Offshore Wind Results and Analysis

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06 August, 2019

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.

```
source("osw_Scripts/osw_setup.R")
source("osw_Scripts/osw_data.R")
source("osw_Scripts/osw_results.R")
```

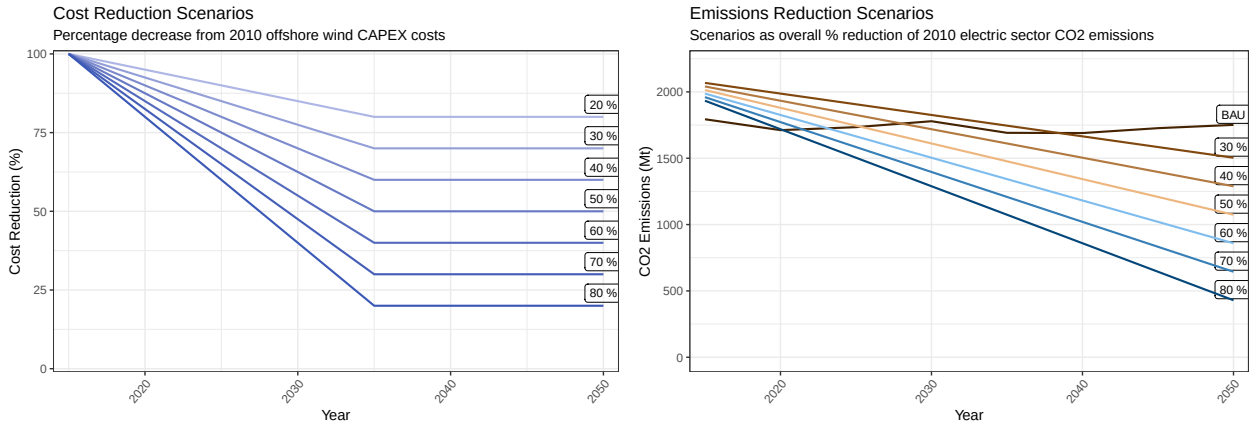
```
color <- 1
bw <- 0
gray <- 0
```

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

```
if(color > 0) cost_col
if(color > 0) emissions_col
```




```
if(bw > 0) cost_bw
if(bw > 0) emissions_bw
```

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.

```
lcoe_table
```

5 Offshore Wind

5.1 Capacity Buildout

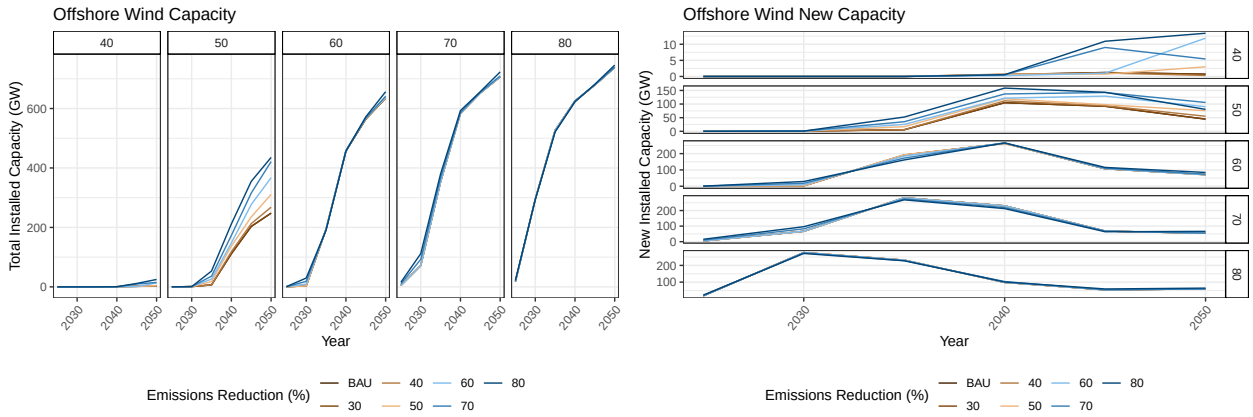
Cumulative and new addition offshore wind capacity across all nine census regions, by cost and emissions reduction scenario.

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

```
if(color > 0) cap_col_side
if(color > 0) newcap_col_top
```




```
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if(bw > 0) newcap_bw_top
```

```
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if(gray > 0) newcap_gray_top
```

5.2 Total Capacity

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

```
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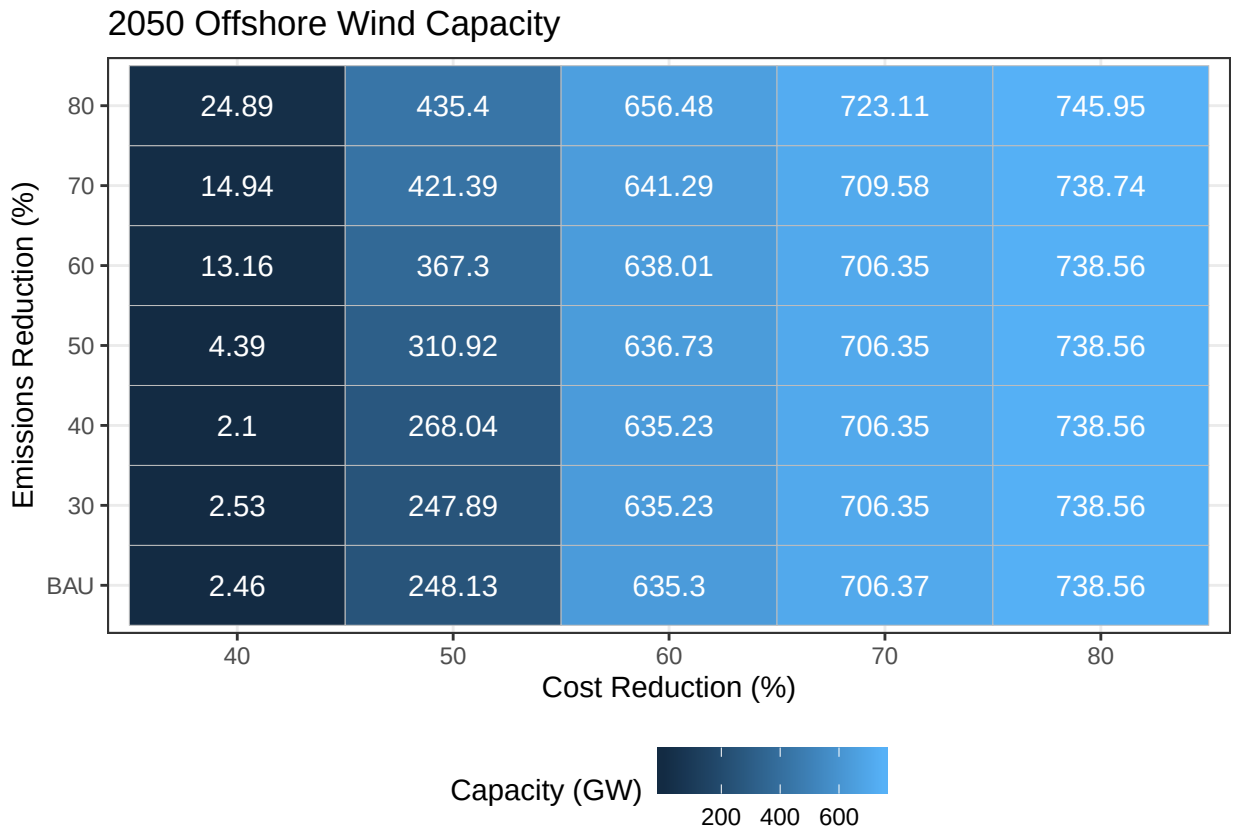


```
if(bw > 0) cap_bw_heat
```

```
cap_2050_table
```

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.

```
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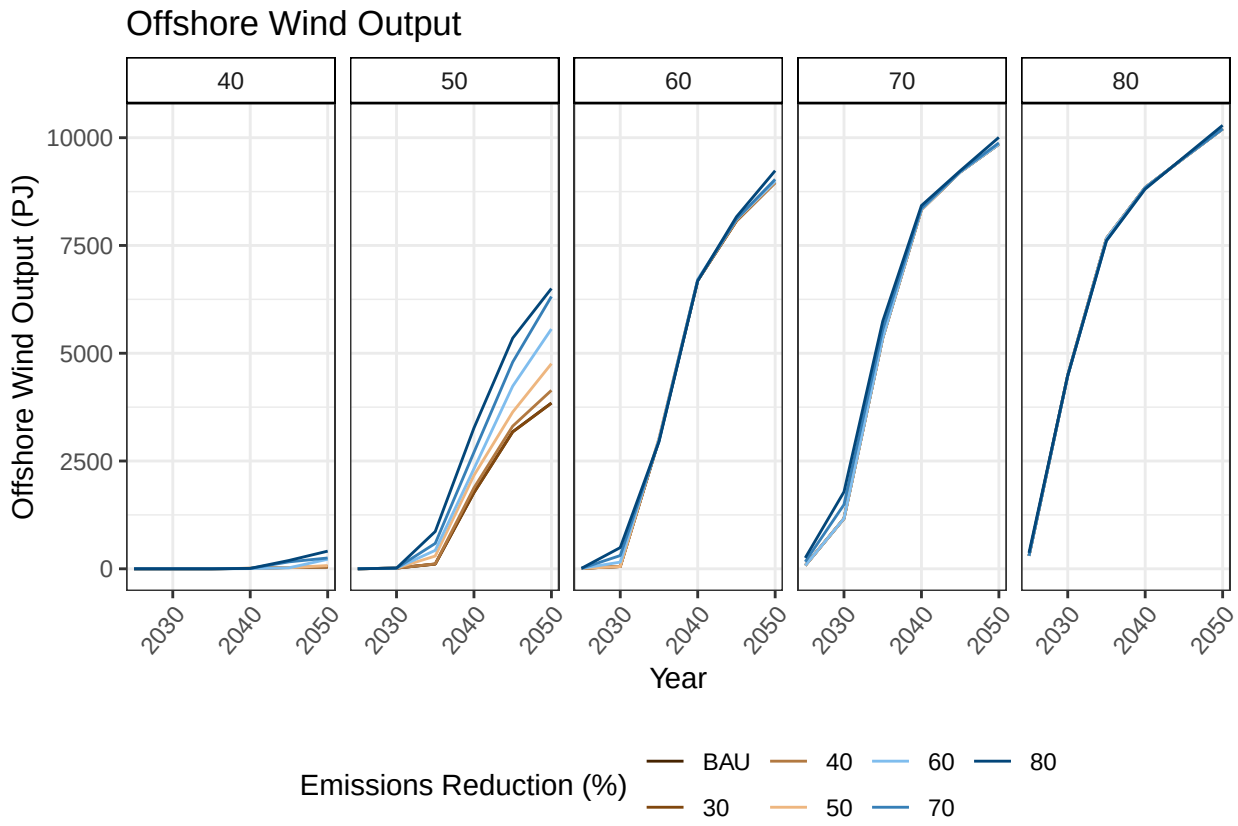


```
if(bw > 0) output_bw_side
if(gray > 0) output_gray_side
```

```
output_2050_table
```

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

5.4 Regions

Cumulative and new addition offshore wind capacity by region.

```
if(color > 0) cap_reg1_col
if(color > 0) newcap_reg1_col
if(color > 0) cap_reg2_col
if(color > 0) newcap_reg2_col
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if(color > 0) newcap_reg3_col
if(color > 0) cap_reg4_col
if(color > 0) newcap_reg4_col
if(color > 0) cap_reg5_col
if(color > 0) newcap_reg5_col
if(color > 0) cap_reg6_col
if(color > 0) newcap_reg6_col
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if(color > 0) newcap_reg7_col
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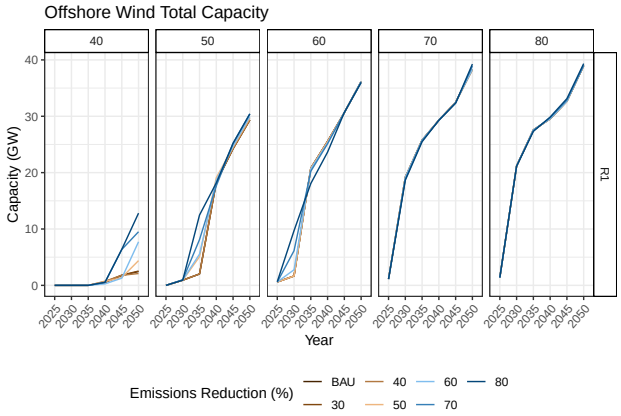
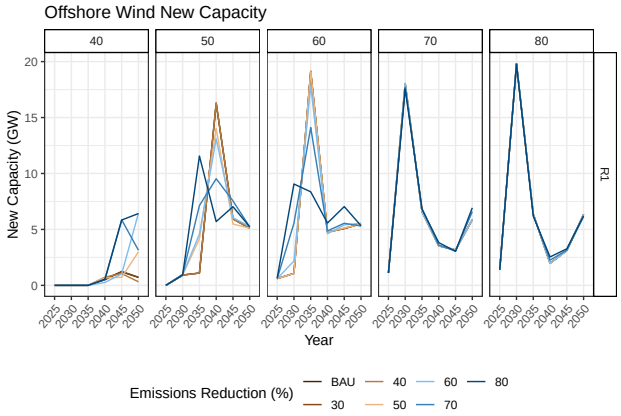
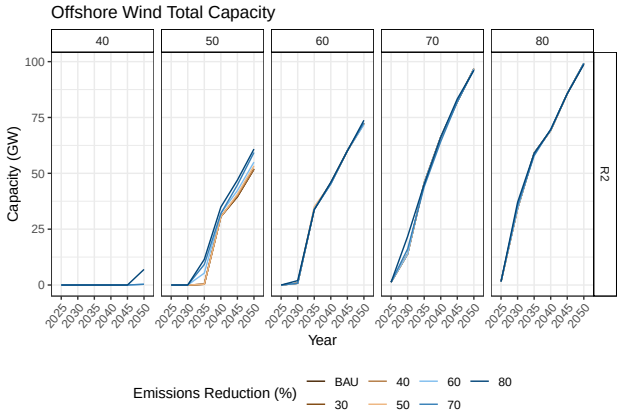
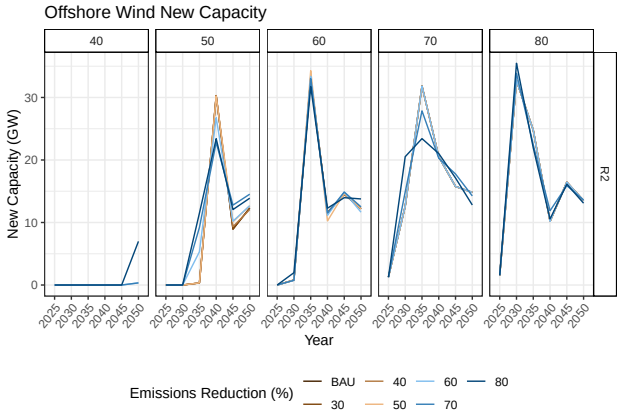
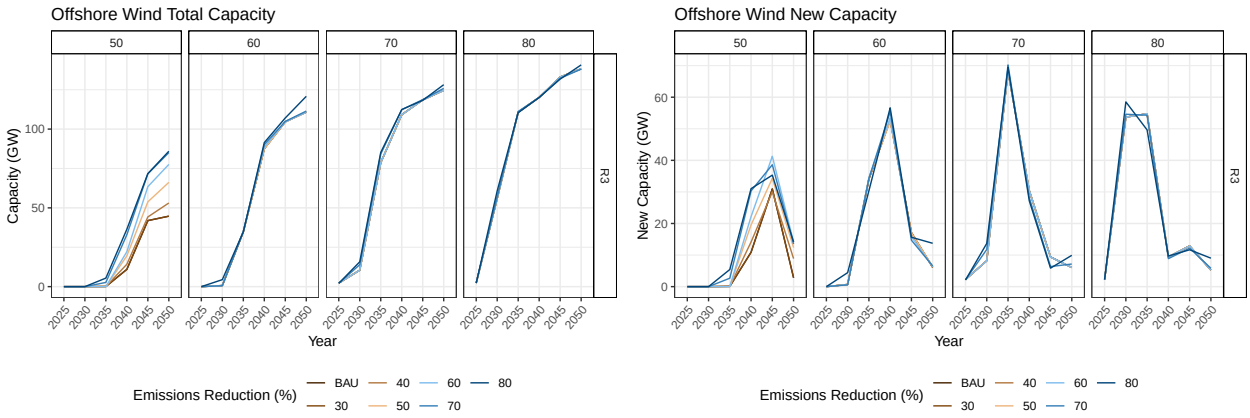


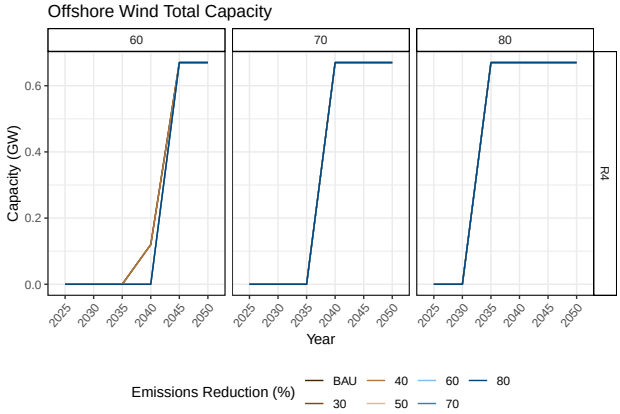







Offshore Wind Total Capacity
50
60
70
80
R3
Capacity (GW)
0
50
100
2025
2030
2035
2040
2045
2050
Year
Emissions Reduction (%)
BAU
30
40
50
60
70
80

Offshore Wind New Capacity
50
60
70
80
R3
New Capacity (GW)
0
20
40
60
2025
2030
2035
2040
2045
2050
Year
Emissions Reduction (%)
BAU
30
40
50
60
70
80


Offshore Wind Total Capacity
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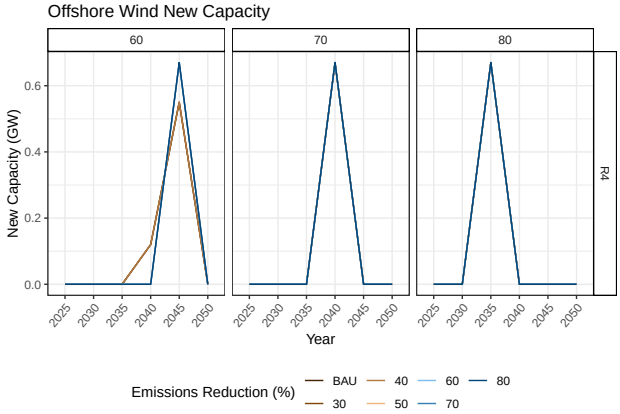
70
80
R4
Capacity (GW)
0.0
0.2
0.4
0.6
2025
2030
2035
2040
2045
2050
Year
Emissions Reduction (%)
BAU
30
40
50
60
70
80


Offshore Wind New Capacity
60
70
80
R4
New Capacity (GW)
0.0
0.2
0.4
0.6
2025
2030
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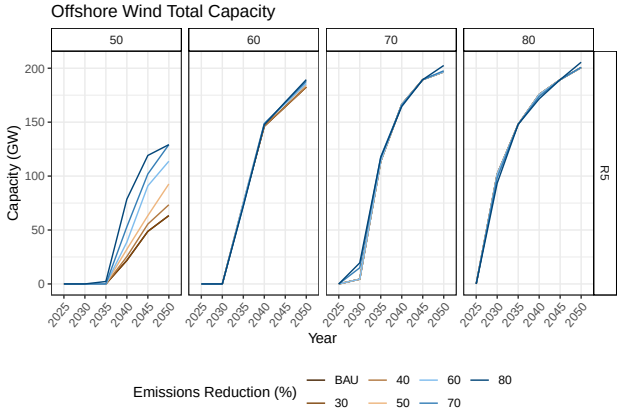
2040
2045
2050
Year
Emissions Reduction (%)
BAU
30
40
50
60
70
80


Offshore Wind Total Capacity
50
60
70
80
R5
Capacity (GW)
0
50
100
150
200
2025
2030
2035
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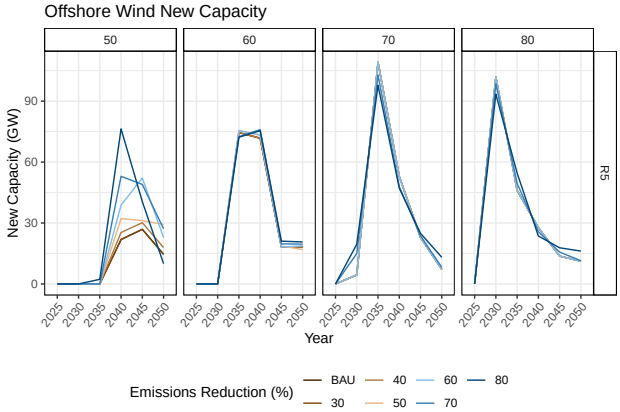
2045
2050
Year
Emissions Reduction (%)
BAU
30
40
50
60
70
80


Offshore Wind New Capacity
50
60
70
80
R5
New Capacity (GW)
0
30
60
90
2025
2030
2035
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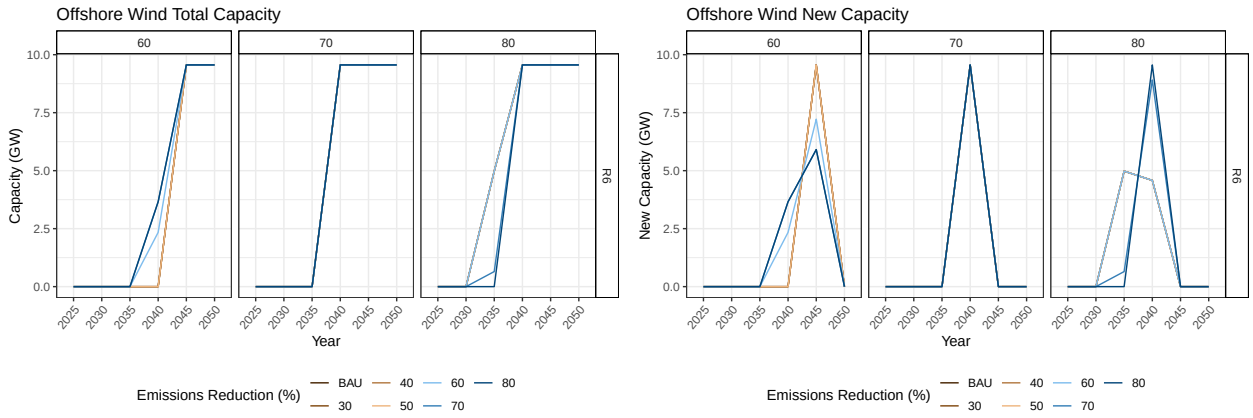
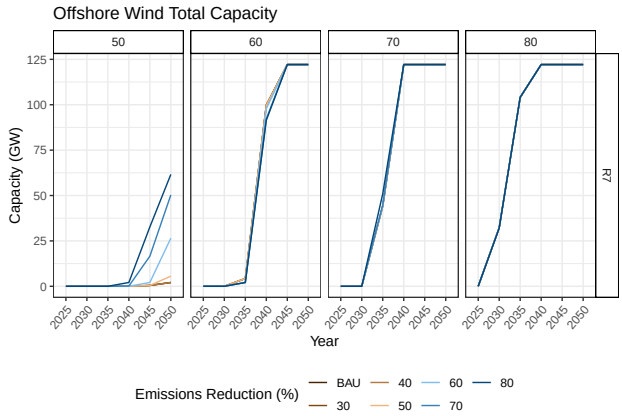
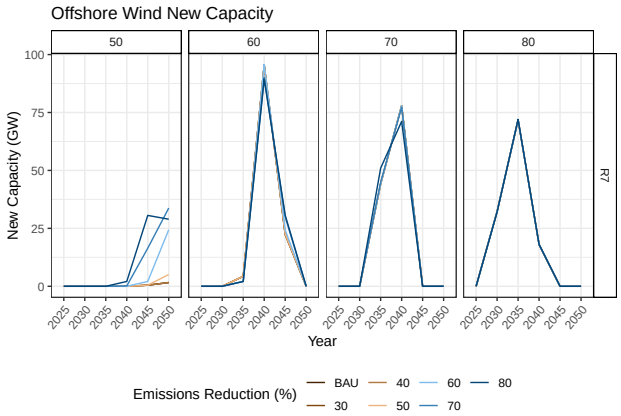
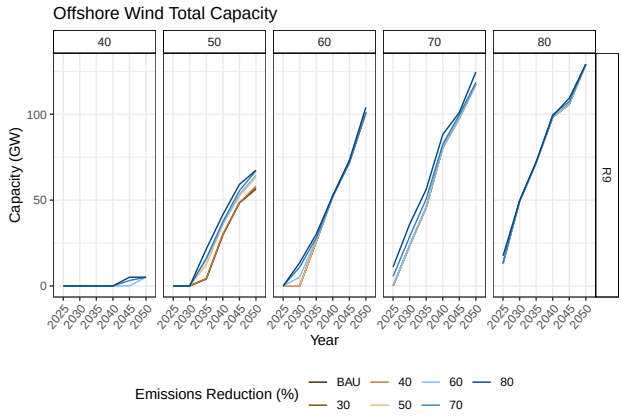
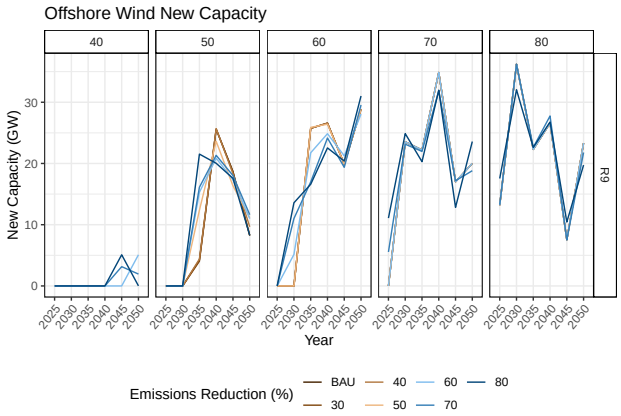
2045
2050
Year
Emissions Reduction (%)
BAU
30
40
50
60
70
80









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if(color > 0) newcap_reg4_col
if(color > 0) cap_reg5_col
if(color > 0) newcap_reg5_col
if(color > 0) cap_reg6_col
if(color > 0) newcap_reg6_col
```

```
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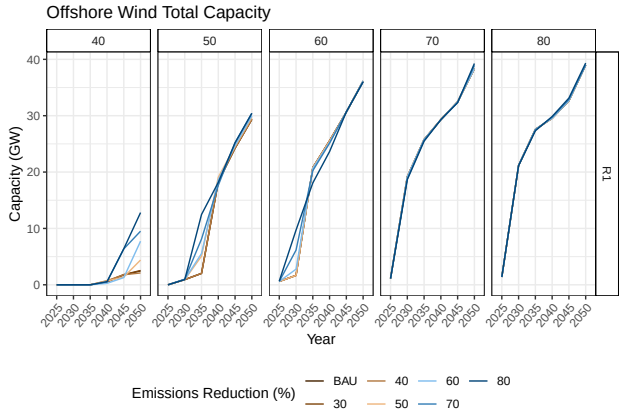

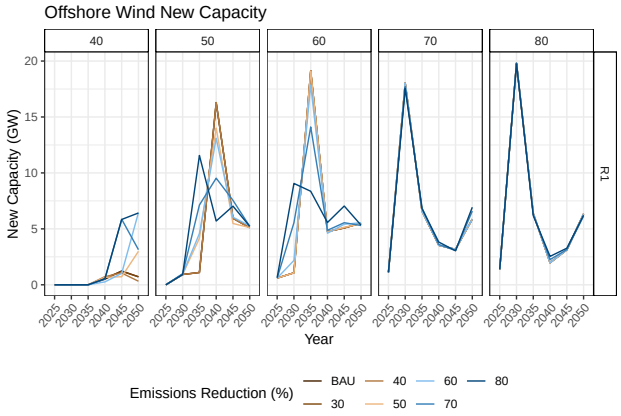

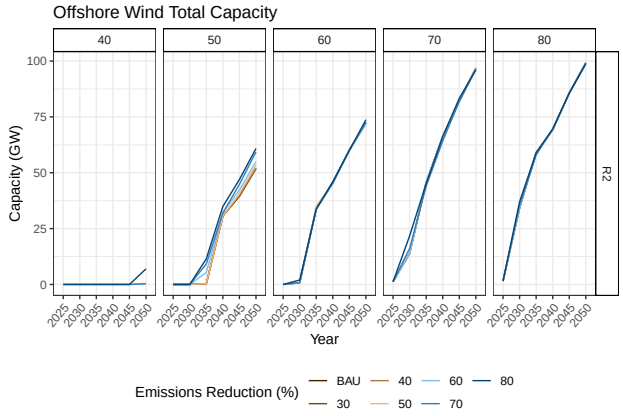

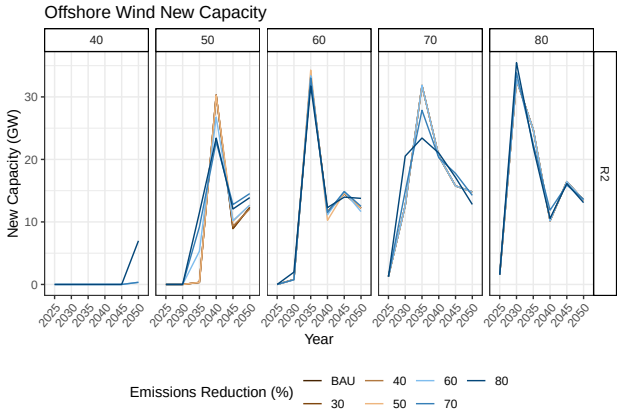

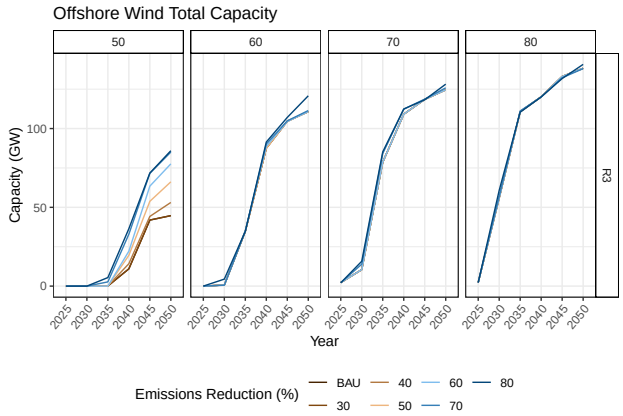

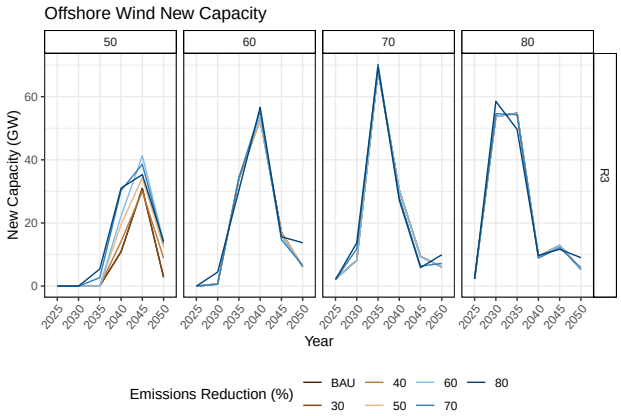

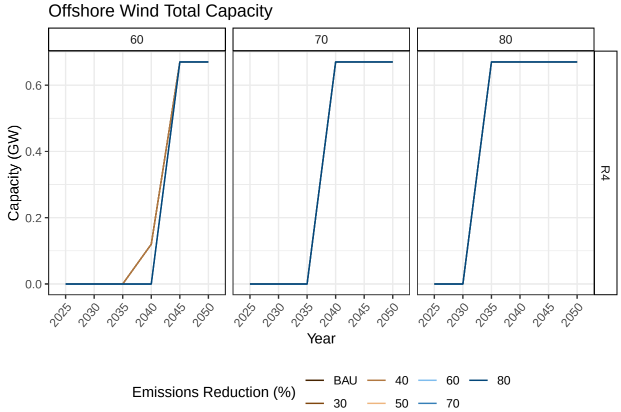
Offshore Wind Total Capacity
60
70
80
R4
Capacity (GW)
0.0
0.2
0.4
0.6
2025
2030
2035
2040
2045
2050
Year
Emissions Reduction (%)
BAU
30
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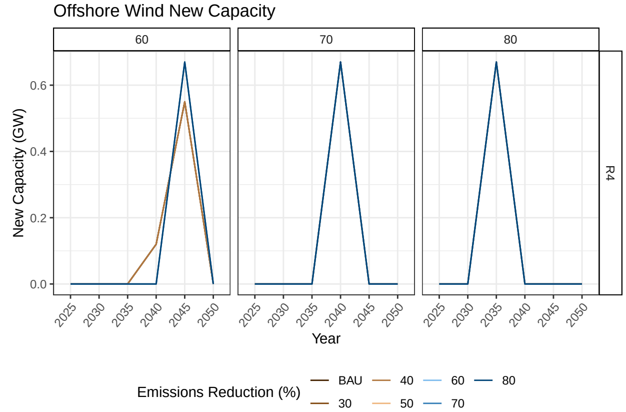
50
60
70
80


Offshore Wind New Capacity
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R4
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0.6
2025
2030
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Emissions Reduction (%)
BAU
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40
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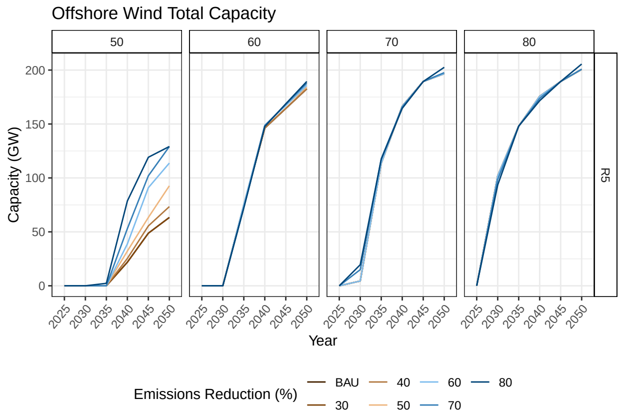
80


Offshore Wind Total Capacity
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60
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R5
Capacity (GW)
0
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100
150
200
2025
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Year
Emissions Reduction (%)
BAU
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60
70
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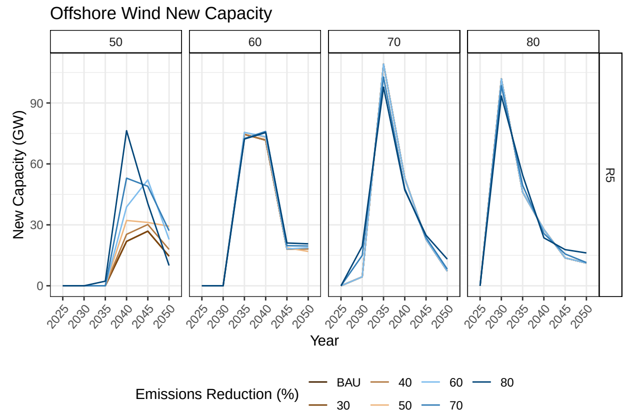
Offshore Wind New Capacity
50
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R5
New Capacity (GW)
0
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60
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2050
Year
Emissions Reduction (%)
BAU
30
40
50
60
70
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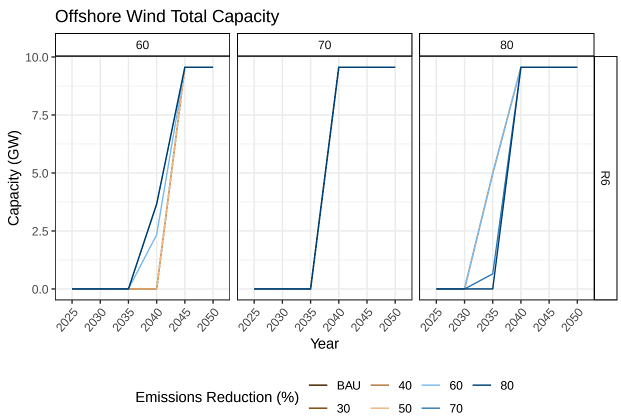
Offshore Wind Total Capacity
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80
R6
Capacity (GW)
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2.5
5.0
7.5
10.0
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Year
Emissions Reduction (%)
BAU
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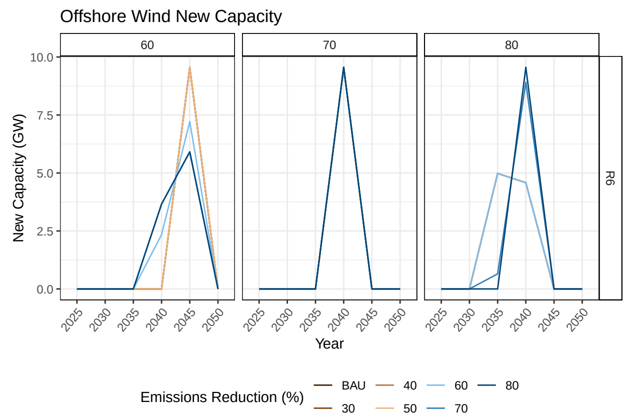
Offshore Wind New Capacity
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70
80
R6
New Capacity (GW)
0.0
2.5
5.0
7.5
10.0
2025
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2040
2045
2050
Year
Emissions Reduction (%)
BAU
30
40
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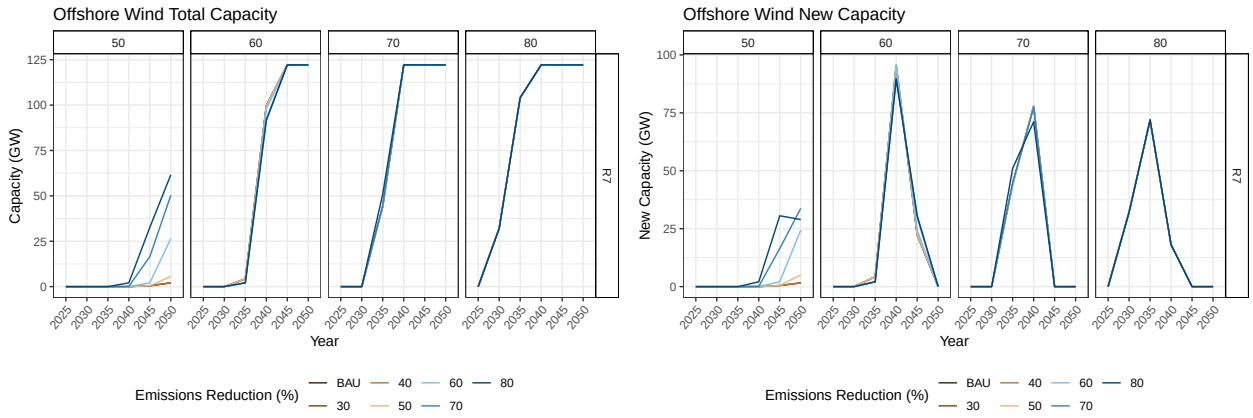

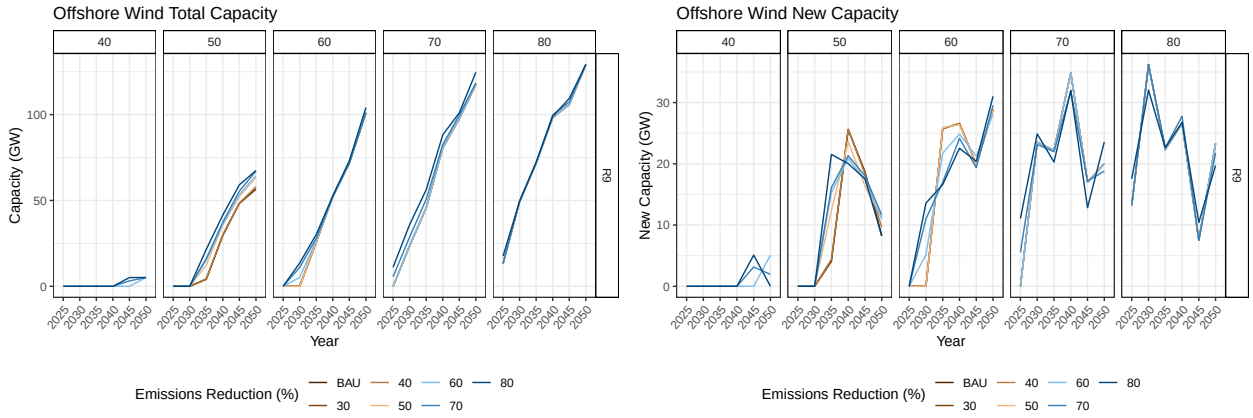

Cumulative and new addition offshore wind capacity by region, emissions reduction, and cost reduction.

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if(color > 0) newcap_allreg_col_free
```
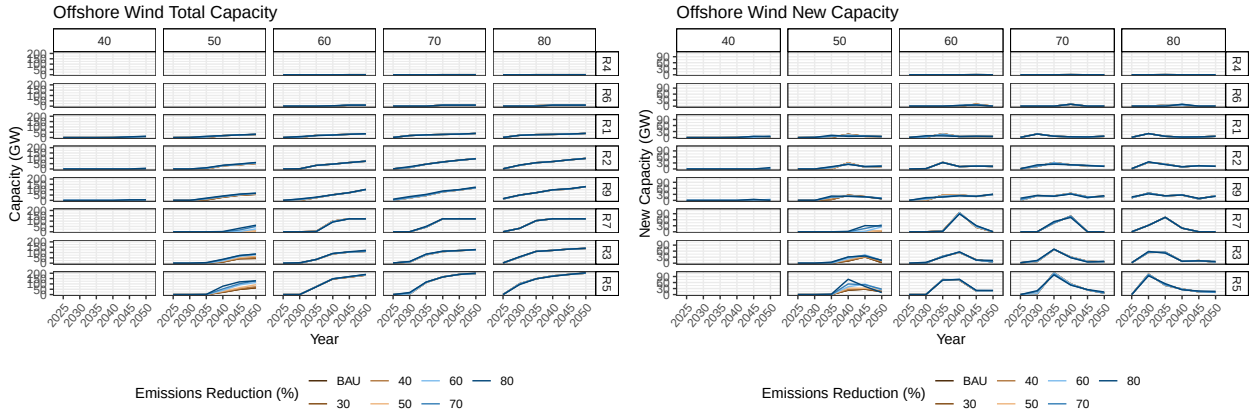
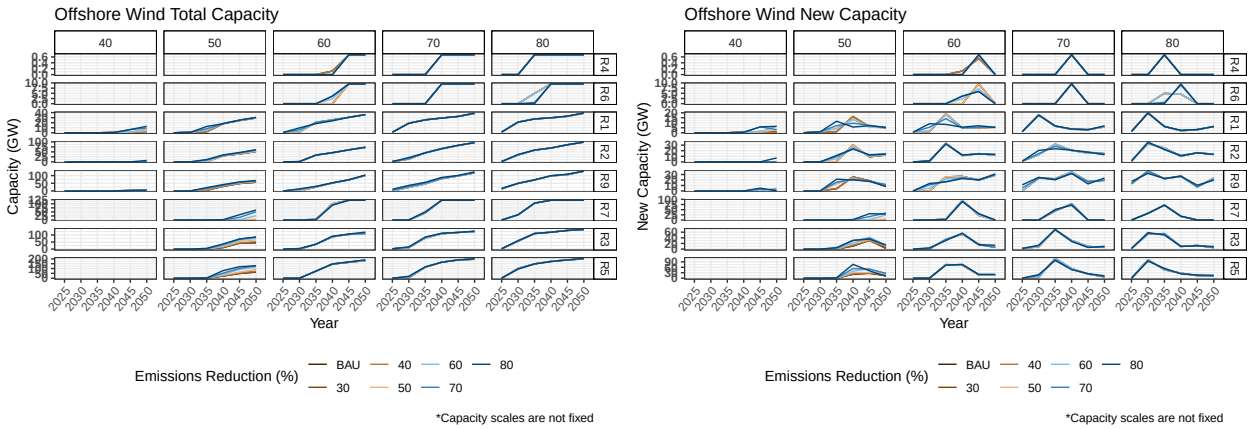






```
cap_region_table
```

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

```
output_region_table
```

Table 5: Average Electricity Output (PJ)

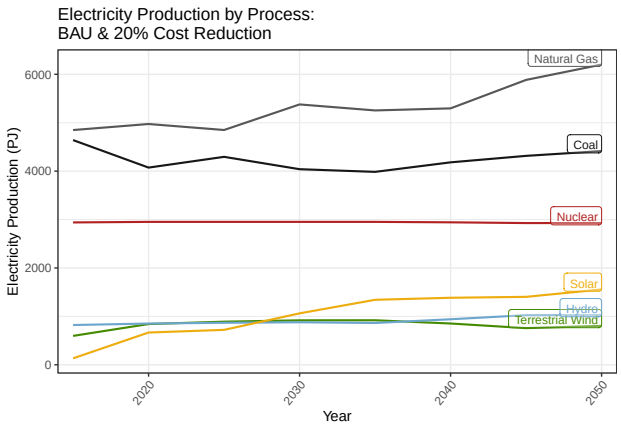
Region	2050 Total
R4	5.85375
R6	68.65600
R1	96.99500
R2	224.66953
R9	284.79601
R3	326.76062
R7	485.47903
R5	526.62200

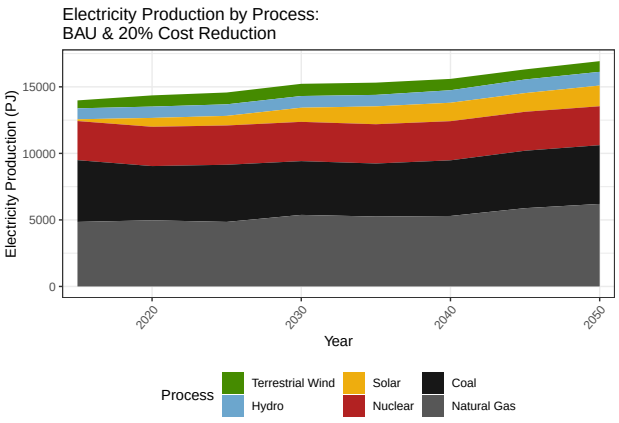
6 Grid Mix

6.1 Baseline Production

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

```
if(color > 0) baseprod_line_col
if(color > 0) baseprod_fill_col
```



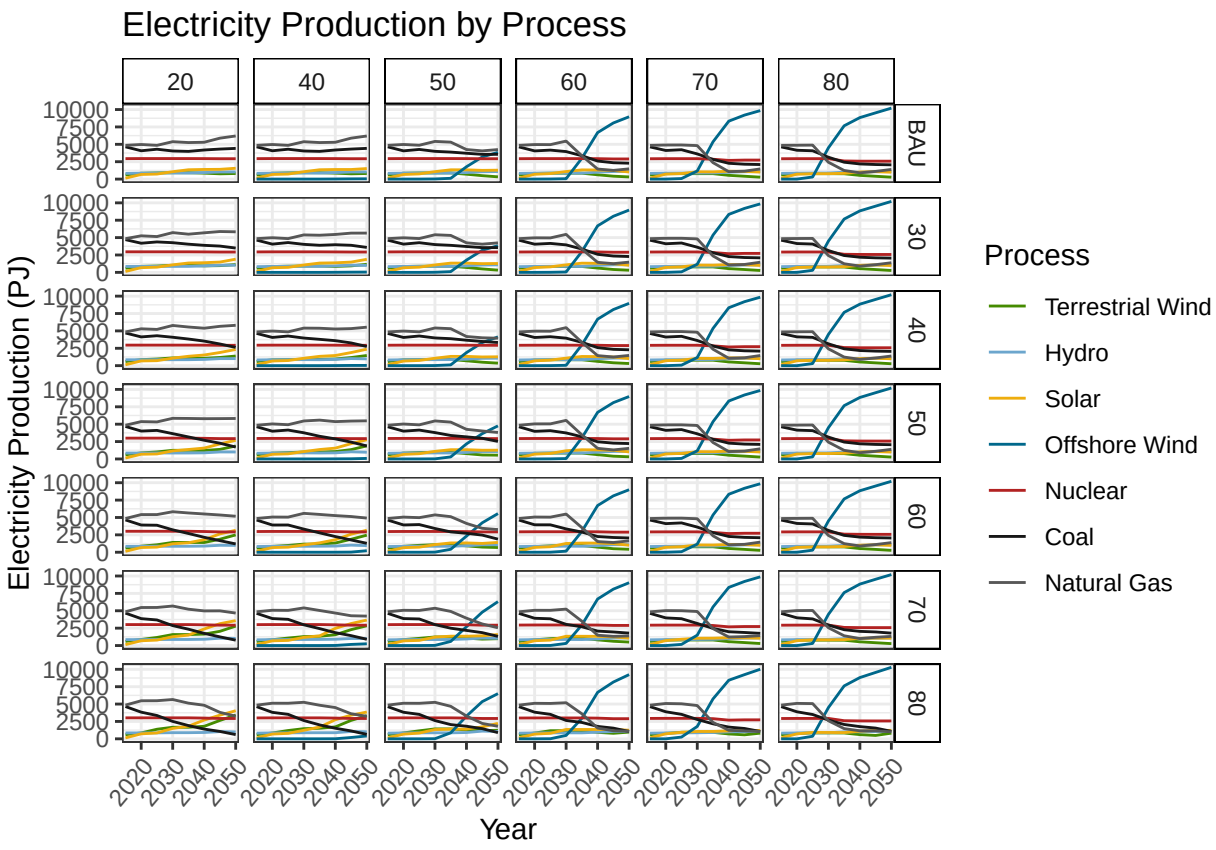



```
if(bw > 0) baseprod_line_bw
if(bw > 0) baseprod_fill_bw
```

6.2 All Scenarios

Complete Set

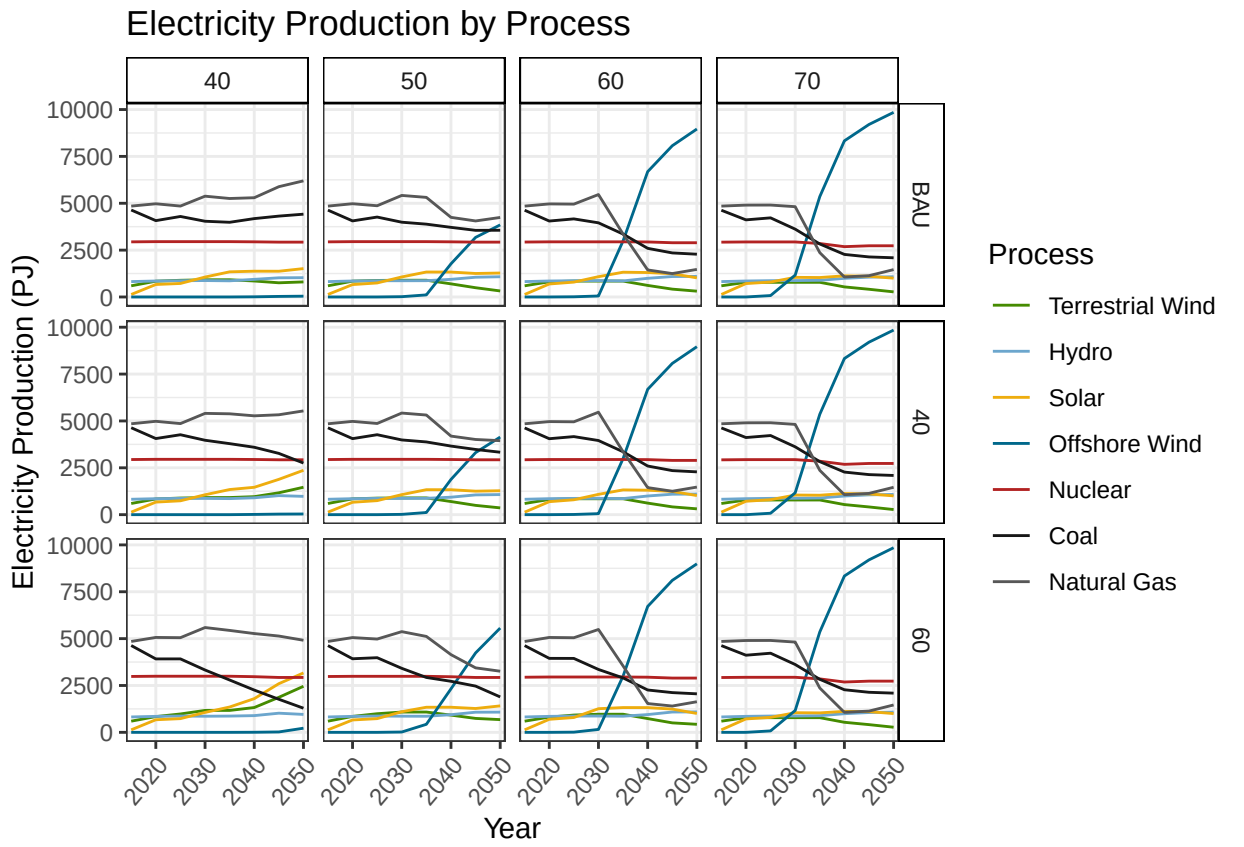
```
if(color > 0) gridmix_all_col
```




```
if(bw > 0) gridmix_all_bw
```

Parsed Set

```
if(color > 0) gridmix_col
```

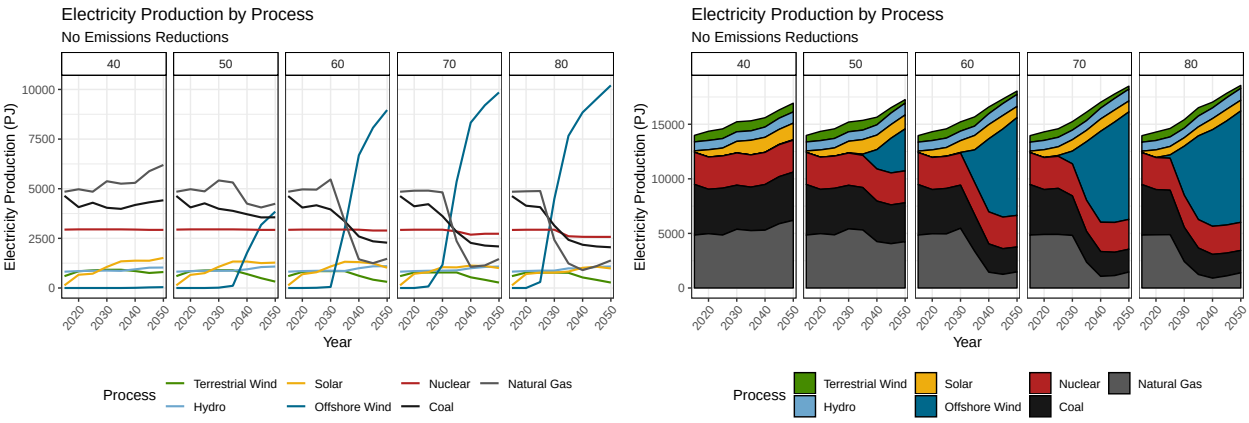



```
if(bw > 0) gridmix_bw
```

6.3 Emissions Cap

BAU emissions

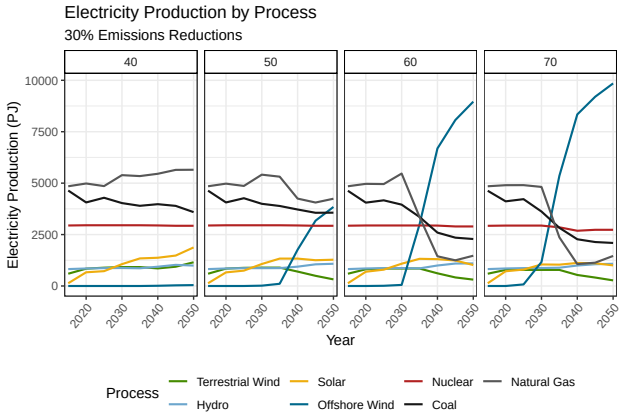
```
if(color > 0) bau_facetcost_line_col
if(color > 0) bau_facetcost_fill_col
```

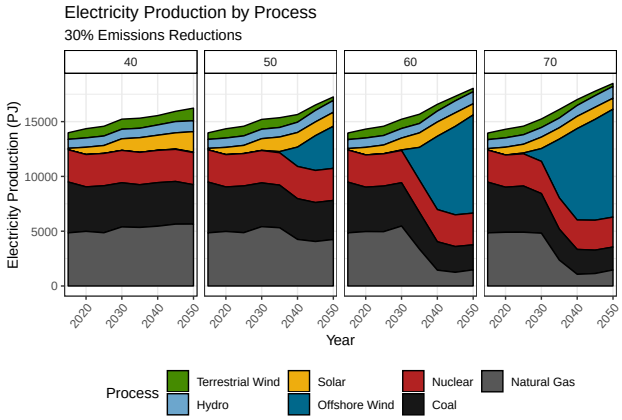


```
if(bw > 0) bau_facetcost_line_bw
if(bw > 0) bau_facetcost_fill_bw
```

30% emissions reduction

```
if(color > 0) em30_facetcost_line_col
if(color > 0) em30_facetcost_fill_col
```

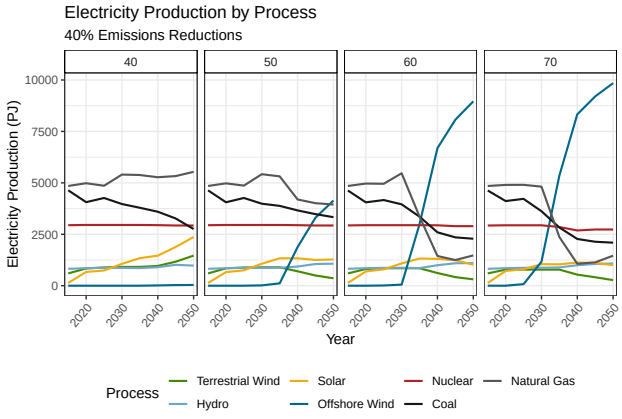


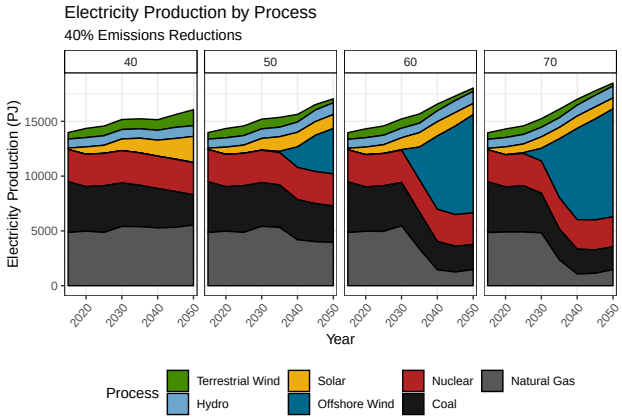



```
if(bw > 0) em30_facetcost_line_bw
if(bw > 0) em30_facetcost_fill_bw
```

40% emissions reduction

```
if(color > 0) em40_facetcost_line_col
if(color > 0) em40_facetcost_fill_col
```

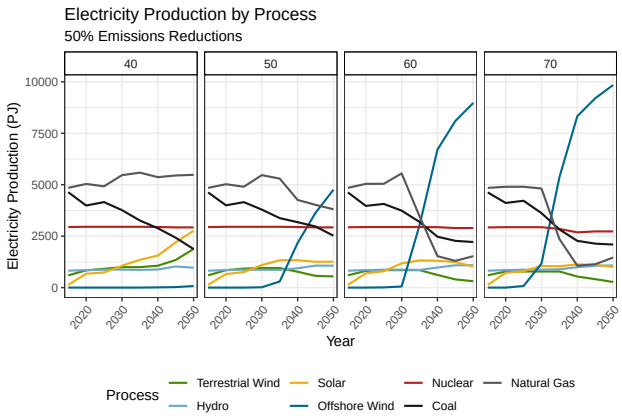


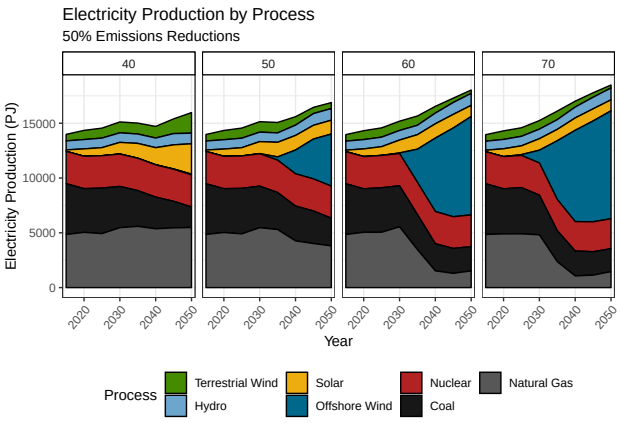



```
if(bw > 0) em40_facetcost_line_bw
if(bw > 0) em40_facetcost_fill_bw
```

50% emissions reduction

```
if(color > 0) em50_facetcost_line_col
if(color > 0) em50_facetcost_fill_col
```

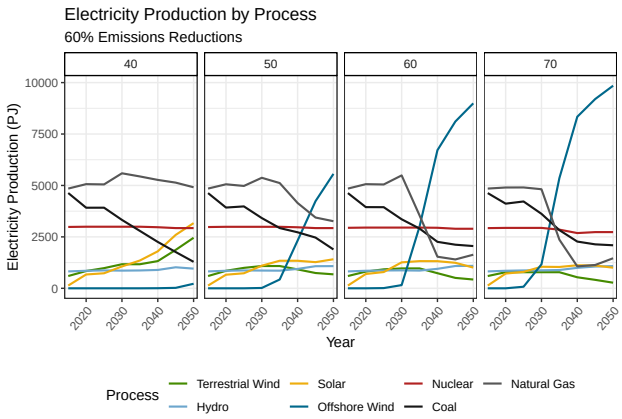


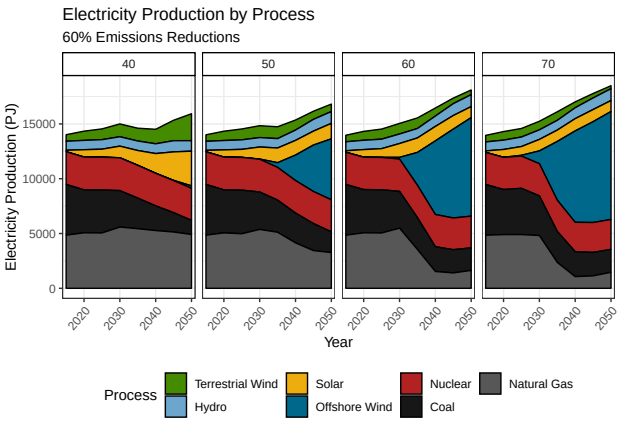



```
if(bw > 0) em50_facetcost_line_bw
if(bw > 0) em50_facetcost_fill_bw
```

60% emissions reduction

```
if(color > 0) em60_facetcost_line_col
if(color > 0) em60_facetcost_fill_col
```

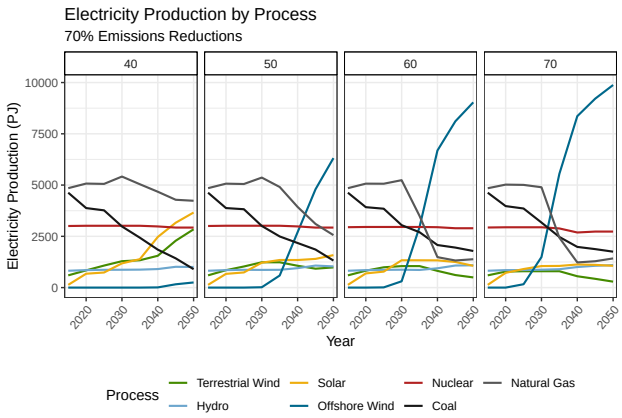


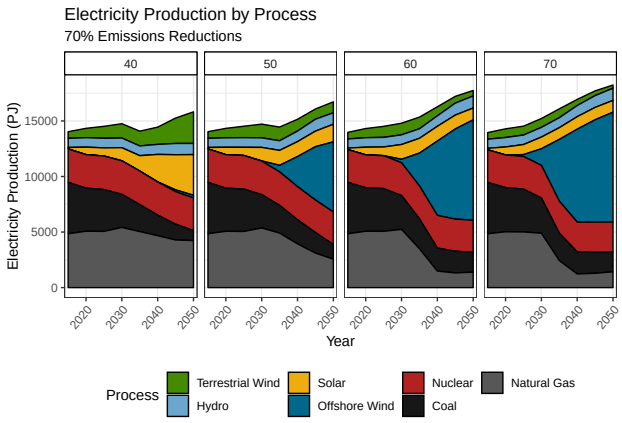



```
if(bw > 0) em60_facetcost_line_bw
if(bw > 0) em60_facetcost_fill_bw
```

70% emissions reduction

```
if(color > 0) em70_facetcost_line_col
if(color > 0) em70_facetcost_fill_col
```

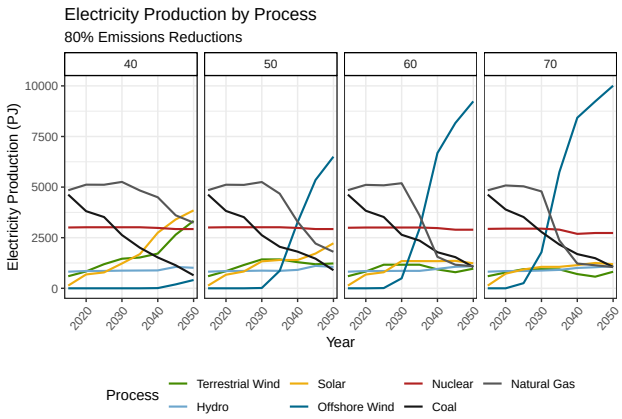


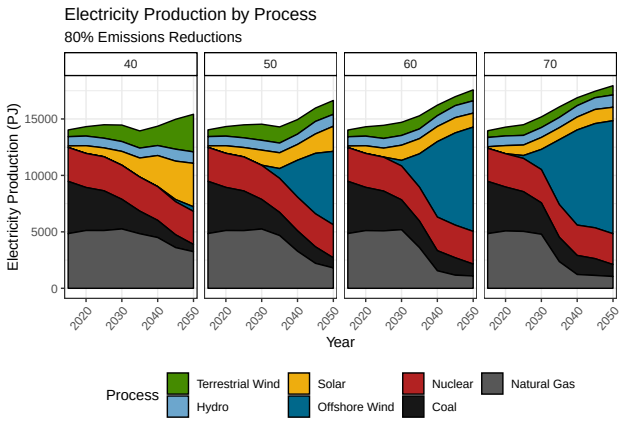



```
if(bw > 0) em70_facetcost_line_bw
if(bw > 0) em70_facetcost_fill_bw
```

80% emissions reduction

```
if(color > 0) em80_facetcost_line_col
if(color > 0) em80_facetcost_fill_col
```



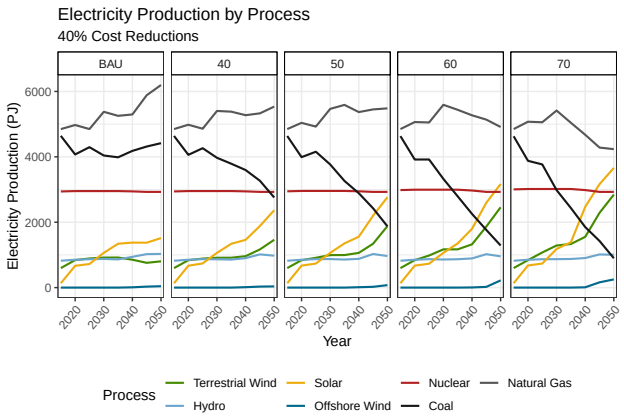


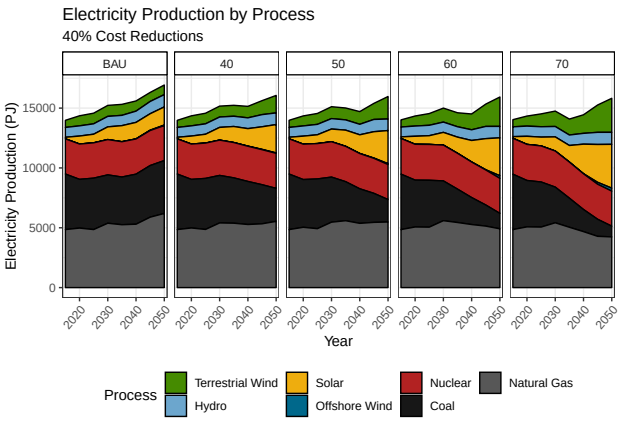

```
if(bw > 0) em80_facetcost_line_bw
if(bw > 0) em80_facetcost_fill_bw
```

6.4 Cost Reductions

40% cost reduction

```
if(color > 0) cost40_facetcost_line_col
if(color > 0) cost40_facetcost_fill_col
```

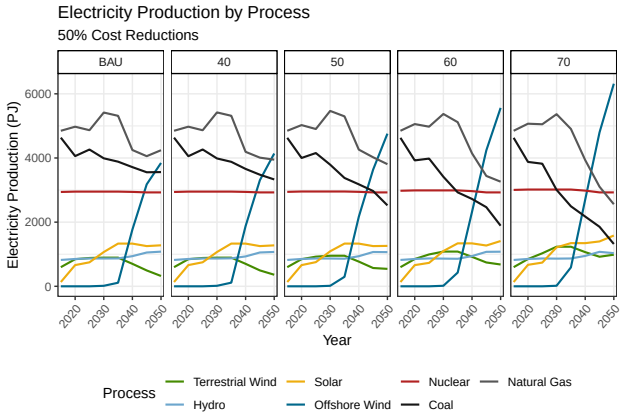


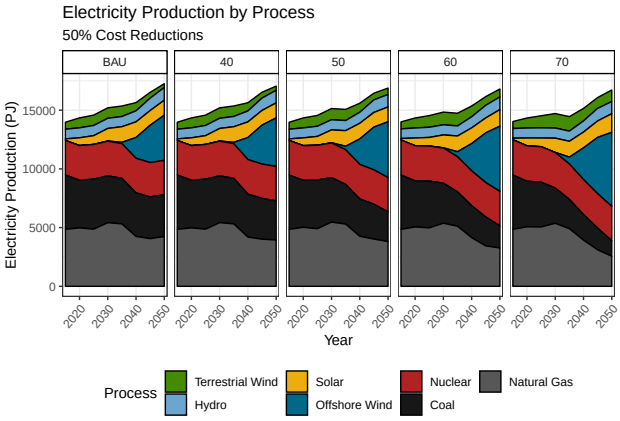



```
if(bw > 0) cost40_facetcost_line_bw
if(bw > 0) cost40_facetcost_fill_bw
```

50% cost reduction

```
if(color > 0) cost50_facetcost_line_col
if(color > 0) cost50_facetcost_fill_col
```

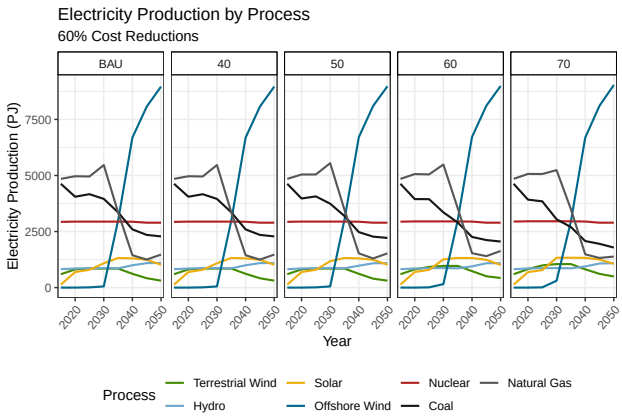


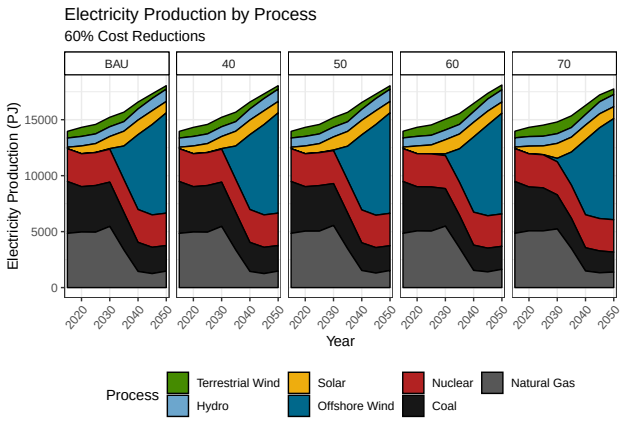



```
if(bw > 0) cost50_facetcost_line_bw
if(bw > 0) cost50_facetcost_fill_bw
```

60% cost reduction

```
if(color > 0) cost60_facetcost_line_col
if(color > 0) cost60_facetcost_fill_col
```

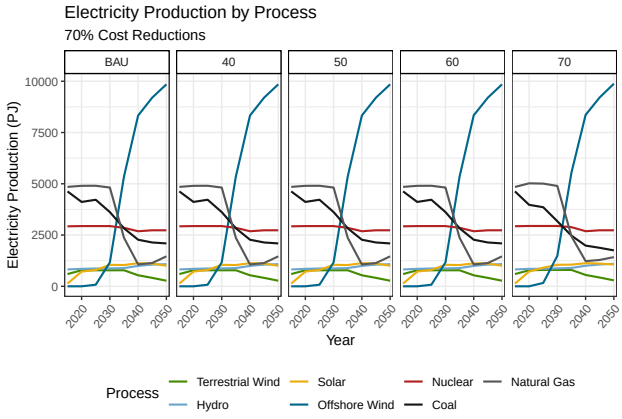


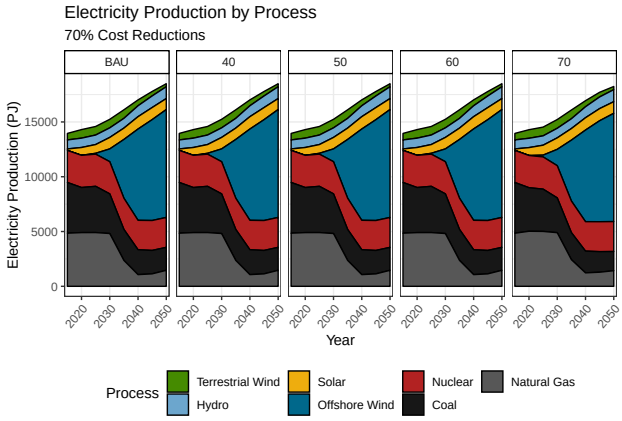



```
if(bw > 0) cost60_facetcost_line_bw
if(bw > 0) cost60_facetcost_fill_bw
```

70% cost reduction

```
if(color > 0) cost70_facetcost_line_col
if(color > 0) cost70_facetcost_fill_col
```

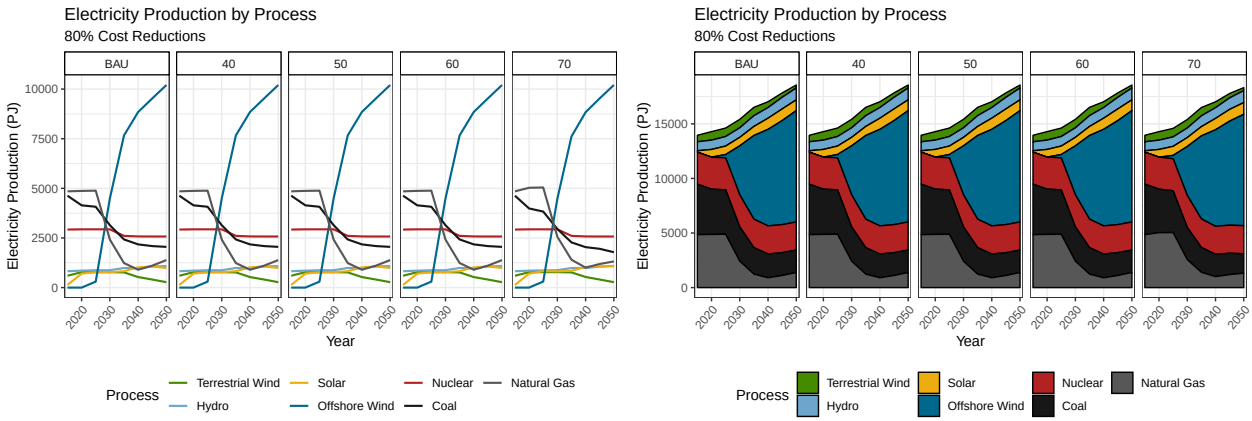





```
if(bw > 0) cost70_facetcost_line_bw
if(bw > 0) cost70_facetcost_fill_bw
```

80% cost reduction

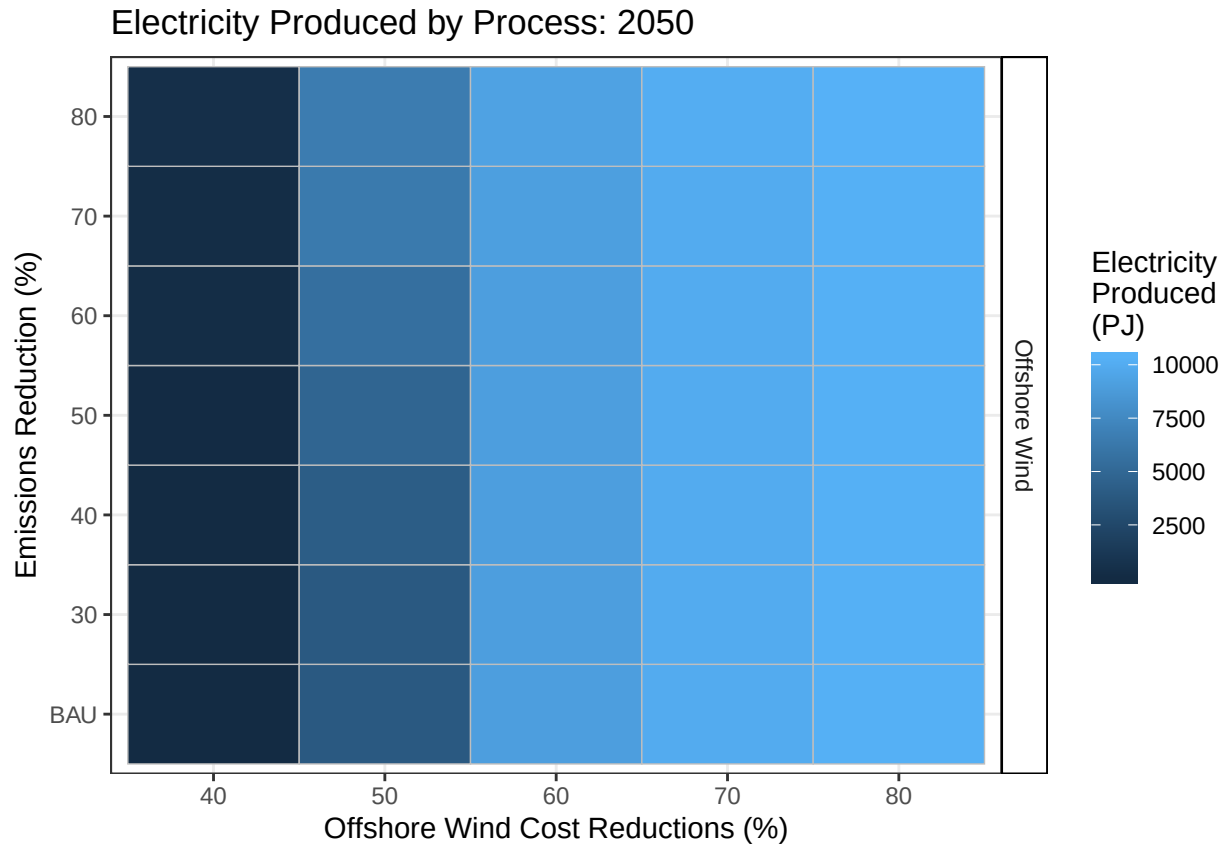
```
if(color > 0) cost80_facetcost_line_col
if(color > 0) cost80_facetcost_fill_col
```



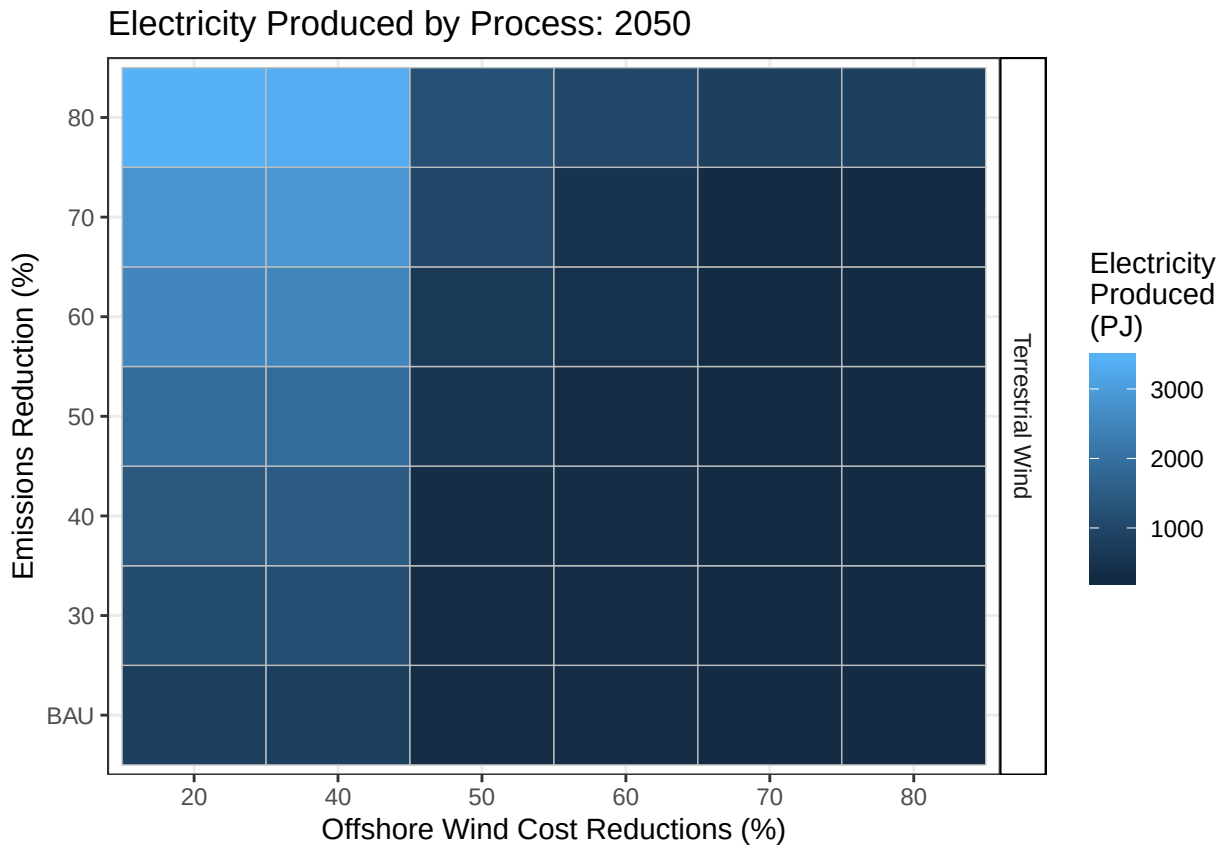

```
if(bw > 0) cost80_facetcost_line_bw
if(bw > 0) cost80_facetcost_fill_bw
```

6.5 Heatmaps

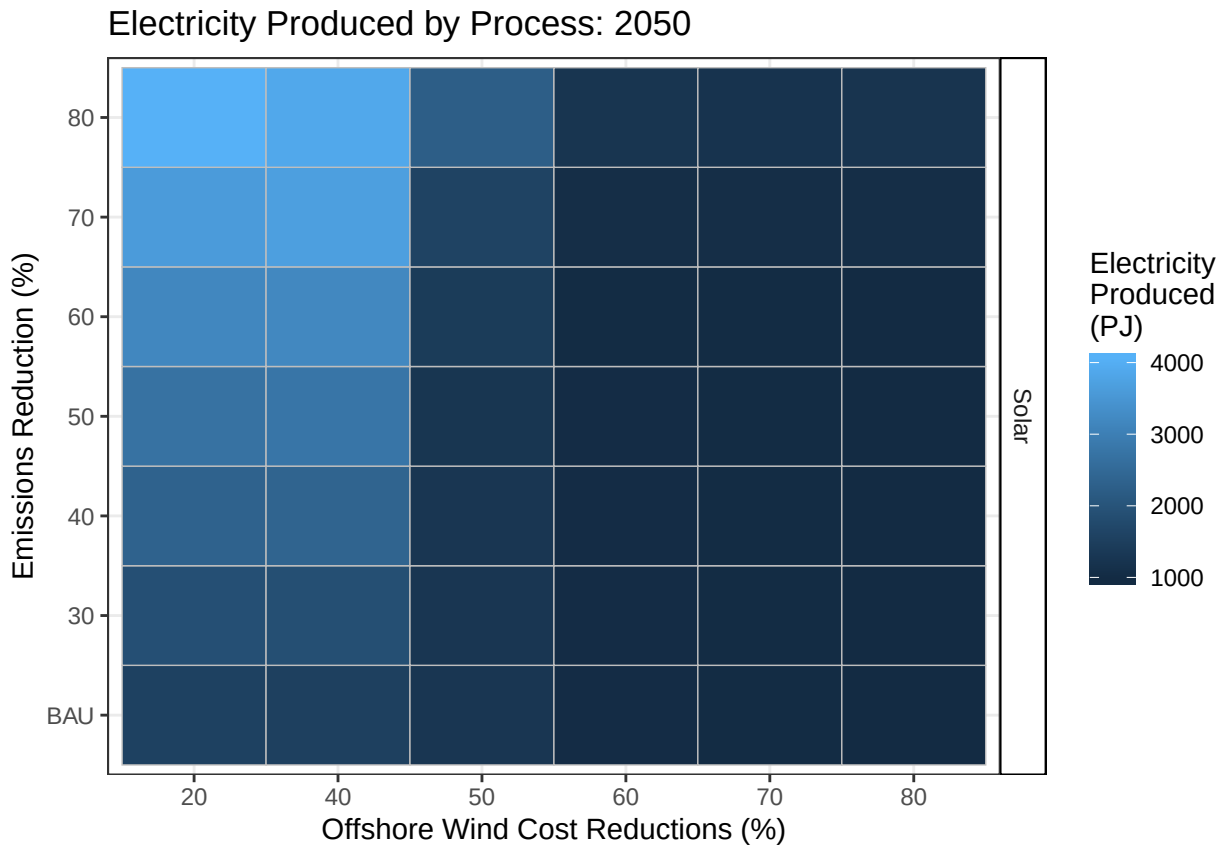
```
if(color > 0) osw_grid_heatmap
```



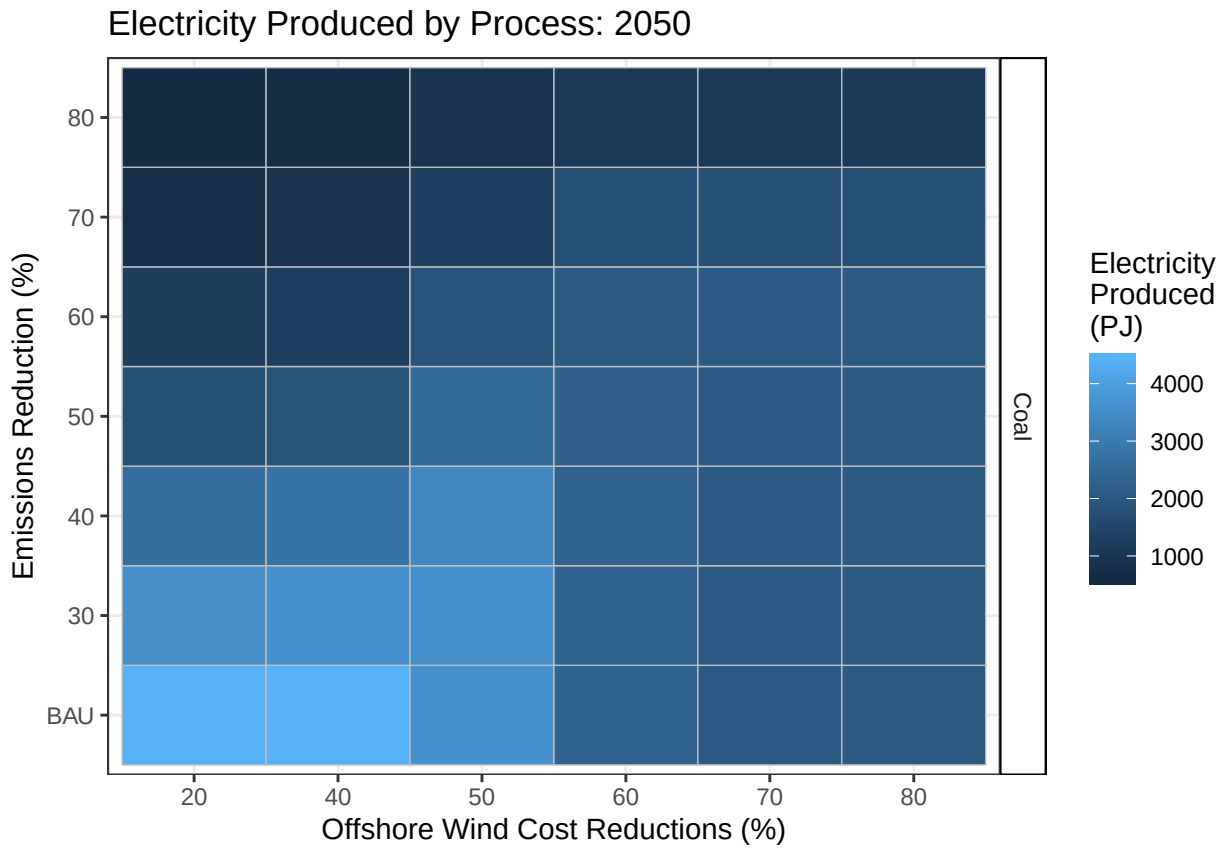

```
if(color > 0) wnd_grid_heatmap
```



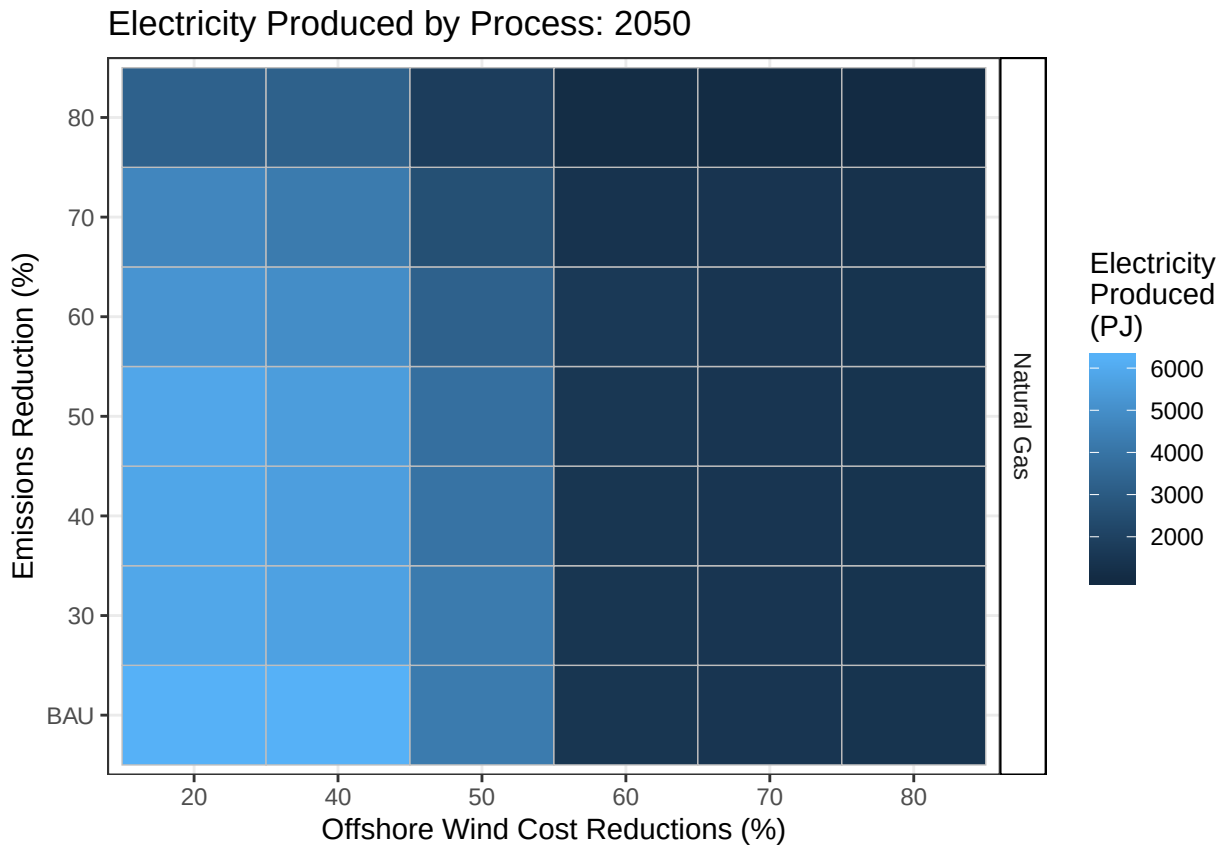

```
if(color > 0) sol_grid_heatmap
```



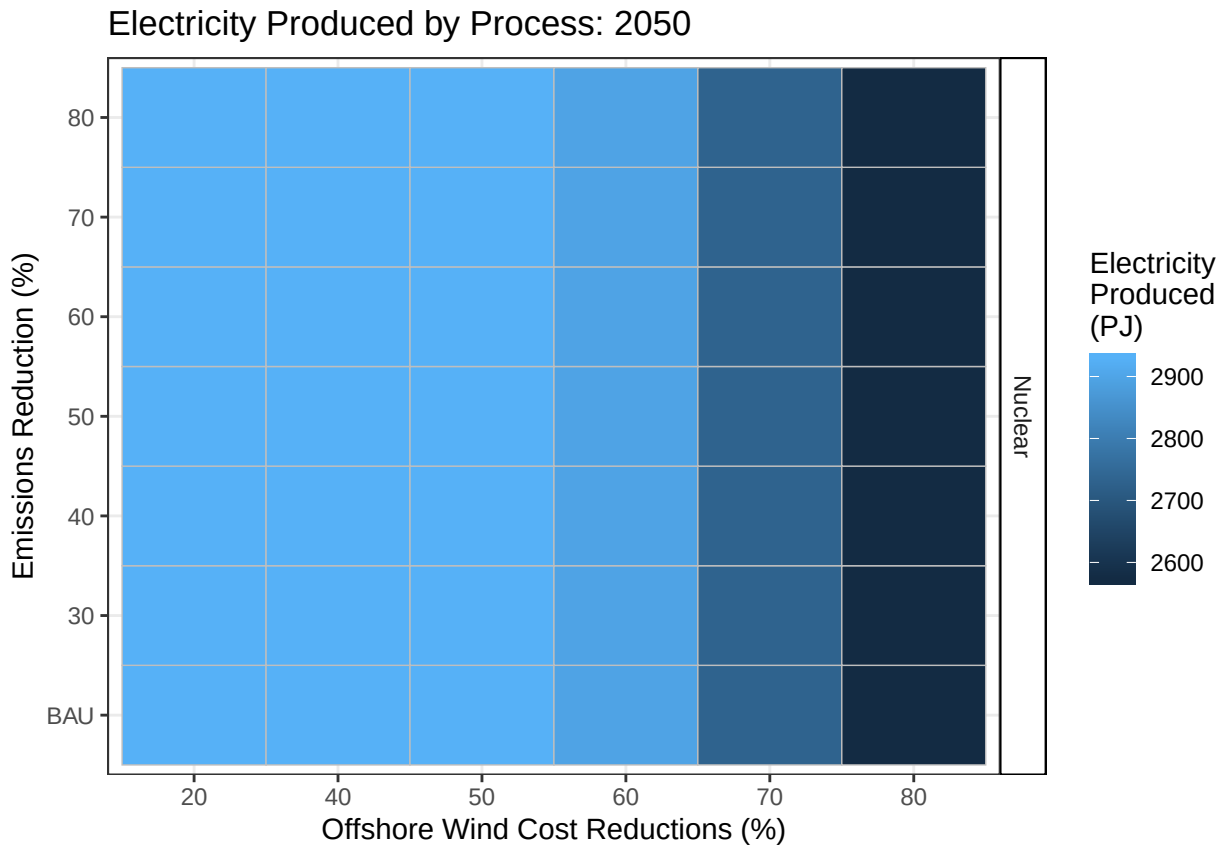

```
if(color > 0) coal_grid_heatmap
```



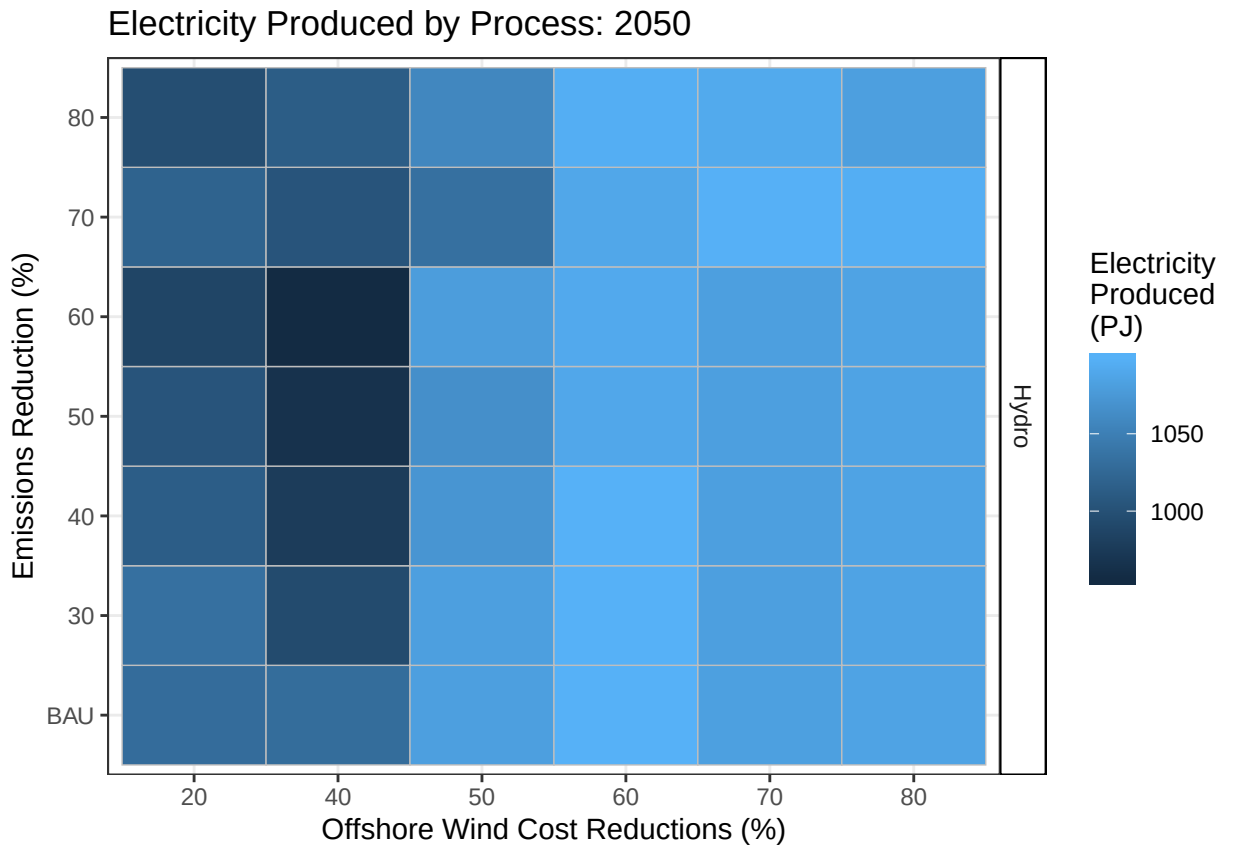

```
if(color > 0) nga_grid_heatmap
```




```
if(color > 0) nuk_grid_heatmap
```



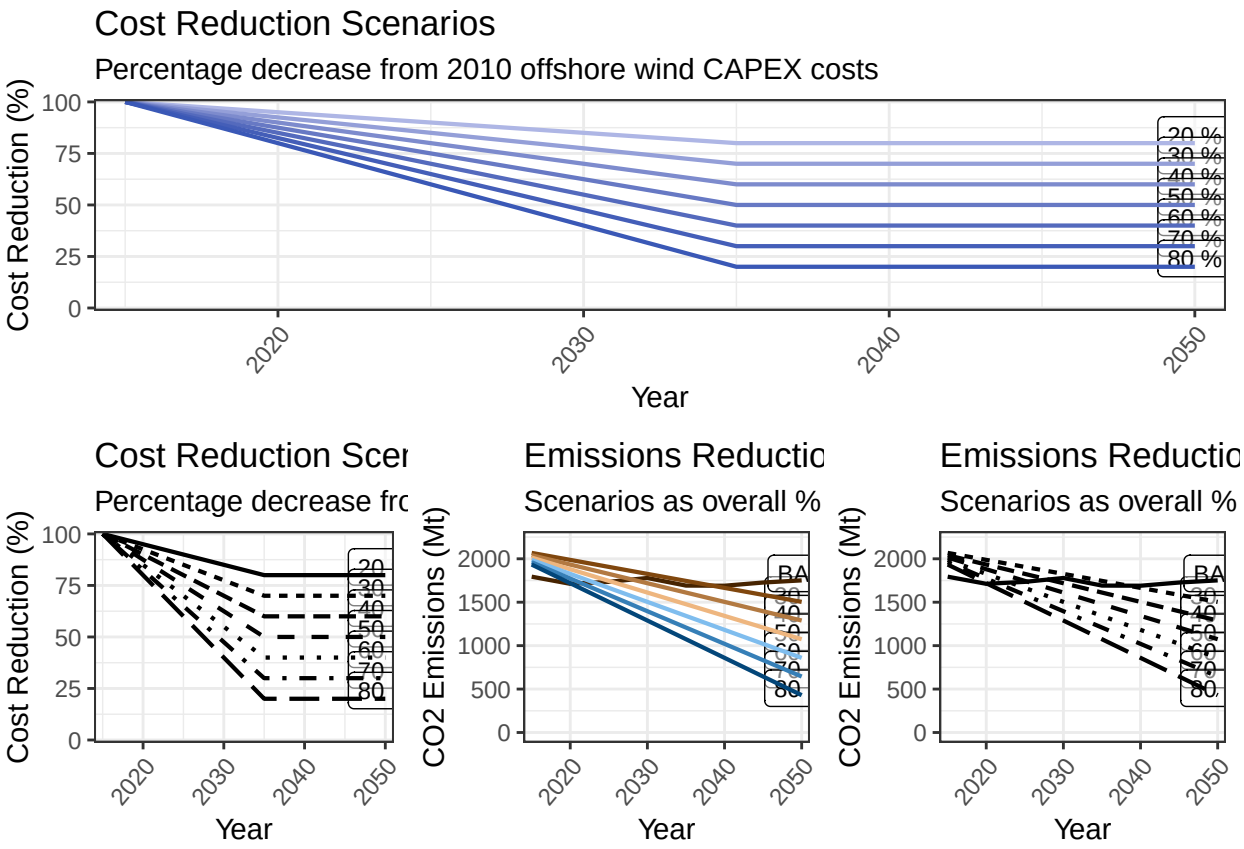

```
if(color > 0) hyd_grid_heatmap
```



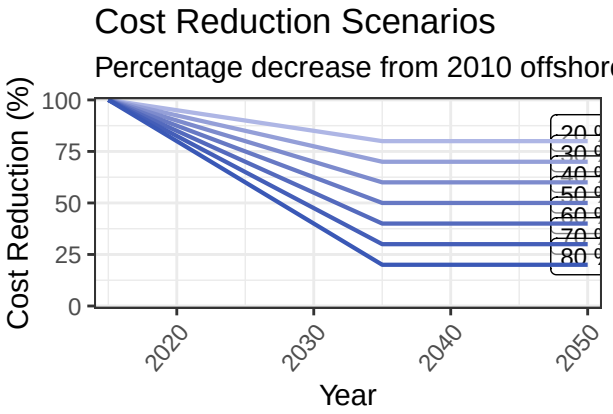

```
if(bw > 0) osw_grid_heatmap_bw
if(bw > 0) wnd_grid_heatmap_bw
if(bw > 0) sol_grid_heatmap_bw
if(bw > 0) coal_grid_heatmap_bw
if(bw > 0) nga_grid_heatmap_bw
if(bw > 0) nuk_grid_heatmap_bw
if(bw > 0) hyd_grid_heatmap_bw
```

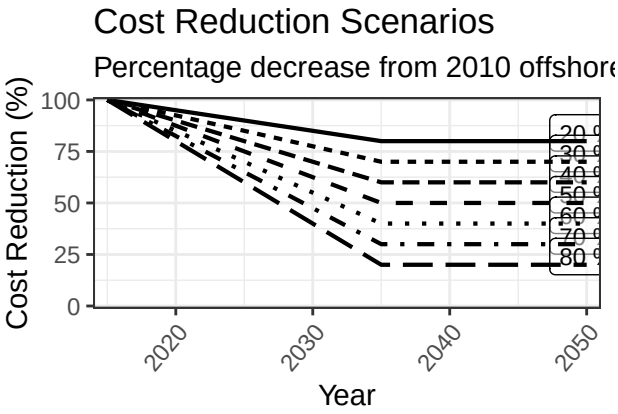
6.6 TEST

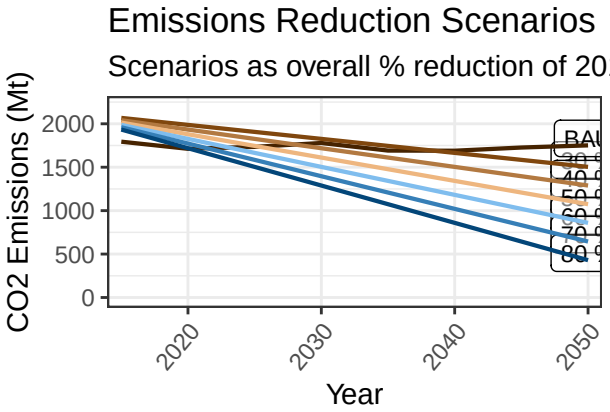
```
grid.arrange(cost_col, cost_bw, emissions_col, emissions_bw, layout_matrix = rbind(c(1,1,1),c(2,3,4)))
```

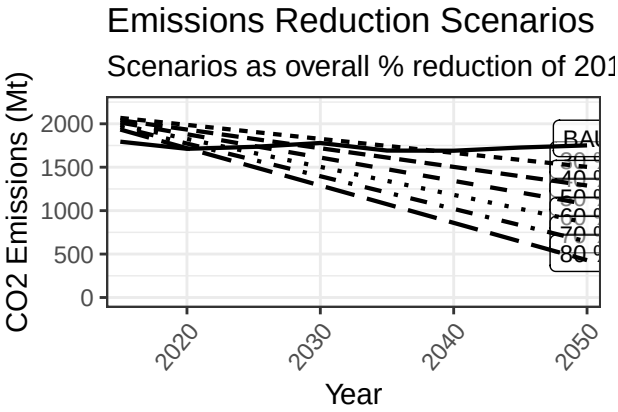



```
grid.arrange(cost_col, cost_bw, emissions_col, emissions_bw, ncol = 2)
```


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