispatch cost increases and prices rise (assuming coal is cheaper than natural gas). Alternatively, we could impose a CO2 price to reduce emissions by making it more expensive for higher emitting power plants (e.g. coal) to operate. A reverse analysis to the one shown here can be helpful in understanding what CO2 emissions prices might be needed for achieving different CO2 emissions goals.