Technical University of Denmark

42002 Modelling and Analysis of Sustainable Energy Systems
Using Operations Research

Final Project

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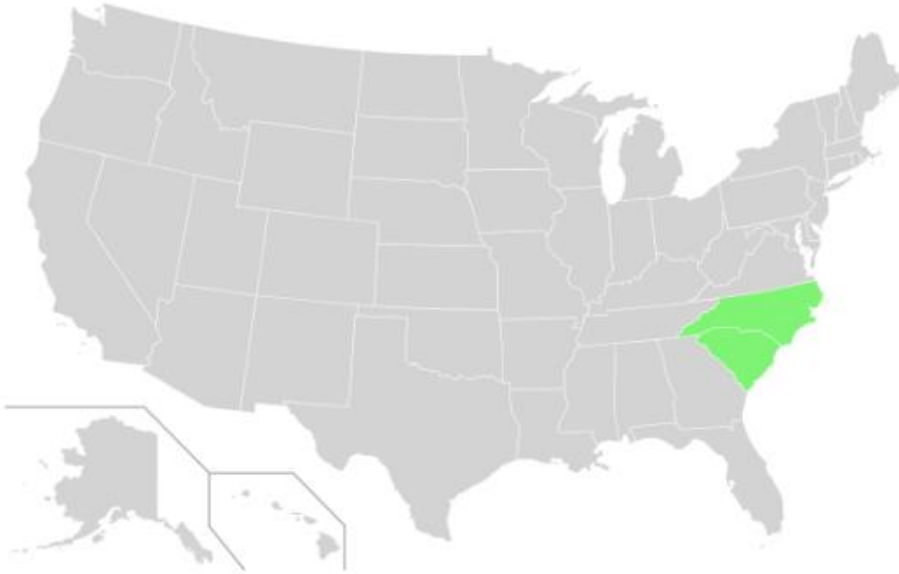
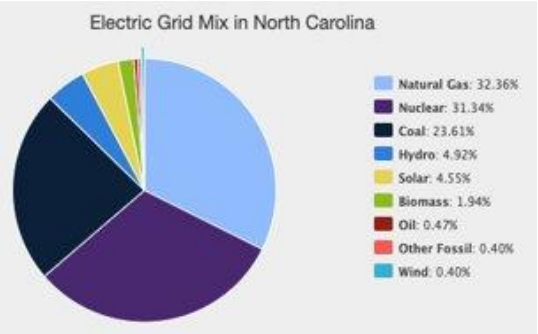
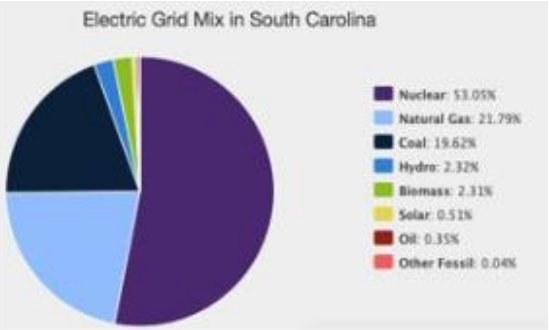
Fall 2019

Base Scenario in 2021

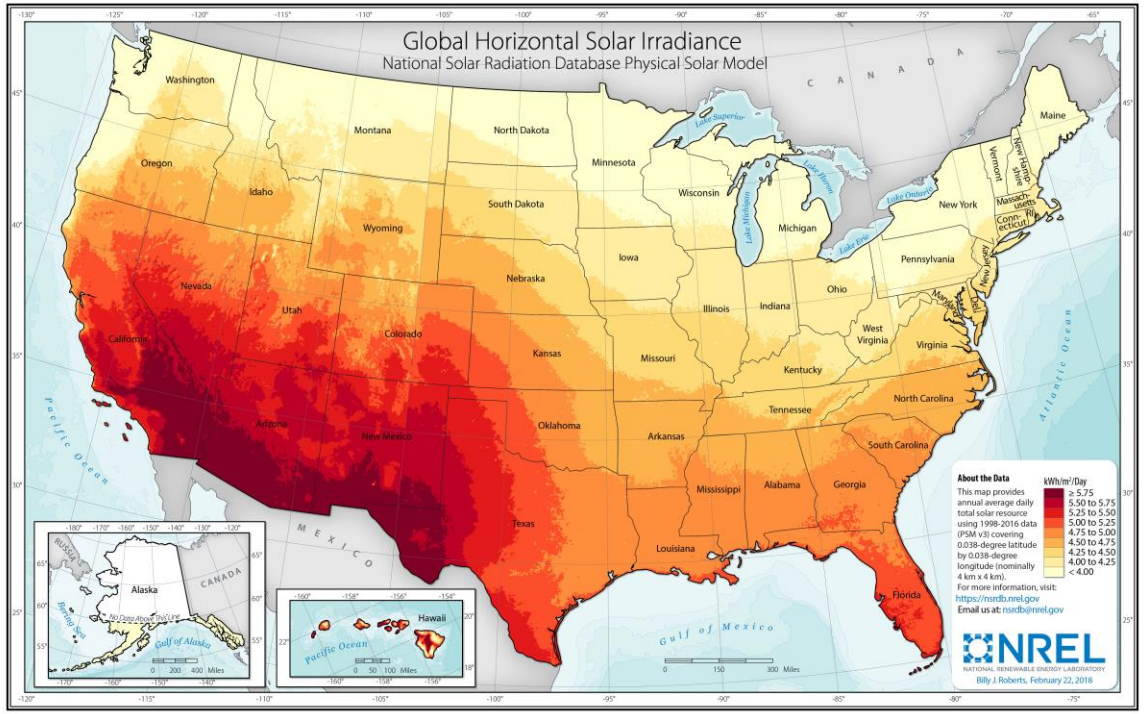
- Region: North and South Carolina, USA
- Electricity mix dominated by Natural Gas, Coal and Nuclear
- Low renewable share, huge potential for solar and wind
- Goal for 2021: 12.5% generation from renewables

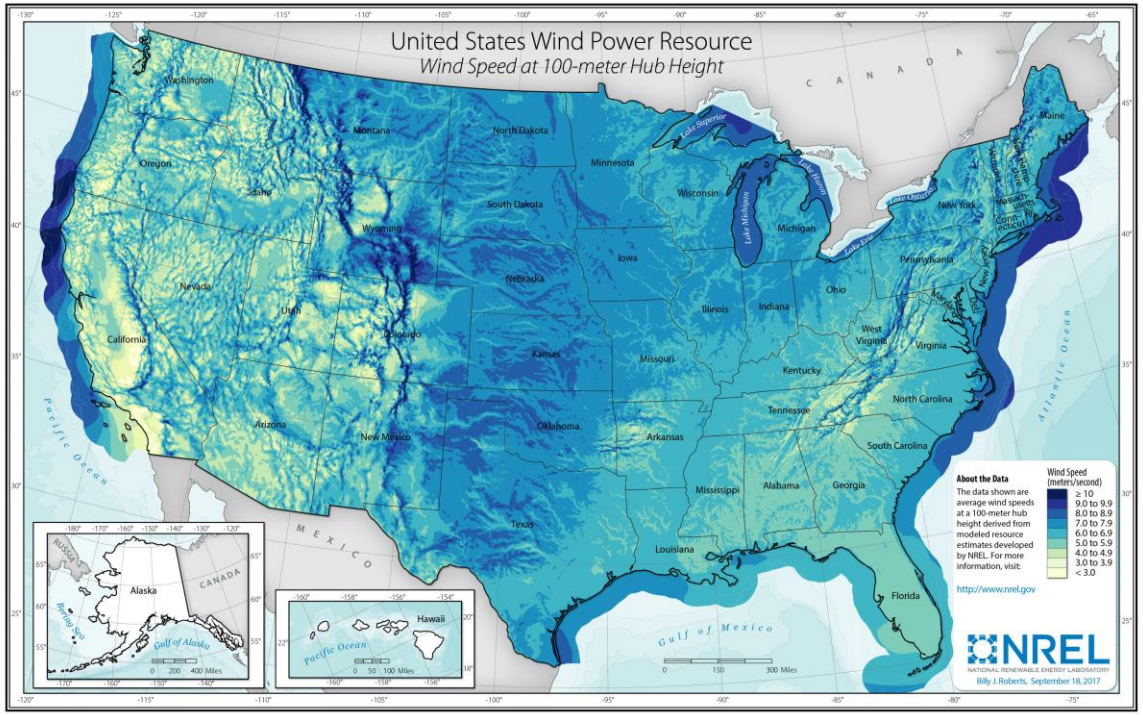






Wind & Solar



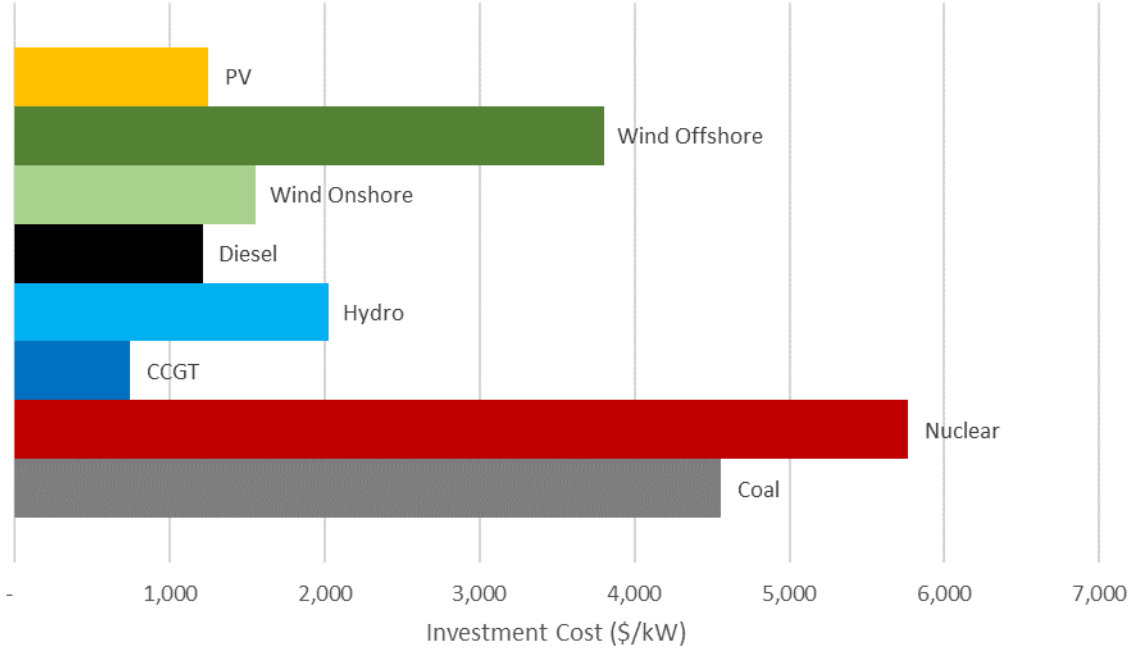


Renewables.ninja
Nrel.gov

Implementations

- Non-renewables
  - Coal
  - Natural Gas
  - Diesel
  - Nuclear
- Renewables
  - Wind
  - Solar
  - Hydro

Data



- eia.gov
- Investment cost: eia.gov & lazard.com
- Emission cost: worldbank.org

Assumptions

- Hydro power: monthly generation production per plant → Base load generation
- Emission costs equal for every non-renewable source
- Rate of return = 10%
- No imports/exports

Mathematical Model

- Objective function

$$\min \; Z = \sum_{t=1}^{T} \sum_{i=1}^{I} (C_i \; P_{it}) + \sum_{i=1}^{I} \left(CAPEX_i^{annualized} + OPEX_i \right) \; P_i^{max}$$

- Demand Satisfaction

$$\sum_{i=1}^{I} P_{it} = d_t - Pt^{solar} - Pt^{wind}$$

- Goal limit

$$\sum_{i=1}^{I} P_i \geq d * 12.5\%$$

Capacity units

Capacity production in unity of a fixed quantity: new variable X_i

Power generation limits

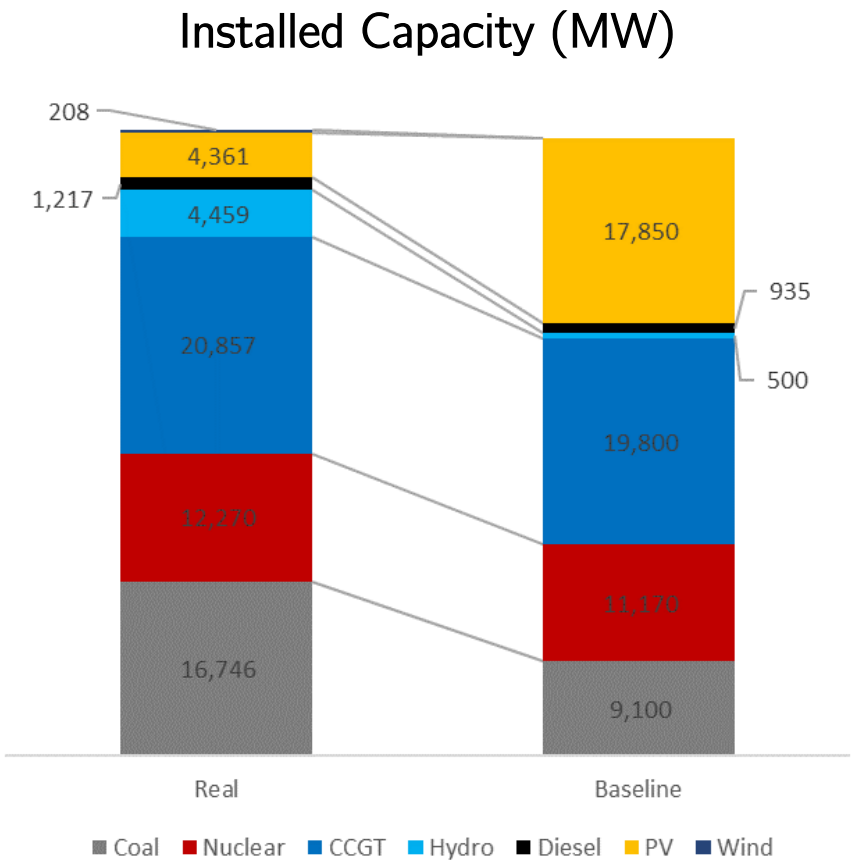
$$0 \leq P_{it} \leq size_i \; X_i = P_i^{max}$$

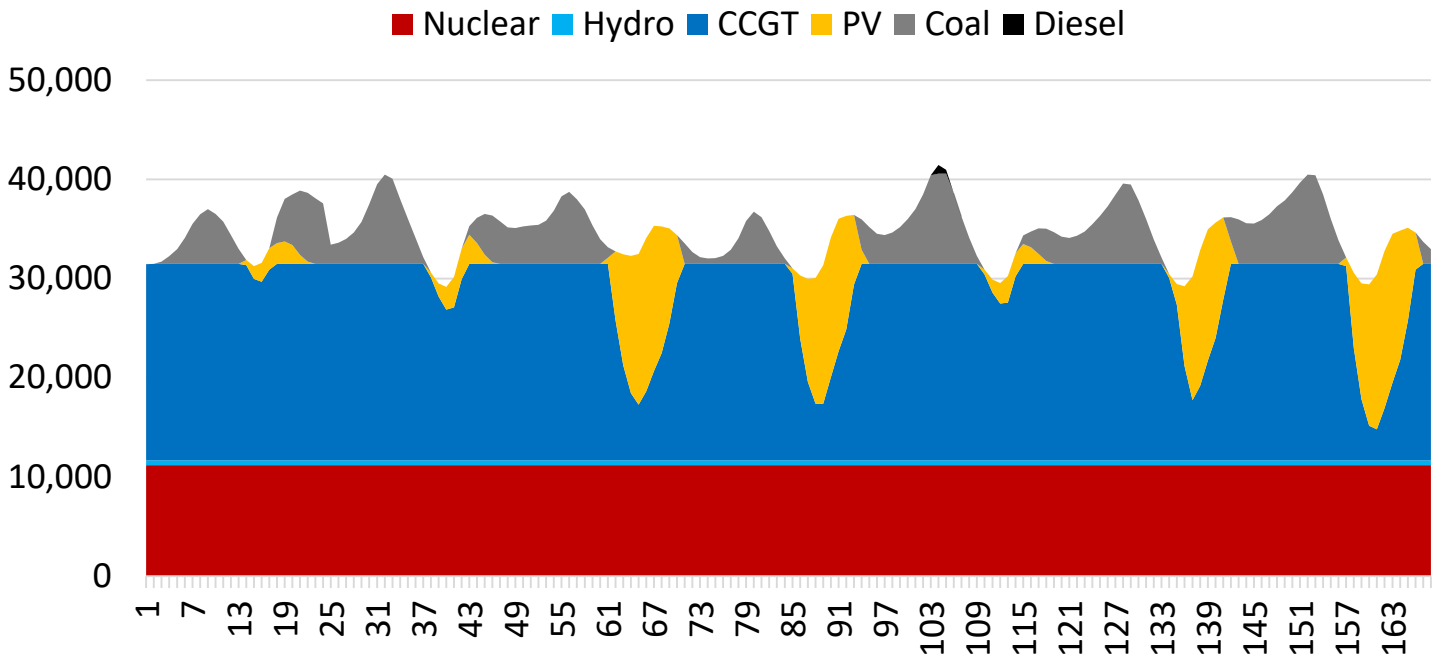
Extensions

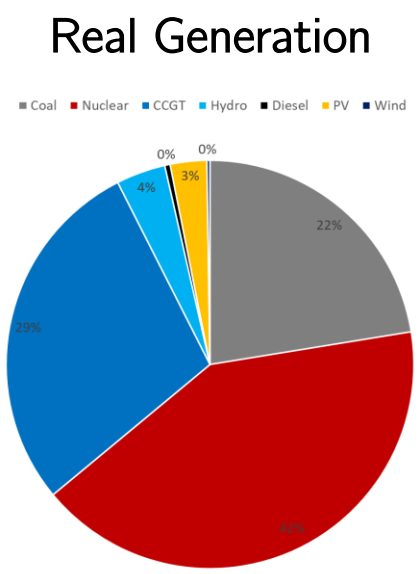
- Electric vehicles
  - From conventional cars to EV
  - Adds flexibility in electricity demand
  - Effects of demand flexibility

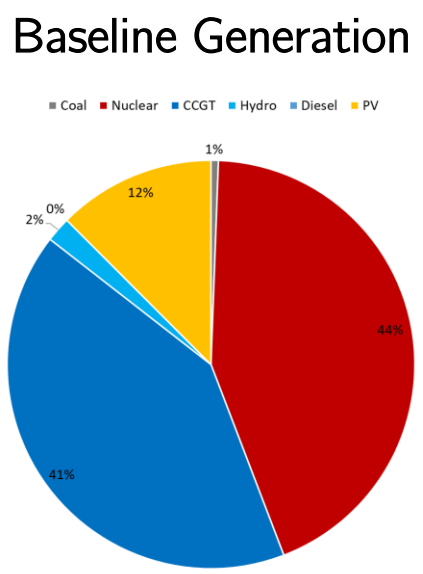
- Hydrogen
  - Electrolysis plant - storage
  - Fuel – fuel cell or gas turbines
  - Flexible, lots of losses

Results


Installed Capacity (MW)
208
4,361
1,217
4,459
20,857
12,270
16,746
17,850
935
500
19,800
11,170
9,100
Real
Baseline
Coal
Nuclear
CCGT
Hydro
Diesel
PV
Wind

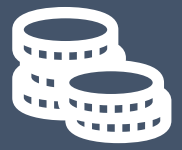

Nuclear
Hydro
CCGT
PV
Coal
Diesel
50,000
40,000
30,000
20,000
10,000
0
1
7
13
19
25
31
37
43
49
55
61
67
73
79
85
91
97
103
109
115
121
127
133
139
145
151
157
163


Real Generation
Coal
Nuclear
CCGT
Hydro
Diesel
PV
Wind
0%
0%
4%
3%
22%
29%
42%


Baseline Generation
Coal
Nuclear
CCGT
Hydro
Diesel
PV
1%
12%
2%
0%
44%
41%

Sensitivity Analysis

- Coal Capacity



- Fuel and Emission cost

- Subsidies

Thank you for your listening.

Questions?