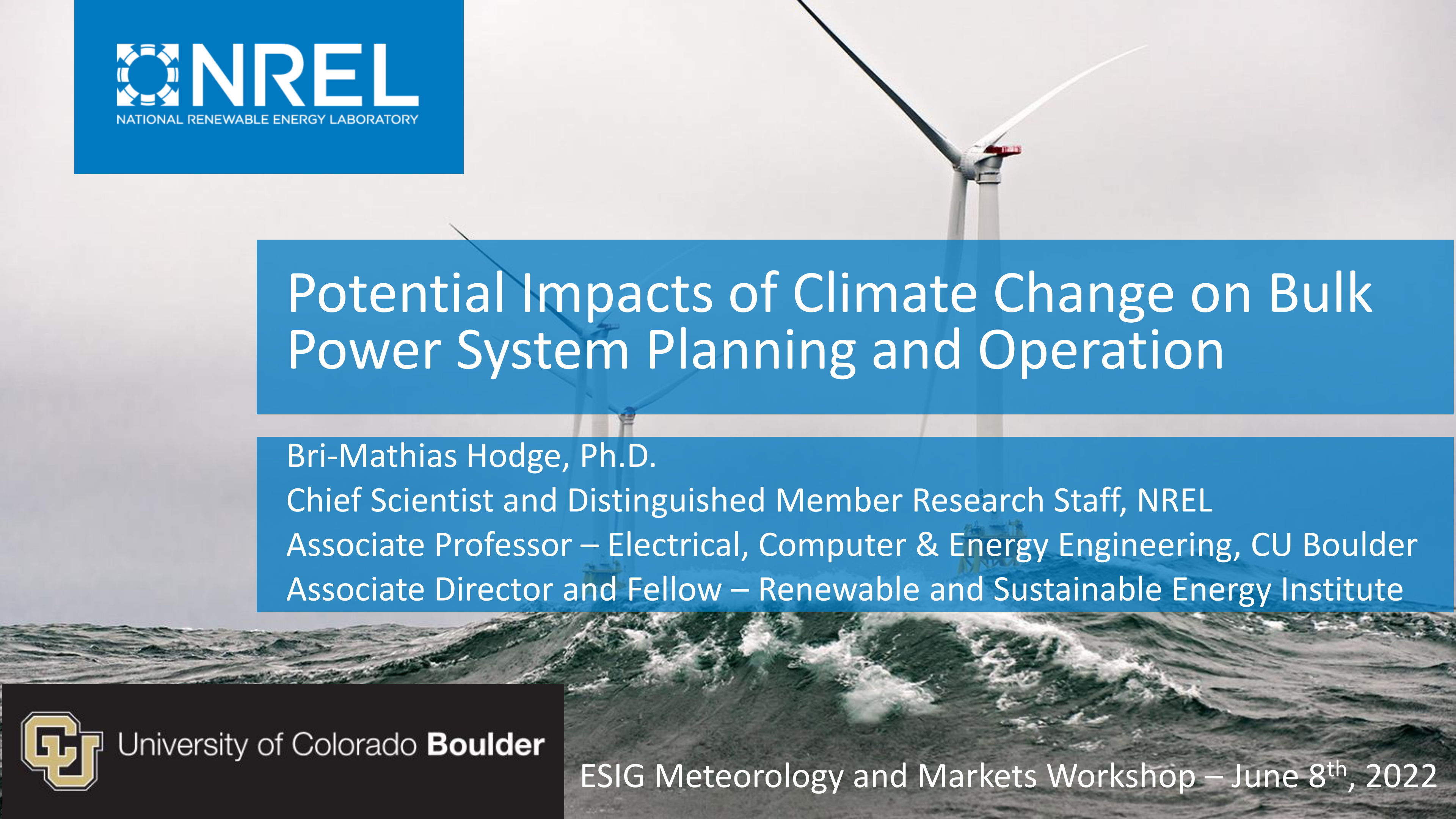
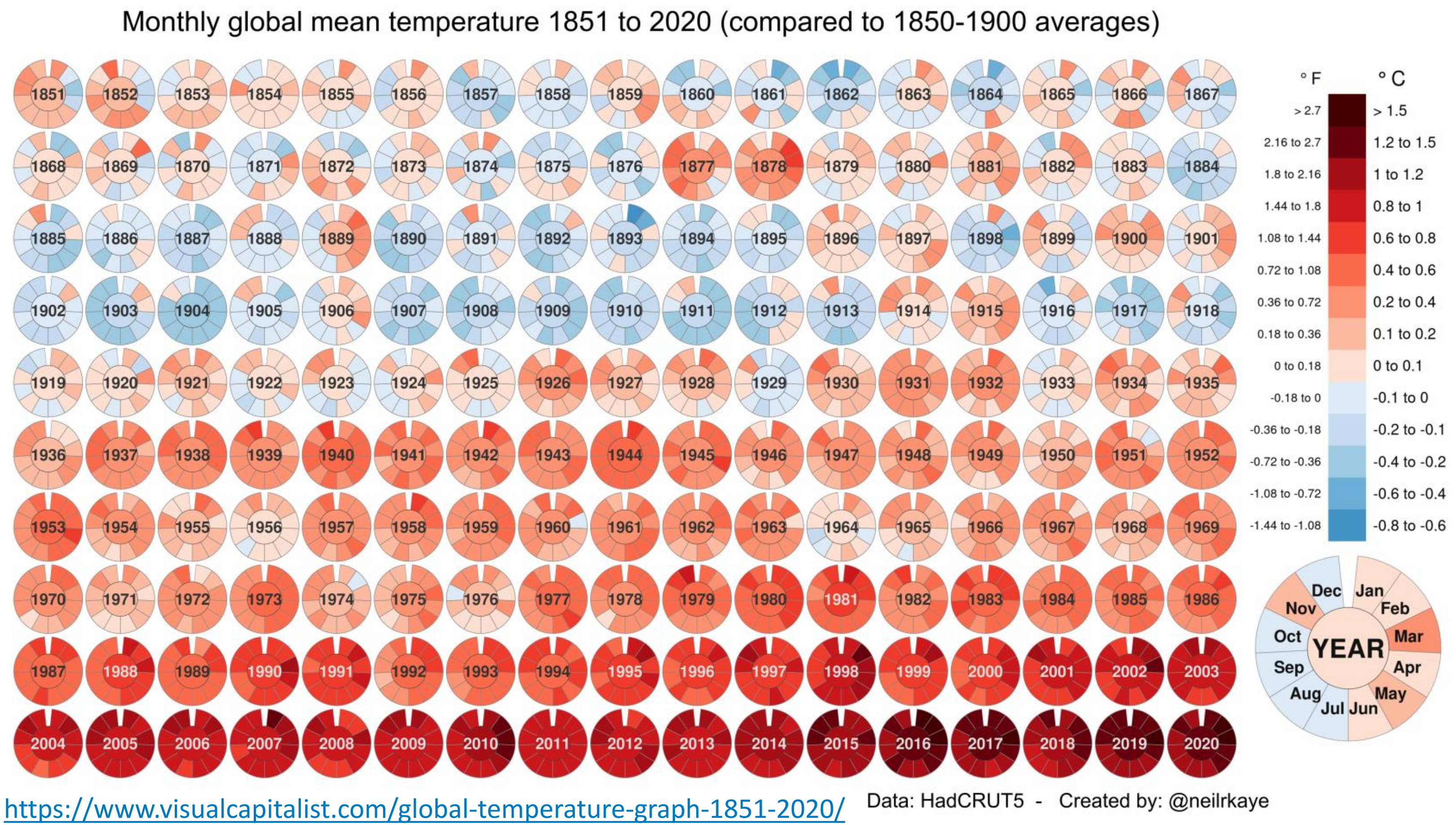


Potential Impacts of Climate Change on Bulk Power System Planning and Operation

Bri-Mathias Hodge, Ph.D.
Chief Scientist and Distinguished Member Research Staff, NREL
Associate Professor – Electrical, Computer & Energy Engineering, CU Boulder
Associate Director and Fellow – Renewable and Sustainable Energy Institute

ESIG Meteorology and Markets Workshop – June 8th, 2022

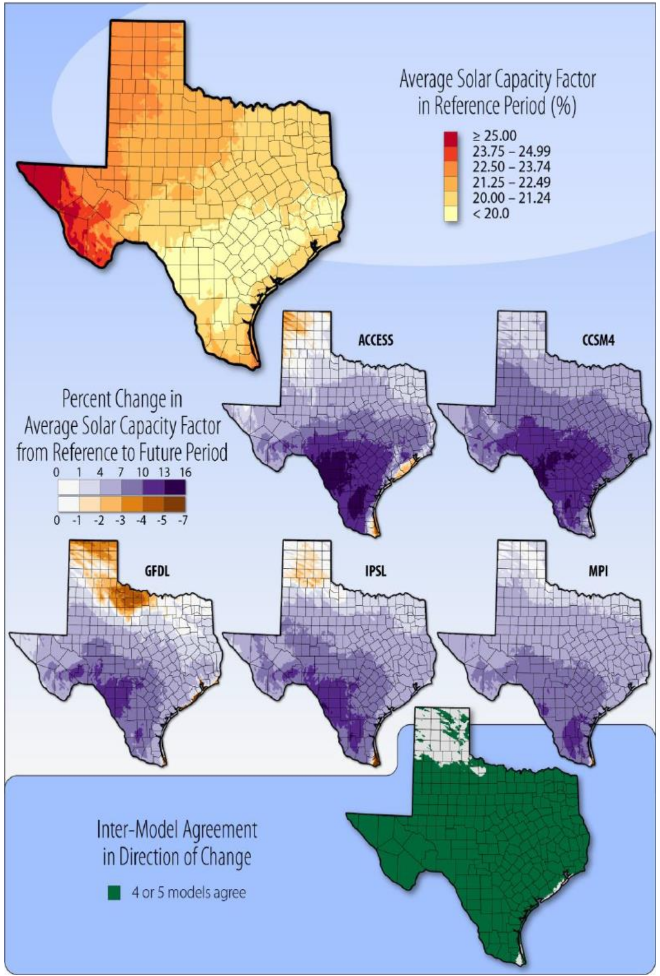
The Elephant in the Room

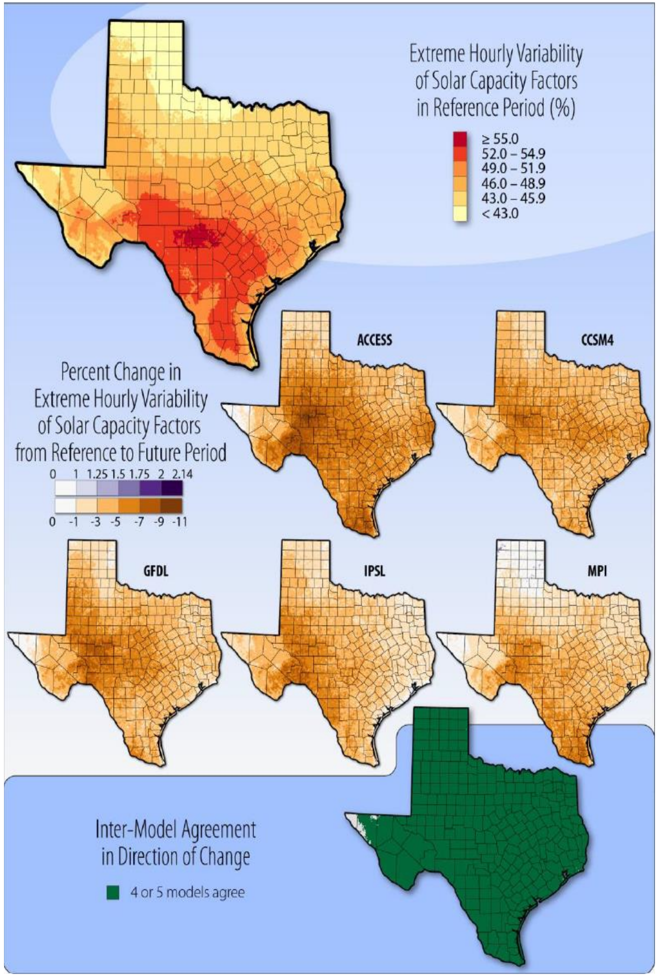

Monthly global mean temperature 1851 to 2020 (compared to 1850-1900 averages)

Data: HadCRUT5 - Created by: @neilrkaye

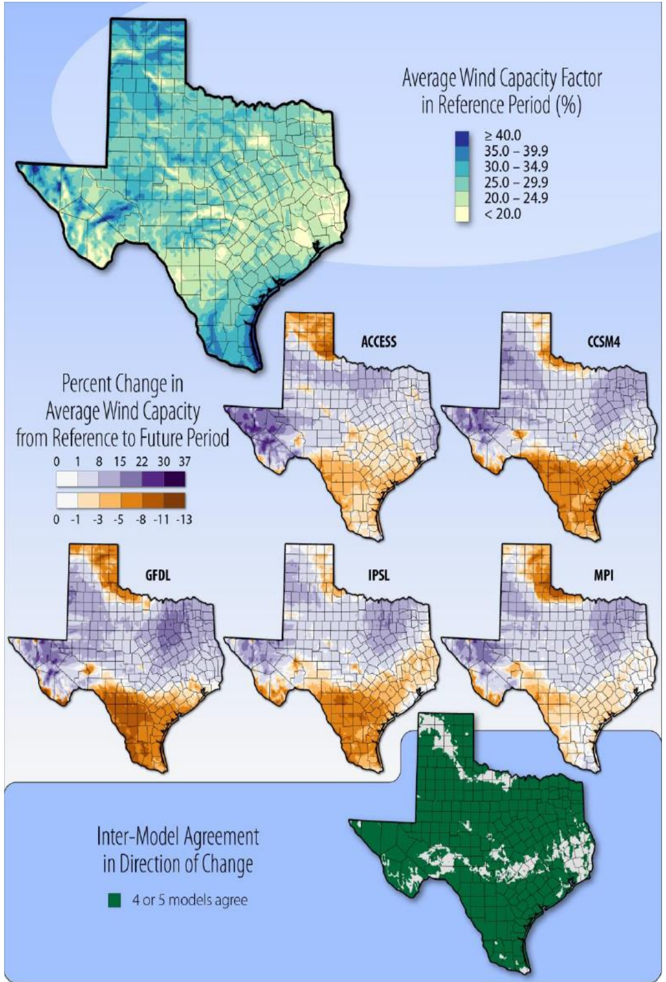
Ref: https://www.visualcapitalist.com/global-temperature-graph-1851-2020/

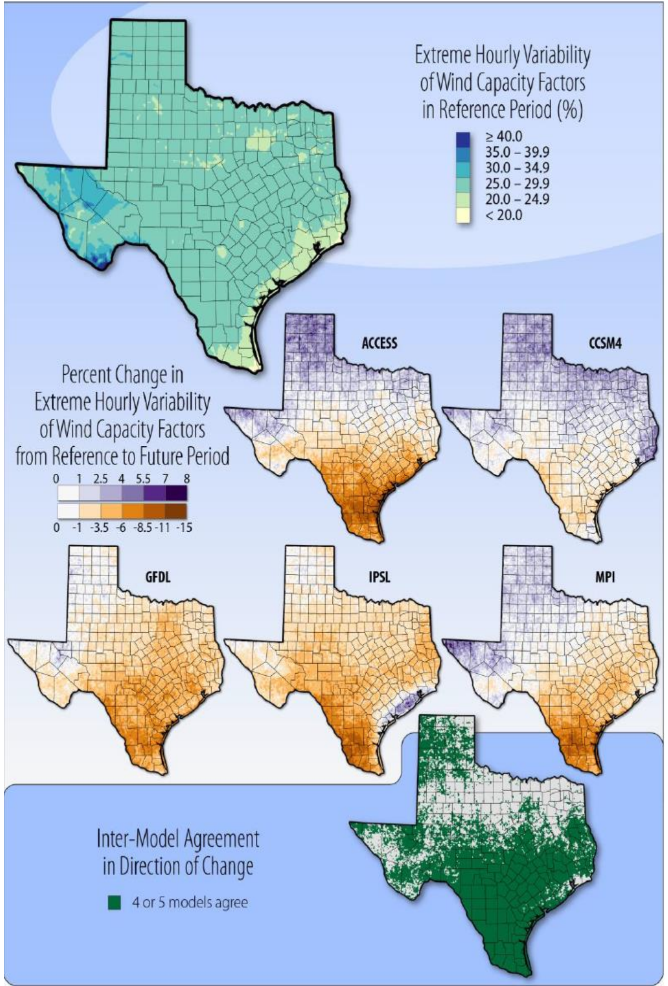
Climate-Driven Changes to Solar PV Power



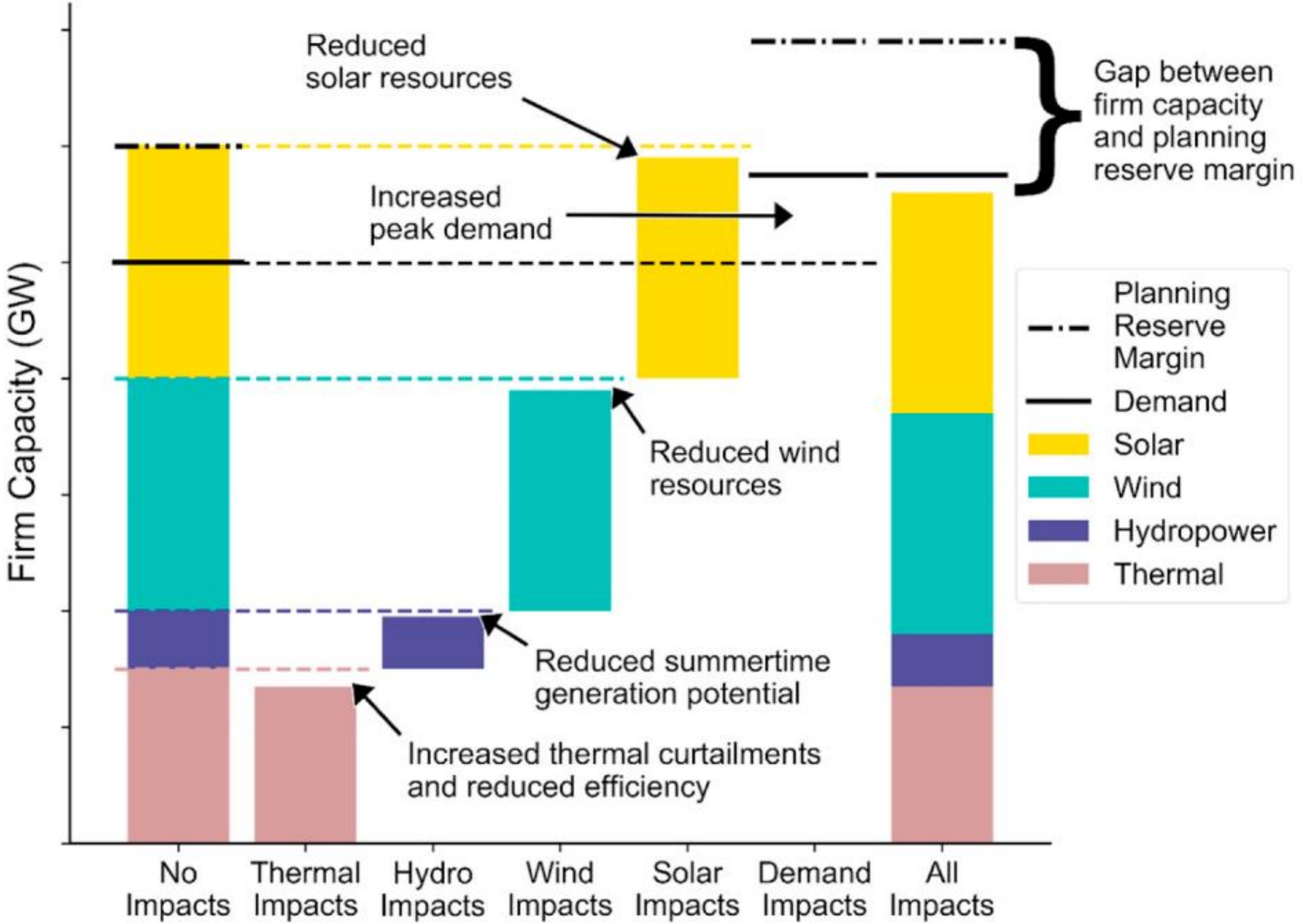


Climate-Driven Changes to Wind Power

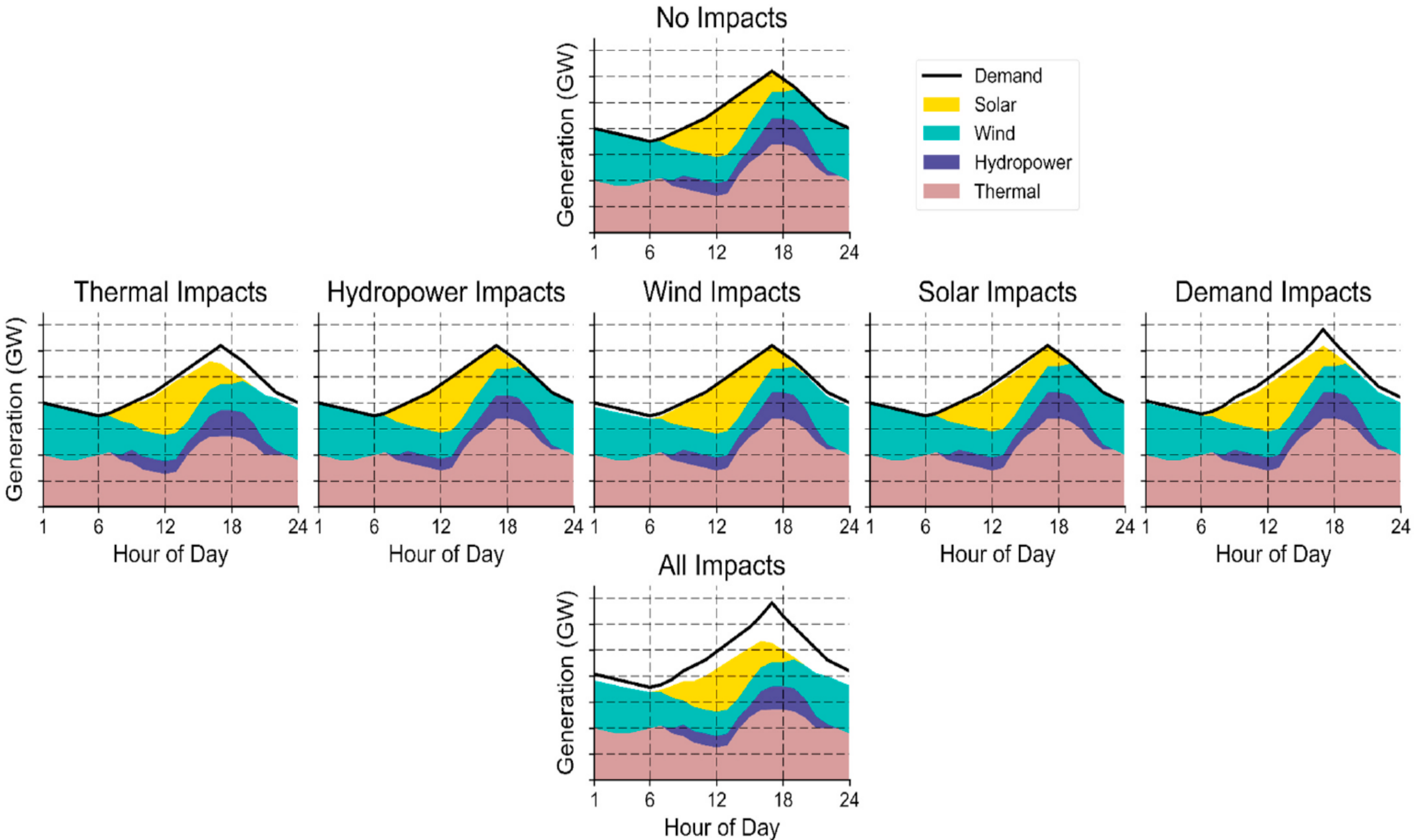




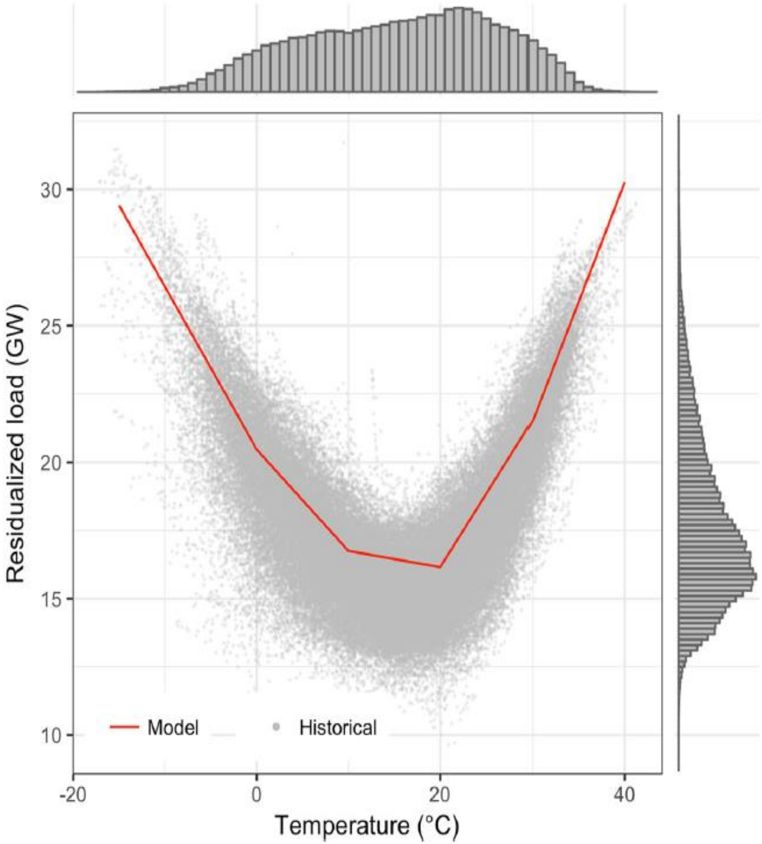
Climate Impacts - Planning

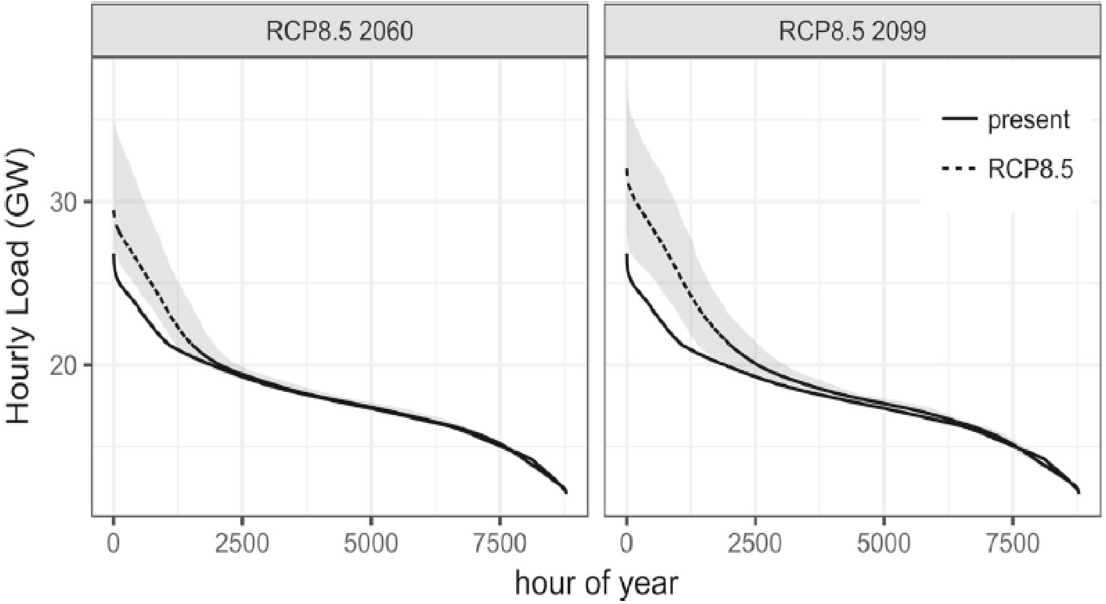


Climate Impacts - Operations



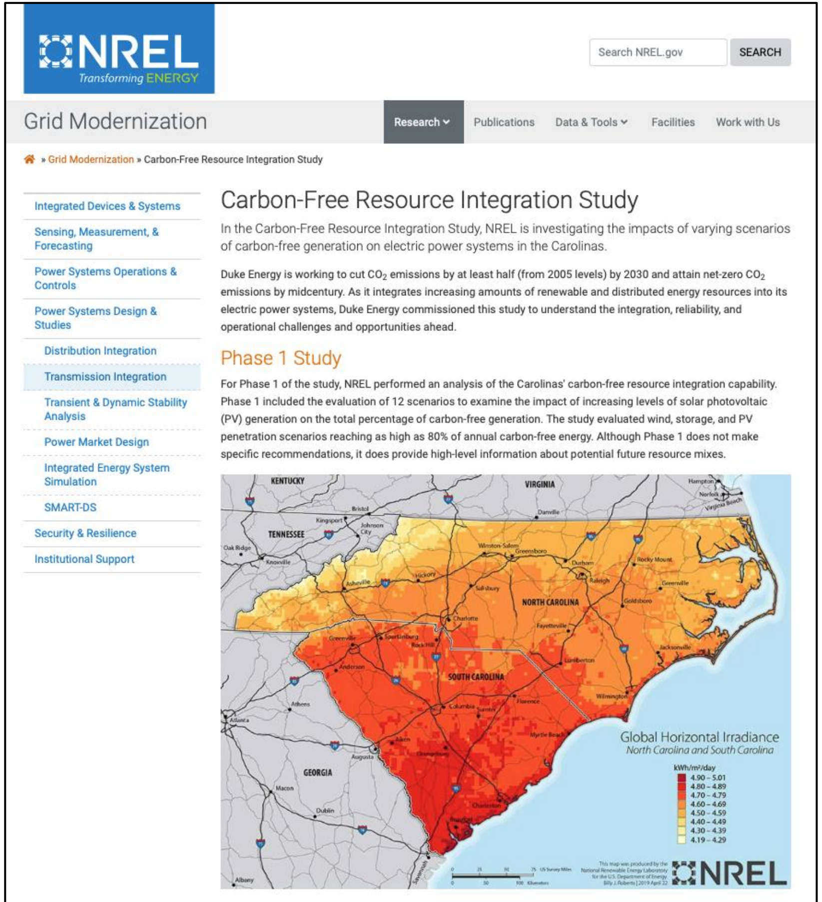
Load Changes with Temperature Changes - TVA





Source: Ralston Fonseca, Jaramillo, Berges, & Severnini, Climatic Change 2019

Duke Energy Carbon-Free Resource Integration Study



Grid Modernization

» Grid Modernization » Carbon-Free Resource Integration Study

- Integrated Devices & Systems
- Sensing, Measurement, & Forecasting
- Power Systems Operations & Controls
- Power Systems Design & Studies
  - Distribution Integration
  - Transmission Integration
  - Transient & Dynamic Stability Analysis
  - Power Market Design
  - Integrated Energy System Simulation
  - SMART-DS
- Security & Resilience
- Institutional Support

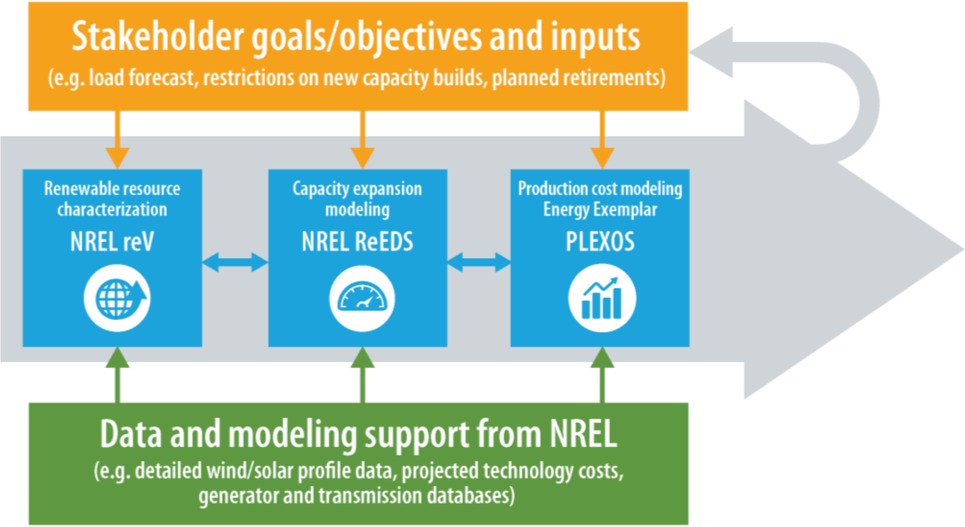
Carbon-Free Resource Integration Study

In the Carbon-Free Resource Integration Study, NREL is investigating the impacts of varying scenarios of carbon-free generation on electric power systems in the Carolinas.

Duke Energy is working to cut CO_2 emissions by at least half (from 2005 levels) by 2030 and attain net-zero CO_2 emissions by midcentury. As it integrates increasing amounts of renewable and distributed energy resources into its electric power systems, Duke Energy commissioned this study to understand the integration, reliability, and operational challenges and opportunities ahead.

Phase 1 Study

For Phase 1 of the study, NREL performed an analysis of the Carolinas' carbon-free resource integration capability. Phase 1 included the evaluation of 12 scenarios to examine the impact of increasing levels of solar photovoltaic (PV) generation on the total percentage of carbon-free generation. The study evaluated wind, storage, and PV penetration scenarios reaching as high as 80% of annual carbon-free energy. Although Phase 1 does not make specific recommendations, it does provide high-level information about potential future resource mixes.



Stakeholder goals/objectives and inputs
(e.g. load forecast, restrictions on new capacity builds, planned retirements)

Renewable resource characterization
NREL reV

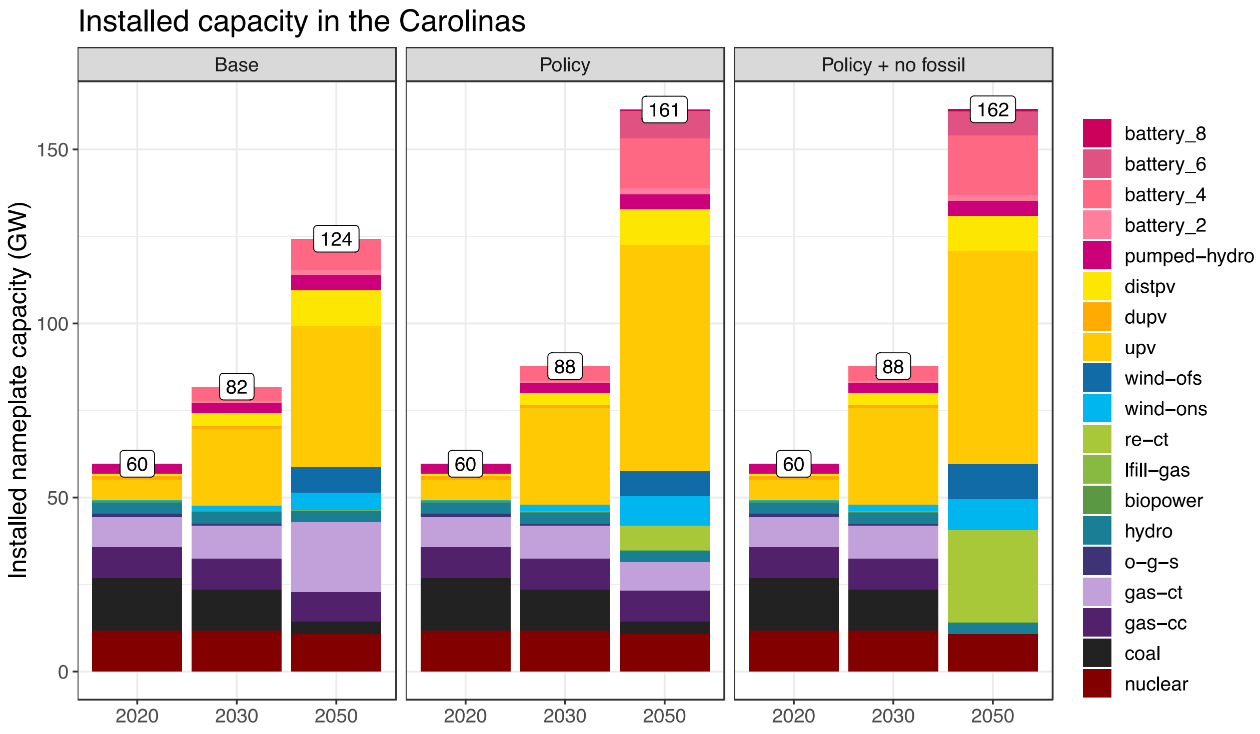
Capacity expansion modeling
NREL ReEDS

Production cost modeling Energy Exemplar
PLEXOS

Data and modeling support from NREL
(e.g. detailed wind/solar profile data, projected technology costs, generator and transmission databases)

Overview of Phase II analysis

Capacity Expansion


Installed capacity in the Carolinas

Note: The coal retirement schedule for these results was specified prior to recent updates. A sensitivity exploring runs with additional coal retirements was tested in production cost modeling.

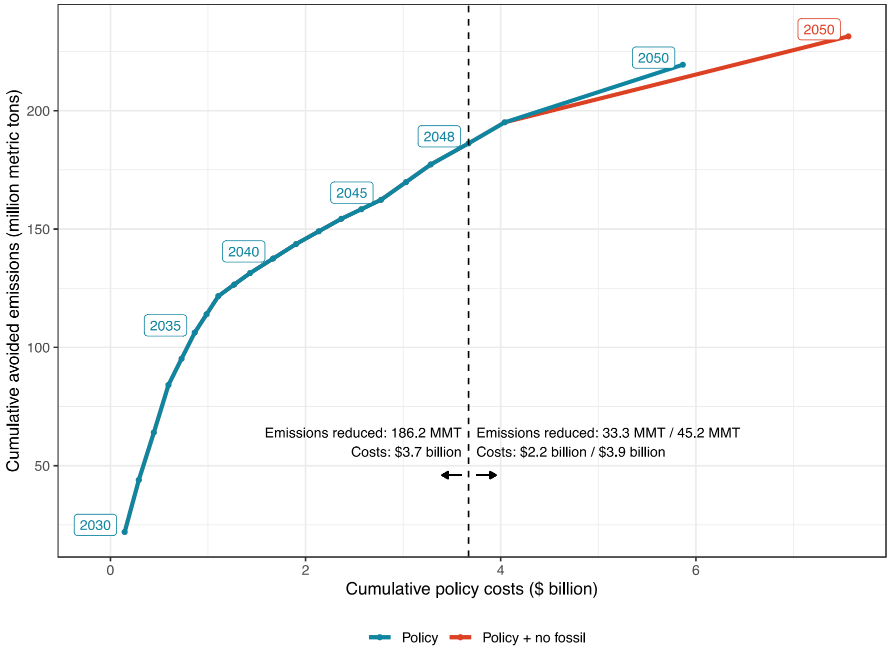
2030 timeframe

- Policy results in increase solar and storage
- Base and policy cases are similar – highlights that a substantial amount of solar and storage are economic under default assumptions

2050 timeframe

- Additional solar, along with longer-duration storage resources and offshore wind
- Deployment of “RE-CTs” as a zero-carbon peaking resource (low-capacity factor)

Capacity Expansion



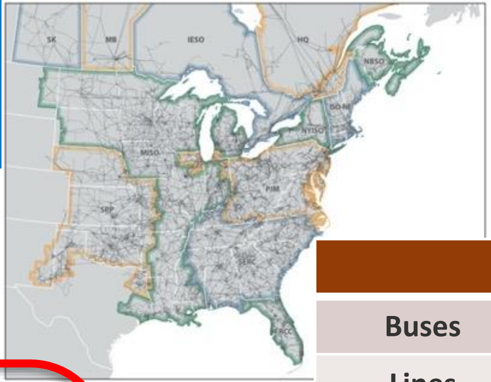
Cumulative CO_2 abatement cost through 2030 and 2050 ($ per metric ton). Values in parentheses indicate range across ReEDS sensitivities.

2030	2050
7 (6-20)	27 (9-34)

Curve illustrates cumulative avoided emissions vs. policy costs

- 2030-2035: steepness of the line reflects the fact that avoided emissions are relatively cheap
- 2035-2048: line flattens out; cost to mitigate are increasing
- 2048-2050: moving to zero carbon results in larger costs
  - Cost of removing the final 30-45 MMT of CO_2 are almost about as high as the cost of removing the first 186 MMT
  - Reflecting the increase in average cost of mitigation from ~$7 per metric ton in 2030 to ~$27 per ton in 2050

Production cost modeling cases



Nodal system

	EI	Duke
Buses	78,463	2,944
Lines	71,328	3,176
Transformers	27,901	890

Two categories of production cost modeling cases: nodal and zonal

Nodal: Full transmission representation of Duke Energy’s system; each case built by adding ReEDS builds to an existing network model

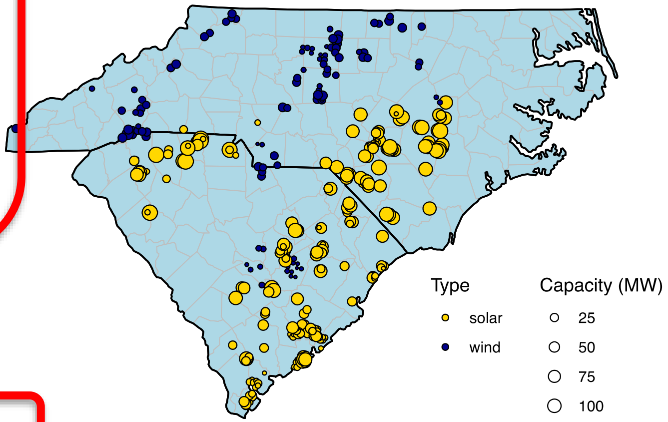
- 2024 buildout + 2012 weather (baseline)
- 2030 buildout + 2012 weather (policy case w/ 70% CO_2 reduction in NC)
- 2030 buildout modified + 2012 weather (includes accelerated coal retirements)
- 2036 buildout + 2018 weather (tests extended cold period; also includes coal retirements and offshore wind)

Zonal: Transmission matches ReEDS aggregation, with only the interfaces between BAs modeled

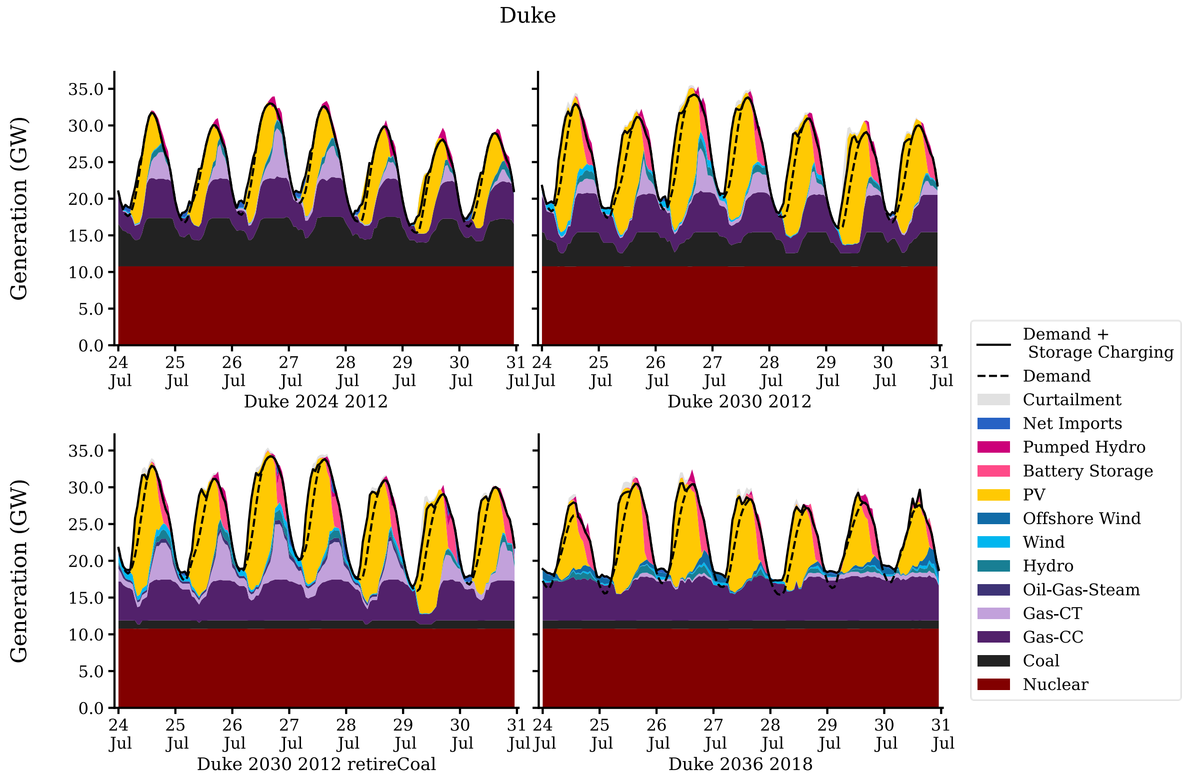
- 2024 buildout + 2012 weather (baseline)
- 2050 buildout + 2012 weather (policy case with zero-emissions)

2030 policy case, nodal model

Placement for onshore wind and utility–scale solar

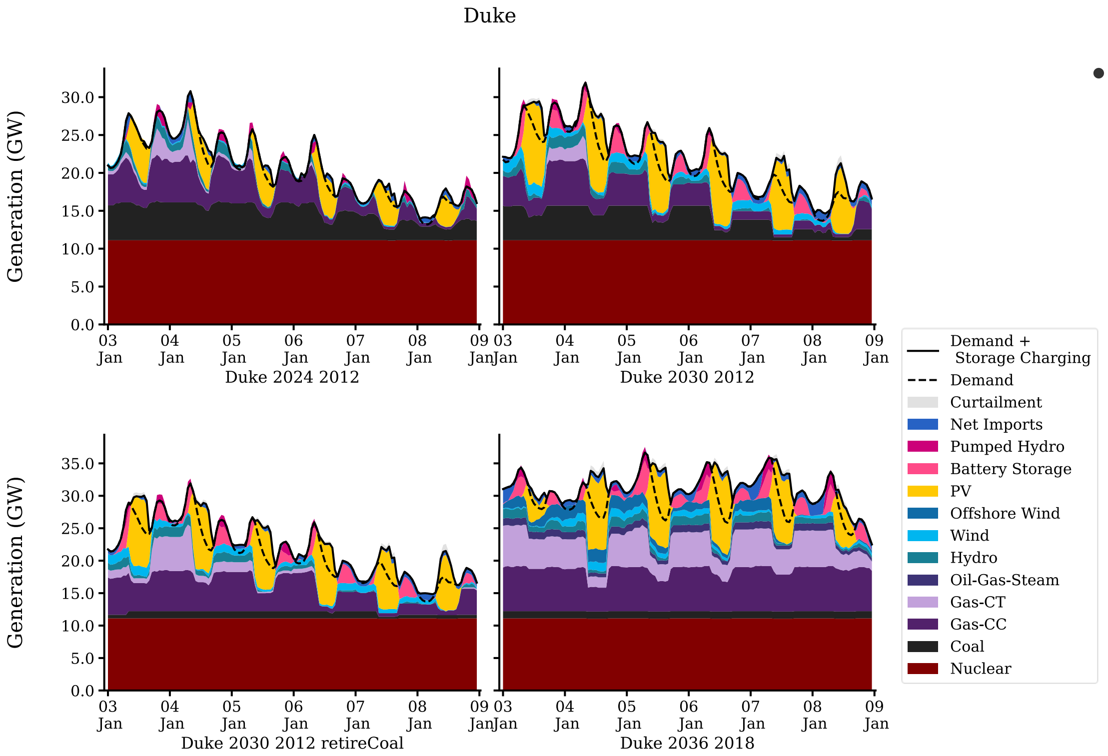


Nodal results – Summer Peak Dispatch



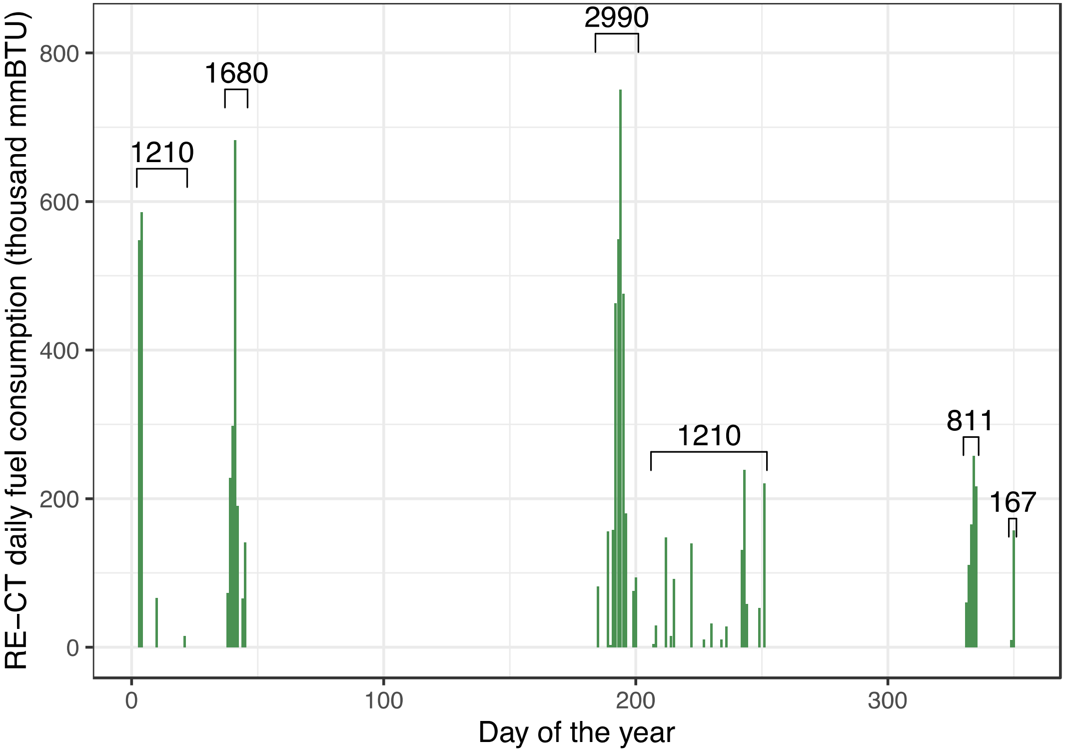
- Coal replaced with natural gas, solar, and in the 2036 buildout wind
  - Gas CTs used heavily in the evening hours after coal is retired
- Storage charges during the morning/daylight hours when solar is prevalent; discharges in the evening when solar ramps down

Nodal results – Winter Peak Dispatch



- 2012 weather year had a relatively brief winter peak which can be met primarily through a combination of nuclear, gas, solar, wind, and storage
- 2018 weather year had sustained low solar output + high load due to an extended cold snap
  - Demand peaks around 37 GW (annual peak)
  - Heavy use of Gas CC and CTs to meet demand
  - Storage charges during the day, discharges overnight
  - Offshore wind and imports help to meet remaining energy needs

RE-CT fuel consumption



- RE-CTs in the “no fossil” case are used to meet peaking requirements
  - Low annual capacity factor
  - High use when deployed
- Plot illustrates the quantity of renewably-sourced fuel that needs to be provided to sustain output in those periods
  - Could be H2, biofuel, or some other peaking resource
  - Implies sufficient pipeline infrastructure or storage capacity to supply ~3 million mmBTU at a time, and that renewable fuel is available
- Other technologies such as seasonal storage could also fill this role

Acknowledgements

- Dr. Brian Sergi – NREL
- Dr. Carlo Brancucci – NREL (Encoord)
- Prof. Michael Craig – NREL (Michigan)
- Prof. Paulina Jaramillo – CMU
- Ignacio Losada Carreno – NREL (Cornell)
- Dr. Omar Guerra – NREL
- Dr. Sue Ellen Haupt – NCAR
- Dr. Caroline Draxl - NREL

Thank you!