Wind Integration in ISO-NE

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Introduction

Goal: To model a hypothetical Unit Commitment schedule for 1 week for the ISO-NE sources (76 thermal generation units) and analyze the difference wind integration can make on the overall system performance and cost, and recommend a policy on how to decarbonize and achieve the best results for the overall electricity cost, reduced carbon emissions, and generator revenue.

Challenges:

- Implement a realistic model that conforms with the physical generation and regulation related system constraints, such as ramp rates and maximum and minimum generation limits.
- Overcome computational complexity so that results can be achieved in timely manner.

Approach

Our group implemented the formulas depicted within the Appendix to accurately reflect the scope of the problem.

The main portions to consider are:

- The objective function (the goal we seek to minimize)

$$\min \sum_t \sum_i (\mathrm{MRC}_i g_{i,t} + \mathrm{NLC}_i u_{i,t} + \mathrm{SUC}_i v_{i,t}) + (9,000) s_t$$

- Set of regulatory and physical operational requirements of generation units

$$\sum_i g_{i,t} + w_t + s_t = D_t : \lambda_t \qquad \sum_i r_{i,t} \geq (3\%) D_t + (5\%) w_t \qquad \mathrm{Gmin}_i u_{i,t} \leq g_{i,t} \leq \mathrm{Gmax}_i u_{i,t}$$

Approach - Code Structure

We utilized CVXPY & Gurobi to solve the minimization of our objective function (the system cost on a given day)

Our group followed the suggested methodology of optimizing the cost to execute a unit commitment for each day and then pass the decision variables representing the last hour of generation and unit commitment (g0 and u0) to the next day for use.

Where We Are Right Now - Functionality

Thus far we have implemented the optimization problem in its full scope (examining the entire week with all three wind penetration levels)

Except:

- The set of constraints presently excludes constraints 6-9 (Gen MinUp Time & MinDown Time requirements)

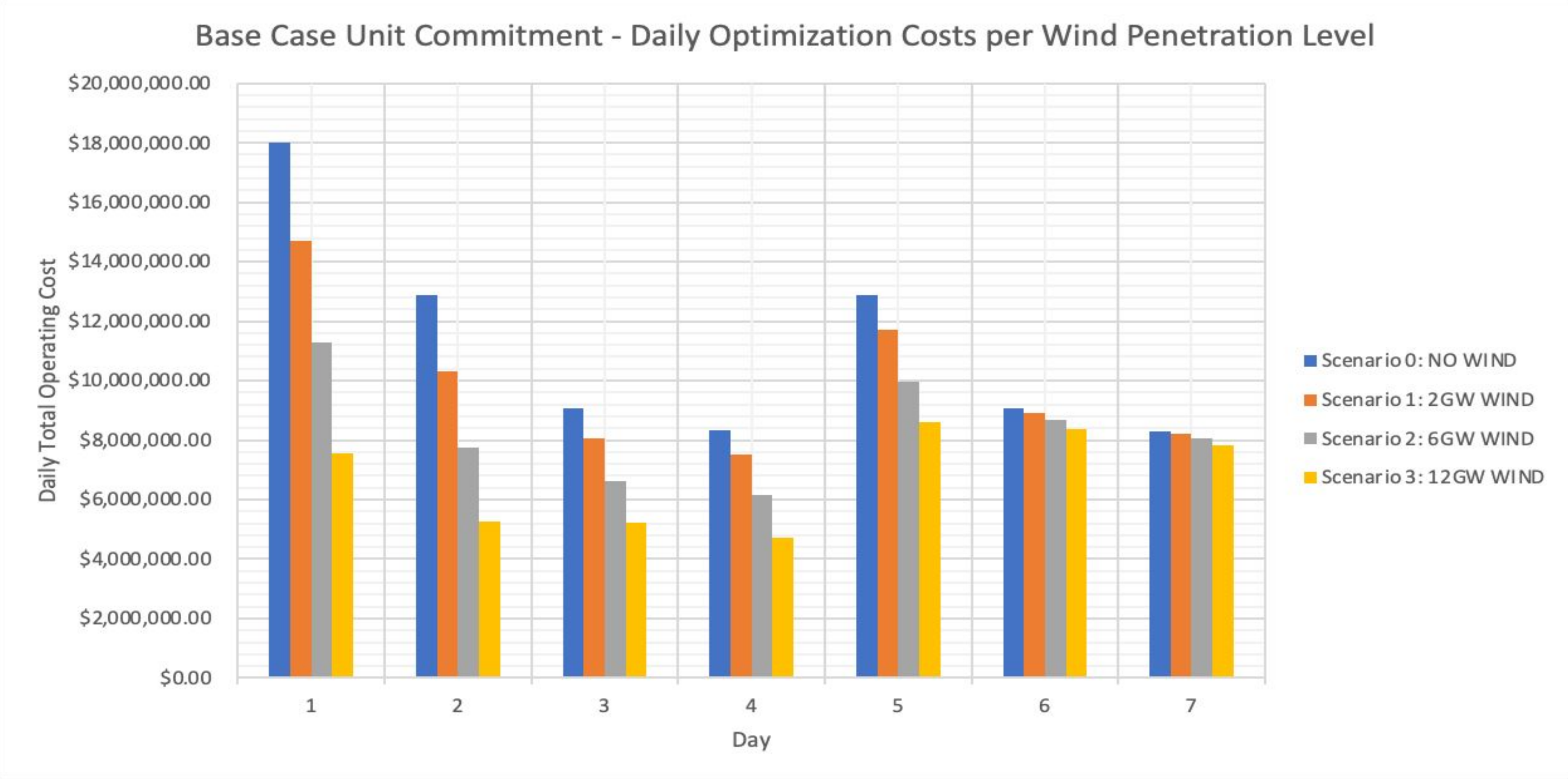
Where We Are Right Now - Deliverables

Observed variables: Daily system cost (and thus the weekly total cost)

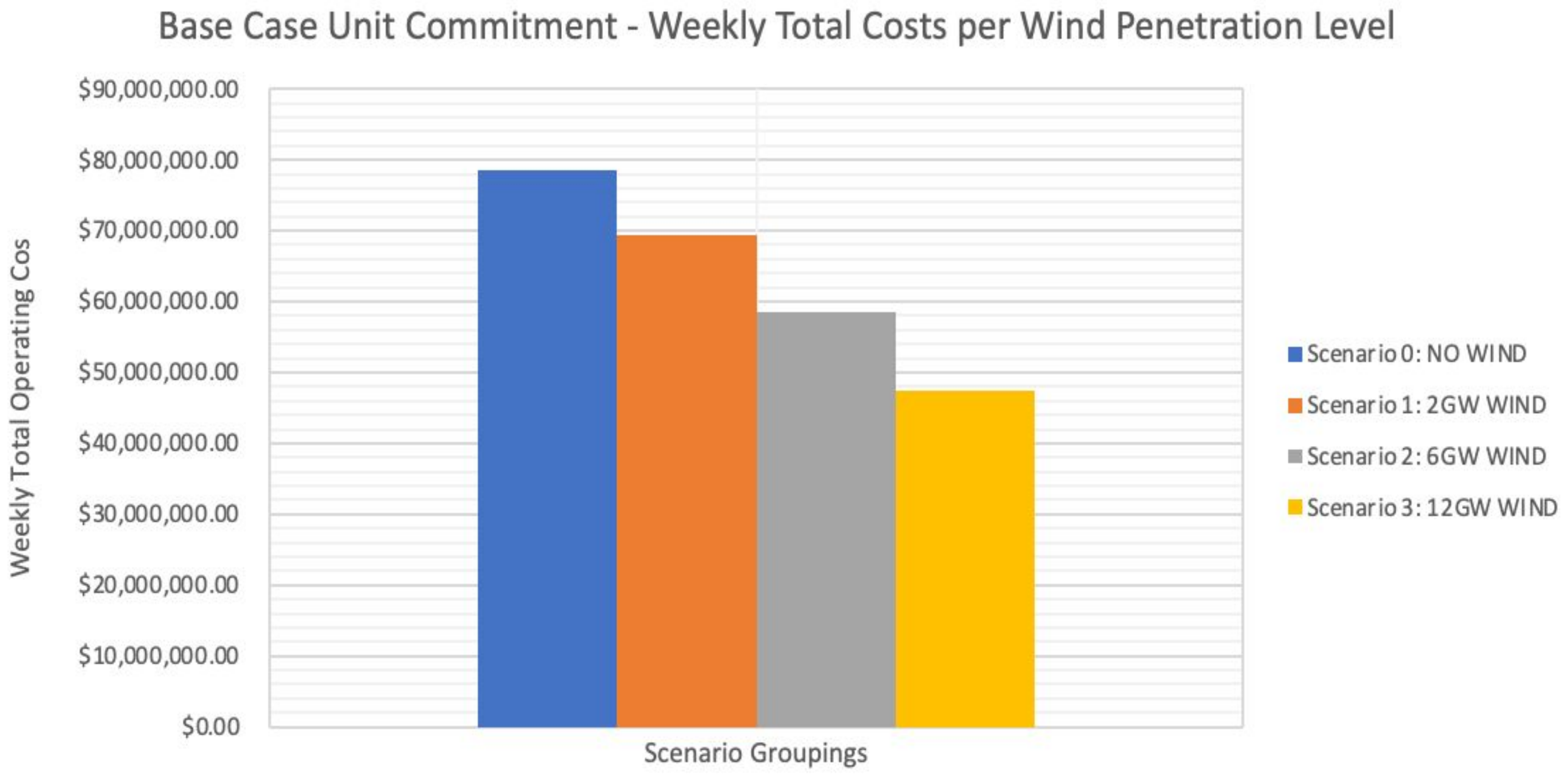
To be implemented (performance metrics to track):

- Wind Curtailment Ratio: (Wt − wt) : Wt
- Profits received by generators
- Average electricity price

Individual Scenarios - Wind Penetration



Base Case Unit Commitment - Daily Optimization Costs per Wind Penetration Level
$20,000,000.00
$18,000,000.00
$16,000,000.00
$14,000,000.00
$12,000,000.00
$10,000,000.00
$8,000,000.00
$6,000,000.00
$4,000,000.00
$2,000,000.00
$0.00
Daily Total Operating Cost
1
2
3
4
5
6
7
Day
Scenario 0: NO WIND
Scenario 1: 2GW WIND
Scenario 2: 6GW WIND
Scenario 3: 12GW WIND


Base Case Unit Commitment - Weekly Total Costs per Wind Penetration Level
$90,000,000.00
$80,000,000.00
$70,000,000.00
$60,000,000.00
$50,000,000.00
$40,000,000.00
$30,000,000.00
$20,000,000.00
$10,000,000.00
$0.00
Weekly Total Operating Cos
Scenario Groupings
Scenario 0: NO WIND
Scenario 1: 2GW WIND
Scenario 2: 6GW WIND
Scenario 3: 12GW WIND

Individual Scenarios - Carbon Tax

Carbon Tax

- With a carbon emissions tax, the government sets a price that generation companies must pay for every ton of greenhouse gases they emit
- The amount of carbon emissions per kWh can vary by the efficiency of the plant and the fuel type used
- Biomass, Hydropower, Solar, Nuclear, and Wind as energy sources are considered carbon neutral
- The carbon tax can vary greatly depending on the country. For the US, the appropriate carbon tax price was estimated to be $36 in 2015, and $46 per ton in 2025

Carbon Tax (Continued)

	Electricity Generation in million kWh	CO_2 emissions in million metric tons	CO_2 emissions in pounds per kWh
Coal	897,885	919	2.26
Natural Gas	1,579,361	696	0.97
Petroleum	19,176	21	2.44

Table 1: Total net electricity generation in the US in 2021, the resulting CO_2 emissions, and the CO_2 emission factor (pounds of CO_2/kWh) for coal, natural gas, and petroleum

Carbon Tax (Continued)

The approach taken:

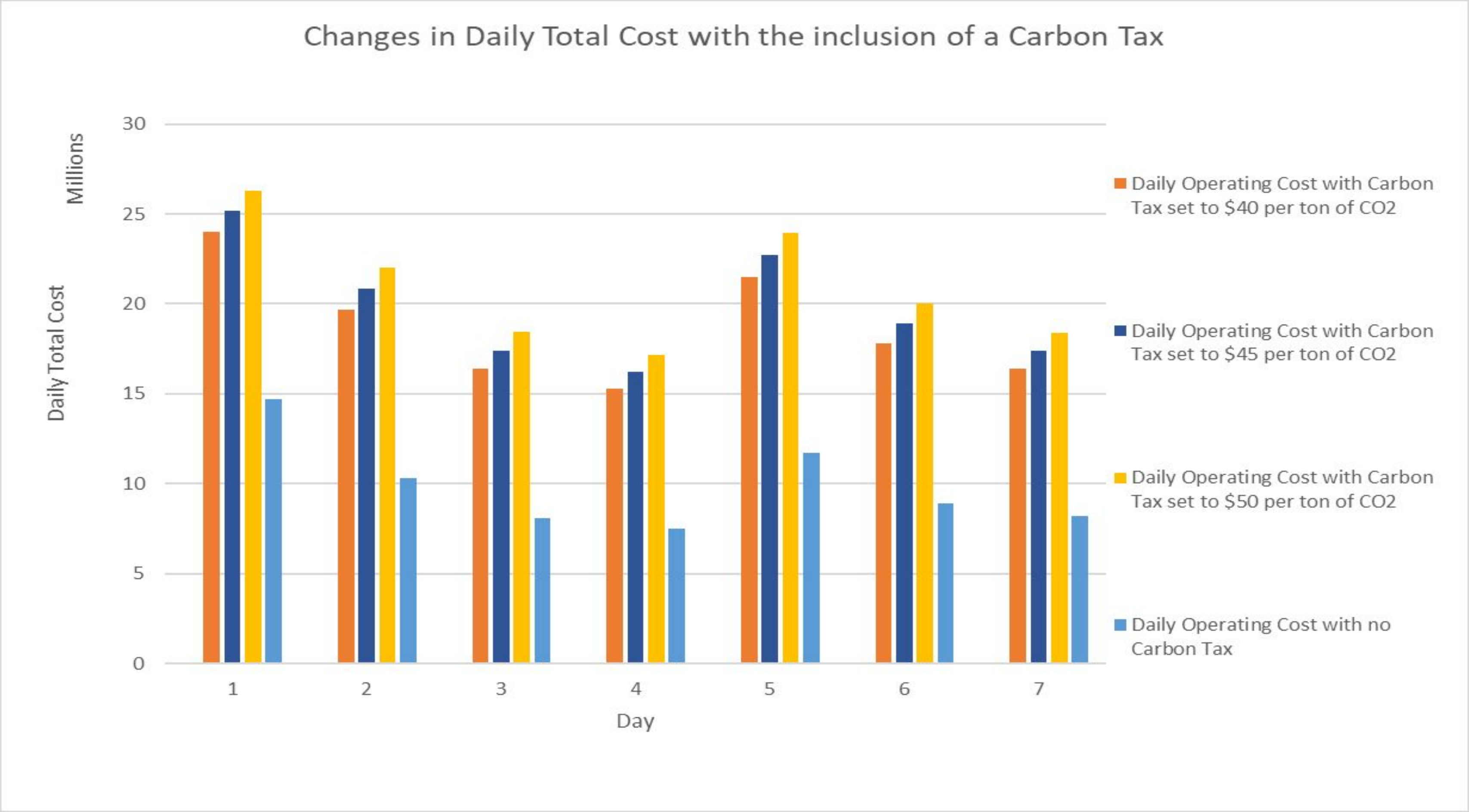
- Convert the lbs per kWh for coal, natural gas, and petroleum to Metric Ton per MWh
- Multiply the Metric Ton per MWh by the amount of electricity each generator is producing, based on their fuel type
- Multiply the Metric Ton of CO_2 by a flat cost of carbon to get the carbon emission tax

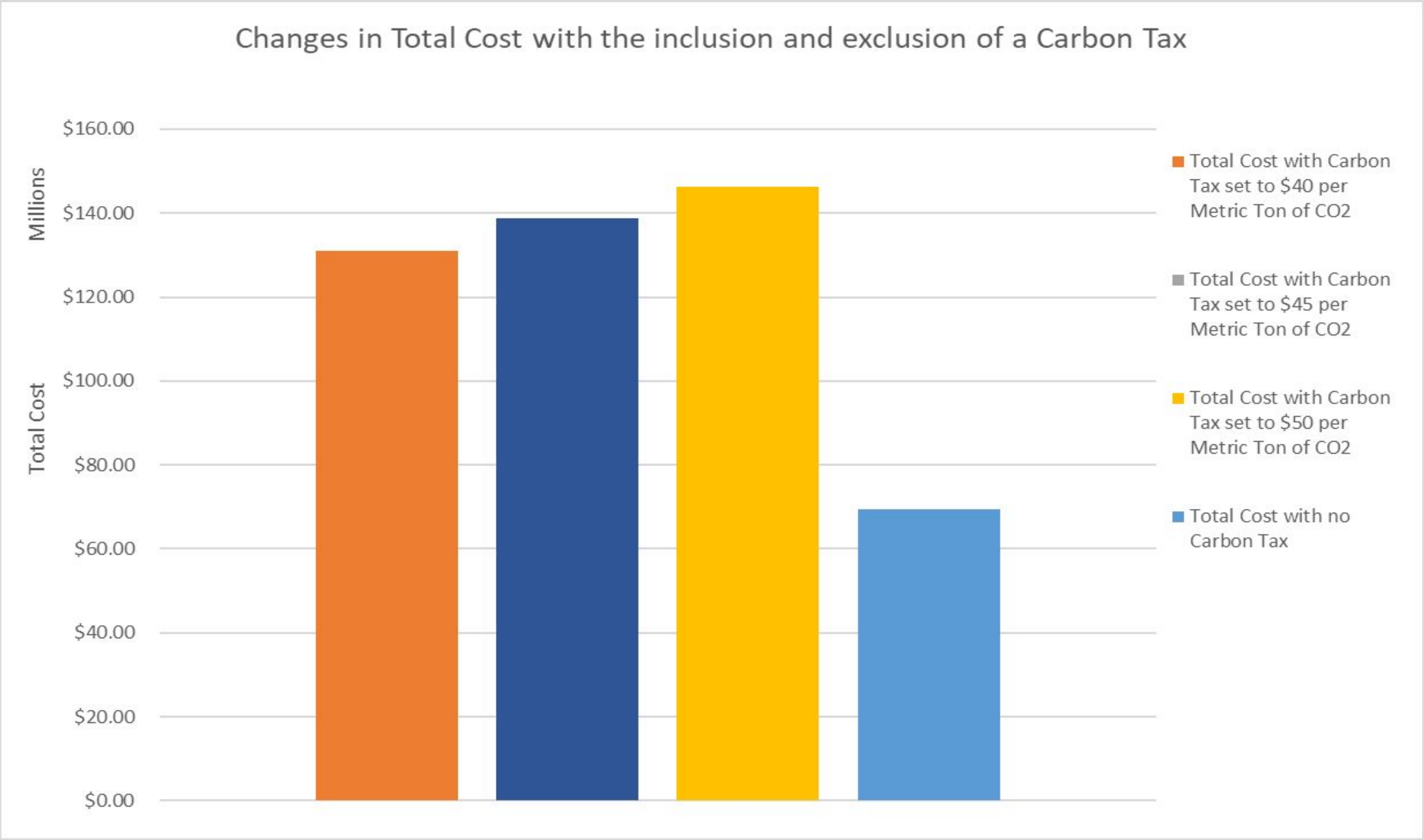
Carbon Tax (Continued)

$$C_1 = \sum_i \sum_t (MRC_i g_{i,t} + NLC_i u_{i,t} + SUC_i v_{i,t}) + 9000 s_t$$

$$C_2 = CoC \sum_i \sum_t \lambda_i g_{i,t} - \theta_i g_{i,t}$$

$$\text{Obj} = \min C_1 + C_2$$


Changes in Daily Total Cost with the inclusion of a Carbon Tax
Millions
Daily Total Cost
30
25
20
15
10
5
0
1
2
3
4
5
6
7
Day
Daily Operating Cost with Carbon Tax set to $40 per ton of CO2
Daily Operating Cost with Carbon Tax set to $45 per ton of CO2
Daily Operating Cost with Carbon Tax set to $50 per ton of CO2
Daily Operating Cost with no Carbon Tax


Changes in Total Cost with the inclusion and exclusion of a Carbon Tax
Total Cost
Millions
$160.00
$140.00
$120.00
$100.00
$80.00
$60.00
$40.00
$20.00
$0.00
Total Cost with Carbon Tax set to $40 per Metric Ton of CO2
Total Cost with Carbon Tax set to $45 per Metric Ton of CO2
Total Cost with Carbon Tax set to $50 per Metric Ton of CO2
Total Cost with no Carbon Tax

Individual Scenarios - Coal Retirement

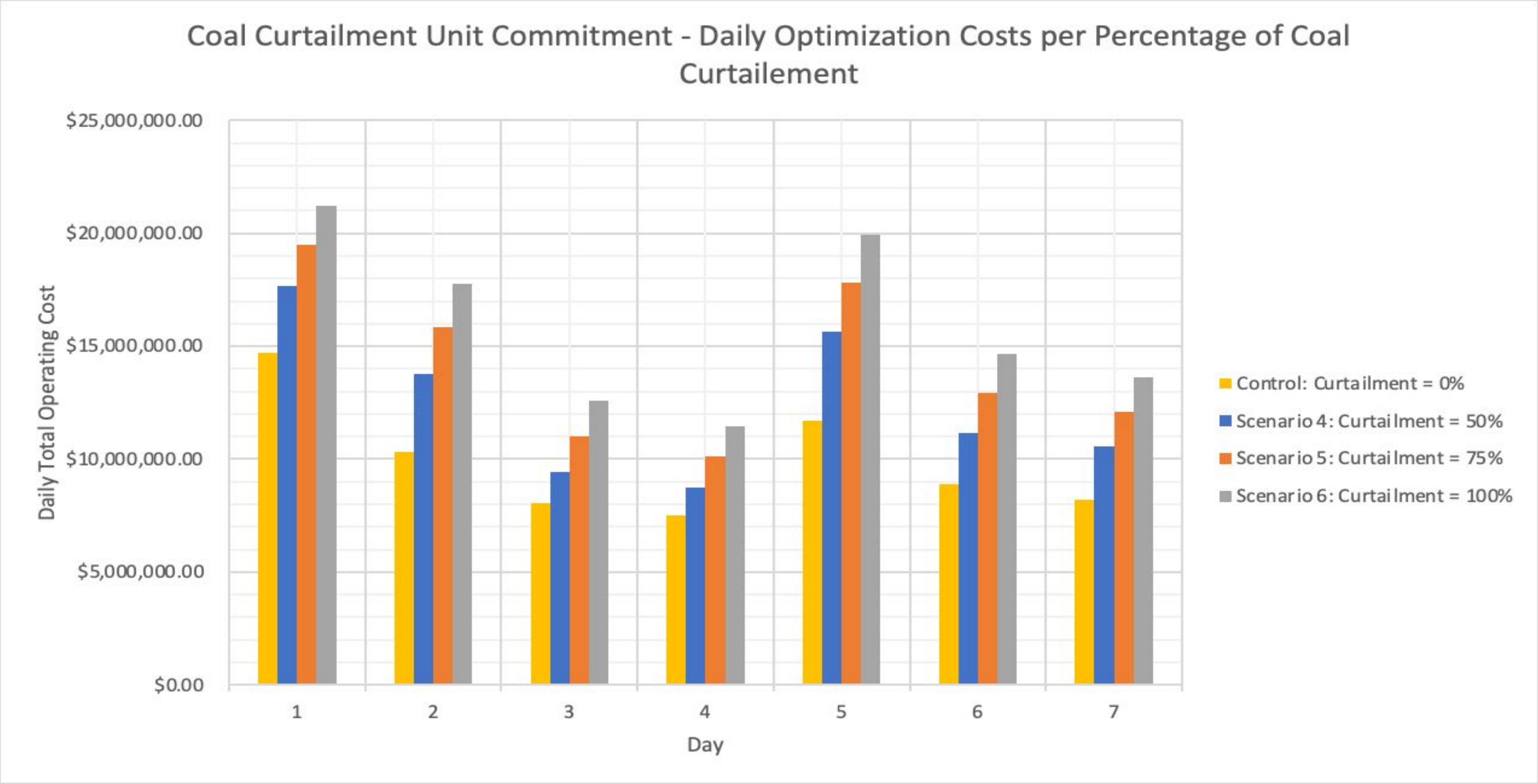
Coal Retirement

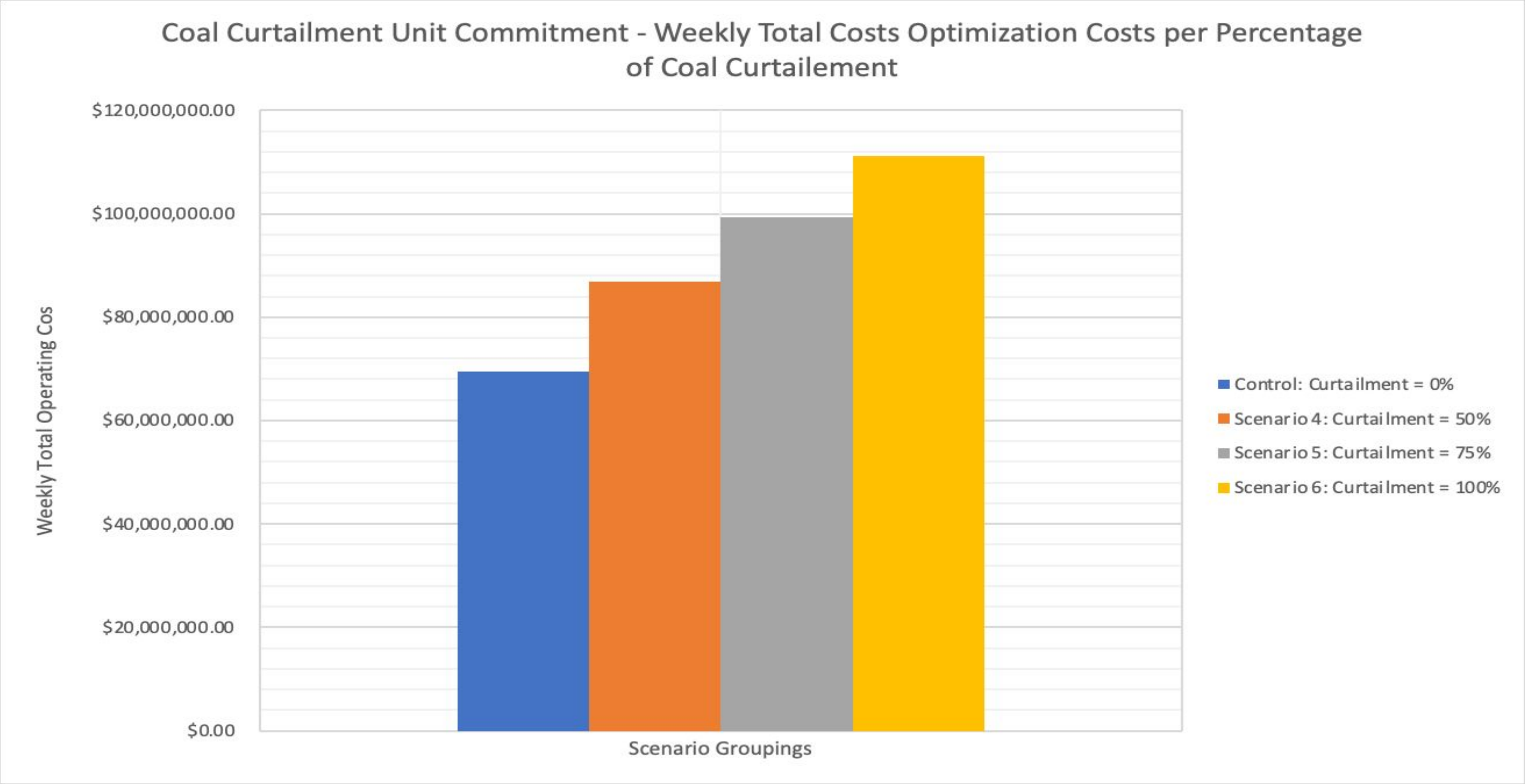
- Exclude the use of Bituminous and Subbituminous Coal (thermal generators 6 - 16)

Bituminous : Contains 45% to 86% carbon. The oldest and most abundant coal type found in the United States, bituminous coal makes up 45% of U.S. coal production by weight and 54% by energy intensity. West Virginia leads production, followed by Kentucky and Pennsylvania.

Subbituminous: Contains 35% to 45% carbon. A major component of U.S. coal production, subbituminous coal makes up 47% of U.S. coal production by weight and 41% by energy intensity. Although subbituminous coal has the second lowest energy content, large quantities are found in thick beds near the surface, resulting in low mining cost and, correspondingly, lower prices. Wyoming produces the vast majority of subbituminous coal in the U.S.

https://www.eia.gov/todayinenergy/detail.php?id=2670


Coal Curtailment Unit Commitment - Daily Optimization Costs per Percentage of Coal Curtailement
$25,000,000.00
$20,000,000.00
$15,000,000.00
$10,000,000.00
$5,000,000.00
$0.00
Daily Total Operating Cost
1
2
3
4
5
6
7
Day
Control: Curtailment = 0%
Scenario 4: Curtailment = 50%
Scenario 5: Curtailment = 75%
Scenario 6: Curtailment = 100%


Coal Curtailment Unit Commitment - Weekly Total Costs Optimization Costs per Percentage of Coal Curtailement
$120,000,000.00
$100,000,000.00
$80,000,000.00
$60,000,000.00
$40,000,000.00
$20,000,000.00
$0.00
Weekly Total Operating Cos
Scenario Groupings
Control: Curtailment = 0%
Scenario 4: Curtailment = 50%
Scenario 5: Curtailment = 75%
Scenario 6: Curtailment = 100%

Individual Scenarios - Tax Incentives

Tax Incentives

- A wind production tax credit may be used to incentivize further investments in wind projects in the region.
- We assessed the impact the current wind PTC of $26/MWh has on the system’s daily operating costs.
- The analysis shows that a tax credit reduces the daily operating costs for each day of the week.


Wind Production Tax Credit of $26/MWh
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
.00
Daily Operating Cost ($M)
1
2
3
4
5
6
7
Day
Scenario 1: 2GW
Scenario 2: 6GW
Scenario 3: 12GW

Thank You. Any Questions?