


ASSESSING UTILITY SCALE ENERGY STORAGE ECONOMICS CONSIDERING GENERATION ADEQUACY SERVICES

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Overview

- Introduction
- Modeling Approach & Assumptions
- Results – North Carolina Case
- Impacts of Storage in Dispatch Costs - Brazil
- Final Comments

Introduction

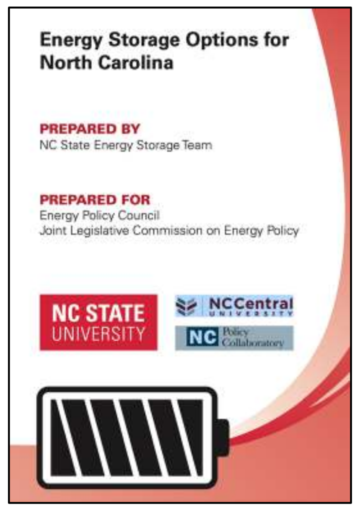
Energy Storage Options for North Carolina

Favorable conditions for energy storage technologies to assist in managing the grid operation

Public utilities commission started **efforts to analyze energy storage** systems in the North Carolina (NC)

State Congressional Order HB589 of 2017 for carvouts of Solar Generation in NC

Technical study to determine the **value of energy storage systems to NC consumers**



Energy storage capacity greater than 1 GW would be economically viable considering prices in 2030

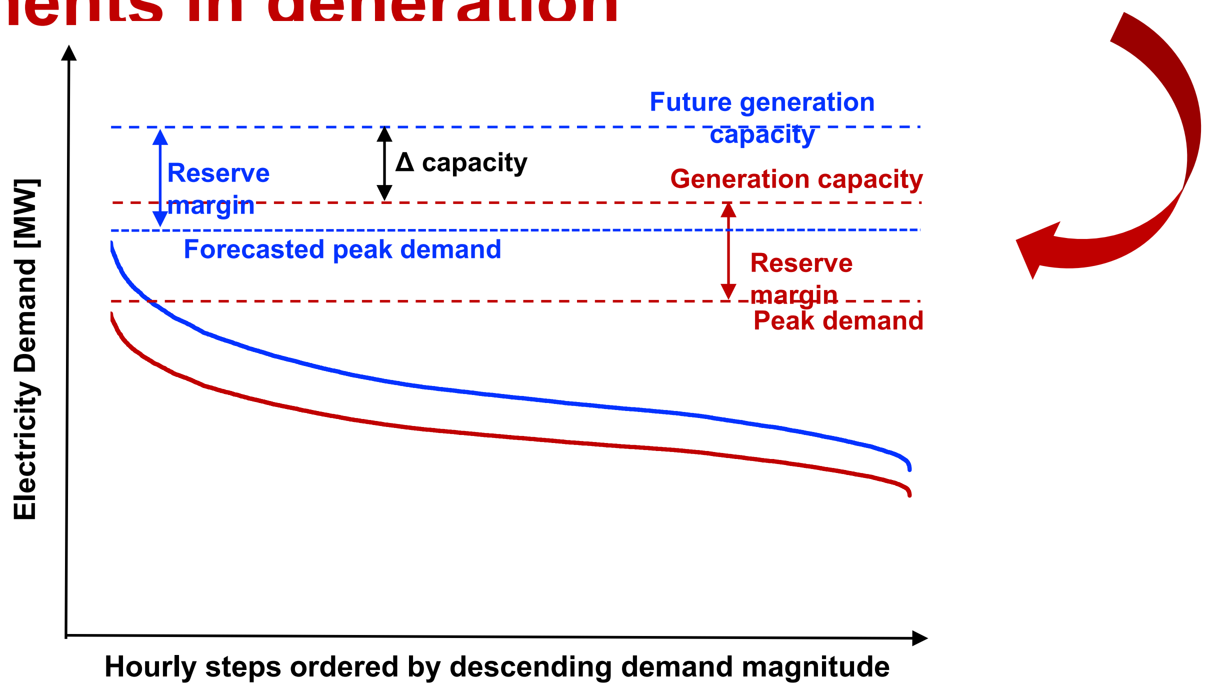
Recently Utilities started to include energy storage in their integrated investment plans

As of 08/2020 the state's largest Li-Ion battery system was deployed in **Asheville 9 MW ($15 million)**

There is still no significant state incentive for energy storage

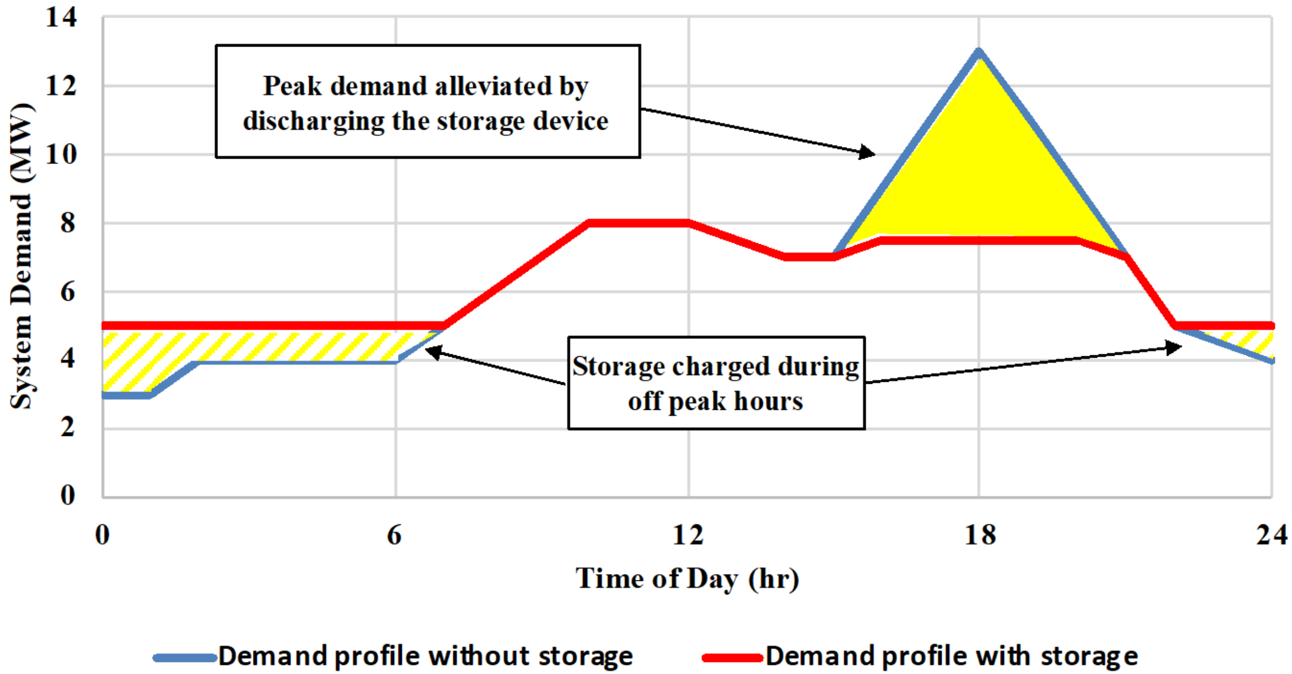
Peak Capacity Deferral

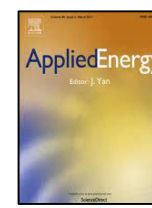
- It refers to the practice of delaying the construction or installation of new generation capacity until it is necessary to meet peak electricity
- How storage can contribute to **postpone investments in generation**



Bulk Energy Time Shifting

- Practice of shifting the delivery of large amounts of energy from one period to another. Take advantage of differences in demand & prices
- H eration
  re





Hafiz, F., de Queiroz, A.R., Fajri, P., Husain, I., (2019) Energy management and optimal storage sizing for a shared community: A multi-stage stochastic programming approach, Applied Energy, 236: 42-54

Hafiz, F., Awal, M.A., de Queiroz, A.R., Husain, I., (2020) Real-time Stochastic Optimization of Energy Storage Management using Deep Learning based Forecasts for Residential PV Applications, IEEE Transactions on Industry Applications, 56(3): 2216 – 2226

Modeling Approach & Assumptions

Optimization Model Overview

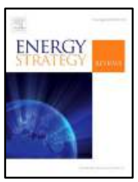
- Energy system optimization model (**Temoa**) used for two purposes:

The TEMOA Project
Tools for Energy Model Optimization and Analysis

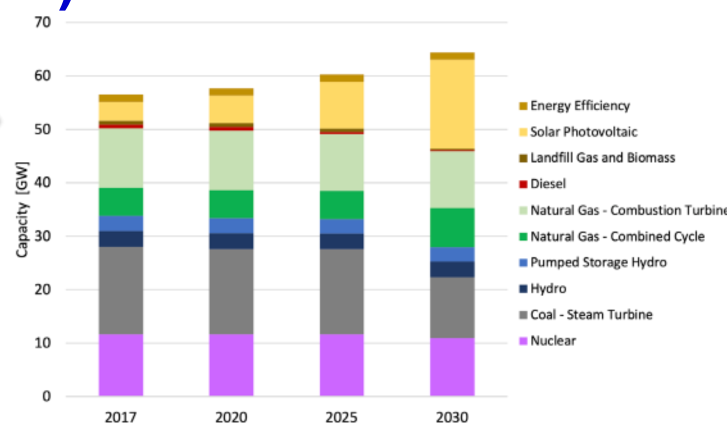
https://github.com/TemoaProject

http://temoaproject.org

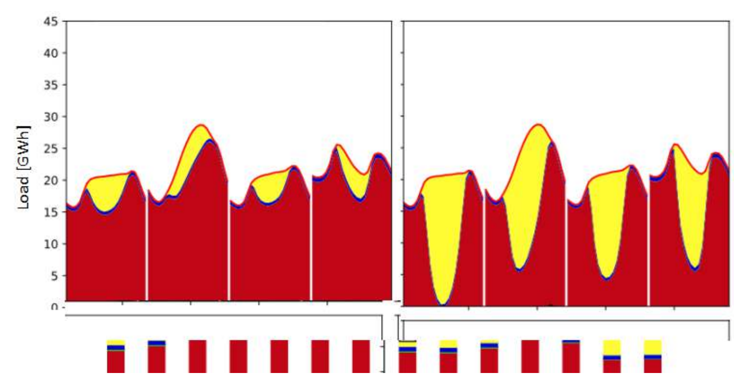
- **Capacity expansion planning (CEP)** for the area in analysis under different scenario configurations



Patankar, N., Eshraghi, H., de Queiroz, A. R., & DeCarolis, J. F. (2022). Using robust optimization to inform US deep decarbonization planning. Energy Strategy Reviews, 42, 100892



- **Operational dispatch** considering system configurations from CEP and different deployment of storage technologies



de Queiroz, A. R., Mulcahy, D., Sankarasubramanian, A., Deane, J. P., Mahinthakumar, G., Lu, N., & DeCarolis, J. F. (2019) Repurposing an energy system optimization model for seasonal power generation planning. Energy, 181, 1321-1330

Approach, Data and Assumptions

Analysis scenarios

Temoa run (Capacity Expansion)

Build out plans for the system

Introduce Energy Storage

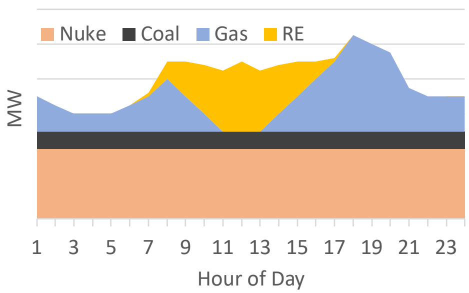
*Assume a fixed duration (energy to power ratio) and efficiency

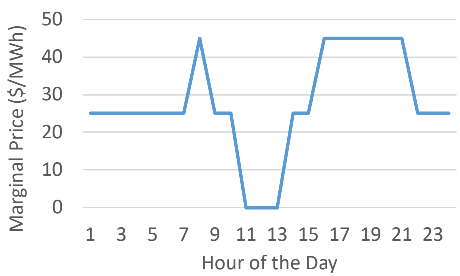
*No energy storage is considered in the initial operational dispatch runs

Temoa run (Operational Dispatch) 8760 hours in 2030

Total dispatch cost

Hourly generation dispatches





Minimize operational costs with storage

Calculate change in production costs [$/year]

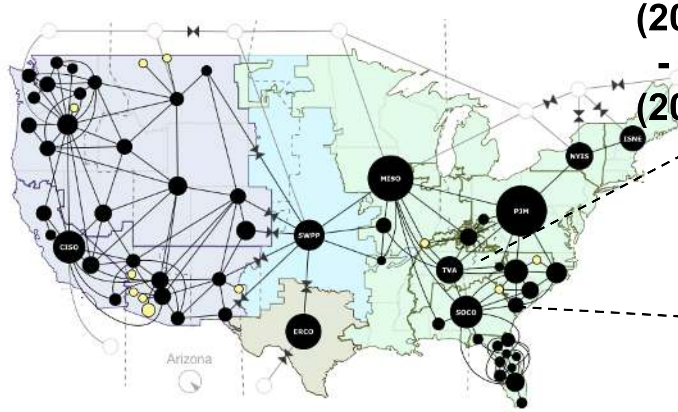
Run different storage-size configurations

Determine cost-optimal build plan for storage

Run sensitivities
- **Storage technologies**
- **Storage costs**
- **Storage efficiency**

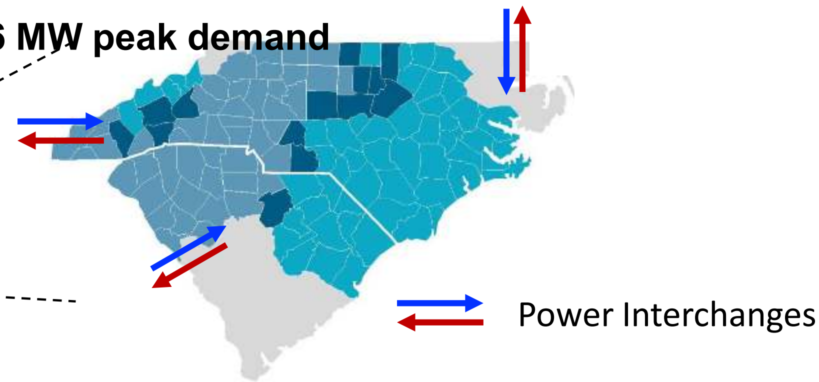
Data & Assumptions

- System representation:



Carolina's power system
- 19412 MW avg demand (2017)
- 33556 MW peak demand (2017)

1.2% increase per year
39185 MW peak demand (2030



- **Existing power generators** represented as individual power plants
- **Future generators** grouped by their respective generation class

- Sources:

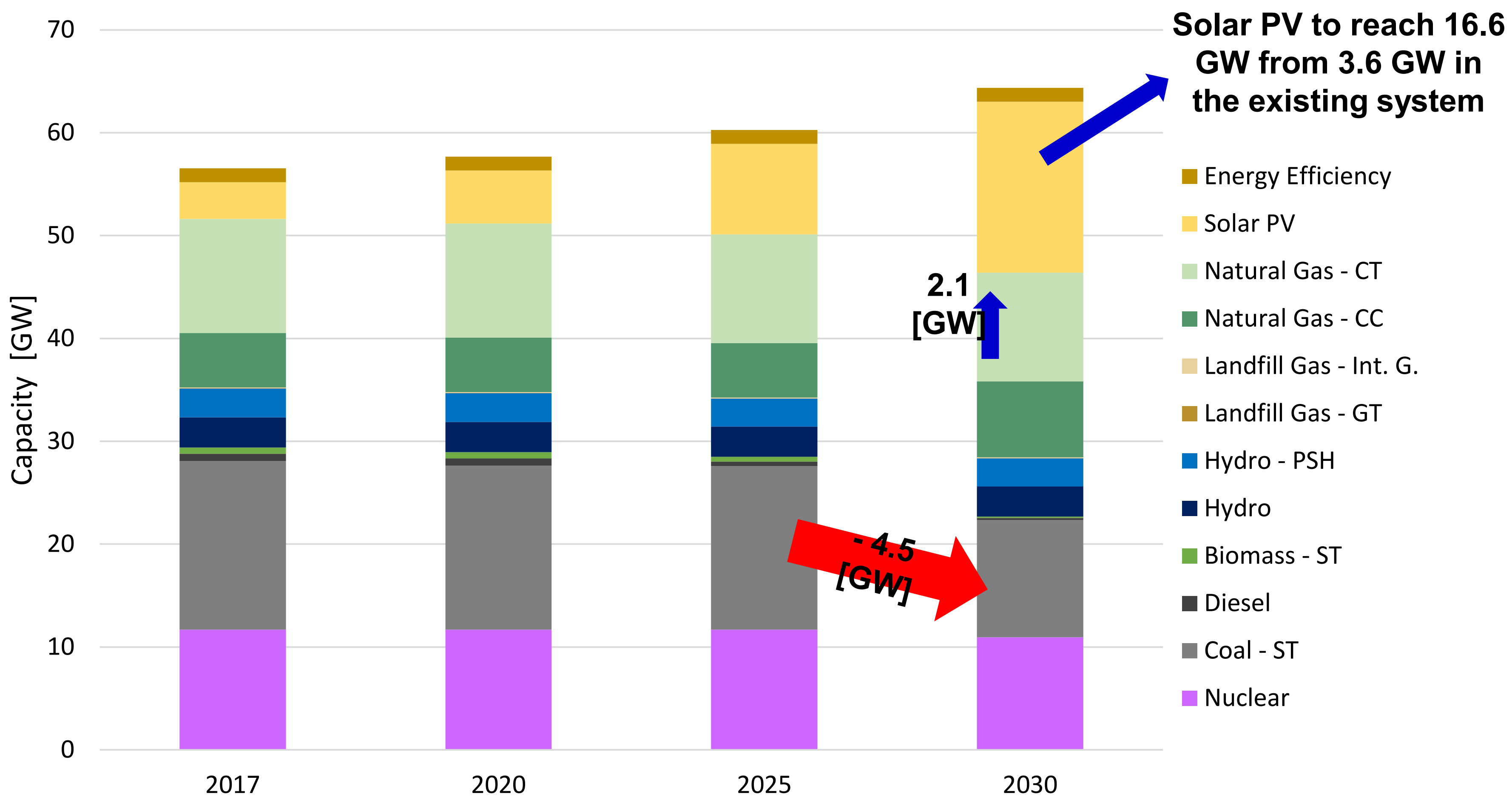
EIA Annual Electric Generator data, form [EIA-860]
EIA electric utility data survey, form [EIA-923]
[EIA's U.S. Electric System Operating Data Tool]
NREL Annual Technology Baseline - [ATB]
NREL Solar and Wind Energy Resource Assessment - [SWERA]

Analysis Scenarios

1. Base case
   - **2017 Carolinas Power generation system**
   - **HB589 solar PV deployments (5.9 GW by 2022)**
   - **Fixed representation of the exchanges**
2. Duke IRP
   - **Scenario matches the build-outs proposed by Duke's 2 IRP**
3. Expanded RPS
   - **RPS expanded to 2030 with a target of 40% for renewables (solar, wind, biomass, small hydro)**
4. Clean Energy Standard
   - **60% target of clean energy sources by 2030**
5. Carbon Cap
   - **Duke's 2017 Climate Report to Shareholders: 40% reduction in 2005 CO_2 emissions levels by 2030**
6. Natural Gas Prices
   - **High Projection from EIA AEO 2018**
7. Deployment of Plug-in Electric Vehicles

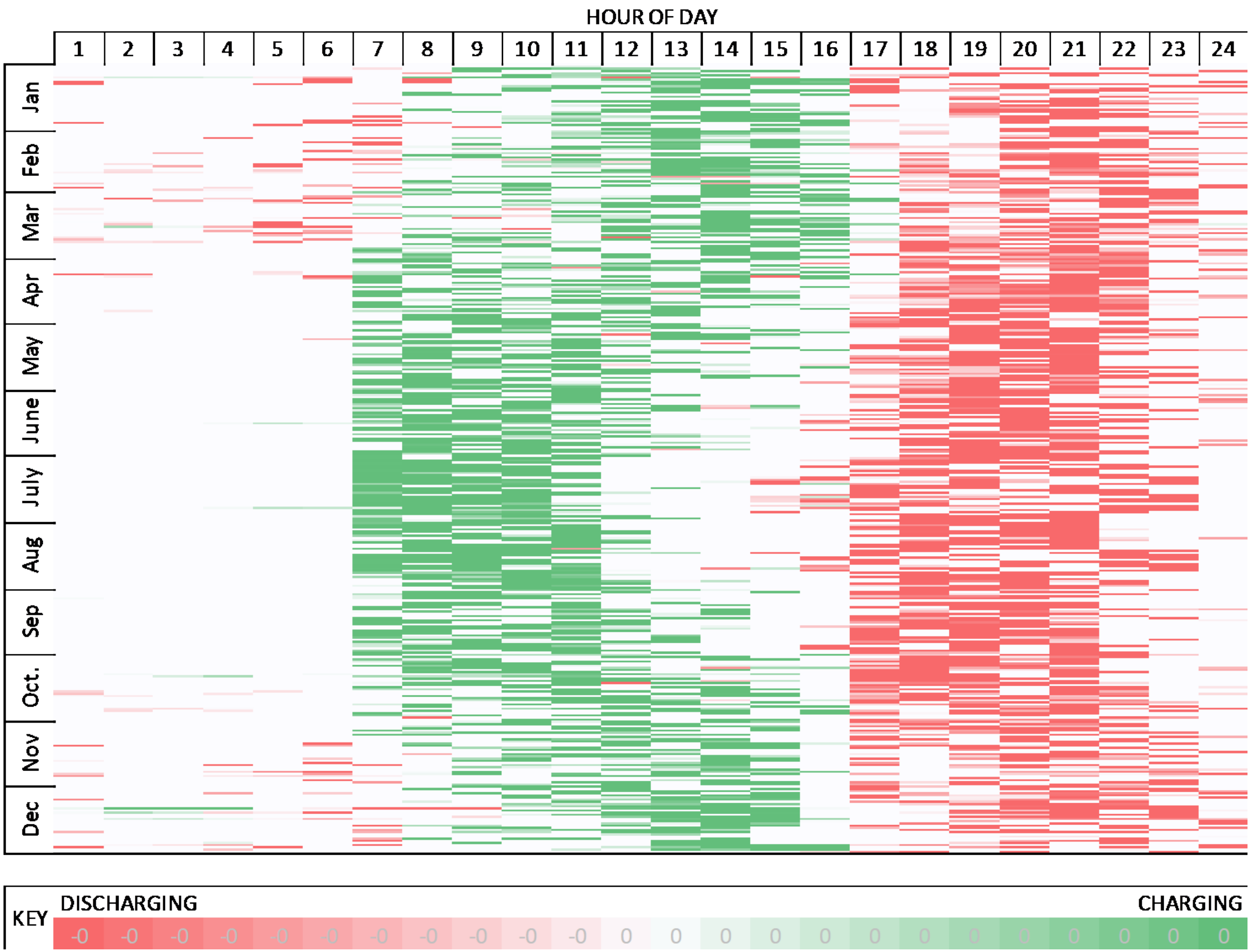
Results – North Carolina Case

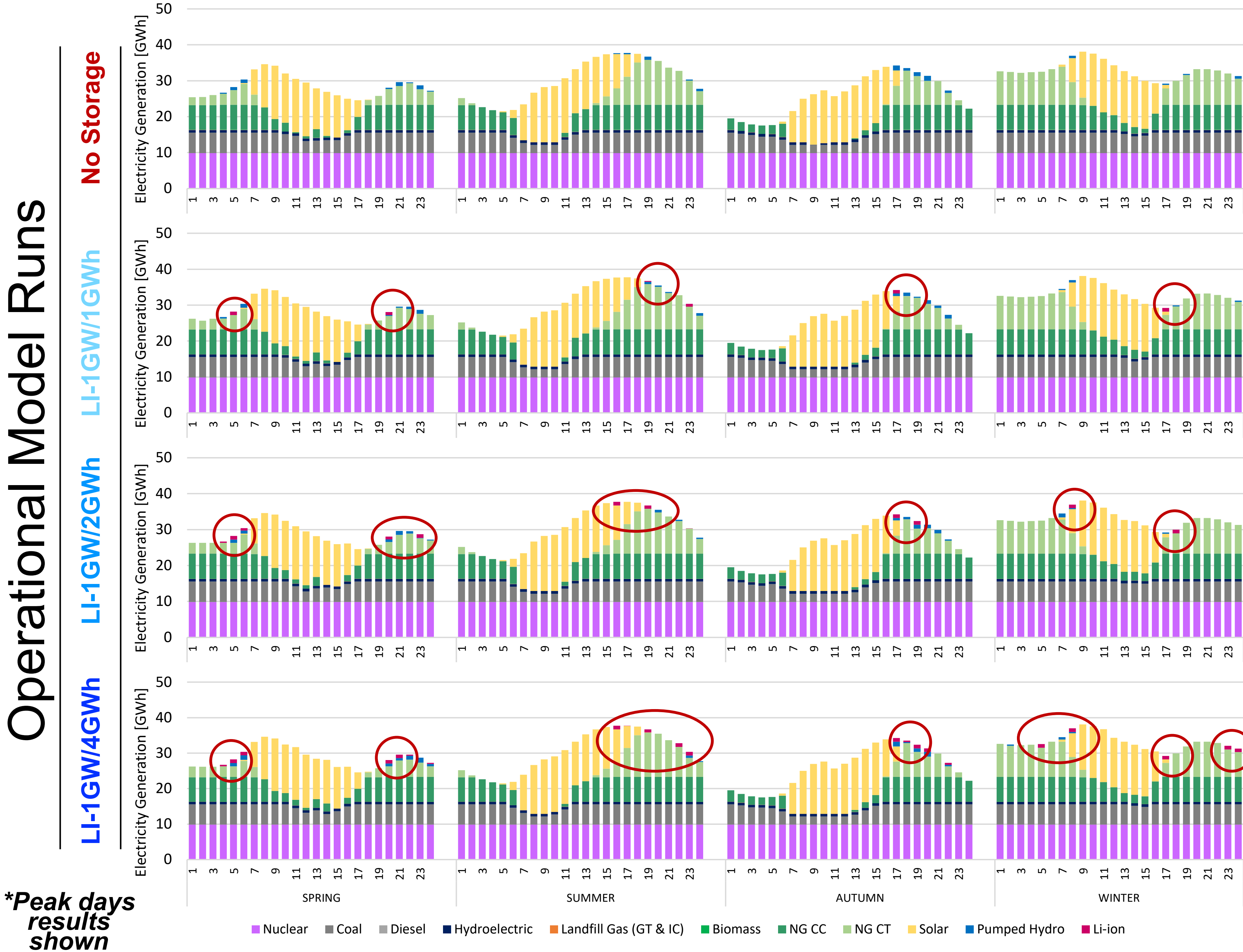
Base Case – Installed Capacity

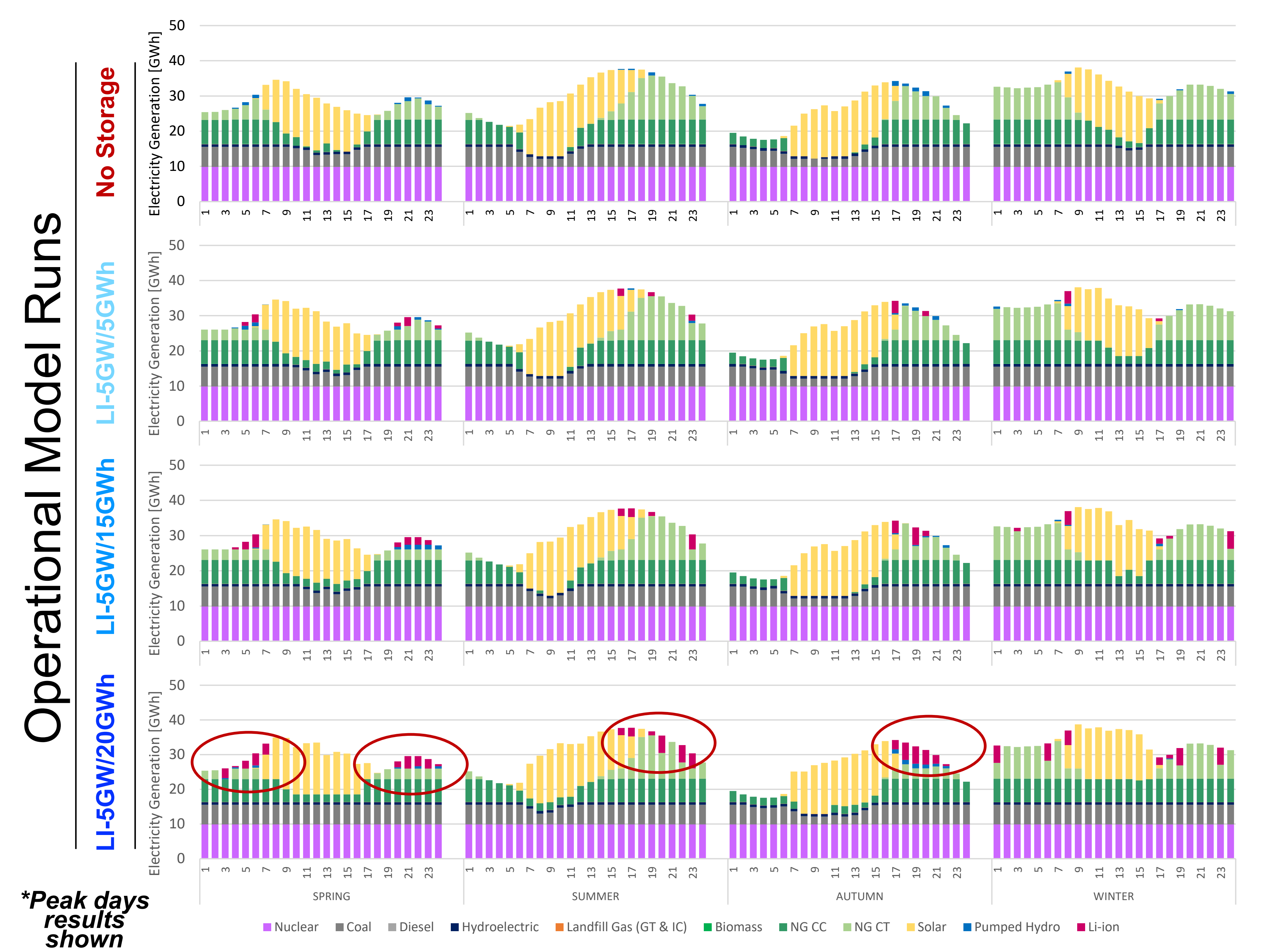


Charging/Discharging Profile - LI-1GW/4GWh

Example of a charging profile for a LI-1GW/4GWh during the course of 8760 hours in the operational model run




Operational Model Runs
No Storage
LI-1GW/1GWh
LI-1GW/2GWh
LI-1GW/4GWh
Electricity Generation [GWh]
0
10
20
30
40
50
SPRING
SUMMER
AUTUMN
WINTER
Nuclear
Coal
Diesel
Hydroelectric
Landfill Gas (GT & IC)
Biomass
NG CC
NG CT
Solar
Pumped Hydro
Li-ion
*Peak days results shown


Operational Model Runs
No Storage
LI-5GW/5GWh
LI-5GW/15GWh
LI-5GW/20GWh
Electricity Generation [GWh]
SPRING
SUMMER
AUTUMN
WINTER
Nuclear
Coal
Diesel
Hydroelectric
Landfill Gas (GT & IC)
Biomass
NG CC
NG CT
Solar
Pumped Hydro
Li-ion
*Peak days results shown

Cost-Benefits Assessment

- Energy Savings

$$ES_i^k = TC_{NS} - TC_i \quad \forall i \in I_k, \forall k \in K$$

Operational dispatch costs with storage

Operational dispatch costs without storage

- Capacity Value

Cost of new entry Gas CT ($/kW-year)

$$CV_i^k = (ECP_i \times P_i)\,CONE \quad \forall i \in I_k, \forall k \in K$$

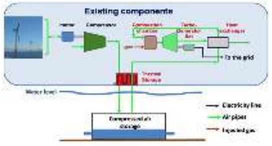
Capacity (kW)

Capacity credit (%)

- Total Benefits

$$SB_i^k = ES_i^k + CV_i^k \quad \forall i \in I_k, \forall k \in K$$

- Finding the best storage configuration



$$\underset{P}{\operatorname{argmax}}\{SB_i^k - (P_i \times RR_i^k)\}$$

Storage revenue requirement ($/kW-year)

**CONE for a Gas CT estimated at 113 ($/kW-year)*

Total Benefits vs Revenue Requirements

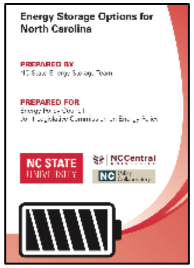
Total net benefits ($/kWyr) of lithium-ion batteries and pumped hydro for **shifting energy** over time and **deferring new investments** in generation

	duration (h)	LI (2019) 0.3GW	LI (2019) 1GW	LI (2019) 3GW	LI (2019) 5GW	LI (2030) 0.3GW	LI (2030) 1GW	LI (2030) 3GW	LI (2030) 5GW
Base Case	1	-100	-101	-102	-100	-13	-14	-15	-13
	2	-80	-81	-84	-86	12	11	8	6
	4	-117	-119	-125	-131	5	3	-4	-10
Duke IRP	1	-87	-97	-101	-101	0	-10	-14	-14
	2	-67	-78	-83	-86	25	14	9	6
	4	-105	-117	-126	-133	17	5	-4	-11
Expanded REPS	1	-77	-90	-95	-96	10	-3	-8	-9
	2	-52	-65	-72	-75	41	27	20	17
	4	-80	-95	-105	-111	42	27	17	11
Clean Energy Standard	1	-99	-99	-101	-101	-12	-12	-14	-14
	2	-66	-79	-82	-83	26	13	11	9
	4	-100	-115	-120	-125	21	7	2	-3
Carbon Cap	1	-97	-98	-100	-100	-10	-11	-13	-13
	2	-75	-77	-80	-82	17	15	12	11
	4	-109	-111	-117	-122	13	10	5	0
High Natural Gas Price	1	-95	-87	-95	-97	-8	0	-8	-10
	2	-42	-64	-73	-76	50	28	19	16
	4	-70	-94	-107	-116	52	28	14	6
Electric Vehicles	1	-111	-106	-105	-105	-24	-19	-18	-18
	2	-93	-88	-89	-91	-1	4	4	1
	4	-134	-131	-136	-143	-12	-9	-14	-21

	duration (h)	PSH 0.3GW	PSH 1GW	PSH 3GW	PSH 5GW
Base Case	8	53	47	30	14
Duke IRP	8	64	48	29	12
Expanded REPS	8	110	94	75	61
Clean Energy Standard	8	67	60	45	30
Carbon Cap	8	73	67	52	38
High Natural Gas Price	8	111	83	56	34
Electric Vehicles	8	26	27	12	-1

We can observe that several configurations of Li-Ion and PSH would provide positive benefits to the NC system projected to 2030

https://energy.ncsu.edu/storage/

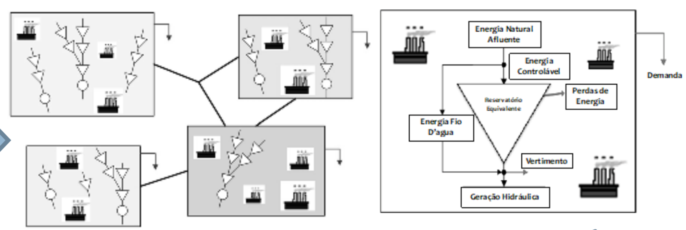


Impacts of Storage in Dispatch Costs - Brazil

Modeling Framework – Brazilian System

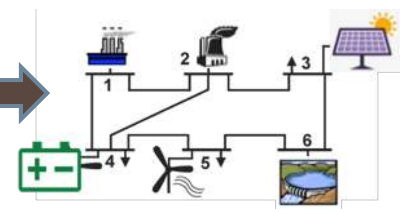
- **Hydro-dominant Power System** (~70% of production of **65GWavg**)
- Individual Hydro and Thermal Plants Representation
- **Interconnection between Regions**
- De-rating factor, efficiency, capacity factor, and transmission losses

NEWAVE



Monthly Hydro Generation by Aggregated Reservoir

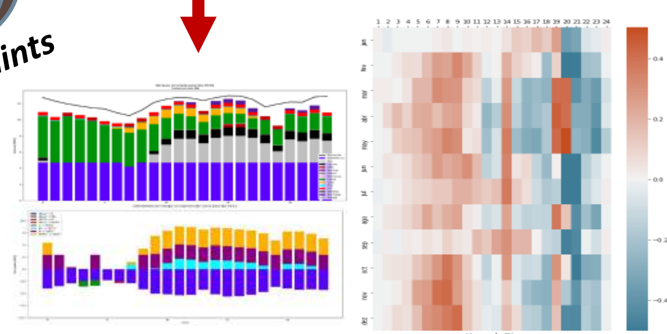
TEMOA



Hourly information by region

- Wind
- Solar
- Demand

Constraints



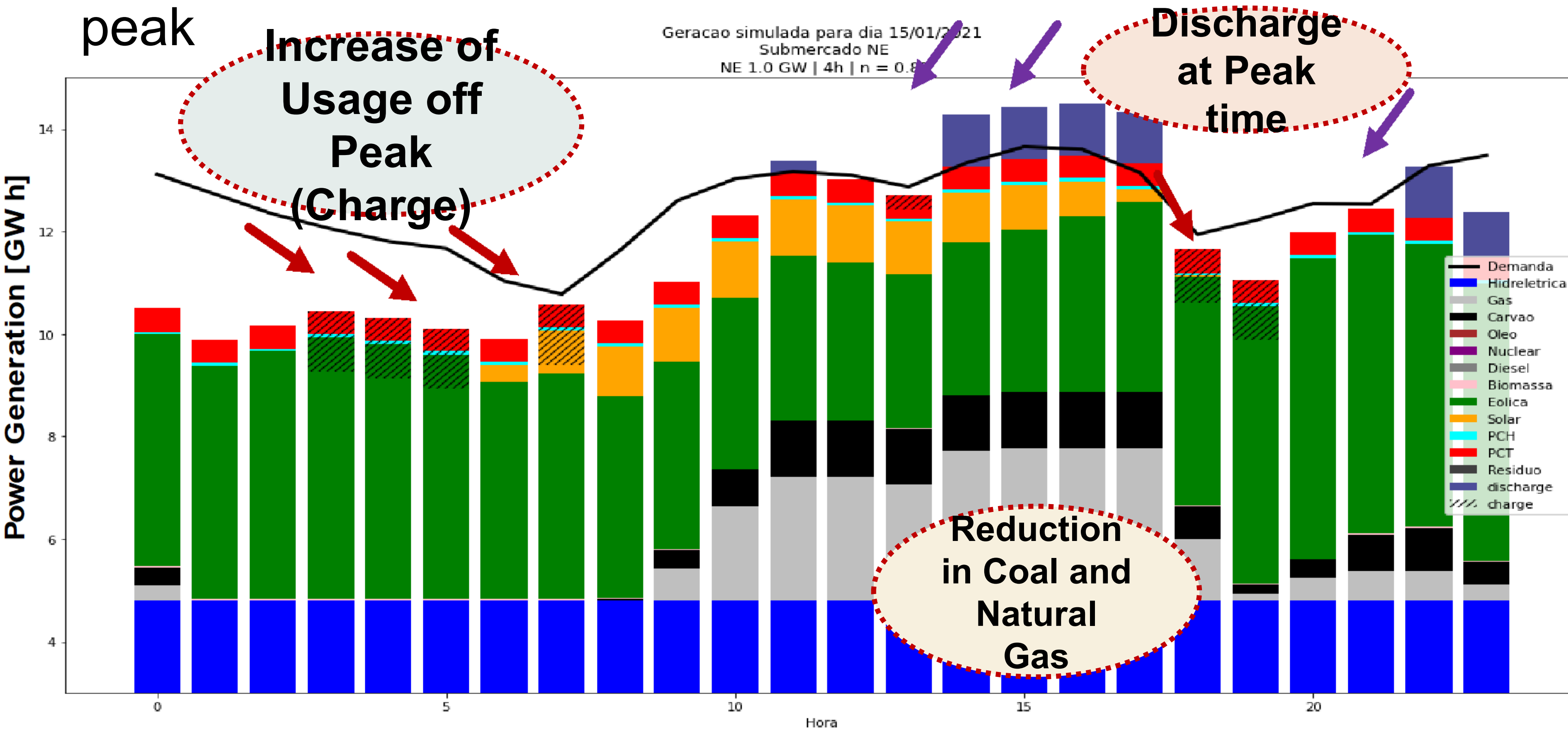
Outputs:

- Generation dispatch per plant
- Storage Charge/Discharge
- Energy Exchanges between Regions
- Total Operational Costs

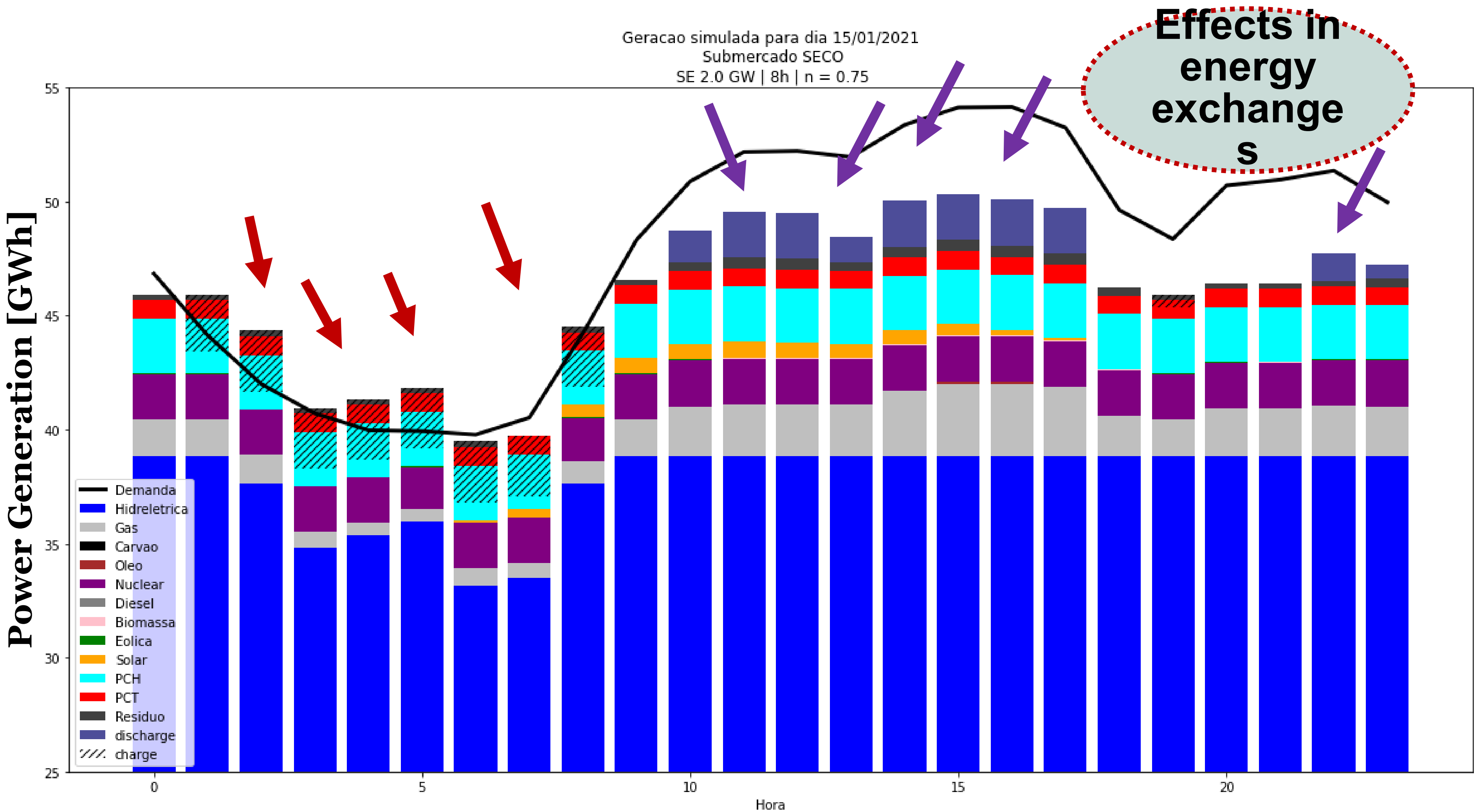
Results – 1GW/4h Deployed in the Northeast

Optimization model decides to charge energy storage off peak and discharge at peak

Case: Deployment of 1GW/4h NE



Results – 2GW/8h Deployed in the Southeast



Impacts in Total Operational Dispatch Costs

		Operational Costs	Yearly ≠	% ≠
PMO JAN 2021	Caso Base	R$ 3,095,735,478.81	-	-
	0.5GW/4h NE	R$ 3,027,438,253.09	R$ 68,297,225.72	2.21%
	1GW/4h NE	R$ 2,968,356,135.78	R$ 127,379,343.03	4.11%
	2GW/4h NE	R$ 2,873,845,056.25	R$ 221,890,422.56	7.17%
	4GW/24h NE	R$ 2,802,850,998.80	R$ 292,884,480.01	9.46%
	2GW/8h SE	R$ 2,721,487,681.82	R$ 374,247,796.99	12.09%
PDE 2030	Caso Base	R$ 12,062,398,526.10	-	-
	0.5GW/4h NE	R$ 11,986,997,334.80	R$ 75,401,191.30	0.63%
	1GW/4h NE	R$ 11,921,727,024.20	R$ 140,671,501.90	1.17%
	2GW/4h NE	R$ 11,812,433,223.20	R$ 249,965,302.90	2.07%
	4GW/24h NE	R$ 11,821,421,457.50	R$ 240,977,068.60	2.00%
	2GW/8h SE	R$ 11,754,140,482.30	R$ 308,258,043.80	2.56%

Significant reductions in terms of total operational dispatch costs, **reaching 12%** in a case with **2GW/8h of pumped hydro storage** placed in the Southeast region of the country

Final Comments

- This is the **first comprehensive** open-source modeling effort to develop projections for the **Carolinas power system**
- It can be used to **assess economic, technical, and policy futures** and provide valuable insights to decision makers
- Model and analyze other scenarios, e.g.:
  - Bidirectional capabilities for EVs
  - 100% of clean energy
  - Wider range of future fuel prices and policies
- Framework adapted to investigate energy storage in **Brazil**
- Collaboration with Polytechnic de Torino to look at **Italy and European** cases

Thank You !

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NC STATE UNIVERSITY

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