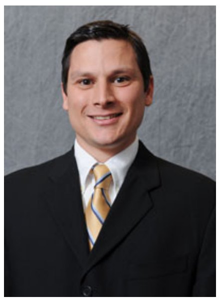
VALUE STREAMS FOR UTILITY SCALE STORAGE PROJECTS FOR PROVIDING GENERATION ADEQUACY SERVICES

Prof. Anderson Rodrigo de Queiroz

Charleston, 11/15/18

The Research Team



Prof. Joseph DeCarolis

Prof. Jeremiah Johnson

Prof. Anderson R. de Queiroz

Eng. Dustin Soutendjik

Eng. Daniel Sodano

FREEDM SYSTEMS CENTER

NC STATE UNIVERSITY

Department of Civil, Construction, & Environmental ENGINEERING

NORTH CAROLINA CENTRAL UNIVERSITY FOUNDED 1910

SCHOOL OF BUSINESS

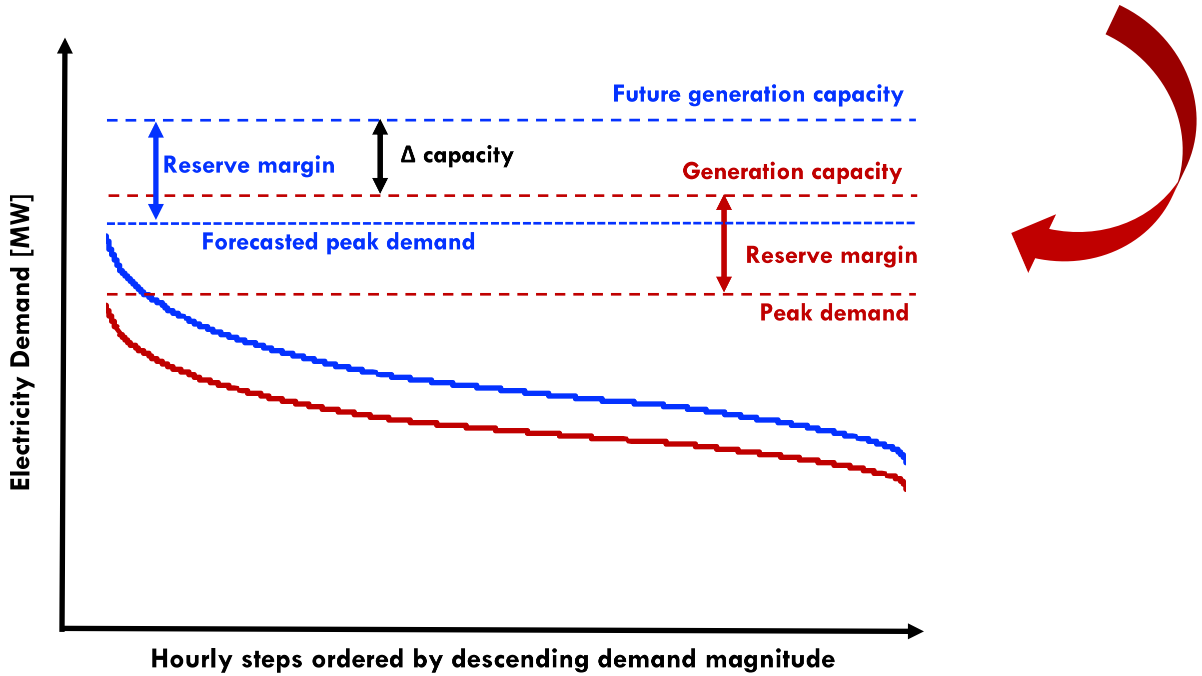
Overview

- Introduction
- Modeling Approach & Assumptions
- Generation Build Outs & Operations
- Cost-Benefit Analysis for Lithium-Ion Batteries
- Final Comments

Introduction

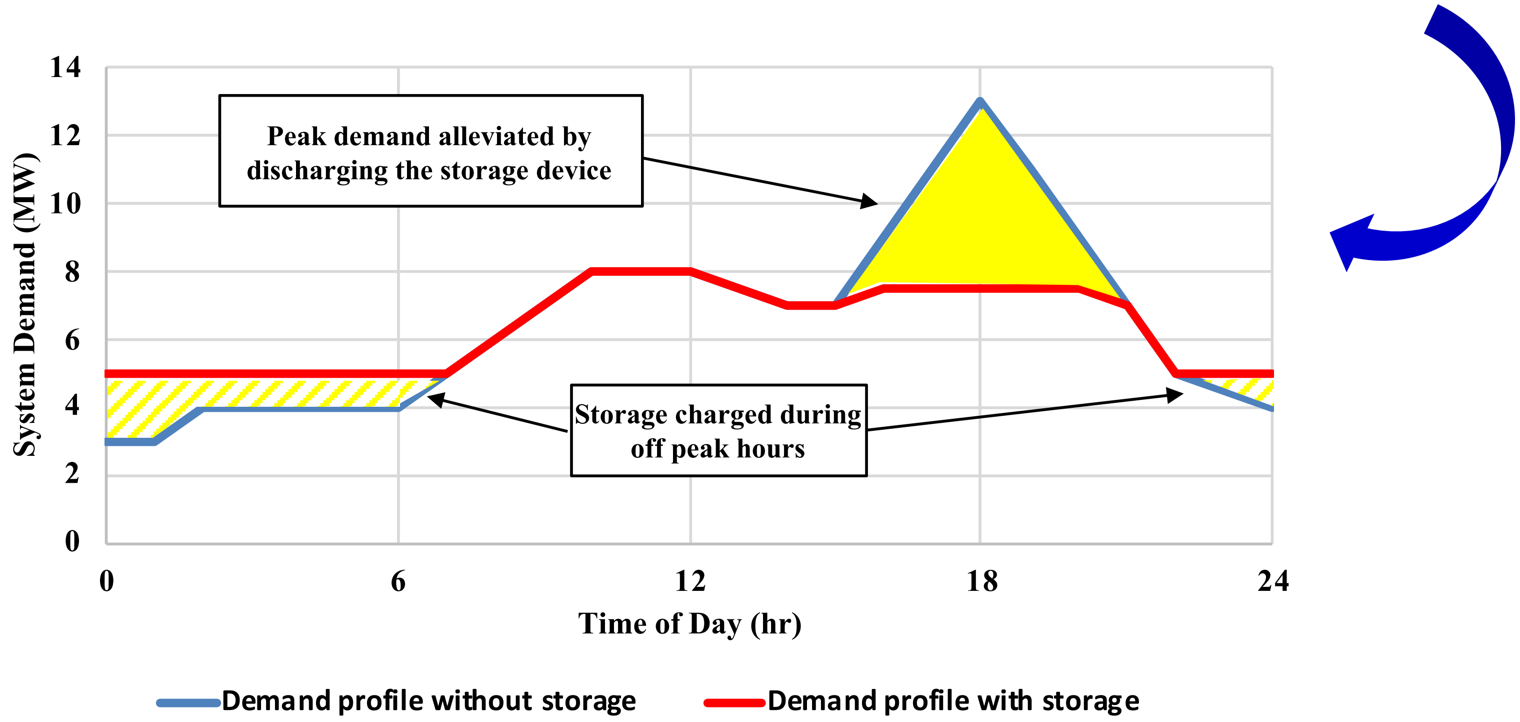
Introduction

- The overall goal is to evaluate how storage can contribute to Generation/Resource Adequacy, more specifically:
  - **Peak Capacity Deferral**
    - How storage can contribute to **postpone investments in generation**



Introduction *(cont.)*

- **Bulk Energy Time Shifting**
  - How storage can contribute to better **economic generation** resources



Storage Technologies to be Considered

Mechanical

- Flywheels
- Pumped storage
- Compressed Air

Electrochemical

- Lithium-ion batteries
- Lead-acid batteries
- High T sodium batteries
- Flow batteries

Chemical

- H_2 electrolysis + storage + fuel cells

Thermal

- Chilled water
- Ice storage
- Phase change materials
- Water heaters

Electrical

- Supercapacitors
- Superconducting magnetic energy storage

Modeling Approach & Assumptions

Optimization Model Overview

- We will run an energy system optimization model (**Temoa**) for two purposes:

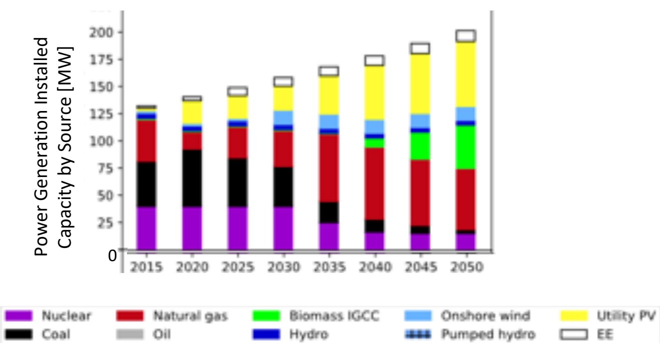
The TEMOA Project

Tools for Energy Model Optimization and Analysis

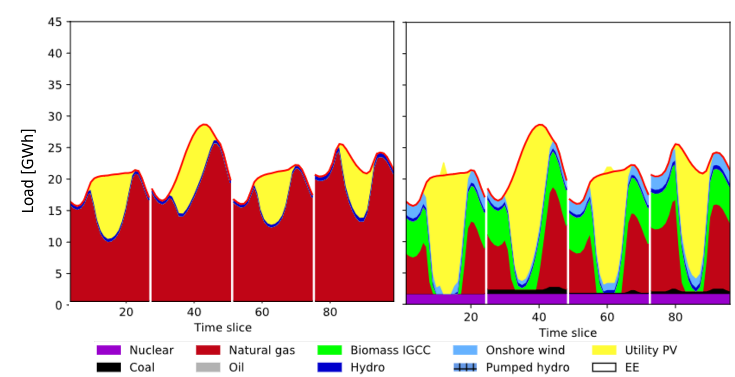
https://github.com/TemoaProject

http://temoaproject.org

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



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



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 2018 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

Approach, Data and Assumptions

Analysis scenarios

Temoa run (Capacity Expansion)

Build out plans for the system

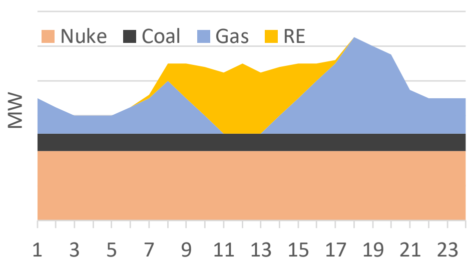
Introduce Energy Storage

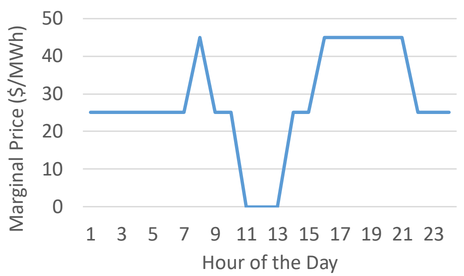
*Assume a fixed duration (energy to power ratio) and efficiency

Temoa run (Operational Dispatch) 8760 hours in 2030

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

- **Total dispatch cost**
- **Hourly power generation dispatches**





- **Minimize operational costs with storage**
- **Calculate change in production costs [$/year]**

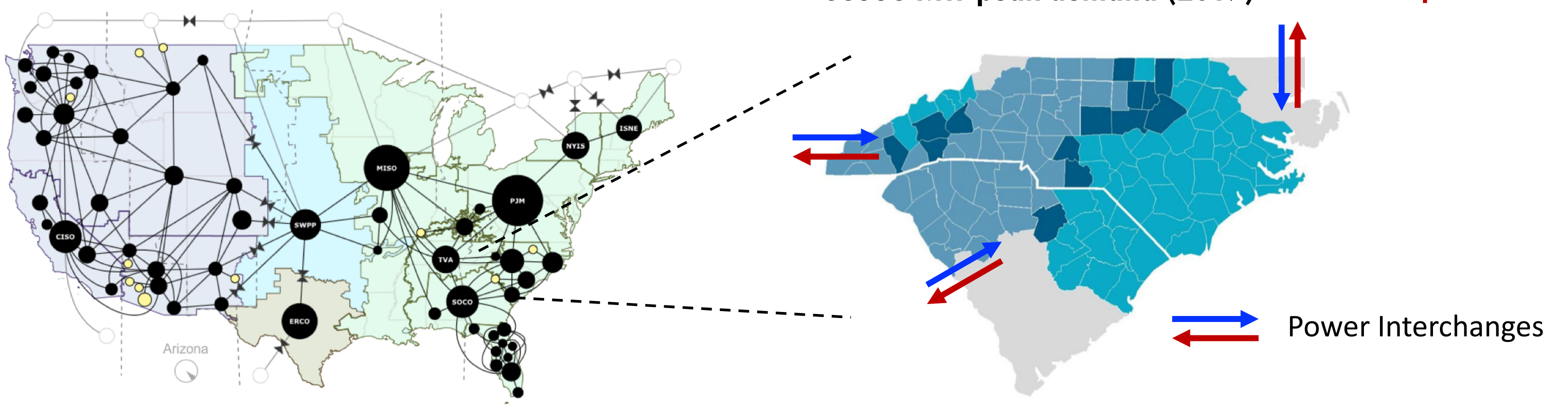
- **Run different storage-size configurations**
- **Determine cost-optimal build plan for storage**

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

Data & Assumptions

- System representation:

Carolina's power system
- 19412 MW avg demand (2017) **1.2% increase per year**
- 33556 MW peak demand (2017) **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

Cost-Benefits Assessment

- Energy Savings

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

TC_i → Operational dispatch costs with storage

TC_{NS} → Operational dispatch costs without storage

- Capacity Value

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

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

P_i → Capacity (kW)

ECP_i → Capacity credit (%)

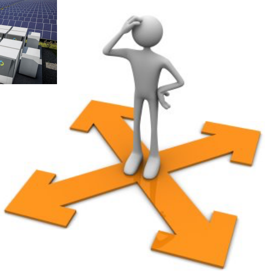
- Total Benefits

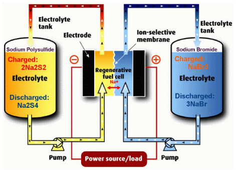
$$SB_i^k = ES_i^k + CV_i^k \quad \forall i \in I_k, \forall k \in K$$

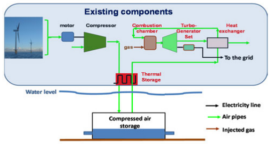
- Finding the best storage configuration

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

RR_i^k → Storage revenue requirement ($/kW-year)







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

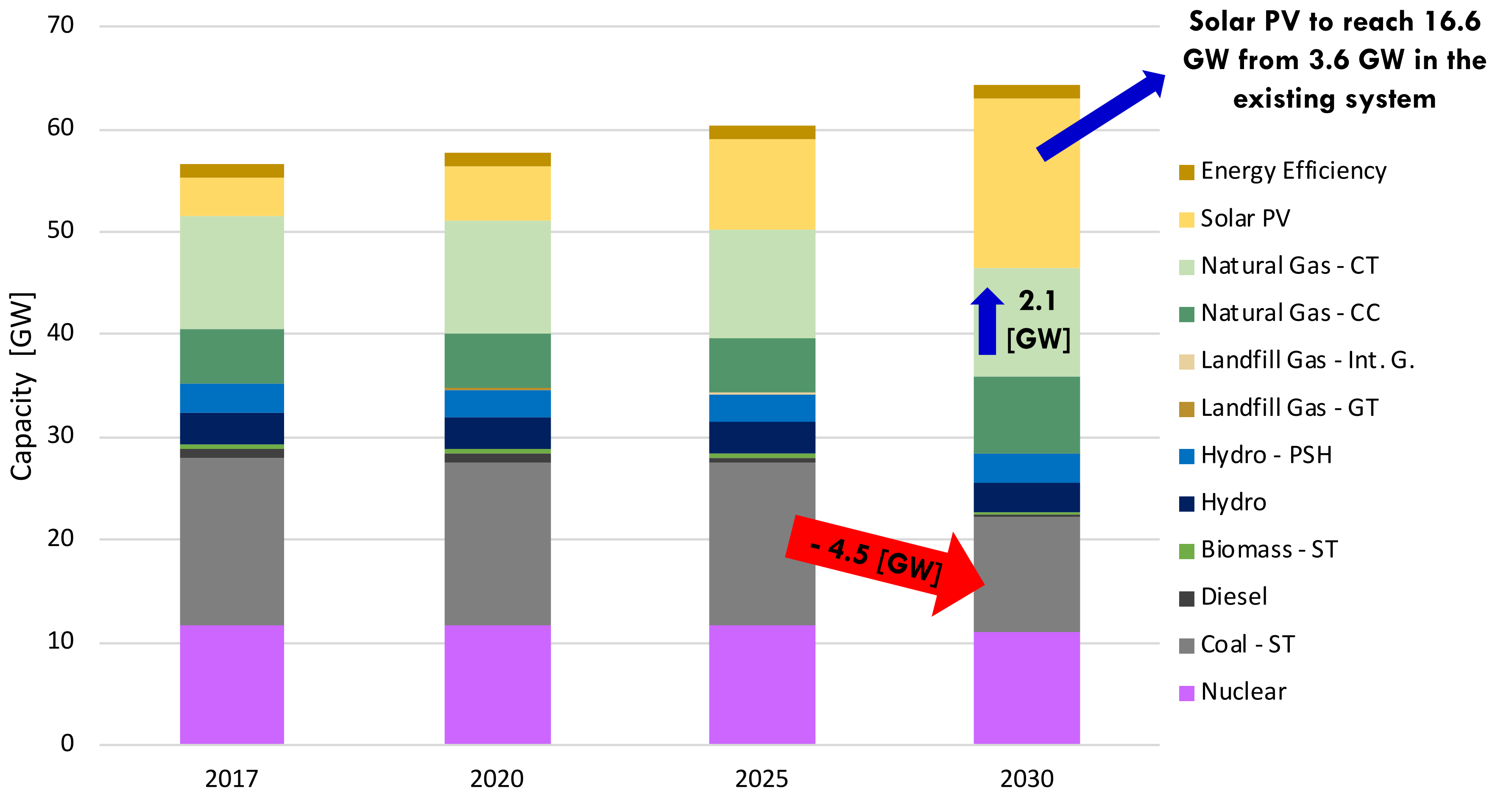
Energy Storage Sizes

- The analysis presented here considers only the base case scenario and lithium-ion batteries
- The following energy storage configurations are considered:

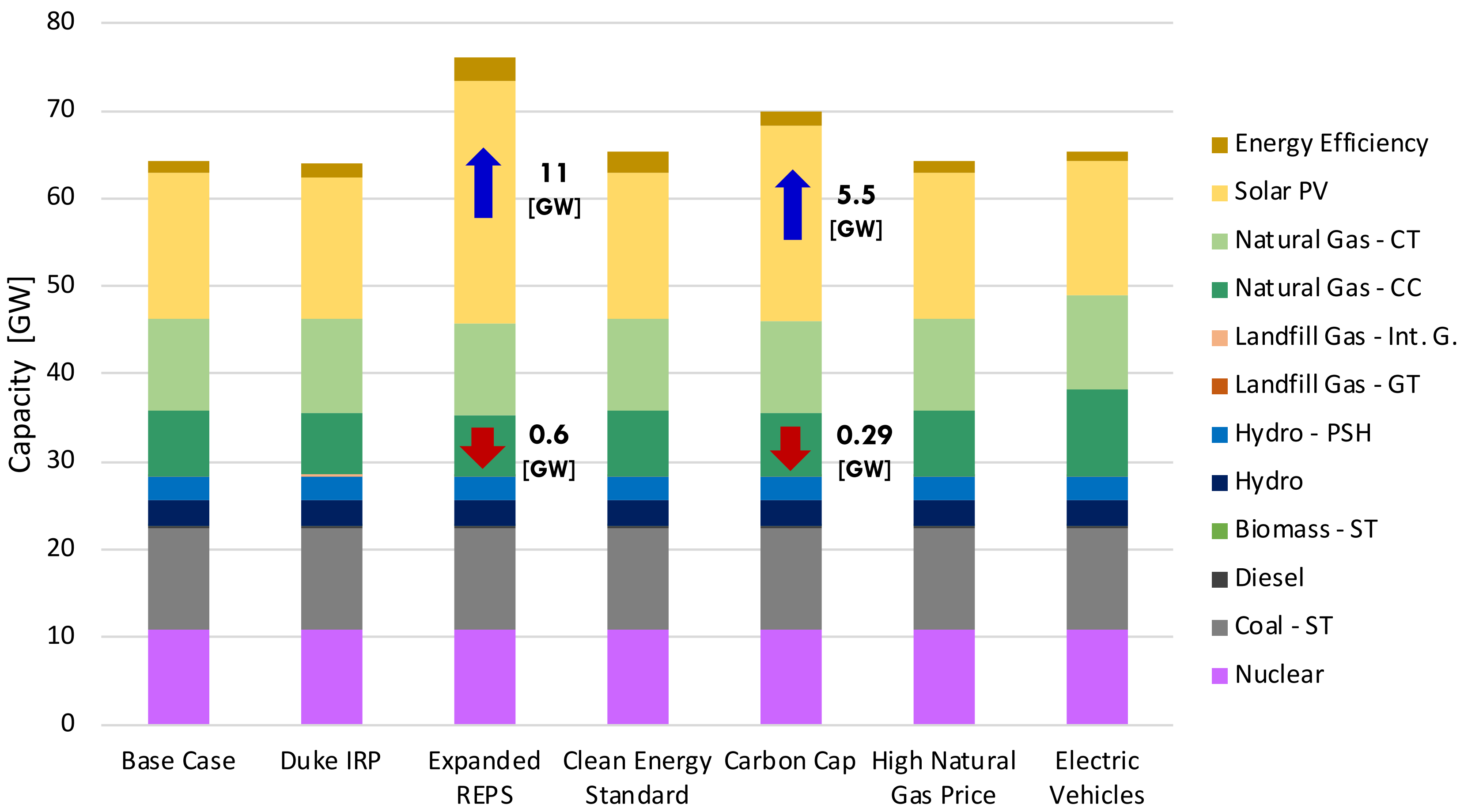
Power/Duration	1 hour	2 hours	4 hours
0.3 GW	LI-0.3GW/0.3GWh	LI-0.3GW/0.6GWh	LI-0.3GW/1.2GWh
1 GW	LI-1GW/1GWh	LI-1GW/2GWh	LI-1GW/4GWh
3 GW	LI-3GW/3GWh	LI-3GW/6GWh	LI-3GW/12GWh
5 GW	LI-5GW/5GWh	LI-5GW/10GWh	LI-5GW/20GWh

Preliminary Results

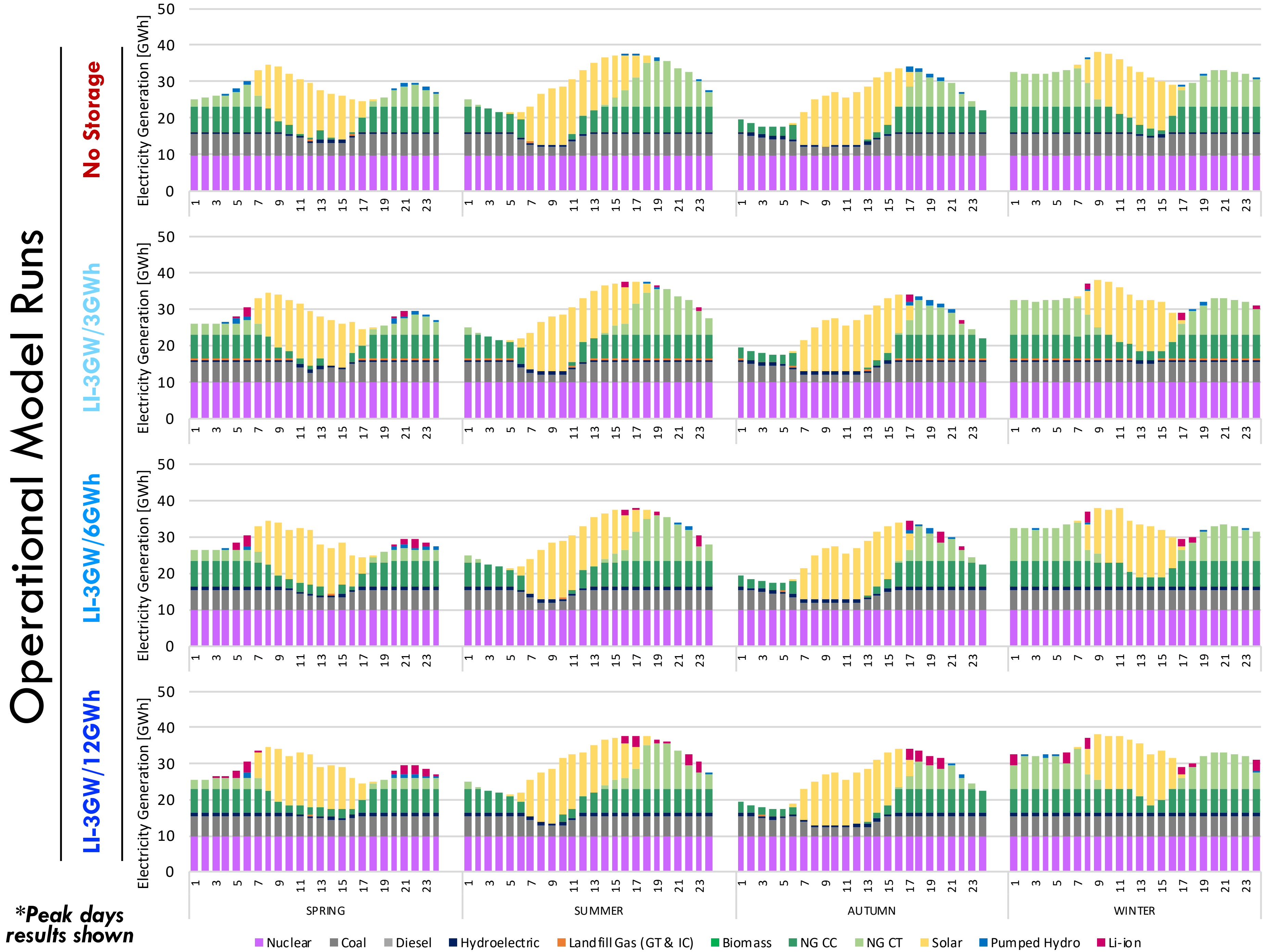
Base Case – Installed Capacity



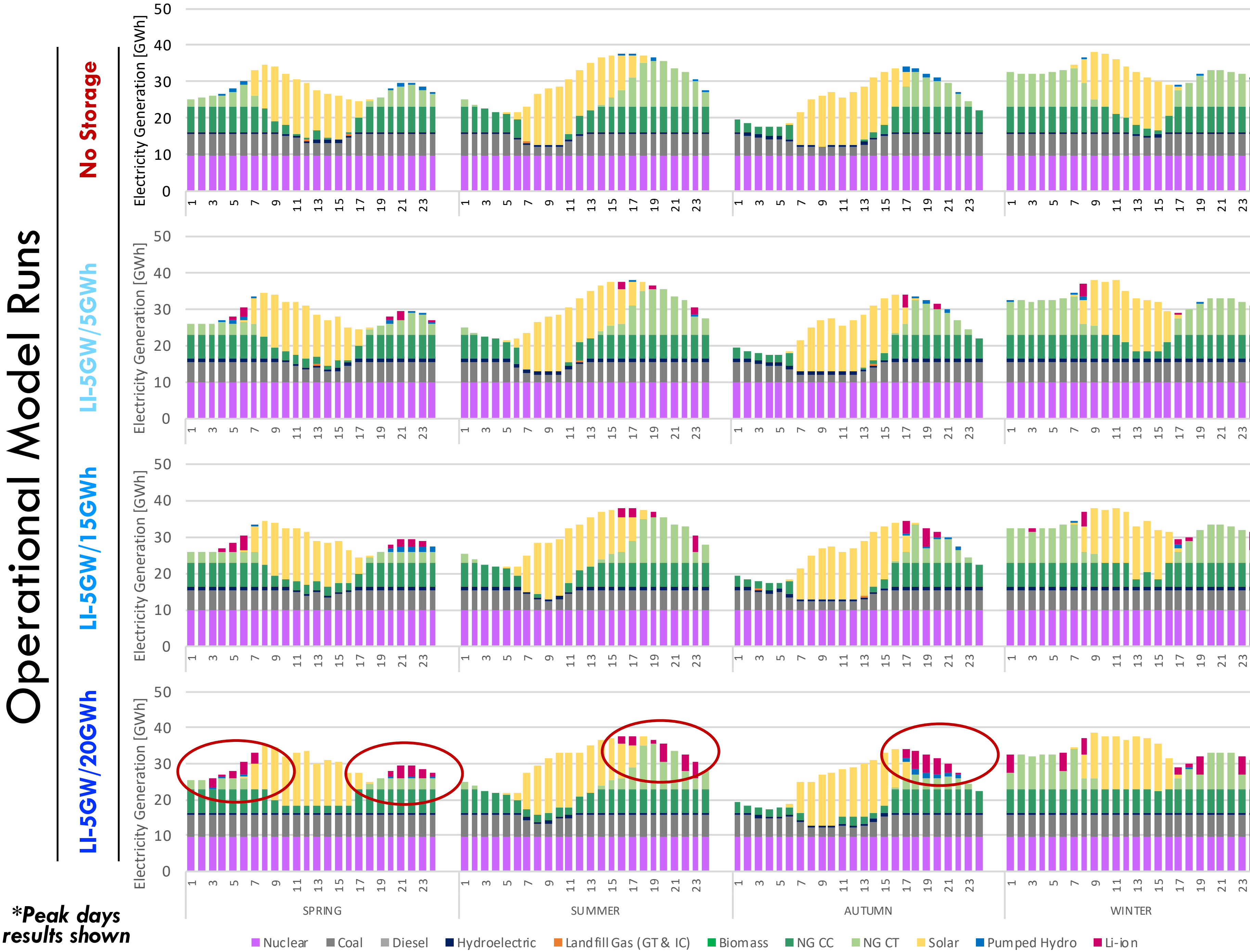
2030 Installed Capacity Across Scenarios



*Peak days results shown



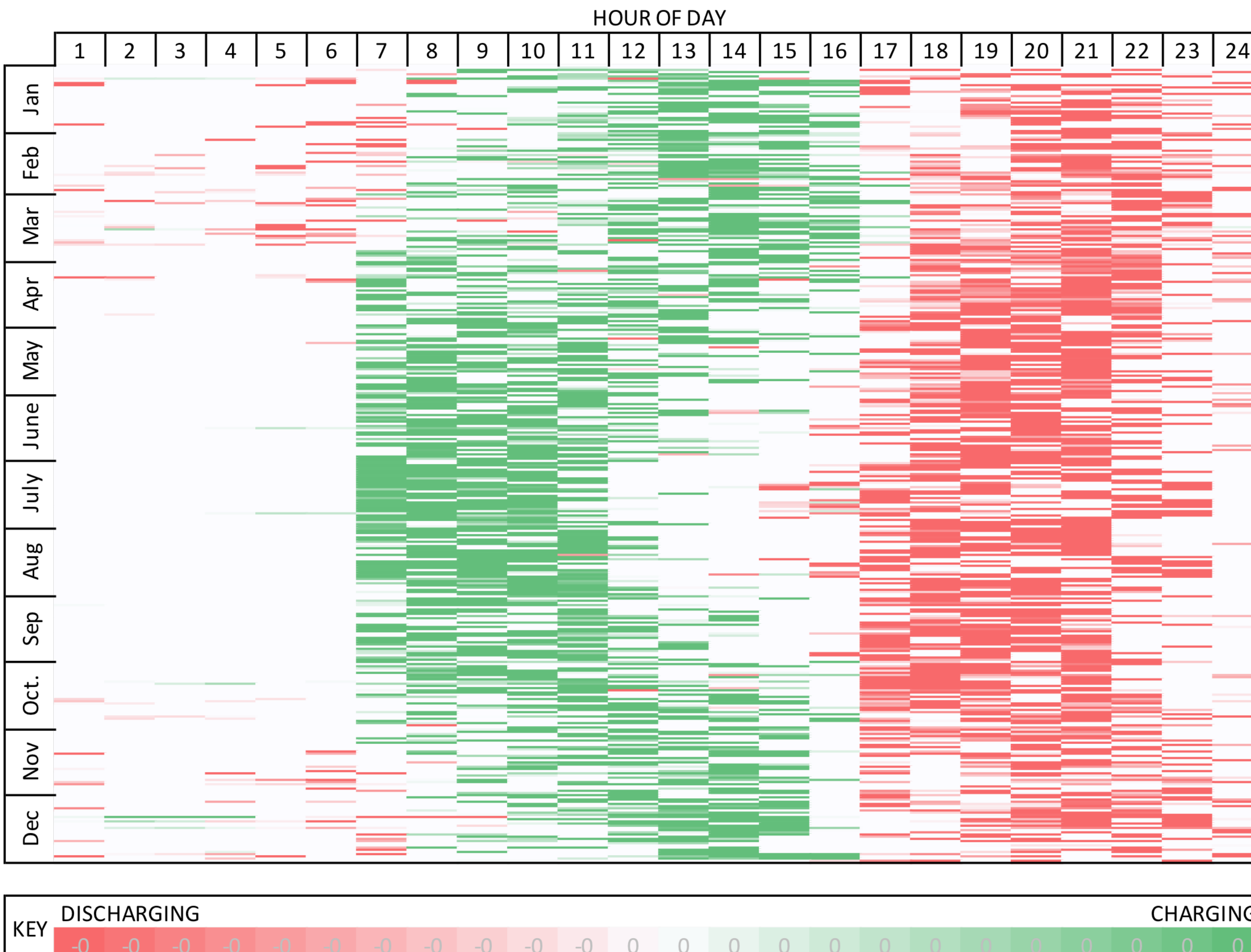
Operational Model Runs
No Storage
LI-3GW/3GWh
LI-3GW/6GWh
LI-3GW/12GWh
*Peak days results shown
Electricity Generation [GWh]
SPRING
SUMMER
AUTUMN
WINTER
Nuclear
Coal
Diesel
Hydroelectric
Landfill Gas (GT & IC)
Biomass
NG CC
NG CT
Solar
Pumped Hydro
Li-ion



*Peak days results shown

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



Costs & Benefit Analysis of Lithium-Ion Batteries

Energy Savings & Capacity Value

Note that results consider the base case scenario and lithium-ion batteries only

Analysis Scenario	Operational Dispatch Simulation Case	Operational Dispatch Total Costs (M$/year)	Energy Savings (M$/year)
Base Case	S01: NS	$12,004.65	
	S01: LI-0.3GW/0.3GWh	$11,999.22	$5.43
	S01: LI-0.3GW/0.6GWh	$11,994.29	$10.36
	S01: LI-0.3GW/1.2GWh	$11,985.13	$19.52
	S01: LI-1GW/1GWh	$11,987.31	$17.34
	S01: LI-1GW/2GWh	$11,971.39	$33.26
	S01: LI-1GW/4GWh	$11,942.05	$62.60
	S01: LI-3GW/3GWh	$11,955.69	$48.96
	S01: LI-3GW/6GWh	$11,911.99	$92.66
	S01: LI-3GW/12GWh	$11,835.64	$169.01
	S01: LI-5GW/5GWh	$11,912.40	$92.25
	S01: LI-5GW/10GWh	$11,859.36	$145.29
	S01: LI-5GW/20GWh	$11,753.79	$250.86

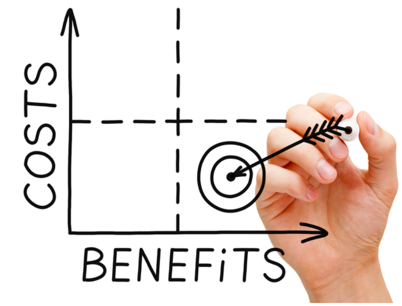
(Sioshansi et al., 2010)

Duration (hours)	ECP (%)	Capacity Credit (GW)				Capacity Value (M$/year)			
		0.3GW	1GW	3GW	5GW	0.3GW	1GW	3GW	5GW
1.0	41%	0.123	0.41	1.23	2.05	13.90	46.33	138.99	231.65
2.0	56%	0.168	0.56	1.68	2.8	18.98	63.28	189.84	316.40
4.0	75%	0.225	0.75	2.25	3.75	25.43	84.75	254.25	423.75

Total Benefits vs Revenue Requirements

Duration (hours)	Total Benefits (M$/year)			
	0.3 GW	1GW	3GW	5GW
1.0	19.3	63.7	188.0	323.9
2.0	29.3	96.5	282.5	461.7
4.0	45.0	147.4	423.3	674.6

Note that results consider the base case scenario and lithium-ion batteries only



Duration (hours)	RR_i^k ($/kW-year)		Total Revenue Requirements (M$/year)							
			2019				2030			
	2019	2030	0.3GW	1GW	3GW	5GW	0.3 GW	1GW	3GW	5GW
1.0	157.4	74.3	47.2	157.4	472.2	787.0	22.3	74.3	222.9	371.5
2.0	175.0	84.5	52.5	175.0	525.0	875.0	25.4	84.5	253.5	422.5
4.0	266.4	144.7	79.9	266.4	799.2	1332.0	43.4	144.7	434.1	723.5

With the base case assumptions, the 2019 costs associated with Li-ion batteries are not fully recovered through energy and capacity benefits

Using 2030 assumptions, however, we observe energy storage configurations that approach or exceed cost parity

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
- We are currently working to complete the other scenario runs
- Model and analyze other scenarios, e.g.:
  - Bidirectional capabilities for EVs
  - 100% of clean energy
  - Wider range of future fuel prices
  - Policies under consideration
- Analyze storage deployment directly in the capacity expansion

Thank You !

adequeiroz@nccu.edu
ar_queiroz@yahoo.com.br
https://arqueiroz.wordpress.ncsu.edu

CAPER CLEMSON UNIVERSITY NC STATE UNIVERSITY NORTH CAROLINA CENTRAL UNIVERSITY FOUNDED 1910