Offshore Wind Results and Analysis

Morgan Browning

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Contents

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1 Purpose

This document functions as an all-inclusive working directory for synthesis and graphical analysis of the results from the offshore wind research of Morgan Browning, an ORISE Fellow at the U.S. Environmental Protection Agency's Office of Research and Development.

This documents and its contents are not finalized nor are intended for publication. It is annotated primarily for ease of reproducability. Graphs are provided with many variations to meet criteria of different publication and presentation platforms.

2 Setup

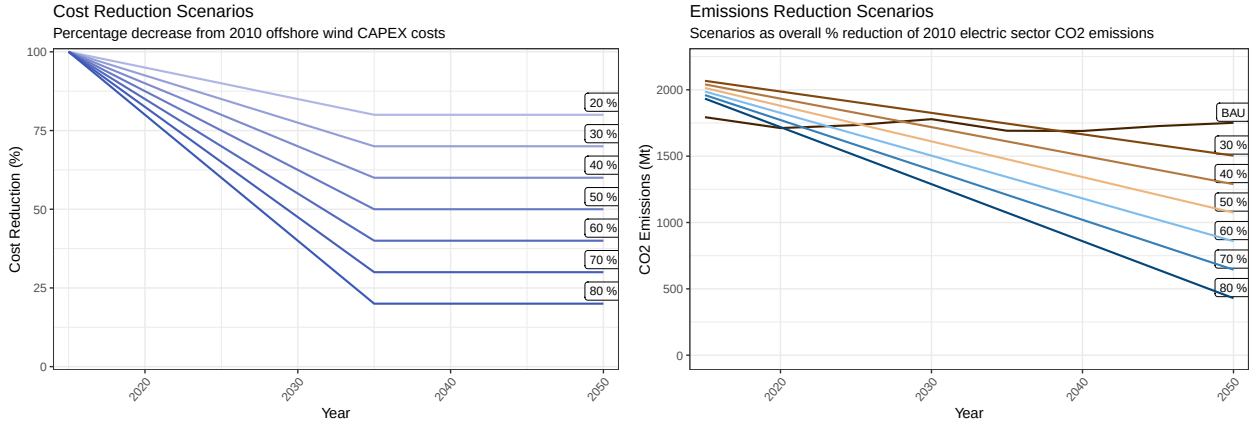
Sets global knit options and loads the setup and data import scripts for the project.

Three scripts are loaded into this markdown document to allow for analysis of the data. The setup script loads the library, creates generalized functions, and creates global variables for color scales and factors.The data script loads the excel spreadsheet with all of the results data and performs the majority of data munging. The results script creates charts, graphs, and tables. This report functions as the annotated synthesis of the data and results.

3 Scenarios

The nested parametric sensitivity analysis was built on combinations of two sets of scenarios:

1. Electric sector CO_2 emissions caps, as a linear decrease to a given % decrease from 2010 emissions by 2050
2. Cost reductions of offshore wind, as a linear decrease to a given % decrease from 2010 costs by 2035, then level costs to 2050



4 LCOE

EIA's AEO 2019 provides the following values for the estimated levelized cost of electricity (capacity-weighted average) for new generation resources entering service in 2023 (2018 $/MWh). Offshore wind has the highest total LCOE by a large margin. The second most expensive technology is biomass.

Table 1: Estimated LCOE capacity-weighted average for new generation resources entering service in 2023 (2018 $/MWh)

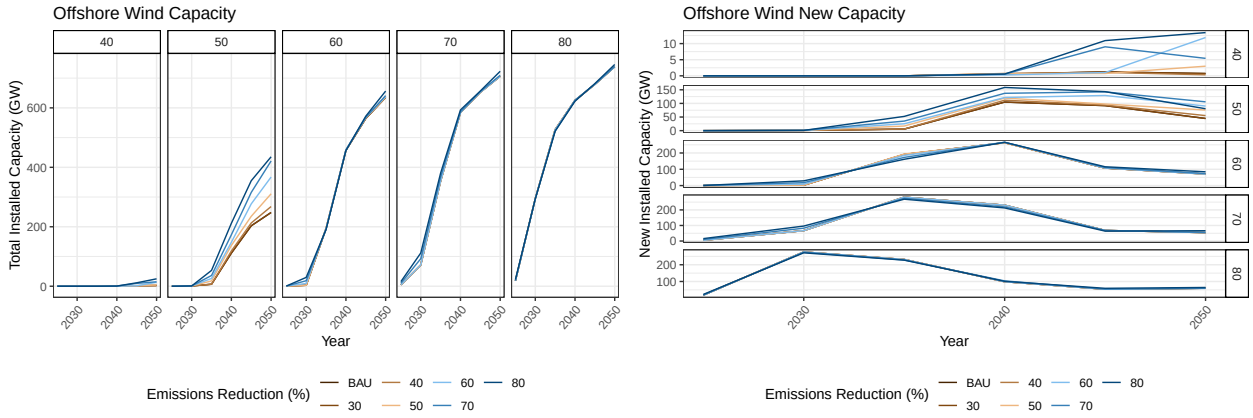
Plant Type	Capacity Factor (%)	Levelized capital cost	Levelized fixed O&M	Levelized variable O&M	Levelized trans-mission cost	Total system LCOE	Levelized tax credit	Total LCOE including tax credit
Dispatchable technologies								
Conventional CC	87	8.1	1.5	32.3	0.9	42.8	NA	42.8
Advanced CC	87	7.1	1.4	30.7	1.0	40.2	NA	40.2
Advanced CT	30	17.2	2.7	54.6	3.0	77.5	NA	77.5
Geothermal	90	24.6	13.3	0.0	1.4	39.4	-2.5	36.9
Biomass	83	37.3	15.7	37.5	1.5	92.1	NA	92.1
Non-dispatchable technologies								
Wind, onshore	44	27.8	12.6	0.0	2.4	42.8	-6.1	36.6
Wind, offshore	45	95.5	20.4	0.0	2.1	117.9	-11.5	106.5
Solar PV	29	37.1	8.8	0.0	2.9	48.8	-11.5	37.6
Hydroelectric	75	29.9	6.2	1.4	1.6	39.1	NA	39.1

Note:
U.S. EIA Annual Energy Outlook 2019

5 Offshore Wind

5.1 Capacity Buildout

Cumulative and new addition offshore wind capacity across all nine census regions, by cost and emissions reduction scenario.



5.2 Total Capacity

Total offshore wind capacity across all nine census regions in 2050, by cost and emissions reduction scenario.

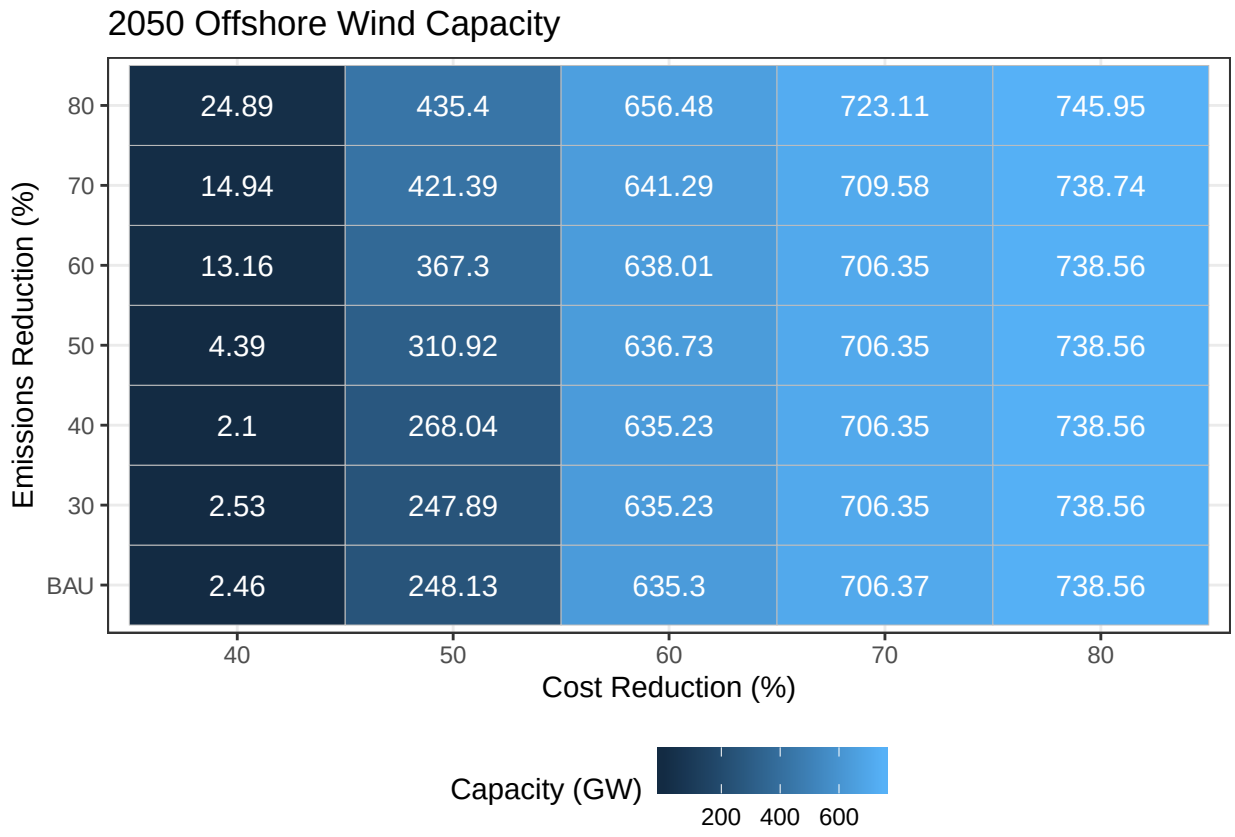
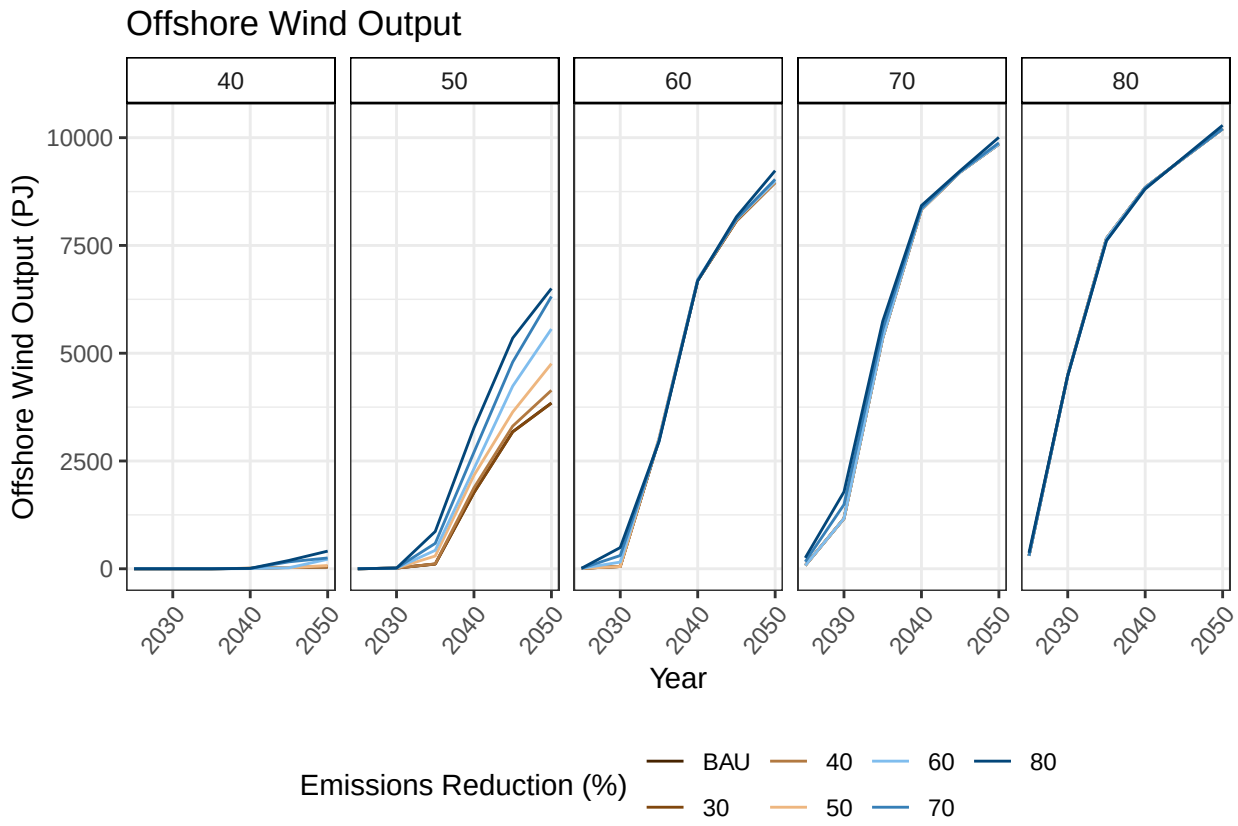


Table 2: Offshore Wind Total Installed Capacity (GW): 2050

Emissions Reduction (%)	Cost Reduction (%)				
	40	50	60	70	80
BAU	2.5	248.1	635.3	706.4	738.6
30	2.5	247.9	635.2	706.4	738.6
40	2.1	268.0	635.2	706.4	738.6
50	4.4	310.9	636.7	706.4	738.6
60	13.2	367.3	638.0	706.4	738.6
70	14.9	421.4	641.3	709.6	738.7
80	24.9	435.4	656.5	723.1	746.0

5.3 Output

Total offshore wind electricity output across all nine census regions, by cost and emissions reduction scenario.

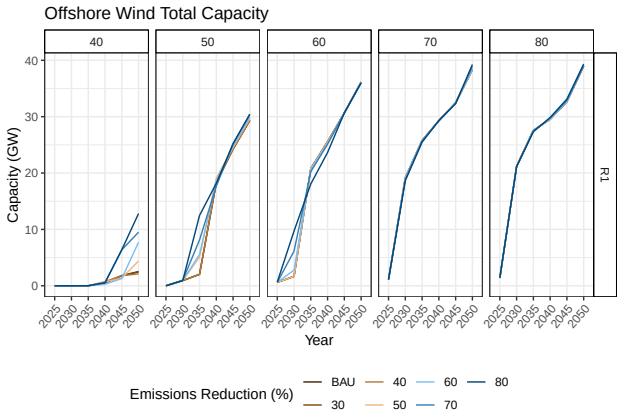


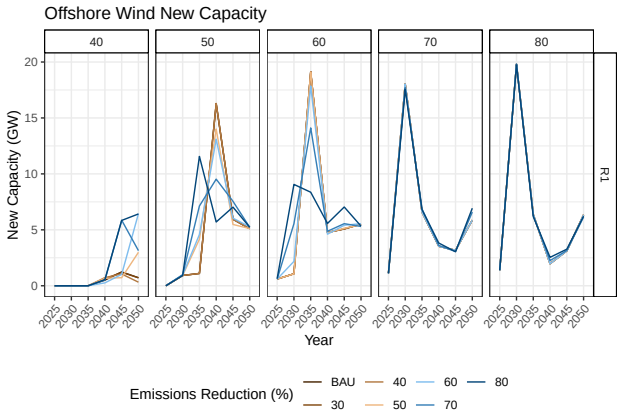
5.4 Regions

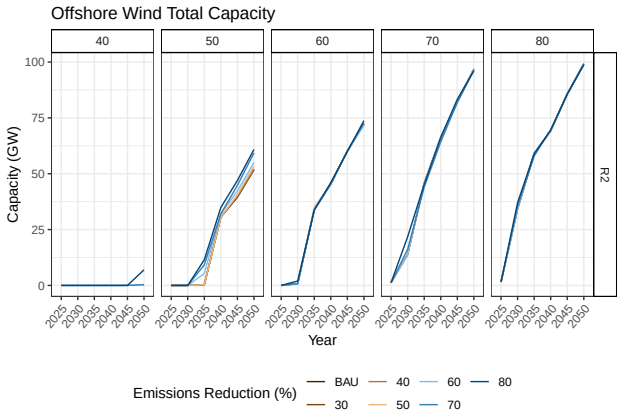
Cumulative and new addition offshore wind capacity by region.

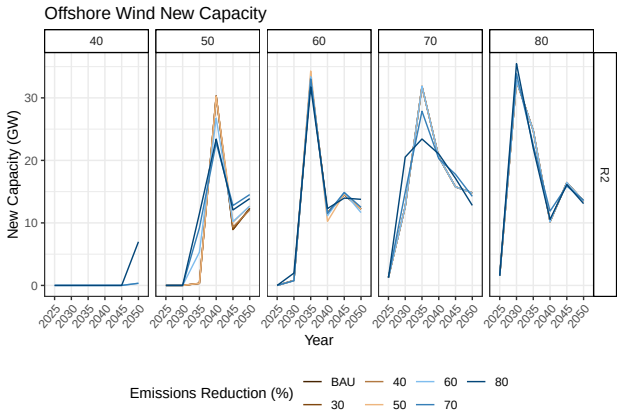
Table 3: Offshore Wind Total Output (PJ): 2050

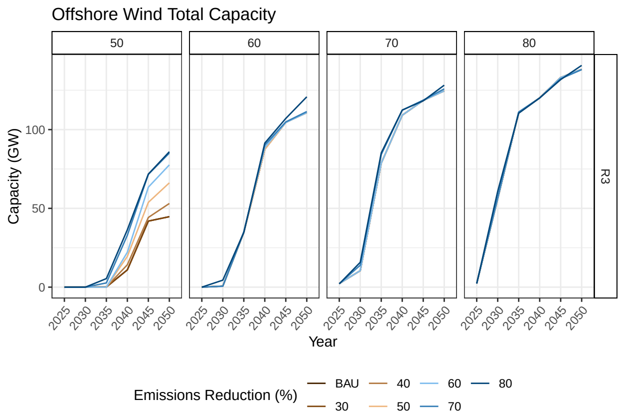
Emissions Reduction (%)	Cost Reduction (%)				
	40	50	60	70	80
BAU	42.3	3845.4	8962.0	9848.8	10204.0
30	43.4	3841.7	8960.8	9848.5	10204.0
40	36.0	4139.4	8960.8	9848.5	10204.0
50	75.3	4758.1	8977.9	9848.5	10204.0
60	221.0	5562.3	8992.0	9848.5	10204.0
70	250.4	6315.4	9034.2	9880.0	10205.3
80	409.6	6502.2	9235.0	10008.3	10287.1

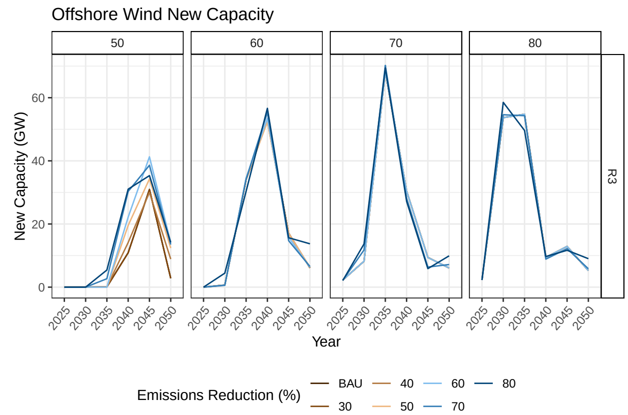


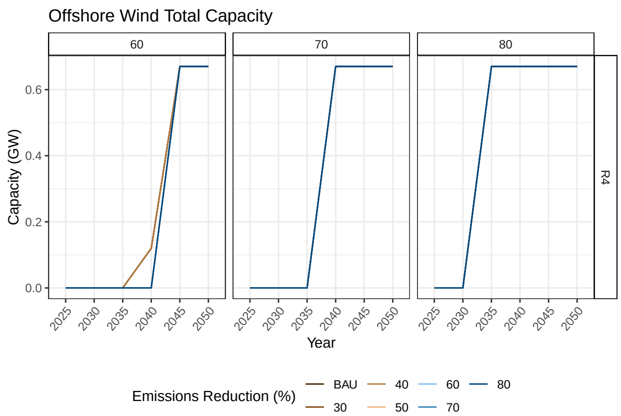


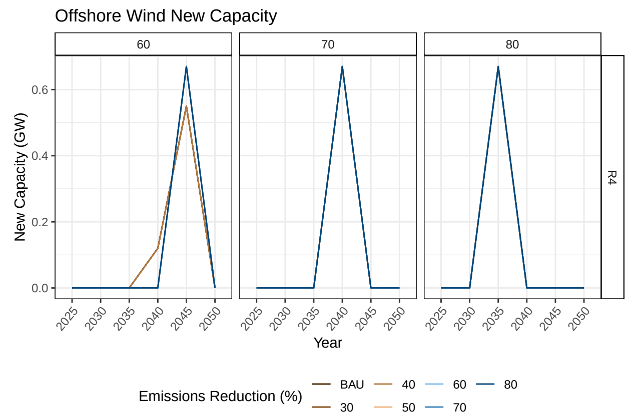


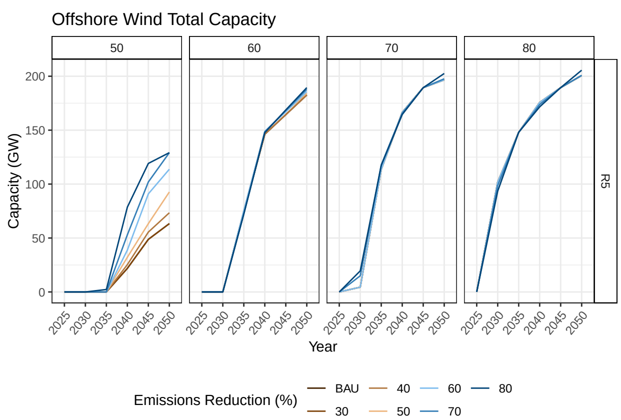


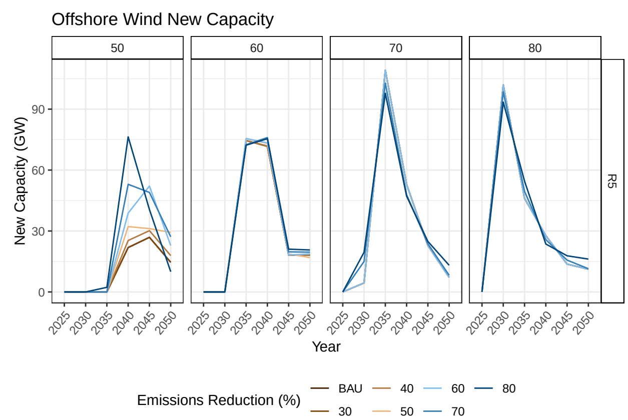

Offshore Wind Total Capacity
50
60
70
80
R3
Capacity (GW)
Year
Emissions Reduction (%)
BAU
30
40
50
60
70
80

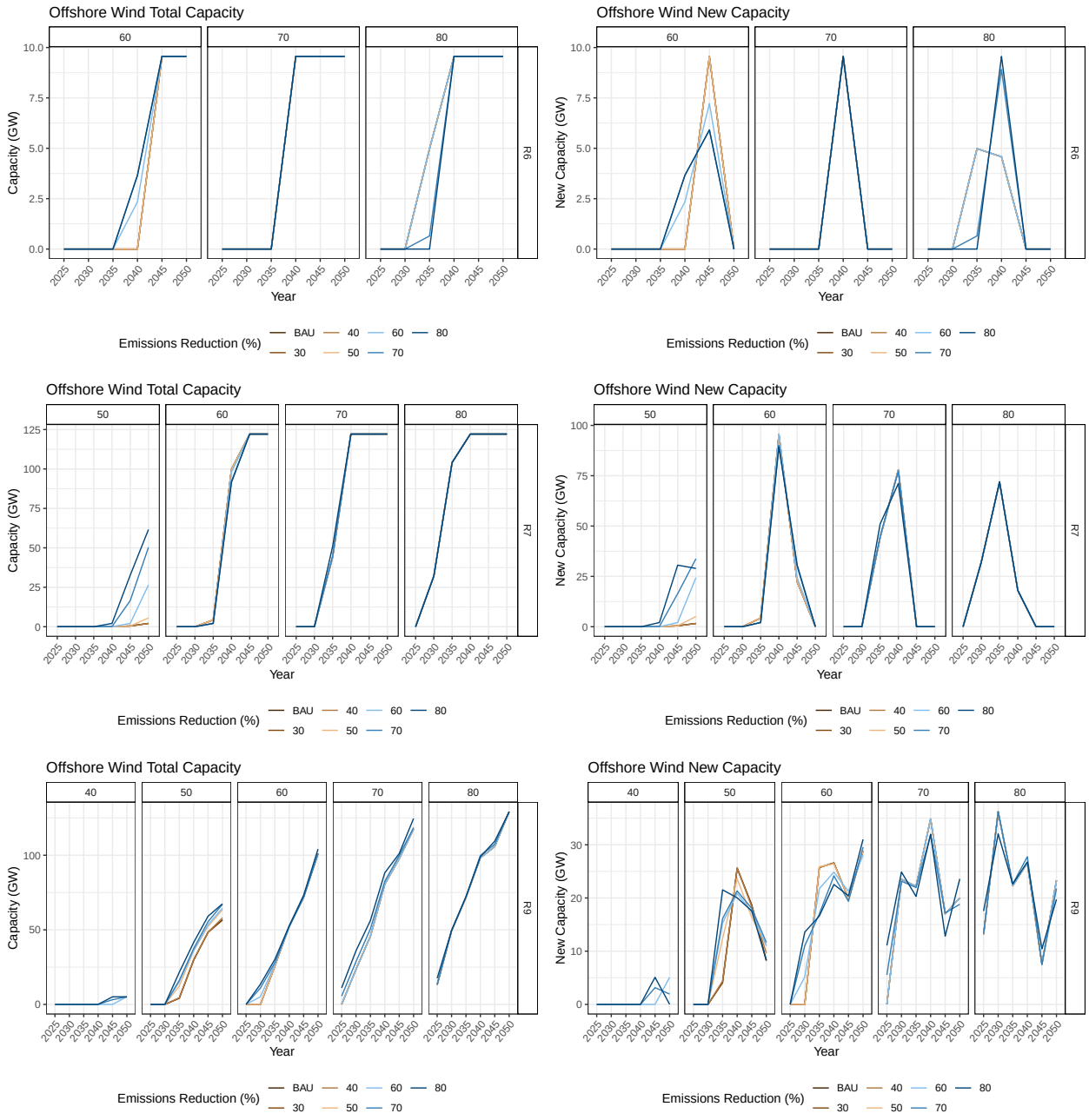

Offshore Wind New Capacity
50
60
70
80
R3
New Capacity (GW)
Year
Emissions Reduction (%)
BAU
30
40
50
60
70
80


Offshore Wind Total Capacity
60
70
80
R4
Capacity (GW)
Year
Emissions Reduction (%)
BAU
30
40
50
60
70
80


Offshore Wind New Capacity
60
70
80
R4
New Capacity (GW)
Year
Emissions Reduction (%)
BAU
30
40
50
60
70
80


Offshore Wind Total Capacity
50
60
70
80
R5
Capacity (GW)
Year
Emissions Reduction (%)
BAU
30
40
50
60
70
80


Offshore Wind New Capacity
50
60
70
80
R5
New Capacity (GW)
Year
Emissions Reduction (%)
BAU
30
40
50
60
70
80



Cumulative and new addition offshore wind capacity by region, emissions reduction, and cost reduction.

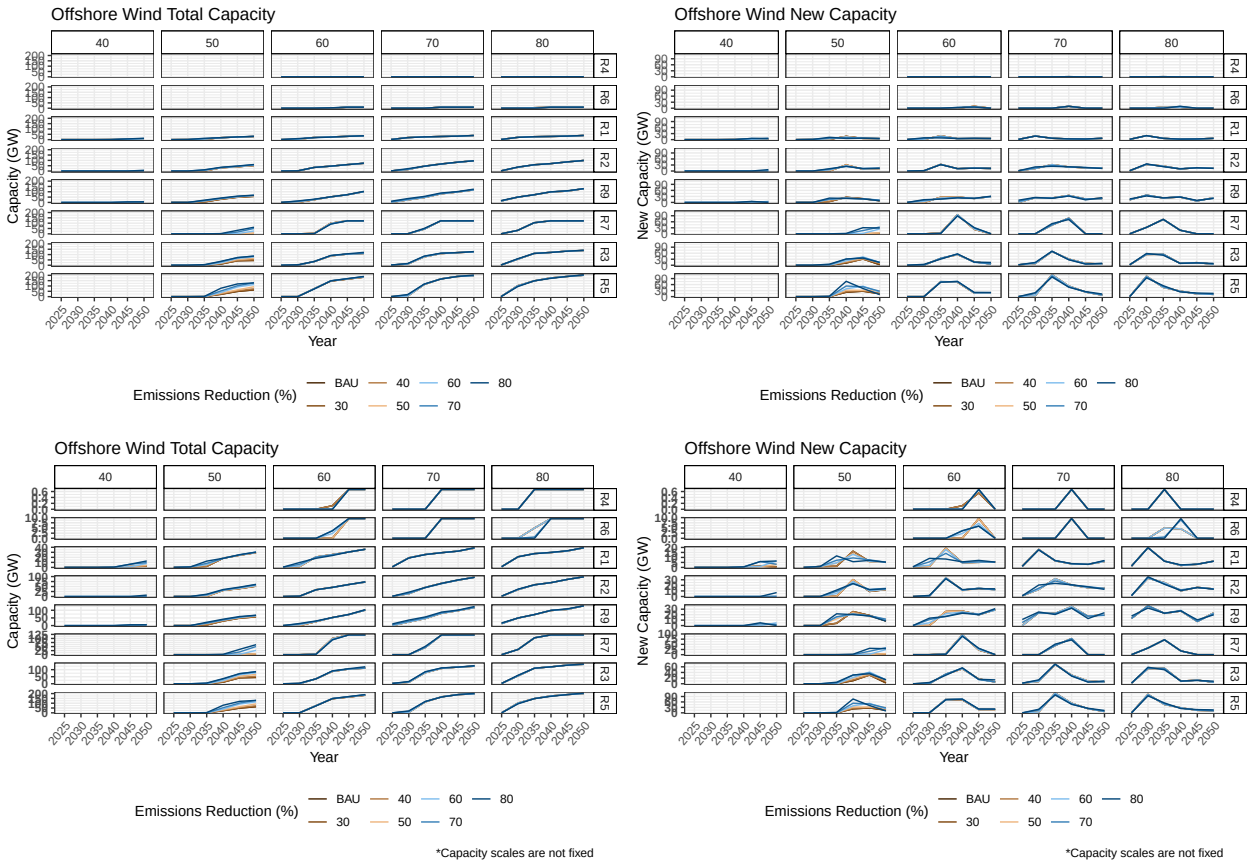


Table 4: Average Installed Capacity (GW)

Region	2050 Total
R4	0.67000
R6	9.56000
R1	29.88514
R2	73.21452
R9	93.38871
R7	96.97286
R3	110.37893
R5	169.72857

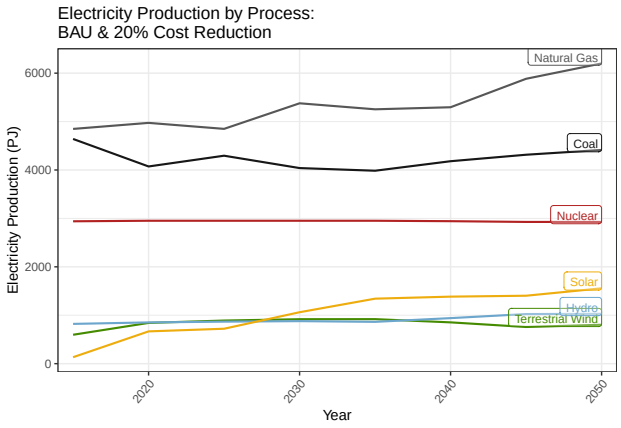
Table 5: Average Electricity Output (PJ)

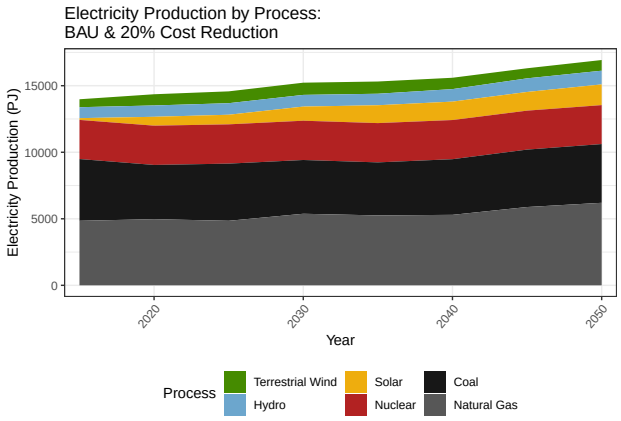
Region	2050 Total
R4	5.85375
R6	68.65600
R1	96.99500
R2	224.66953
R9	284.79601
R3	326.76062
R7	485.47903
R5	526.62200

6 Grid Mix

6.1 Baseline Production

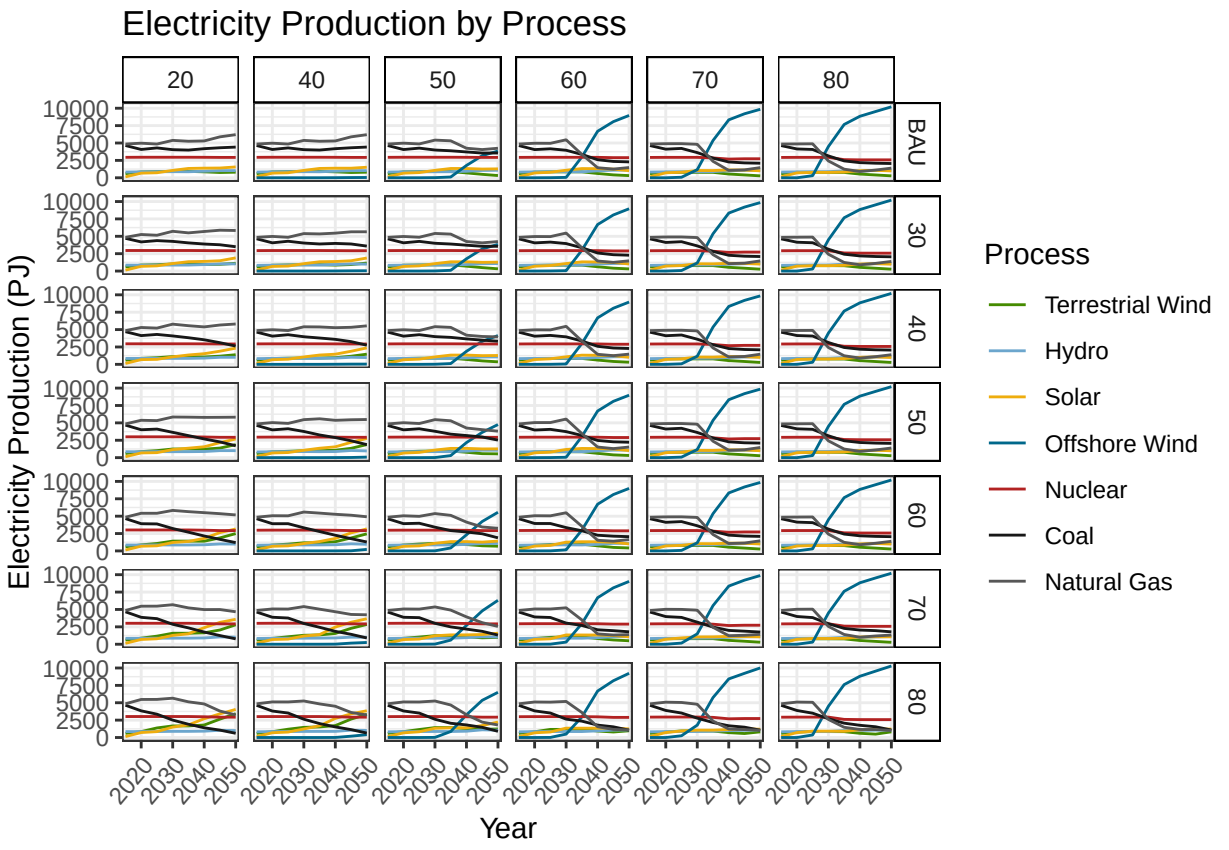
Grid mix without any offshore wind cost reduction or emissions cap.



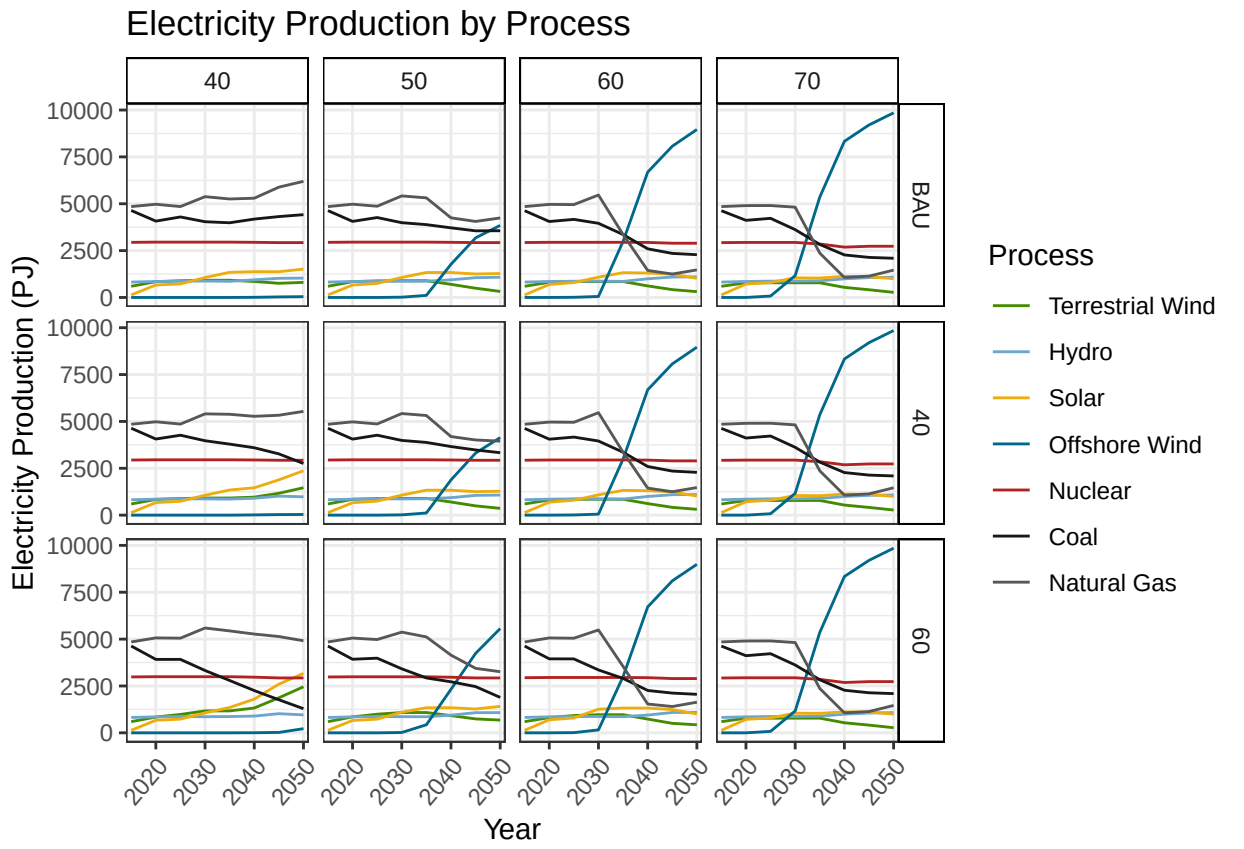


6.2 All Scenarios

Complete Set

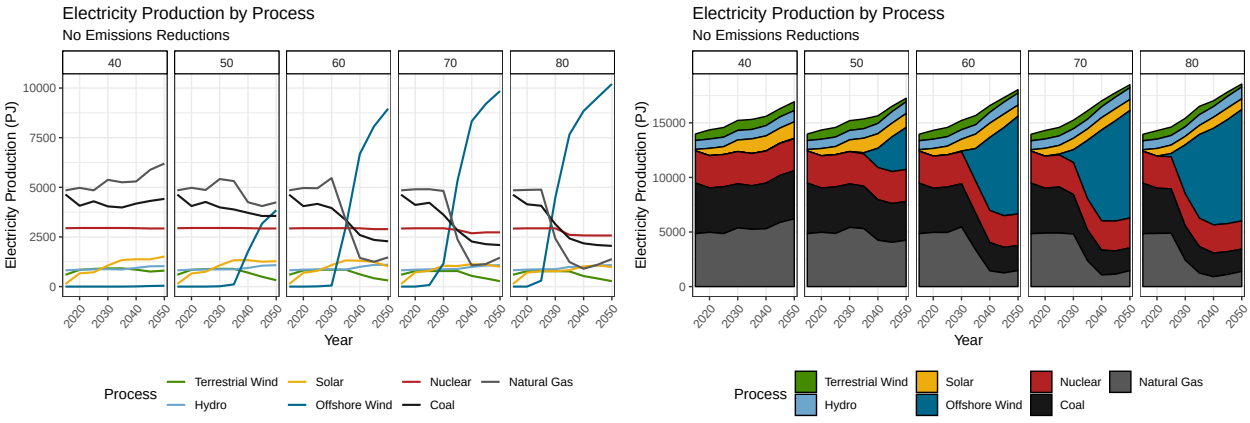


Parsed Set

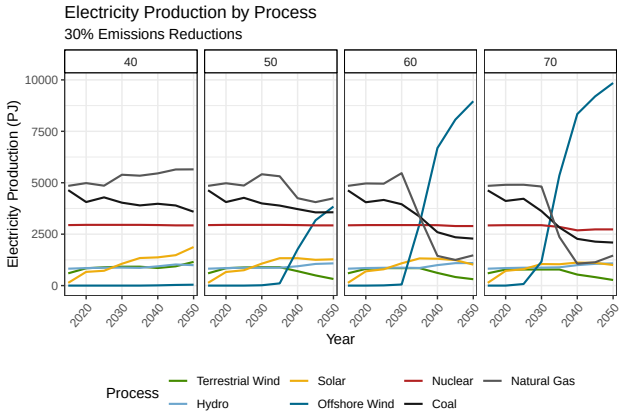


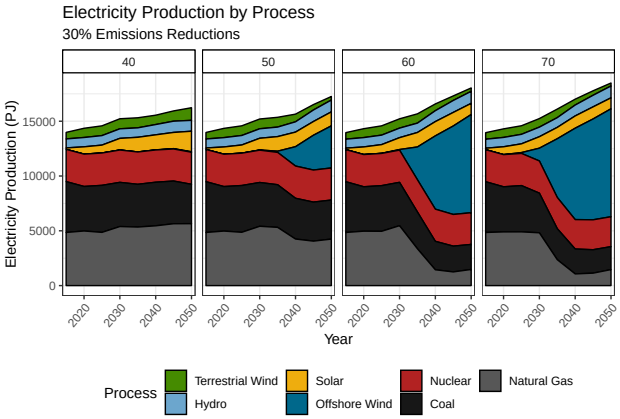
6.3 Emissions Cap

BAU emissions

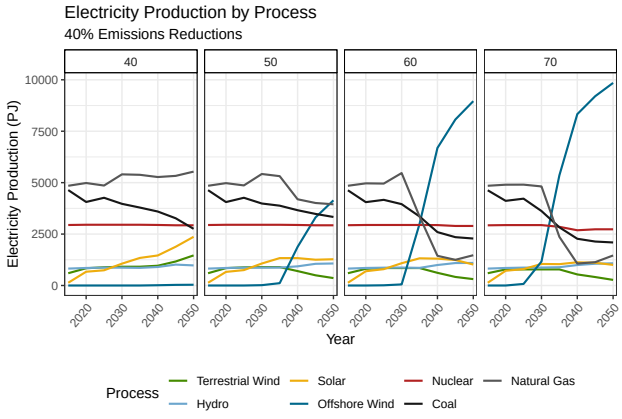


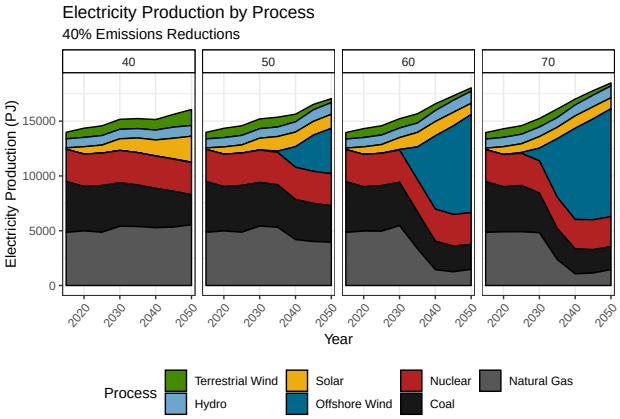
30% emissions reduction



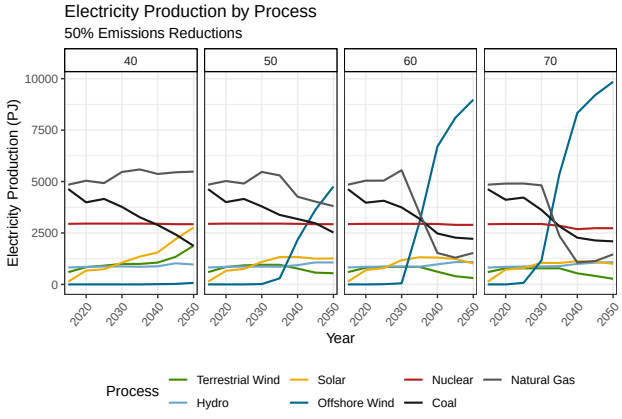


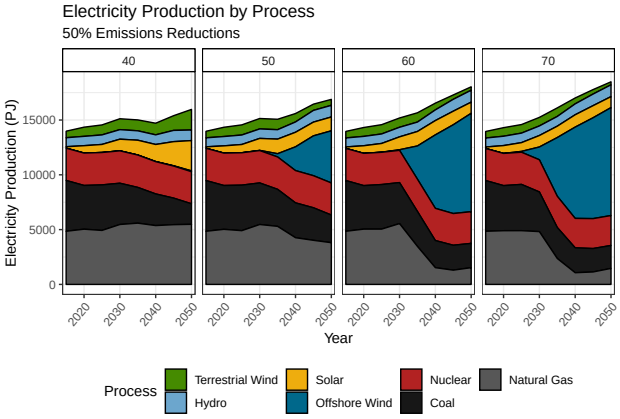
40% emissions reduction



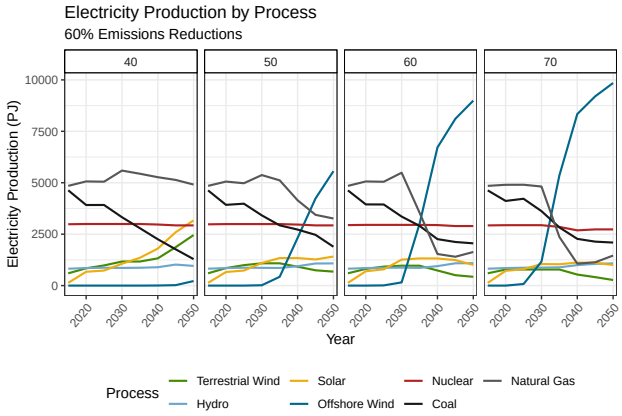


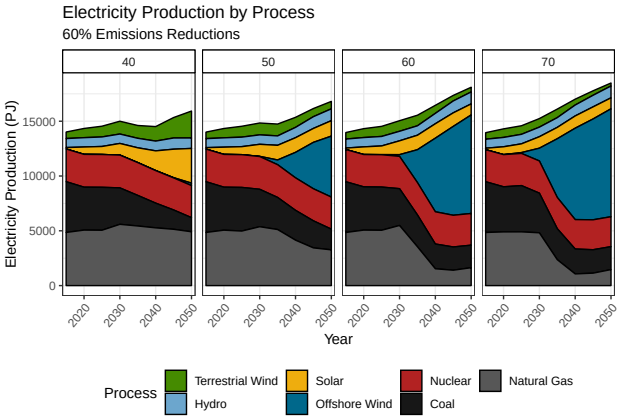
50% emissions reduction



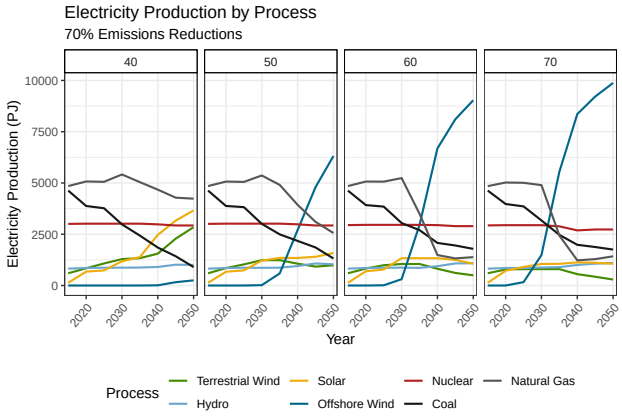


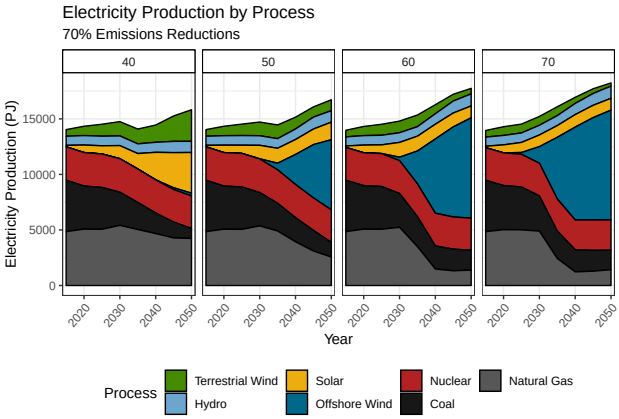
60% emissions reduction



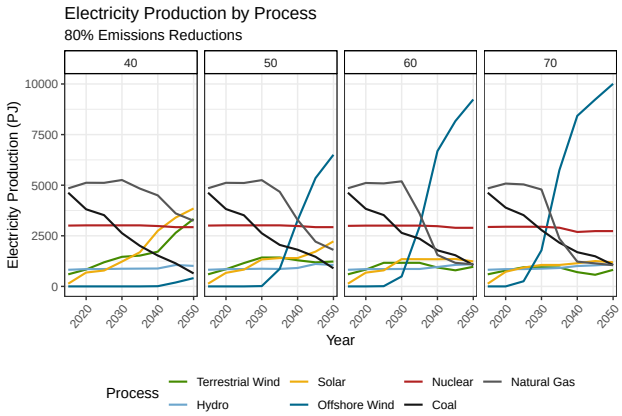


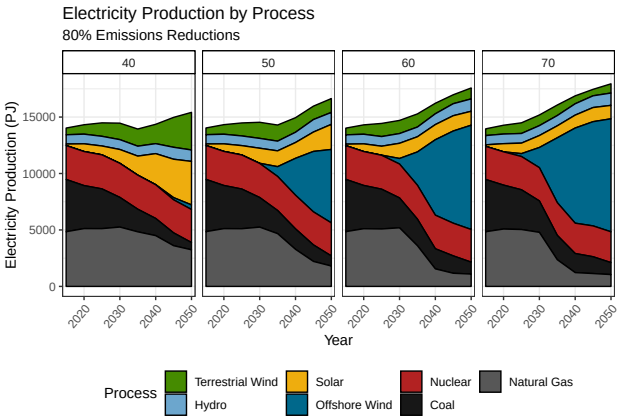
70% emissions reduction





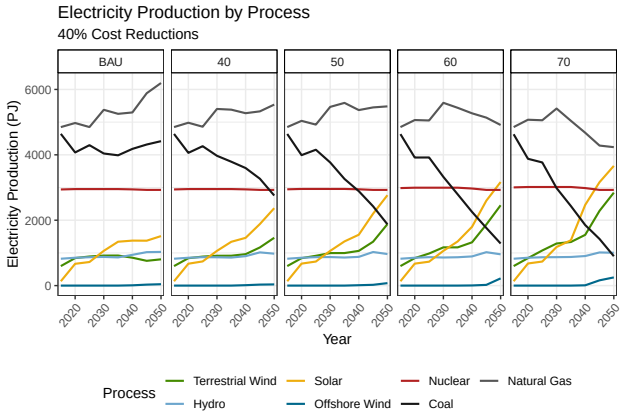
80% emissions reduction

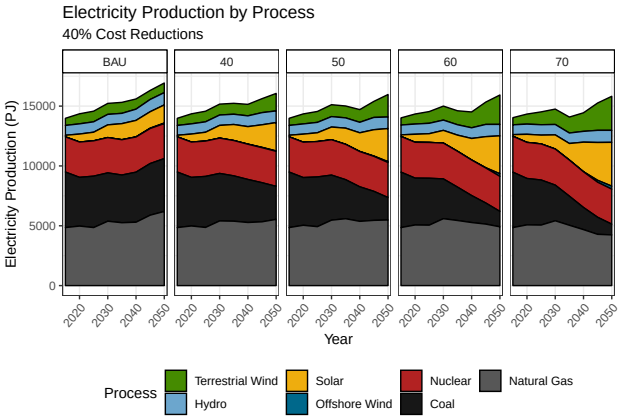




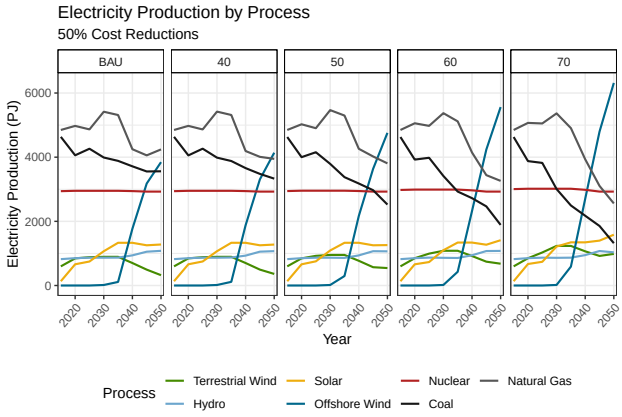
6.4 Cost Reductions

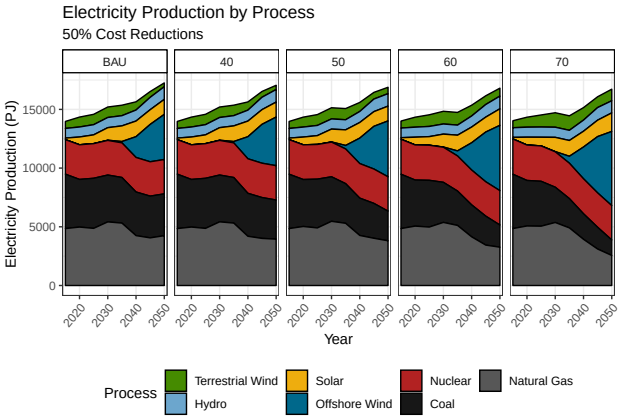
40% cost reduction



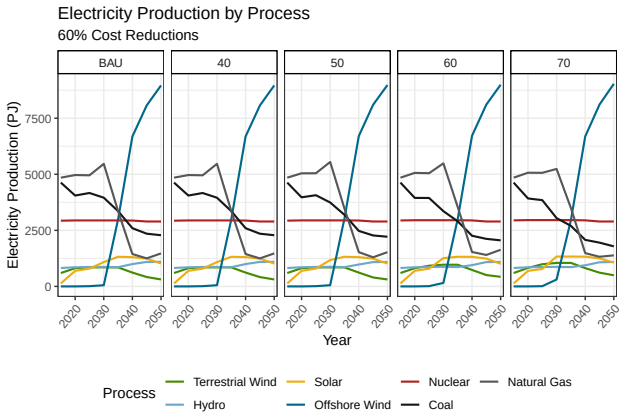


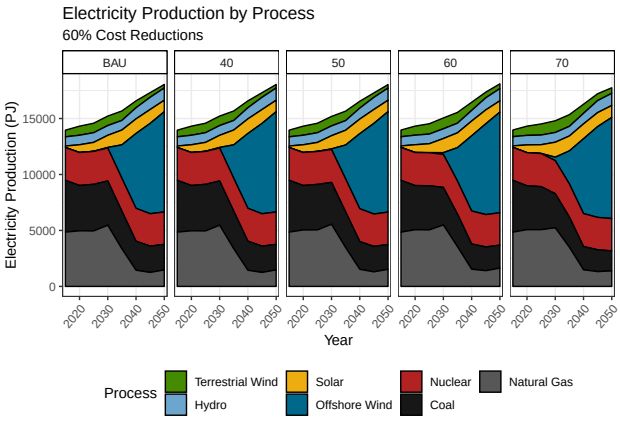
50% cost reduction



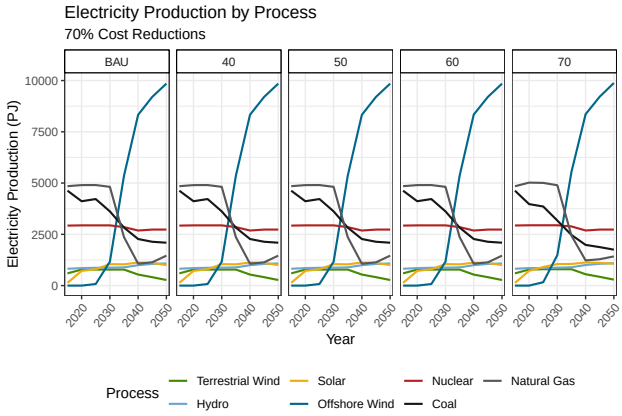


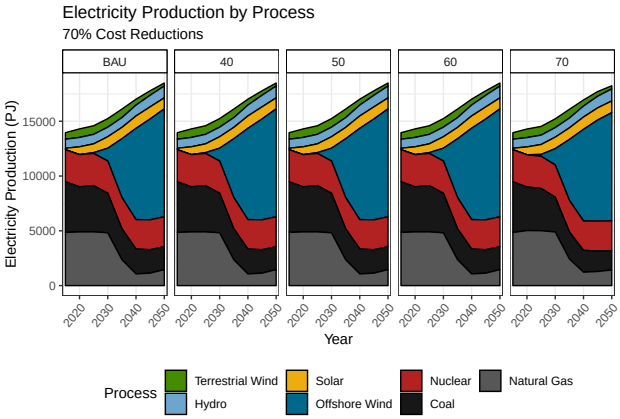
60% cost reduction



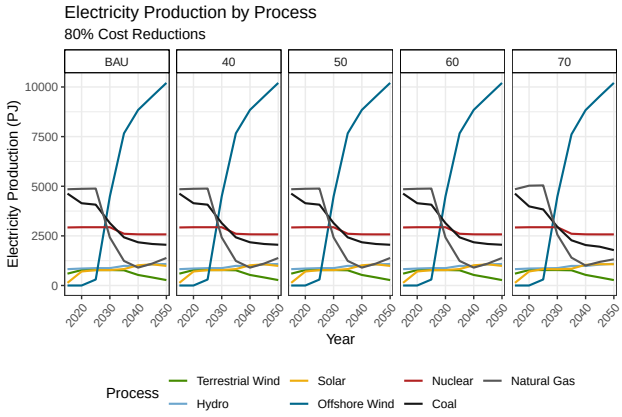


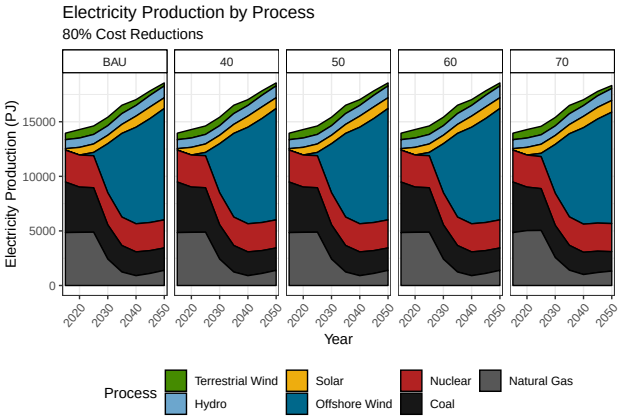
70% cost reduction



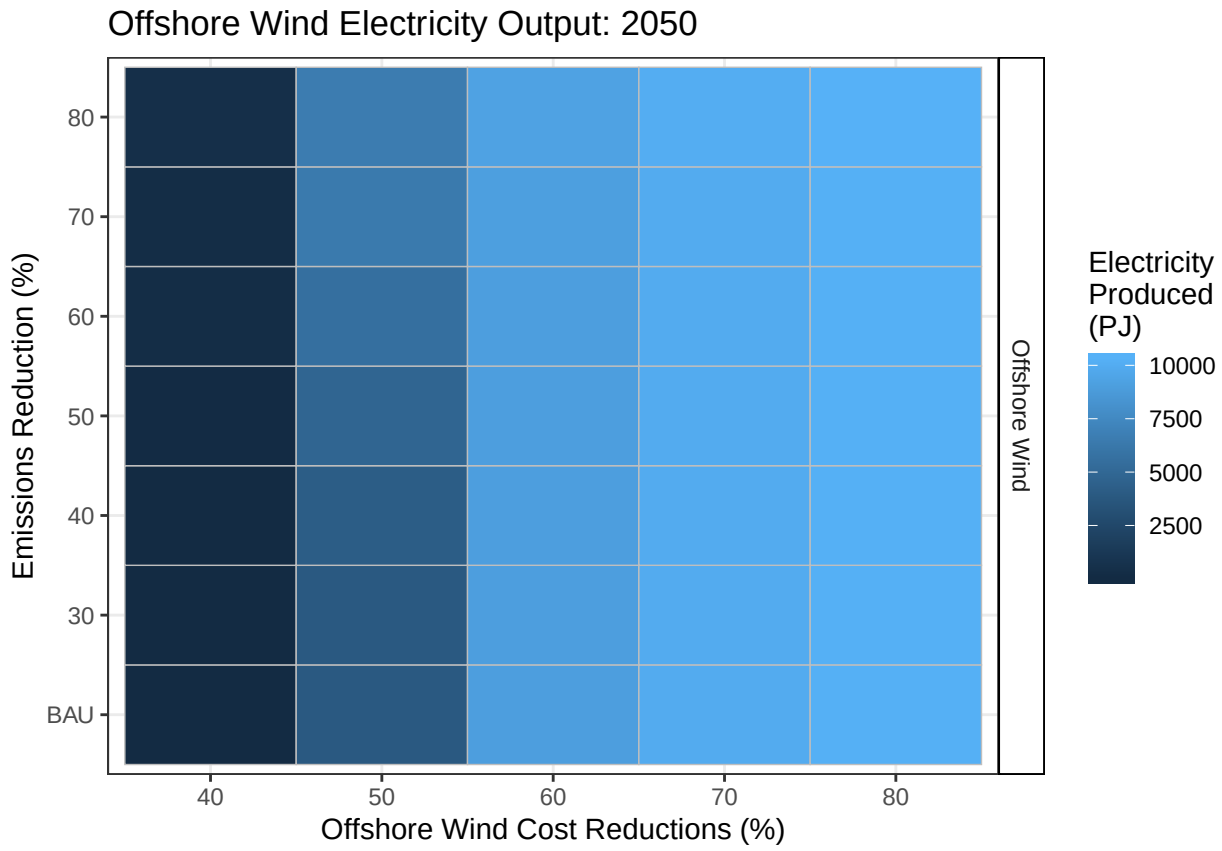


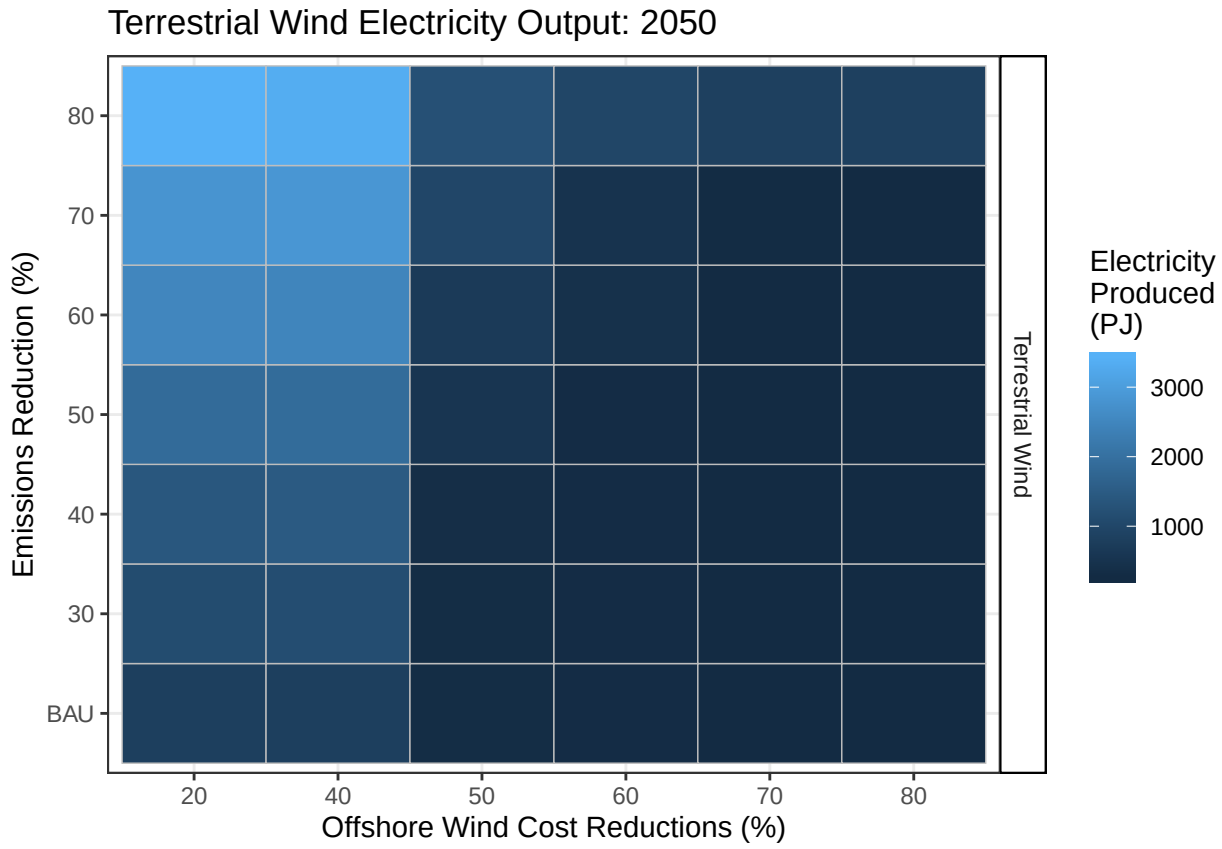
80% cost reduction

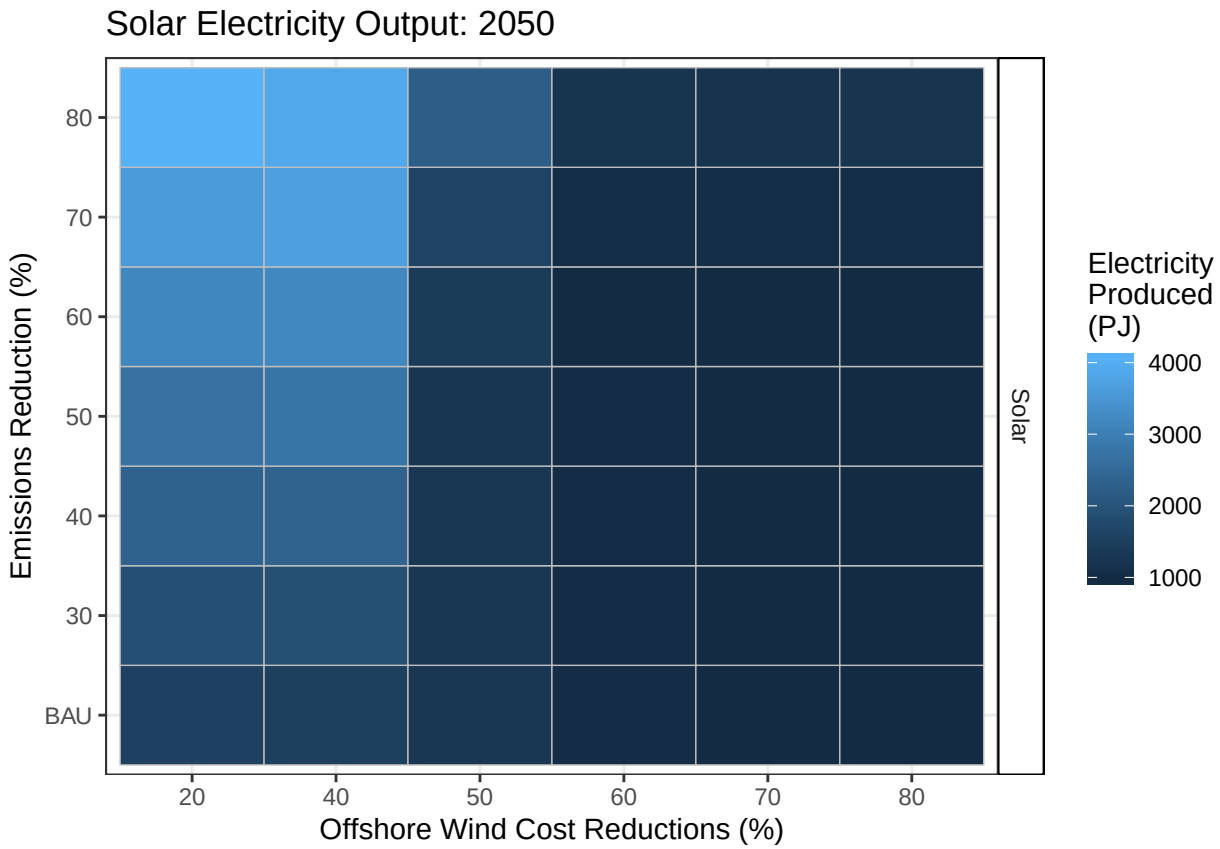


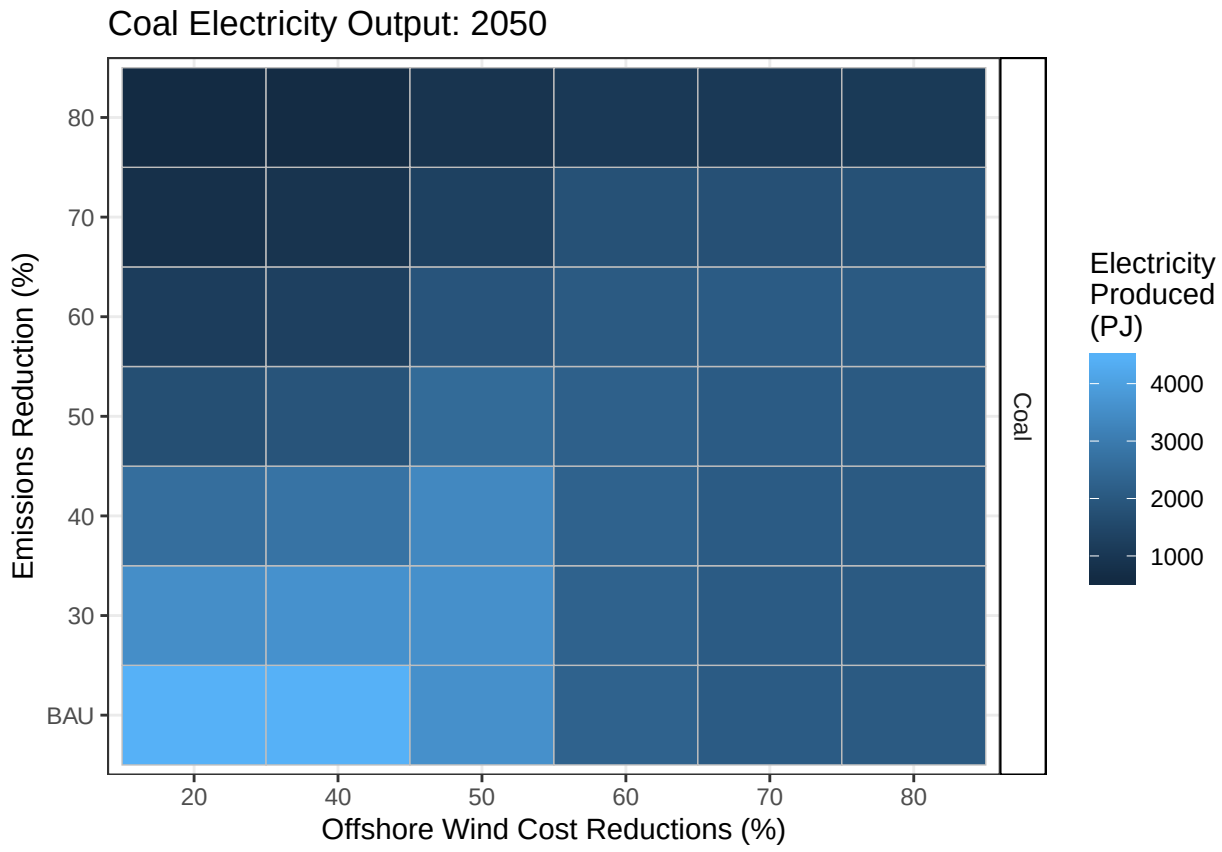


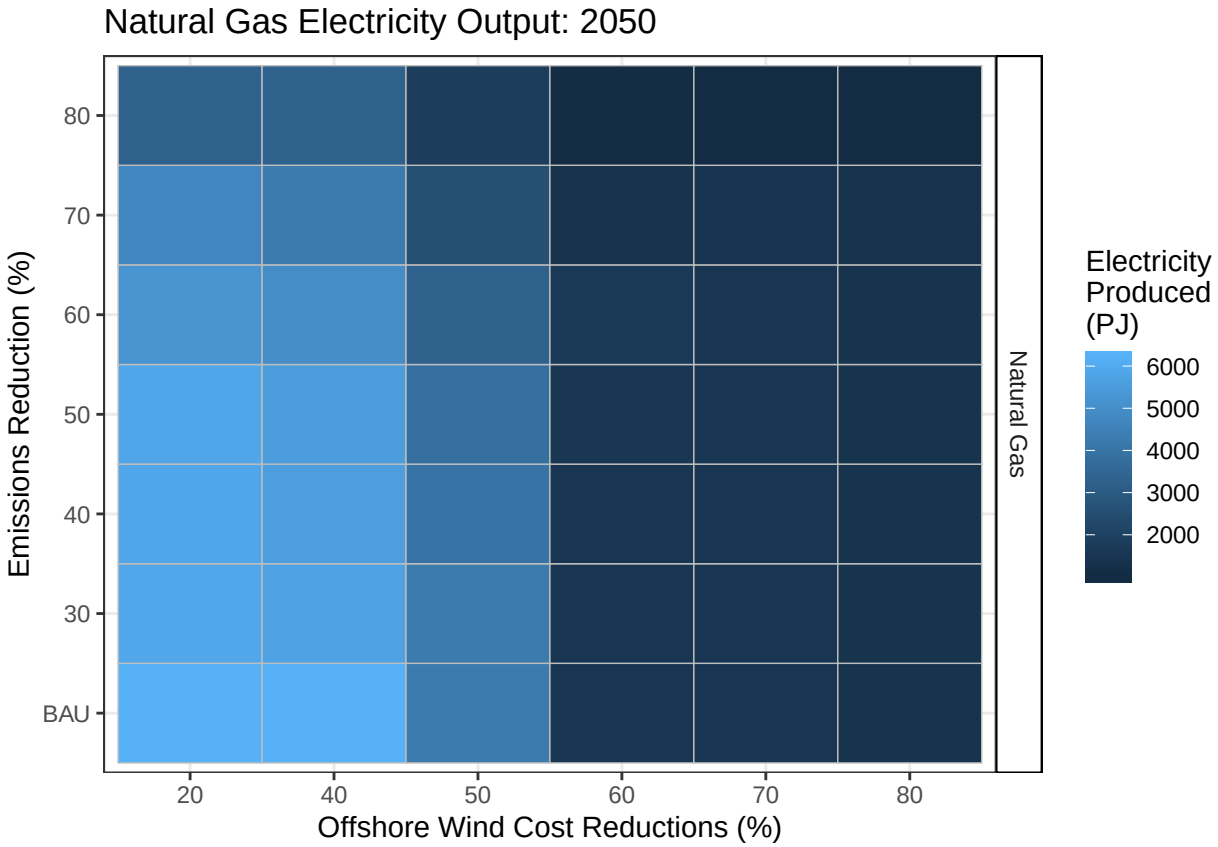
6.5 Heatmaps

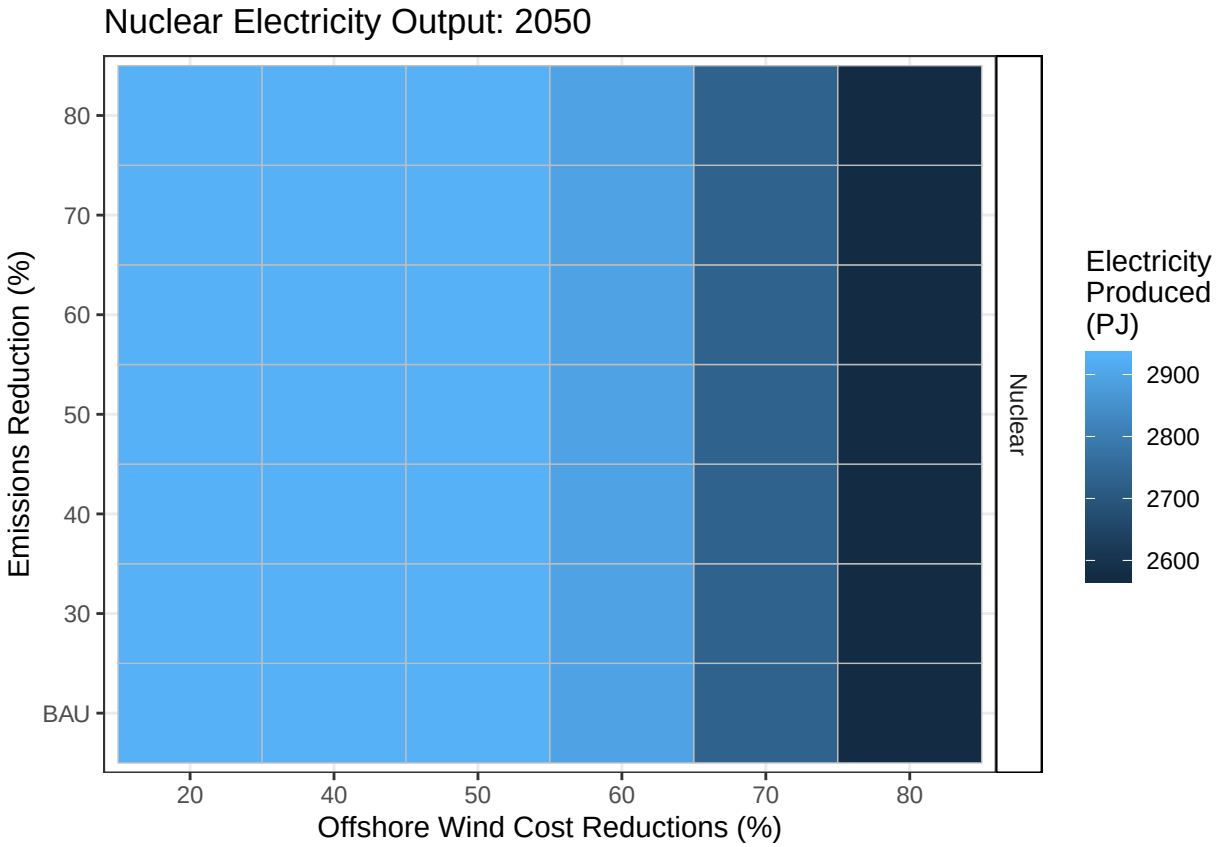

Offshore Wind Electricity Output: 2050
Emissions Reduction (%)
80
70
60
50
40
30
BAU
40
50
60
70
80
Offshore Wind Cost Reductions (%)
Offshore Wind
Electricity Produced (PJ)
10000
7500
5000
2500

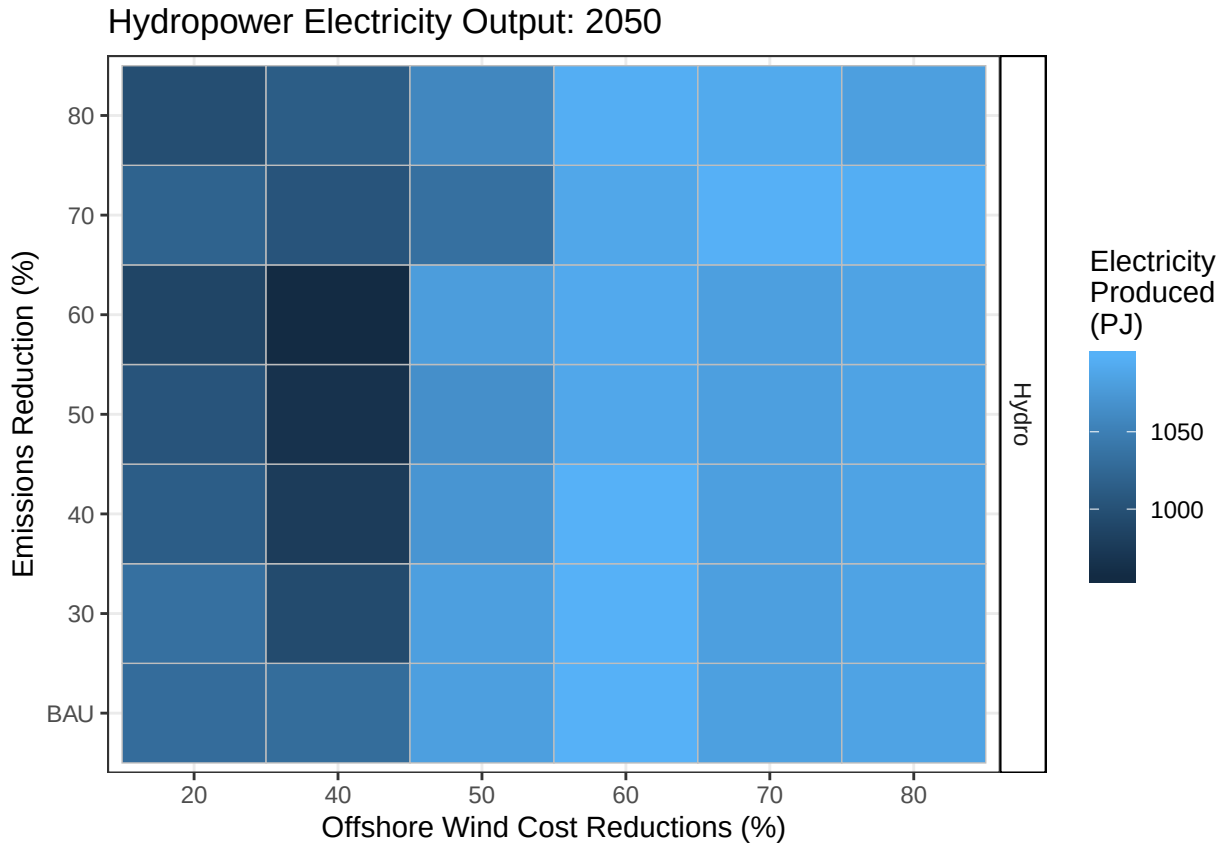

Terrestrial Wind Electricity Output: 2050
Emissions Reduction (%)
80
70
60
50
40
30
BAU
20
40
50
60
70
80
Offshore Wind Cost Reductions (%)
Terrestrial Wind
Electricity Produced (PJ)
3000
2000
1000


Solar Electricity Output: 2050
Emissions Reduction (%)
80
70
60
50
40
30
BAU
20
40
50
60
70
80
Offshore Wind Cost Reductions (%)
Solar
Electricity Produced (PJ)
4000
3000
2000
1000

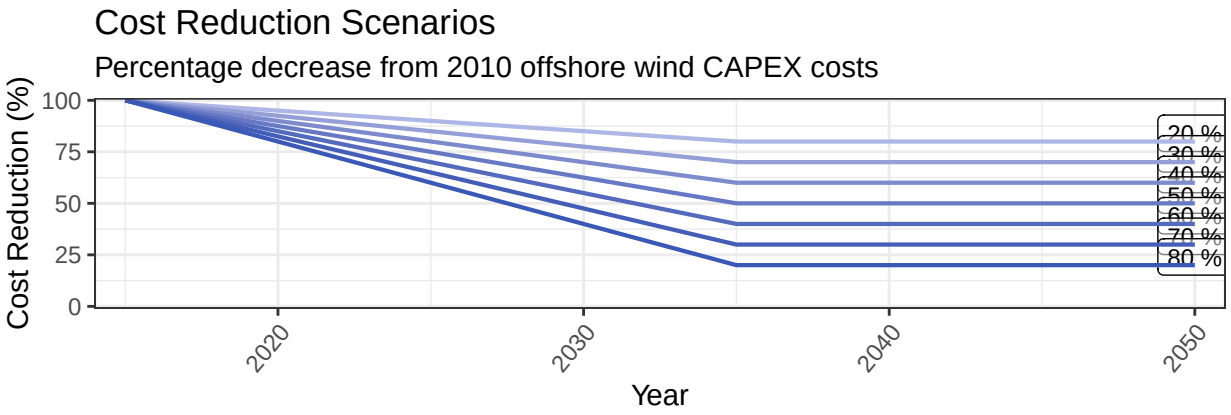

Coal Electricity Output: 2050
Emissions Reduction (%)
80
70
60
50
40
30
BAU
20
40
50
60
70
80
Offshore Wind Cost Reductions (%)
Coal
Electricity Produced (PJ)
4000
3000
2000
1000

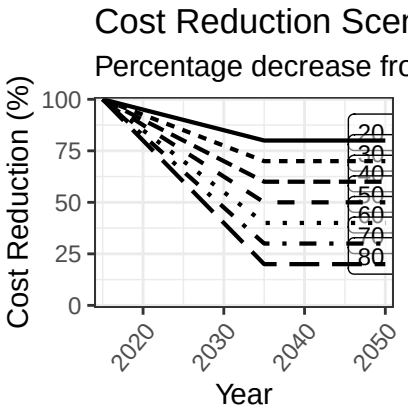

Natural Gas Electricity Output: 2050
Emissions Reduction (%)
80
70
60
50
40
30
BAU
20
40
50
60
70
80
Offshore Wind Cost Reductions (%)
Natural Gas
Electricity Produced (PJ)
6000
5000
4000
3000
2000

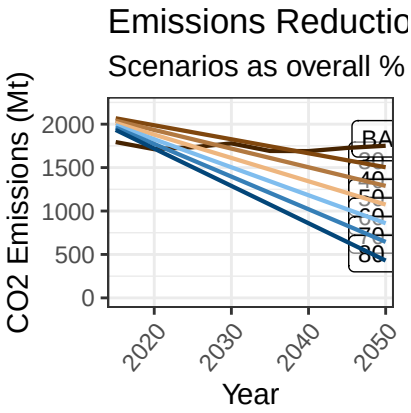

Nuclear Electricity Output: 2050
Emissions Reduction (%)
80
70
60
50
40
30
BAU
20
40
50
60
70
80
Offshore Wind Cost Reductions (%)
Nuclear
Electricity Produced (PJ)
2900
2800
2700
2600

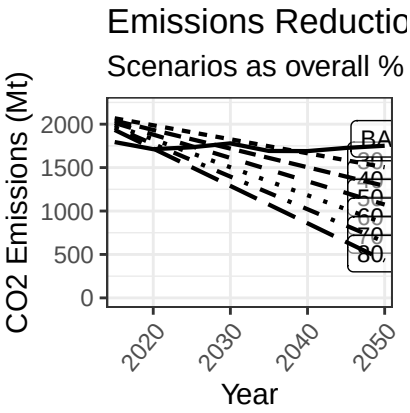

Hydropower Electricity Output: 2050
Emissions Reduction (%)
80
70
60
50
40
30
BAU
20
40
50
60
70
80
Offshore Wind Cost Reductions (%)
Hydro
Electricity Produced (PJ)
1050
1000

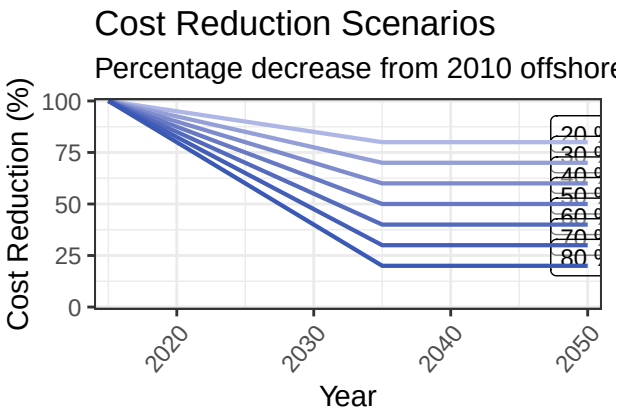
6.6 TEST

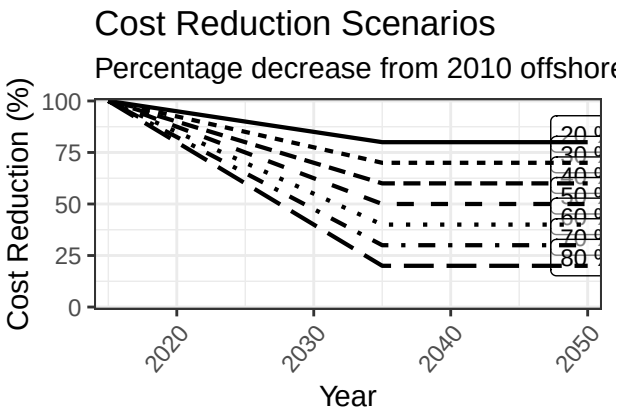

Cost Reduction Scenarios
Percentage decrease from 2010 offshore wind CAPEX costs
Cost Reduction (%)
100
75
50
25
0
2020
2030
2040
2050
Year
20 %
30 %
40 %
50 %
60 %
70 %
80 %

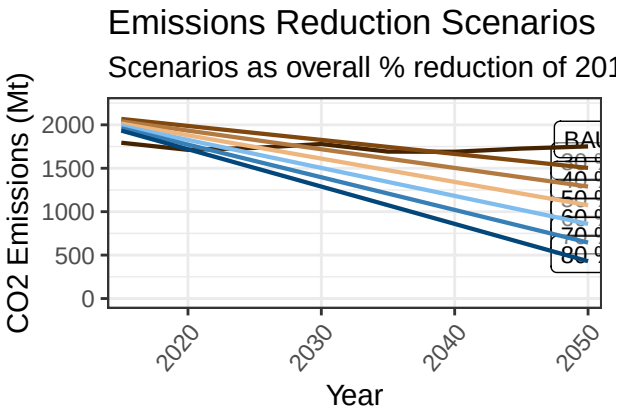

Cost Reduction Scer
Percentage decrease fro
Cost Reduction (%)
100
75
50
25
0
2020
2030
2040
2050
Year

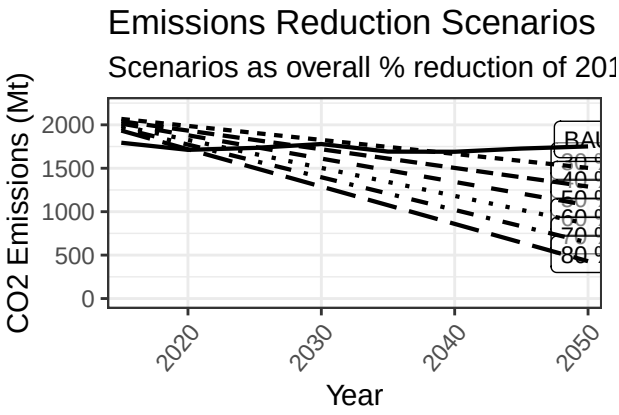

Emissions Reductio
Scenarios as overall %
CO2 Emissions (Mt)
2000
1500
1000
500
0
2020
2030
2040
2050
Year


Emissions Reductio
Scenarios as overall %
CO2 Emissions (Mt)
2000
1500
1000
500
0
2020
2030
2040
2050
Year


Cost Reduction Scenarios
Percentage decrease from 2010 offshore
Cost Reduction (%)
100
75
50
25
0
2020
2030
2040
2050
Year


Cost Reduction Scenarios
Percentage decrease from 2010 offshore
Cost Reduction (%)
100
75
50
25
0
2020
2030
2040
2050
Year


Emissions Reduction Scenarios
Scenarios as overall % reduction of 201
CO2 Emissions (Mt)
2000
1500
1000
500
0
2020
2030
2040
2050
Year


Emissions Reduction Scenarios
Scenarios as overall % reduction of 201
CO2 Emissions (Mt)
2000
1500
1000
500
0
2020
2030
2040
2050
Year