Capacity Expansion Planning Under the Risk of Hurricanes: An Analysis of The US East Coast

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1. **Database Construction For The Florida Energy System**
2. **Database Construction For The North Carolina Energy System**

Section 2 details the data and considerations followed in the construction of the database for the North Carolina Energy System.

* 1. **Technologies**

Tables 2.1 and 2.2 provide a description of the existing and new energy generation technologies considered in our simulations, and Table 2.3 describes the non-energy generation technologies.

**Table 2.1:** Existing Generation Technologies Represented in The Model

|  |  |
| --- | --- |
| **Technology Code** | **Description** (Following EIA 860 Nomenclature) [1] |
| AB\_ST\_EXISTING | Steam Turbine Using Agricultural By-Products |
| BIT\_ST\_EXISTING | Steam Turbine Using Bituminous Coal |
| BLQ\_ST\_EXISTING | Steam Turbine Using Black Liquor |
| DFO\_CC\_EXISTING | Combined Cycle Combustion Turbine Using Petroleum |
| DFO\_GT\_EXISTING | Combustion Turbine Using Petroleum |
| DFO\_IC\_EXISTING | Internal Combustion Engine Using Petroleum |
| LFG\_GT\_EXISTING | Combustion Turbine Using Landfill Gas |
| LFG\_IC\_EXISTING | Internal Combustion Engine Using Landfill Gas |
| MWH\_BA1H\_EXISTING | Battery Storage- 1h |
| MWH\_BA2H\_EXISTING | Battery Storage- 2h |
| NG\_CC\_EXISTING | Combined Cycle Combustion Turbine Using Natural Gas |
| NG\_GT\_EXISTING | Combustion Turbine Using Natural Gas |
| NG\_ST\_EXISTING | Steam Turbine Using Natural Gas |
| NUC\_ST\_EXISTING | Nuclear Turbine |
| OBG\_IC\_EXISTING | Internal Combustion Engine Using Other Biomass Gas |
| SUN\_PV\_EXISTING | Solar Photovoltaic - Utility |
| WAT\_HY\_EXISTING | Conventional Hydroelectric |
| WAT\_PS\_EXISTING | Hydroelectric Pumped Storage |
| WDS\_ST\_EXISTING | Steam Turbine Using Wood Waste |
| WH\_ST\_EXISTING | Steam Turbine Using Waste Heat |
| WND\_WT\_EXISTING | Onshore Wind Turbine |

**Table 2.2:** New Generation Technologies Represented in The Model

|  |  |
| --- | --- |
| **Technology Code** | **Description** |
| BATT\_2H\_NEW | Battery Storage 2h (NREL ATB 2022 Technology) |
| BATT\_4H\_NEW | Battery Storage 4h (NREL ATB 2022 Technology) |
| BATT\_6H\_NEW | Battery Storage 6h (NREL ATB 2022 Technology) |
| BATT\_8H\_NEW | Battery Storage 8h (NREL ATB 2022 Technology) |
| BIOMASS\_CC90\_NEW | Generation From Biomass With 90% Carbon Capture (Technology from NREL ReEDS model Using BECC-mod) |
| BIOMASS\_NEW | Generation From Biomass (NREL ATB 2022 Technology) |
| COAL\_95CC\_NEW | Generation From Coal With 95% Carbon Capture (NREL ATB 2022 Technology) |
| COAL\_99CC\_NEW | Generation From Coal With 99% Carbon Capture (NREL ATB 2022 Technology) |
| COAL\_NEW | Generation From Coal (NREL ATB 2022 Technology) |
| NG\_F-FRAME\_CC\_95CC\_NEW | Combined Cycle Natural Gas Turbine F-Frame With 95 % of Carbon Capture (NREL ATB 2022 Technology) |
| NG\_F-FRAME\_CC\_97CC\_NEW | Combined Cycle Natural Gas Turbine F-Frame With 97 % of Carbon Capture (NREL ATB 2022 Technology) |
| NG\_F-FRAME\_CC\_NEW | Combined Cycle Natural Gas Turbine F-Frame (NREL ATB 2022 Technology) |
| NG\_F-FRAME\_CT\_NEW | Natural Gas Combustion Turbine F-Frame - Simple Cycle (NREL ATB 2022 Technology) |
| NG\_H-FRAME\_CC\_95CC\_NEW | Combined Cycle Natural Gas Turbine H-Frame With 95 % of Carbon Capture (NREL ATB 2022 Technology) |
| NG\_H-FRAME\_CC\_97CC\_NEW | Combined Cycle Natural Gas Turbine H-Frame With 97 % of Carbon Capture (NREL ATB 2022 Technology) |
| NG\_H-FRAME\_CC\_NEW | Combined Cycle Natural Gas Turbine H-Frame (NREL ATB 2022 Technology) |
| NUCLEAR-AP1000\_NEW | Nuclear Generation Using AP1000 PWR (NREL ATB 2022 Technology) |
| NUCLEAR-SMR\_NEW | Small Modular Nuclear Reactor (NREL ATB 2022 Technology) |
| PV-COMMERCIAL\_NEW | Commercial Solar PV (NREL ATB 2022 Technology) |
| PV-RESIDENTIAL\_NEW | Residential Solar PV (NREL ATB 2022 Technology) |
| PV-UTILITY\_NEW | Utility Solar PV (NREL ATB 2022 Technology) |
| WAT\_HY\_NEW | Conventional Hydroelectric (NREL ATB 2022 Technology) |
| WAT\_PS\_NEW | Hydroelectric Pumped Storage (NREL ATB 2022 Technology) |
| WIND-LAND-C8\_NEW | Onshore Wind Turbine Class 8 From NREL ATB 2022 (NREL ATB 2023 Technology) |
| WIND-OFFSHORE-C6\_NEW | Offshore Wind Turbine Class 6 From NREL ATB 2022 (NREL ATB 2023 Technology) |

**Table 2.3:** Non-Generation Technologies Represented in The Model

|  |  |
| --- | --- |
| **Technology Code** | **Description** |
| CO2\_STORAGE | CO2 Storage |
| DISTRIBUTION | Energy Distribution |
| FT\_BIOMASS | Fuel for Generation Technologies That Use Biomass |
| FT\_COAL | Fuel for Generation Technologies That Use Coal |
| FT\_NG | Fuel for Generation Technologies That Use Natural Gas |
| FT\_NUCLEAR | Fuel for Nuclear Generation Technologies |
| FT\_PETROLEUM | Fuel for Generation Technologies That Use Petroleum |
| TRANSMISSION\_INTERREGIONAL | Transmission Between Different Regions |
| TRANSMISSION\_REGIONAL | Transmission In the Same Region |

* 1. **Existing Capacity**

Data from existing generation capacity comes from the EIA-860M reports [1]. Figure 2.1 shows the vintage (operational year) of each existing technology on the NC system and its corresponding capacity. On the left legend, the total existing capacity is shown in parathesis.

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Description automatically generated

**Figure 2.1:** Total Existing Capacity on the NC Power System by Different Operational Years (Vintage)

* 1. **Lifetime Tech and Loan**

The default lifetimes of the technologies considered in our models are detailed in Tables 2.4, 2.5, and 2.6 with their corresponding references.

**Table 2.4:** Default Technologies Lifetime and Loans For Existing Generation Technologies

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Technology Code** | **Lifetime Tech** | | **Loan** | |
| **Years** | **Reference** | **Years** | **Reference** |
| AB\_ST\_EXISTING | 50 | From NREL ReEDS [2] | 20 | From NREL ReEDS [2] |
| BIT\_ST\_EXISTING | 57 | Average from DEC/DEP in IRPs [3, 4] | 20 | From NREL ReEDS [2] |
| BLQ\_ST\_EXISTING | 50 | From NREL ReEDS [2] | 20 | From NREL ReEDS [2] |
| DFO\_CC\_EXISTING | 68 | Average from DEC/DEP in IRPs [3, 4] for DFO\_GT. Consistent with NREL ReEDS [2] | 20 | From NREL ReEDS [2] |
| DFO\_GT\_EXISTING | 68 | 20 | From NREL ReEDS [2] |
| DFO\_IC\_EXISTING | 68 | 20 | From NREL ReEDS [2] |
| LFG\_GT\_EXISTING | 50 | From NREL ReEDS [2] | 20 | From NREL ReEDS [2] |
| LFG\_IC\_EXISTING | 50 | From NREL ReEDS [2] | 20 | From NREL ReEDS [2] |
| MWH\_BA1H\_EXISTING | 15 | From NREL ReEDS [2] | 15 | From NREL ReEDS [2] |
| MWH\_BA2H\_EXISTING | 15 | From NREL ReEDS [2] | 15 | From NREL ReEDS [2] |
| NG\_CC\_EXISTING | 37 | Average from DEC/DEP in IRPs [3, 4] for NG CA and CT | 20 | From NREL ReEDS [2] |
| NG\_GT\_EXISTING | 42 | Average from DEC/DEP in IRPs [3, 4] | 20 | From NREL ReEDS [2] |
| NG\_ST\_EXISTING | 50 | From NREL ReEDS [2] | 20 | From NREL ReEDS [2] |
| NUC\_ST\_EXISTING | 59 | Average from DEC/DEP in IRPs [3, 4] | 20 | From NREL ReEDS [2] |
| OBG\_IC\_EXISTING | 50 | From NREL ReEDS [2] | 20 | From NREL ReEDS [2] |
| SUN\_PV\_EXISTING | 30 | From NREL ReEDS [2] | 20 | From NREL ReEDS [2] |
| WAT\_HY\_EXISTING | 120 | Average from DEC/DEP in IRPs [3, 4] for WAT\_HY | 20 | From NREL ReEDS [2] |
| WAT\_PS\_EXISTING | 120 | 20 | From NREL ReEDS [2] |
| WDS\_ST\_EXISTING | 50 | From NREL ReEDS [2] | 20 | From NREL ReEDS [2] |
| WH\_ST\_EXISTING | 50 | From NREL ReEDS [2] for steam tech | 20 | From NREL ReEDS [2] |
| WND\_WT\_EXISTING | 30 | From NREL ReEDS [2] | 20 | From NREL ReEDS [2] |

**Table 2.5:** Default Technologies Lifetime and Loans For New Generation Technologies

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Technology Code** | **Lifetime Tech** | | **Loan** | |
| **Years** | **Reference** | **Years** | **Reference** |
| BATT\_2H\_NEW | 15 | From NREL ReEDS [2] | 15 | From NREL ReEDS [2] |
| BATT\_4H\_NEW | 15 | From NREL ReEDS [2] | 15 | From NREL ReEDS [2] |
| BATT\_6H\_NEW | 15 | From NREL ReEDS [2] | 15 | From NREL ReEDS [2] |
| BATT\_8H\_NEW | 15 | From NREL ReEDS [2] | 15 | From NREL ReEDS [2] |
| BIOMASS\_CC90\_NEW | 50 | From NREL ReEDS [2] | 20 | From NREL ReEDS [2] |
| BIOMASS\_NEW | 50 | From NREL ReEDS [2] | 20 | From NREL ReEDS [2] |
| COAL\_95CC\_NEW | 65 | From NREL ReEDS [2] | 20 | From NREL ReEDS [2] |
| COAL\_99CC\_NEW | 65 | From NREL ReEDS [2] | 20 | From NREL ReEDS [2] |
| COAL\_NEW | 65 | From NREL ReEDS [2] | 20 | From NREL ReEDS [2] |
| NG\_F-FRAME\_CC\_95CC\_NEW | 60 | From NREL ReEDS [2] | 20 | From NREL ReEDS [2] |
| NG\_F-FRAME\_CC\_97CC\_NEW | 60 | From NREL ReEDS [2] | 20 | From NREL ReEDS [2] |
| NG\_F-FRAME\_CC\_NEW | 60 | From NREL ReEDS [2] | 20 | From NREL ReEDS [2] |
| NG\_F-FRAME\_CT\_NEW | 50 | From NREL ReEDS [2] | 20 | From NREL ReEDS [2] |
| NG\_H-FRAME\_CC\_95CC\_NEW | 60 | From NREL ReEDS [2] | 20 | From NREL ReEDS [2] |
| NG\_H-FRAME\_CC\_97CC\_NEW | 60 | From NREL ReEDS [2] | 20 | From NREL ReEDS [2] |
| NG\_H-FRAME\_CC\_NEW | 60 | From NREL ReEDS [2] | 20 | From NREL ReEDS [2] |
| NUCLEAR-AP1000\_NEW | 60 | From NREL ReEDS [2] | 20 | From NREL ReEDS [2] |
| NUCLEAR-SMR\_NEW | 60 | From NREL ReEDS [2] | 20 | From NREL ReEDS [2] |
| PV-COMMERCIAL\_NEW | 30 | From NREL ReEDS [2] | 20 | From NREL ReEDS [2] |
| PV-RESIDENTIAL\_NEW | 30 | From NREL ReEDS [2] | 20 | From NREL ReEDS [2] |
| PV-UTILITY\_NEW | 30 | From NREL ReEDS [2] | 20 | From NREL ReEDS [2] |
| WAT\_HY\_NEW | 120 | Average from DEC/DEP in IRPs [3, 4] for WAT\_HY | 20 | From NREL ReEDS [2] |
| WAT\_PS\_NEW | 120 | 20 | From NREL ReEDS [2] |
| WIND-LAND-C8\_NEW | 30 | From NREL ReEDS [2] | 20 | From NREL ReEDS [2] |
| WIND-OFFSHORE-C6\_NEW | 30 | From NREL ReEDS [2] | 20 | From NREL ReEDS [2] |

**Table 2.6:** Default Technologies Lifetime and Loans For Non-Generation Technologies

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Technology Code** | **Lifetime Tech** | | **Loan** | |
| **Years** | **Reference** | **Years** | **Reference** |
| DISTRIBUTION | 60 |  | 20 |  |
| TRANSMISSION\_INTERREGIONAL | 60 |  | 20 |  |
| TRANSMISSION\_REGIONAL | 60 |  | 20 |  |
| CO2\_STORAGE\* | NA\* | | | |
| FT\_BIOMASS\* | NA\* | | | |
| FT\_COAL\* | NA\* | | | |
| FT\_NG\* | NA\* | | | |
| FT\_NUCLEAR\* | NA\* | | | |
| FT\_PETROLEUM\* | NA\* | | | |

\*We do not consider investment costs for this technology (all costs for it are variable or fixed); as such, the lifetime of the tech and its loan period can be ignored.

Some specific generation units (123 units – 24.5 GW) managed by Duke Energy in North Carolina have estimated retirement dates available at [3, 4]. Because of those generation units, modifications to the available capacity were made at each vintage to ensure proper capacity retirement of each technology type. However, for generators without estimated retirement dates from Duke Energy [3, 4], it was assumed the lifetimes reported in Tables 2.4, 2.5, and 2.6.

It is important to mention that due to limitations on data availability and model approximations, an existing generator reported at the EIA-860M [1] and not available at [3, 4] may be retired prior to the first year of simulation (year 2023) as we consider an average retirement date for all generators not referenced on [3, 4]. In this case, this capacity is eliminated from the pool of existing capacity; however, it is important to mention that these correspond to less than 0.32GW (less than 0.8% of the existing capacity).

Figure 2.2 shows the retirement dates and capacity for existing technologies retired after 2023, and Figure 2.3 shows the retirement dates and capacity for existing technologies retired before or at 2023 (a modeling effect of the values on Table 2.4, 2.5, and 2.6)

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\*A technology retired at year X does not contribute to the generation at year X.

**Figure 2.2:** Retirement Year and Capacity for Existing Technologies Retired After 2023.

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\*A technology retired at year X does not contribute to the generation at year X.

**Figure 2.3:** Retirement Year and Capacity for Existing Technologies Retired Before 2023. This Happens Because of the Average Lifetime Approximations Considered and Limitations on Data Availability.

* 1. **Costs**

**>Table with Cost Investment (Also put discount rate)**

**>Table with Cost Fixed**

**>Table with Cost Variable**

**If otherwise not state the costs values of the tech is zero**

* 1. **Efficiency**
  2. **Emission Activity and Limits**

**>emission per activity**

**>Limits of emission**

* 1. **Capacity Factors**
  2. **Capacity Credit and Planning Reserve Margin**
  3. **Maximum Capacity**

**>Hydro and pumped**

* 1. **Maximum Activity**

**>Biomass**

**>Wind (Discuss)**

**>Solar (Discuss)**

* 1. **Minimum Activity**

**>Solar Residential**

**>Solar Commercial**

* 1. **Regionalization**

**>**Differentiate existing and future tech

**>**Plot with their Location

* 1. **Fragility Curves and Damage Statistics**

>Define fragilities considered

>Table with damages at each hurricane speed and per scenario

# **References**

|  |  |
| --- | --- |
| [1] | EIA, "Preliminary Monthly Electric Generator Inventory (based on Form EIA-860M as a supplement to Form EIA-860)," February 2023. [Online]. Available: https://www.eia.gov/electricity/data/eia860m/. [Accessed July 2023]. |
| [2] | NREL, "Regional Energy Deployment System (ReEDS) Model Documentation: Version 2020," 2020. |
| [3] | Duke Energy, "Duke Energy Progress Integrated Resource Plan Update 2022," 2022. |
| [4] | Duke Energy, "Duke Energy Carolinas Integrated Resource Plan Update 2022," 2022. |