Energy+Environmental Economics

NorthWestern Energy Incremental ELCC Study

Project Results

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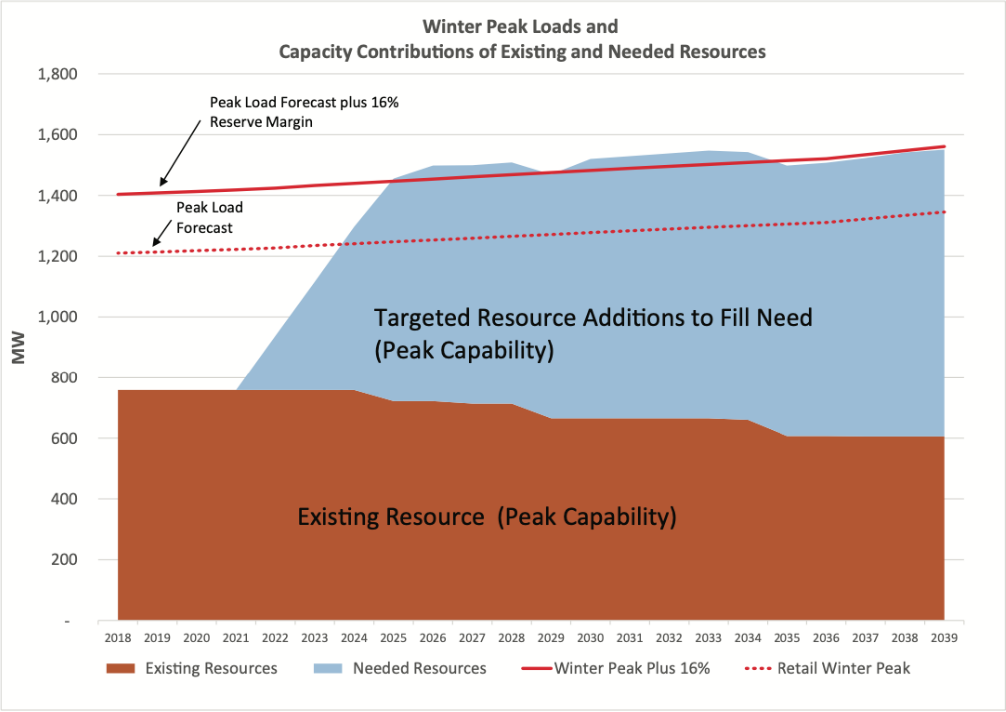
Background

Project Background

+ **NorthWestern Energy hired E3 to analyze the capacity value (ELCC) of additional renewable energy, energy storage, and hybrid resources**
  - NWE's current capacity shortfall is ~650 MW identified in their 2019 Electricity Supply Resource Procurement Plan
  - Results from E3's ELCC modeling to be used to inform the analysis of bids in NWE's all-source capacity RFP
    - RFP seeks 280 MW of effective capacity to partially fill NWE's identified capacity shortfall

NWE-identified Capacity Need

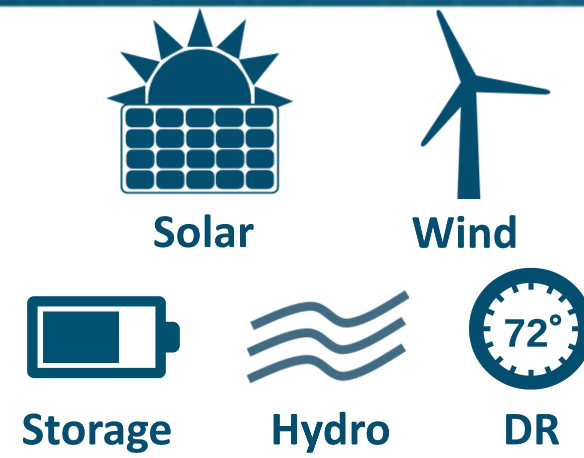


Source: 2019 Electric Supply Resource Procurement Plan

Analytical Approach

This Study Utilizes E3's Renewable Energy Capacity Planning (RECAP) Model

- **Resource adequacy is a critical concern under high renewable and decarbonized systems**
  - Renewable energy availability depends on the weather
  - Storage and Demand Response availability depends on many factors
- **RECAP evaluates adequacy through time-sequential simulations over thousands of years of plausible load, renewable, hydro, and stochastic forced outage conditions**
  - Captures thermal resource and transmission forced outages
  - Captures variable availability of renewables & correlations to load
  - Tracks hydro and storage state of charge
- **RECAP has been used to study reliability in the Greater NW, CA, Hawaii, and many other jurisdictions**



Key Reliability Metrics:

- **LOLP: Loss of Load Probability**
- **LOLE: Loss of Load Expectation**
- **EUE: Expected Unserved Energy**
- **ELCC: Effective Load-Carrying Capability for hydro, wind, solar, storage and DR**
- **PRM: Planning Reserve Margin needed to meet specified LOLE**

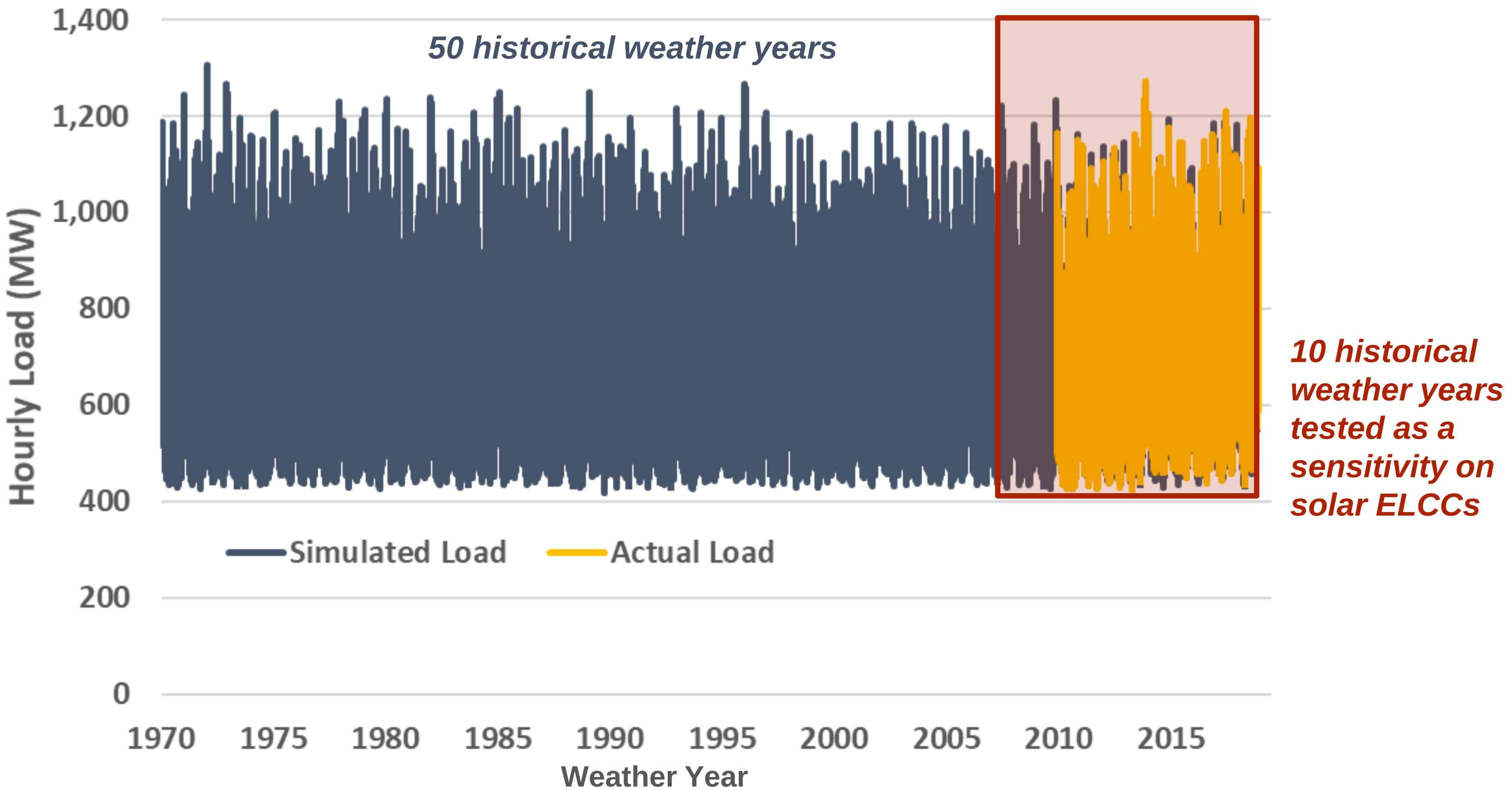
Information about E3's RECAP model can be found here:
https://www.ethree.com/tools/recap-renewable-energy-capacity-planning-model/

Key RECAP Assumptions

+ **Target reliability metric = 0.1 days/yr loss of load expectation (LOLE)**
  - System was tuned to 0.1 LOLE by adding perfect capacity to the system before calculating ELCC
  - Seasonal ELCCs were developed assuming 0.05 days/season for both winter and summer
+ **Loads considered = 50-yr historical weather based supply function load**
  - Historical load developed using E3's neural network algorithm using 2010-2018 actual NorthWestern supply function hourly loads and 50-years of historical weather data

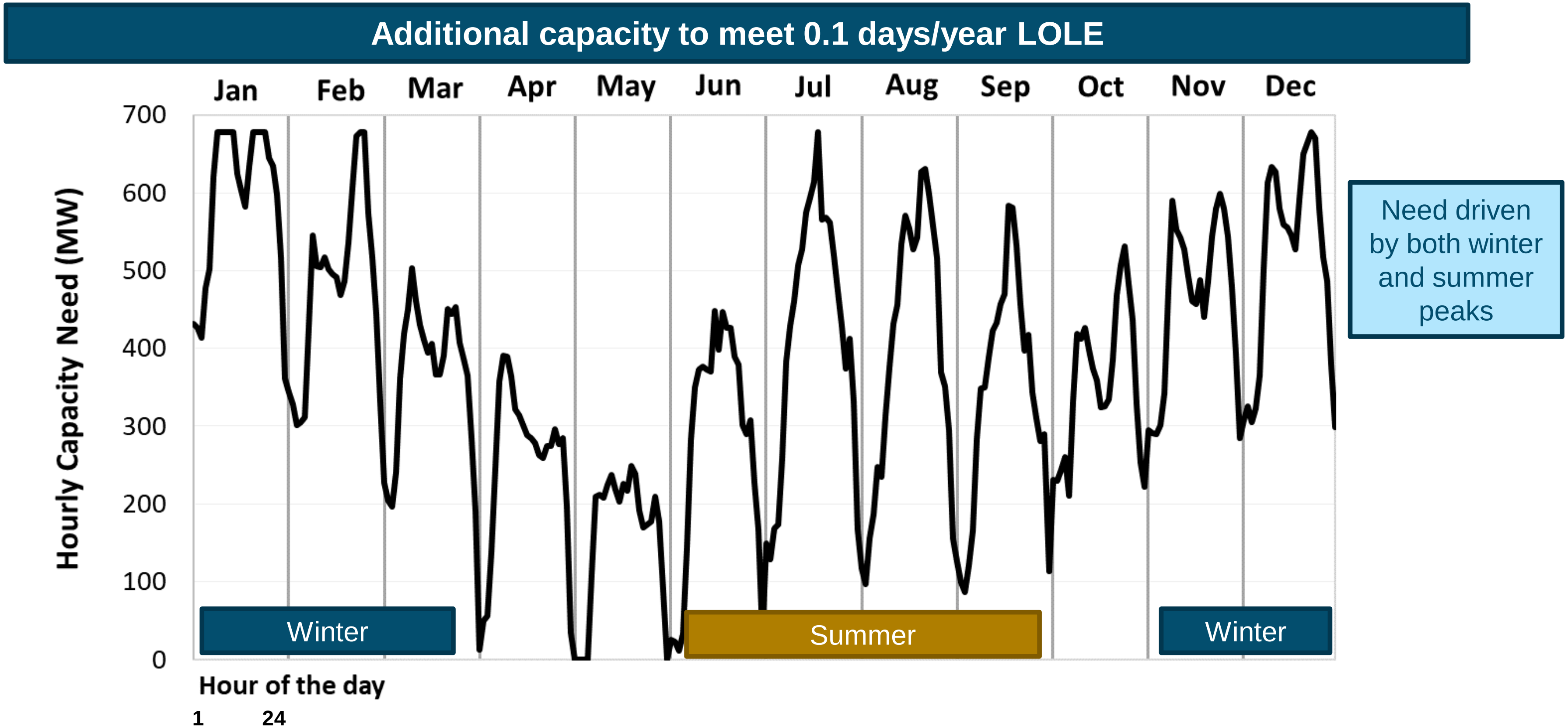
Load Simulation Results

+ **The result of RECAP's neural network load model is a set of hourly loads that represent what hourly load would have been under 2018 economic conditions for NorthWestern supply function customers for the weather years 1970-2018**
  - E3 tested a sensitivity considering 10 historical years



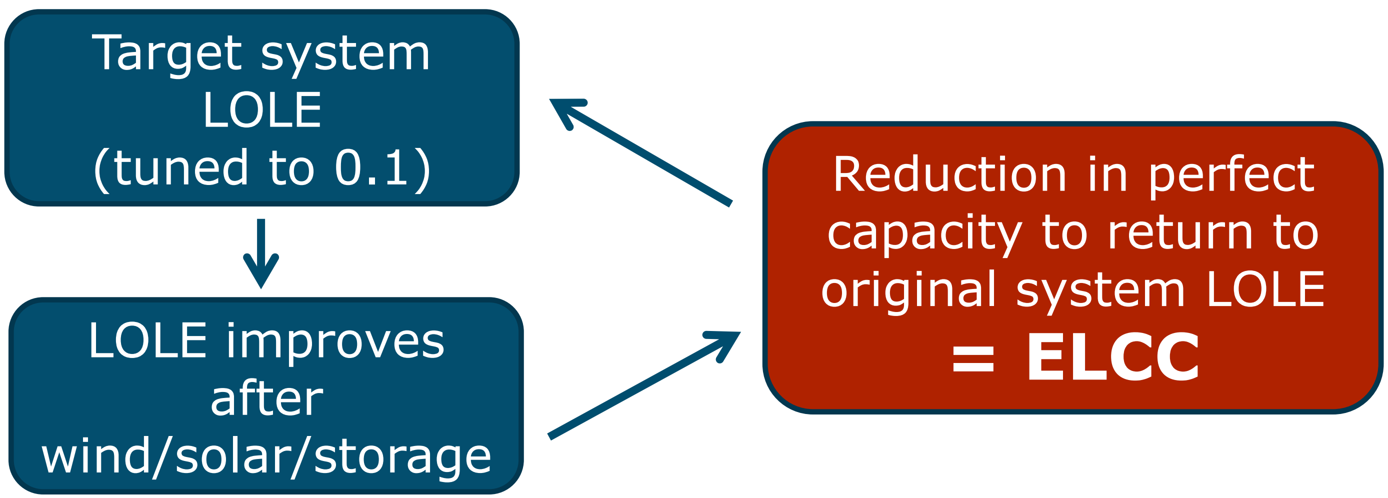
Additional Capacity Needed to Meet Reliability Target

- **Capacity need above existing resources driven by resource shortfall during winter + summer peak periods**
  - **678 MW effective capacity needed** to meet 0.1 LOLE standard
- **Level of need indicates additional generation required to meet reliability target**
  - The capacity need in each hour represents the maximum need across all weather conditions
  - No imports are assumed



ELCC Calculation in RECAP

- Effective load carrying capability (ELCC) is the quantity of 'perfect capacity' that could be replaced or avoided with wind, solar, storage, etc. while providing equivalent system reliability



- ELCC is the most rigorous and accurate method for calculating qualifying capacity of energy limited resources (solar, wind, storage, etc.)

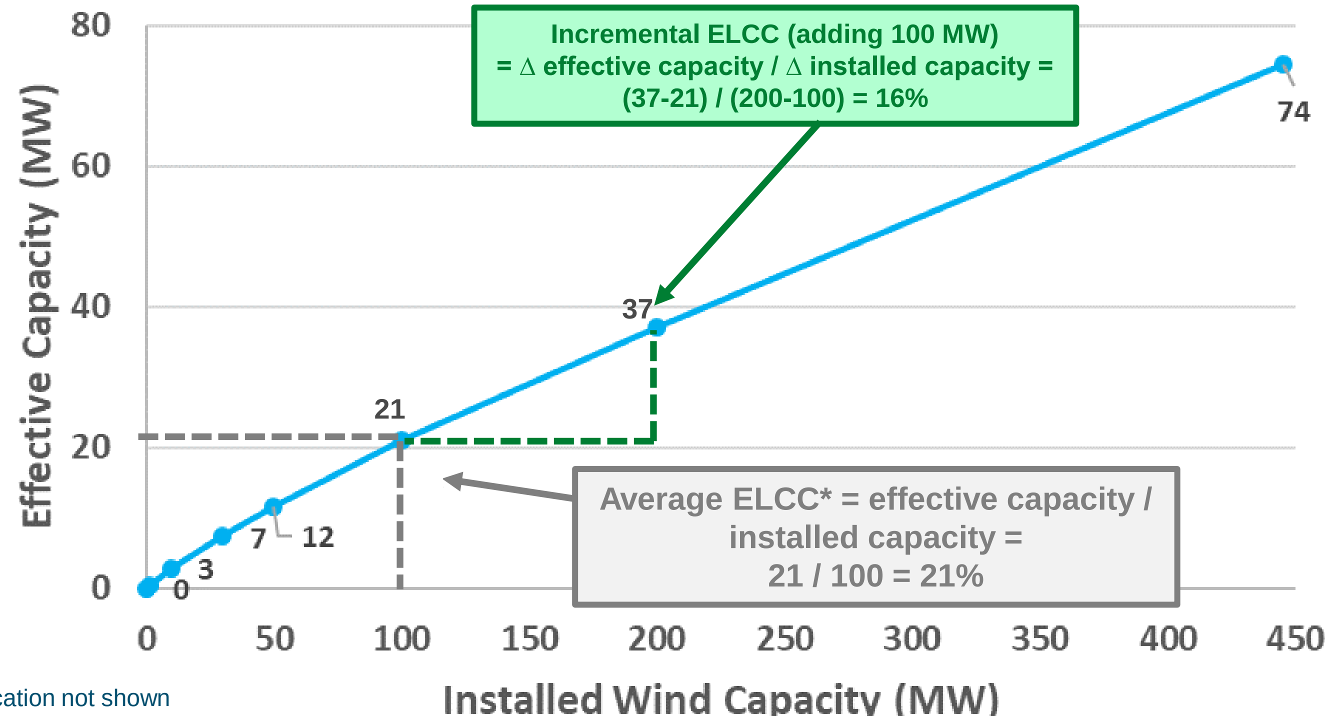
Defining Incremental ELCCs

Focus of this project

+ **Average ELCC:** Aggregate capacity credit (QC) for existing resources in RA program
  - Requires allocating diversity benefits amongst a portfolio of resources

+ **Incremental ELCC:** Reliability benefit of adding X MW for procurement
  - Calculated as incremental capacity additions on top of existing installed capacity

Effective Capacity Curve w/ Increasing Wind Penetration (*illustrative*)



Note: marginal capacity benefits decline with increasing penetration

* Diversity benefit allocation not shown in this simplified example

Resources Considered

New Resources Modeled in RECAP

Resource	Configuration	Capacity Levels	Input Data
Wind	New MT wind	50, 100, 200, 300 MW	Historical NWE wind shapes (2014-2018) + 1 simulated shape sensitivity
Solar PV	New MT solar	50, 100, 200, 300 MW	E3 simulated shapes + 2 sensitivities considered
Li-Ion Storage	3, 4, 6 hr duration	25, 50, 100, 200, 300, 400, 500 MW	
Pumped Hydro Storage	6, 8, 10 hr duration	100, 200, 300, 400, 500 MW	
Solar + battery hybrid	1:1, 2:1, 4:1 solar to storage MW 4 hour duration	100 MW	Multiple configurations considered
Wind + battery hybrid	2:1, 4:1 solar to storage MW 4 hour duration	100 MW	Multiple configurations considered

Hybrid Resource Configurations

- **E3 considered the following hybrid resources in RECAP**
  - "RE charging" constraint assumes storage must charge from solar or wind, limiting its ability to fully charge during periods of low renewable output
  - No RE charging constraint means storage can charge from the grid

Technology	Renewable Capacity / Interconnection Limit (MW-AC)	Battery Capacity (MW-AC)	Battery Duration	RE Charging Constraints	AC or DC Coupled	ILR
Solar	100 MW	100 MW	4 hours	No	DC	1.7
Solar	100 MW	100 MW	4 hours	**Yes**	DC	1.7
Solar	100 MW	50 MW	4 hours	No	AC	1.3
Solar	100 MW	25 MW	4 hours	No	AC	1.3
Wind	100 MW	50 MW	4 hours	No	n/a	n/a
Wind	100 MW	50 MW	4 hours	**Yes**	n/a	n/a
Wind	100 MW	25 MW	4 hours	No	n/a	n/a

Hybrid Solar – Coupling Method

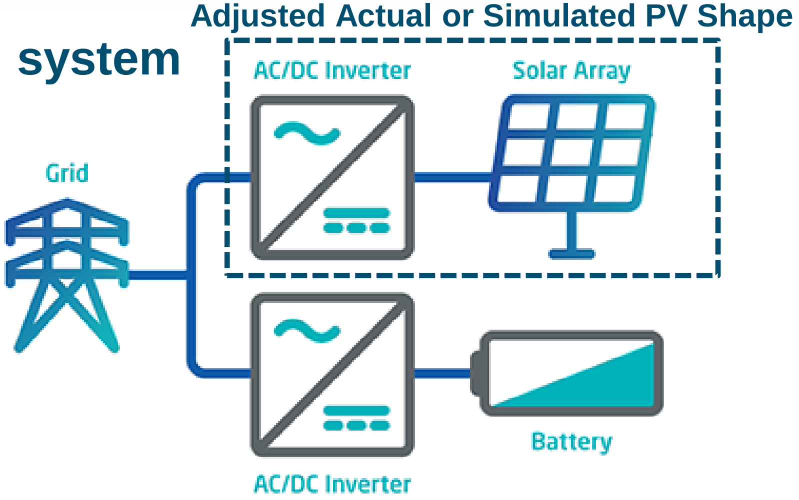
+ AC-Coupled

- Pros:
  - Easy to retrofit, more operational flexibility
- Cons:
  - Higher inverter losses

+ DC-Coupled

- Pros:
  - Cheaper
  - Lower losses
  - Might be able to obtain the solar energy that will otherwise be clipped
- Cons:
  - PV Generation + Battery discharge constrained by the shared inverter

AC-Coupled system



DC-Coupled system

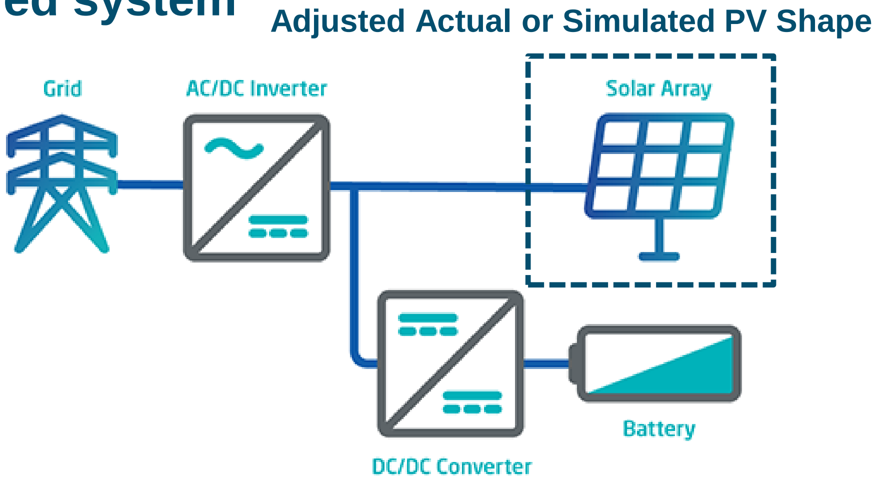
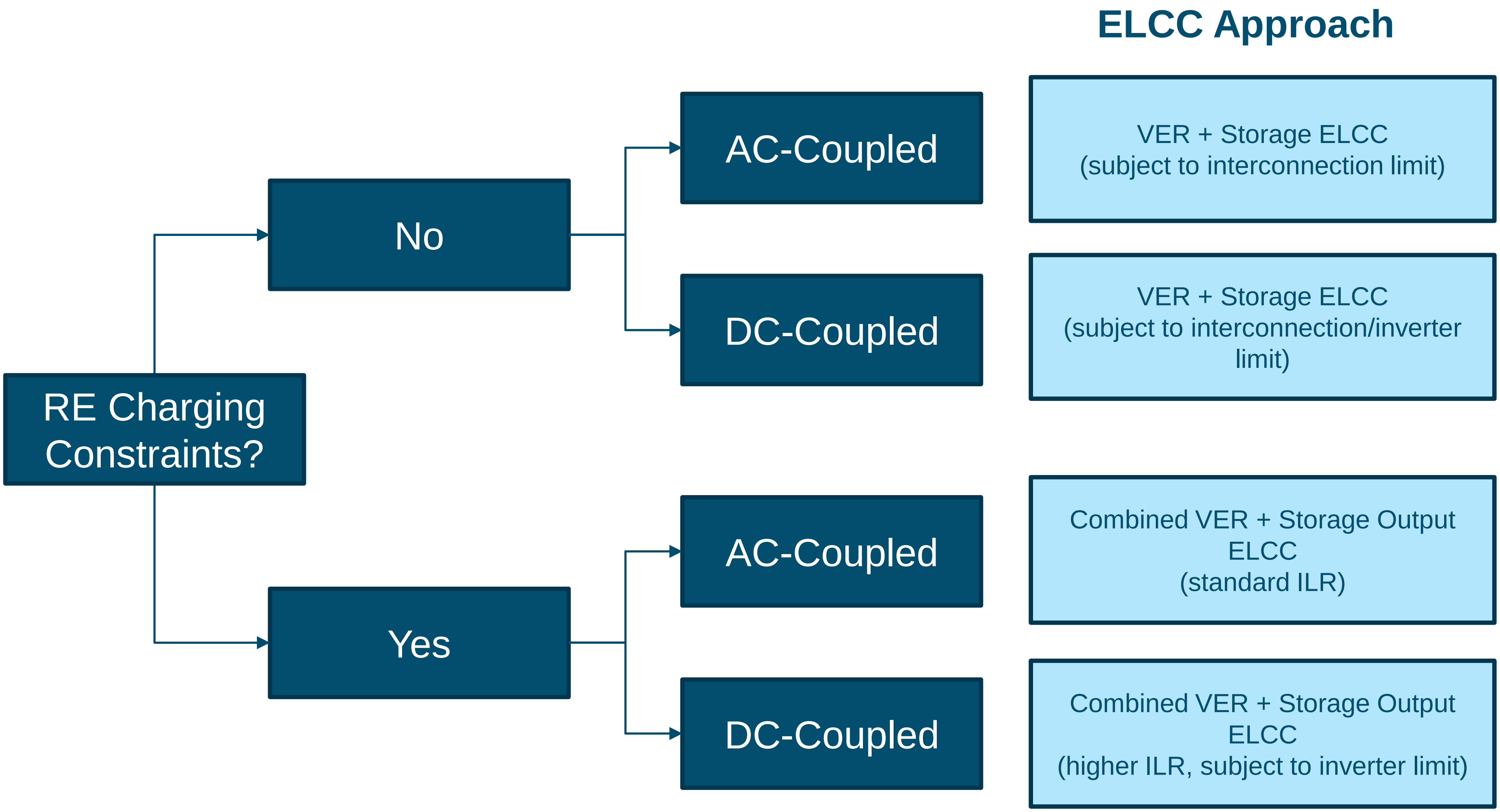


*Diagram source: https://blog.fluenceenergy.com/energy-storage-ac-dc-coupled-solar

Treatment of RE Charging Constraints



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ELCC Results (Summary)

Incremental ELCC Results Overview

Annual

Incremental ELCC Provided by Different Resources, 2020									
Incremental Nameplate Capacity (MW)		Charging From	25 MW	50 MW	100MW	200MW	300MW	400MW	500MW
Standalone Storage	3hr	Grid	100%	100%	99%	82%	65%	54%	47%
	4hr	Grid	100%	100%	100%	91%	72%	61%	53%
	6hr	Grid	100%	100%	100%	98%	84%	70%	59%
	8hr	Grid			100%	100%	92%	76%	65%
	10hr	Grid			100%	100%	97%	81%	69%
Solar PV	Simulated			5%	4%	3%	2%		
	Simulated With Snow Losses			4%	3%	3%	2%		
	Historical			2%	2%	1%	1%		
Wind	Historical			6%	5%	5%	5%		
	Simulated			11%	10%	9%	8%		
4-Hr Storage + Solar	25% of Solar PV	Grid			29%				
	50% of Solar PV	Grid			54%				
	100% of Solar PV	Grid			100%				
	100% of Solar PV	Solar			66%				
4-Hr Storage + Wind	50% of Wind	Grid			54%				
	25% of Wind	Grid			30%				
	50% of Wind	Wind			46%				

Light grey denotes sensitivity cases

Incremental ELCC Results Overview

Winter

Incremental ELCC Provided by Different Resources, 2020									
Incremental Nameplate Capacity (MW)		Charging From	25 MW	50 MW	100MW	200MW	300MW	400MW	500MW
Standalone Storage	3hr	Grid	100%	100%	100%	88%	70%	58%	51%
	4hr	Grid	100%	100%	100%	95%	77%	65%	56%
	6hr	Grid	100%	100%	100%	99%	90%	74%	63%
	8hr	Grid			100%	100%	97%	80%	68%
	10hr	Grid			100%	100%	99%	85%	72%
Solar PV	Simulated			5%	4%	3%	2%		
	Simulated With Snow Losses			5%	4%	3%	2%		
	Historical			2%	2%	1%	1%		
Wind	Historical			6%	6%	5%	5%		
	Simulated			11%	10%	9%	8%		
4-Hr Storage + Solar	25% of Solar PV	Grid			29%				
	50% of Solar PV	Grid			54%				
	100% of Solar PV	Grid			100%				
	100% of Solar PV	Solar			48%				
4-Hr Storage + Wind	50% of Wind	Grid			54%				
	25% of Wind	Grid			30%				
	50% of Wind	Wind			54%				

Light grey denotes sensitivity cases

Incremental ELCC Results Overview

Summer

Incremental ELCC Provided by Different Resources, 2020									
Incremental Nameplate Capacity (MW)		Charging From	25 MW	50 MW	100MW	200MW	300MW	400MW	500MW
Standalone Storage	3hr	Grid	100%	100%	100%	86%	70%	60%	53%
	4hr	Grid	100%	100%	100%	96%	80%	69%	61%
	6hr	Grid	100%	100%	100%	100%	95%	82%	70%
	8hr	Grid			100%	100%	99%	89%	75%
	10hr	Grid			100%	100%	100%	93%	80%
Solar PV	Simulated			66%	63%	54%	45%		
	Simulated With Snow Losses			66%	63%	54%	45%		
	Historical			67%	62%	51%	40%		
Wind	Historical			3%	3%	3%	3%		
	Simulated			14%	13%	11%	9%		
4-Hr Storage + Solar	25% of Solar PV	Grid			87%				
	50% of Solar PV	Grid			100%				
	100% of Solar PV	Grid			100%				
	100% of Solar PV	Solar			97%				
4-Hr Storage + Wind	50% of Wind	Grid			50%				
	25% of Wind	Grid			28%				
	50% of Wind	Wind			36%				

Light grey denotes sensitivity cases

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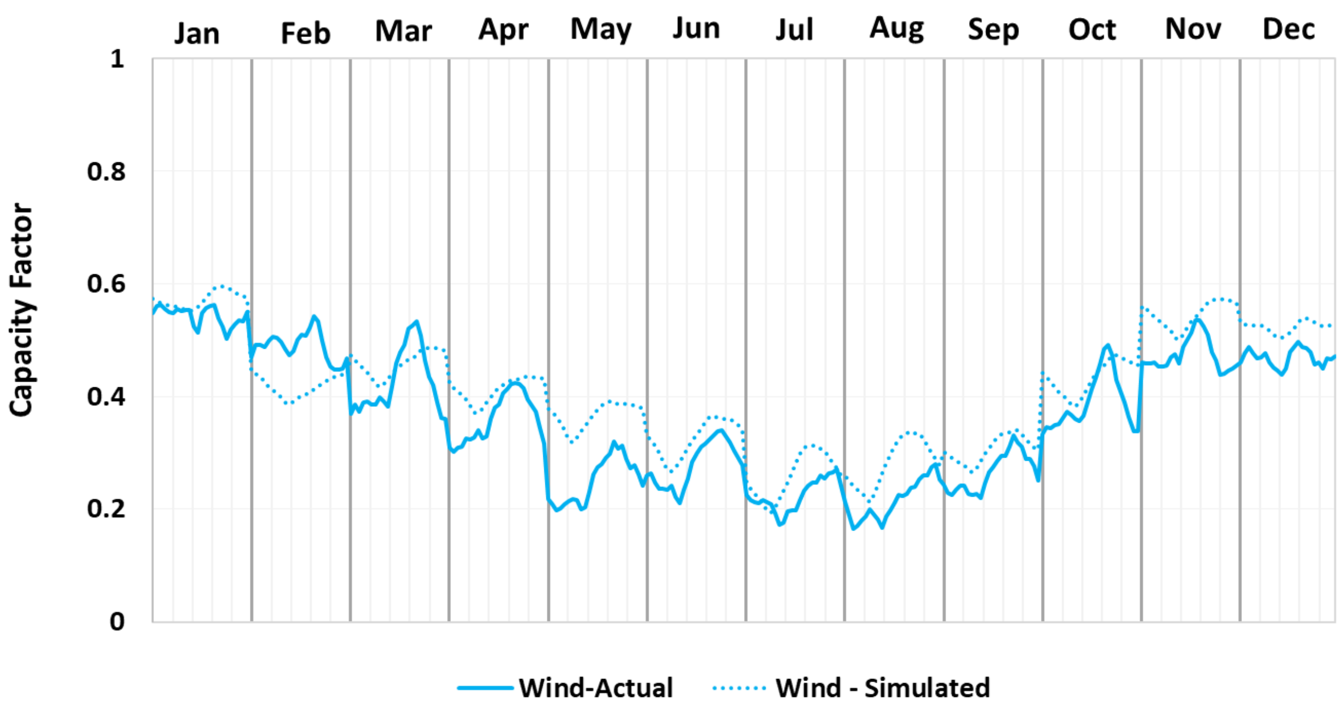
ELCC Results (Details)

Wind Shapes

+ **E3 used NorthWestern Energy's 2014-2018 historical wind output shapes (at an avg ~36% CF) to determine incremental ELCCs of new wind**
  - A sensitivity was considered using NREL Wind Toolkit based simulated wind shapes at different resource sites (~41% CF)

Month/Hour Average Output

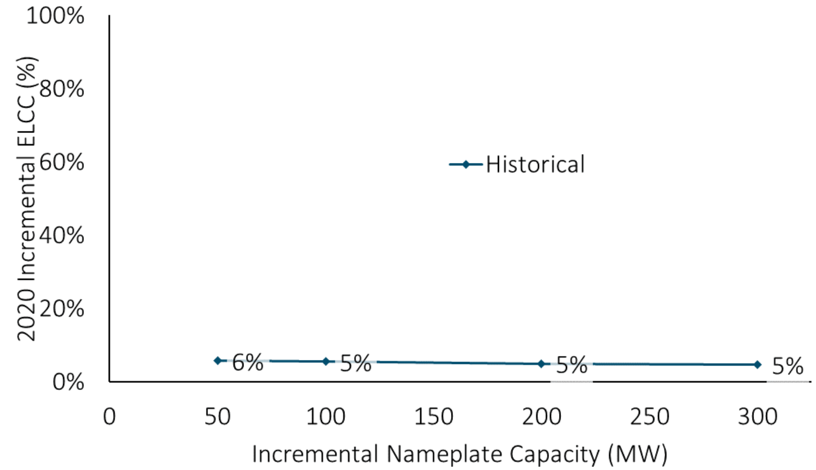


Wind Incremental ELCCs

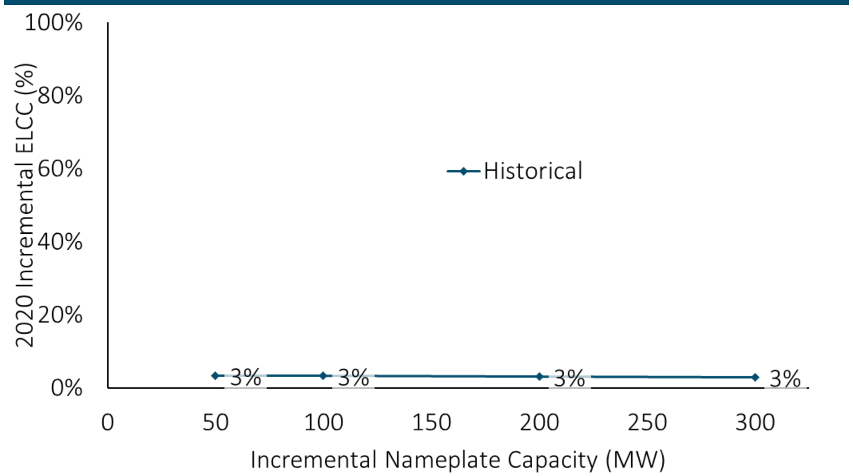
Historical Shapes

- Wind calculated using NorthWestern Energy's historical wind output shapes (36% CF)
- Low ELCCs are in part influenced by significant existing wind penetration (~450 MW)

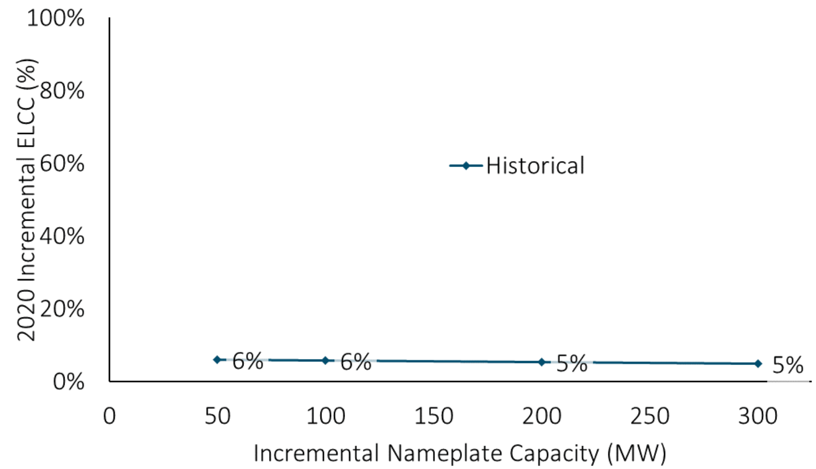
Annual ELCC Curve



Summer ELCC Curve



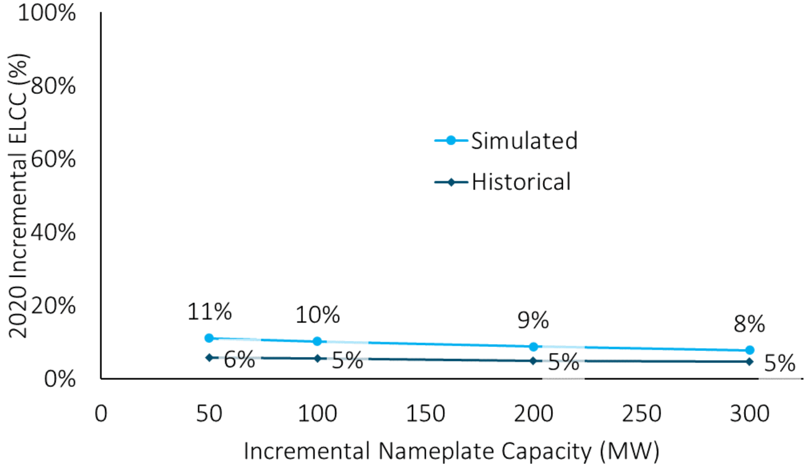
Winter ELCC Curve



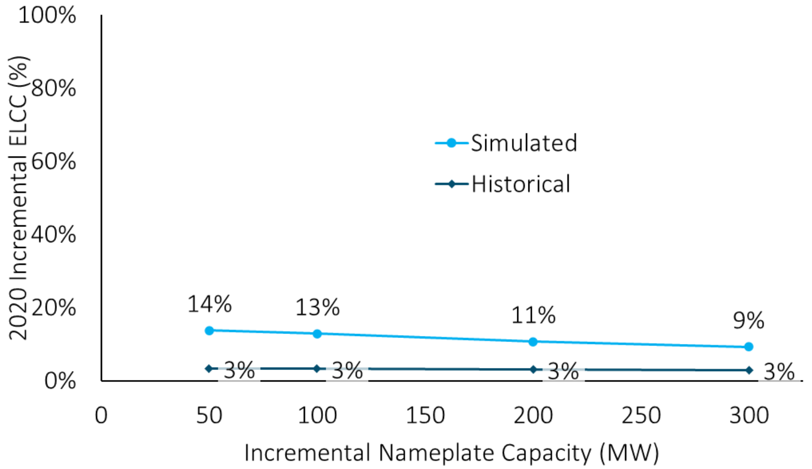
Wind Incremental ELCCs
Simulated Shapes Sensitivity

+ **A sensitivity was run with simulated wind shapes**
+ **Using NREL's Wind Toolkit, E3 compared NWE's existing wind resources against simulated profiles with these assumptions**
  - Hub height: 100m
  - Turbines: NREL's Class 2
  - Locations: blended profiles of recent wind builds in MT
  - Capacity Factor: 41%

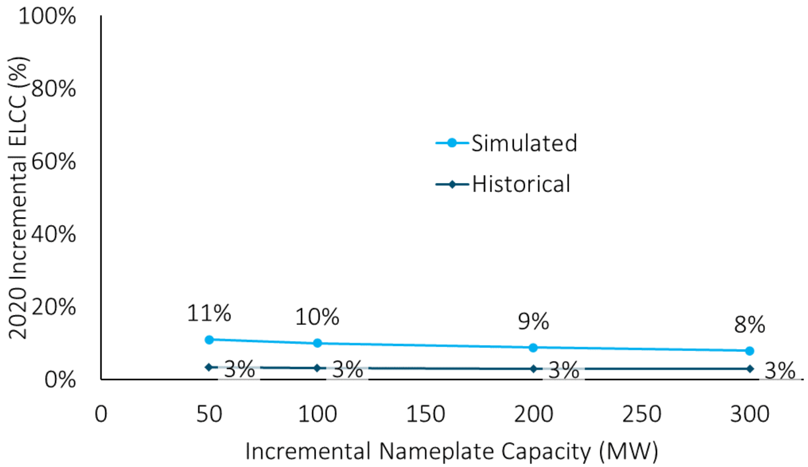
Annual ELCC Curve



Summer ELCC Curve



Winter ELCC Curve



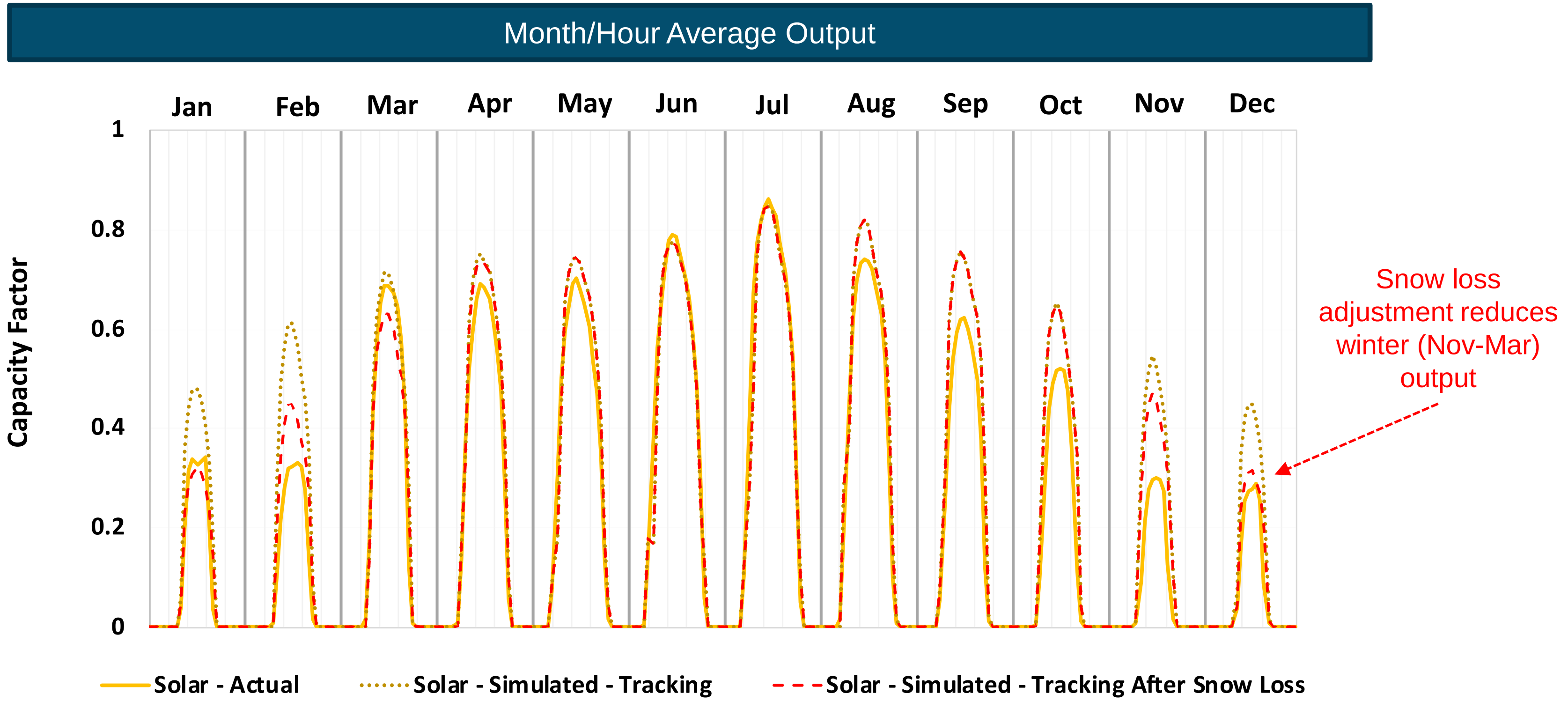
Why Simulated Wind ELCCs Are Higher

+ **The increase in simulated wind ELCCs (vs. historical wind shapes) is likely due to multiple interrelated factors**

1. **Technology Improvements**
   - Simulated shapes assume new state of the art turbines at 100m hub heights, which increases wind output (i.e. + 5% annual capacity factor)
2. **Resource Diversity**
   - Simulated shapes were chosen at diverse locations away from existing sites
   - This geographic diversity provides diversity in output, benefitting ELCCs by increased wind output in different hours than existing wind sites
3. **Simulated vs. Historical Data Differences**
   - Simulated shapes tend to be smoother than actual historical data, which may provide a slight boost to ELCCs
   - Historical data better captures actual operating conditions (such as cold temperature cut-offs, maintenance outages, etc.)

Solar Shapes

+ **E3 developed a snow-loss adjusted simulated solar shape using NREL's snow loss algorithm**
  - However, NREL's approach likely overestimates snow losses for tracking PV sites as it is designed and calibrated to fixed tilt resources
  - It is also based on TMY, so not synched to the actual annual hourly insolation data used in E3's simulated shapes

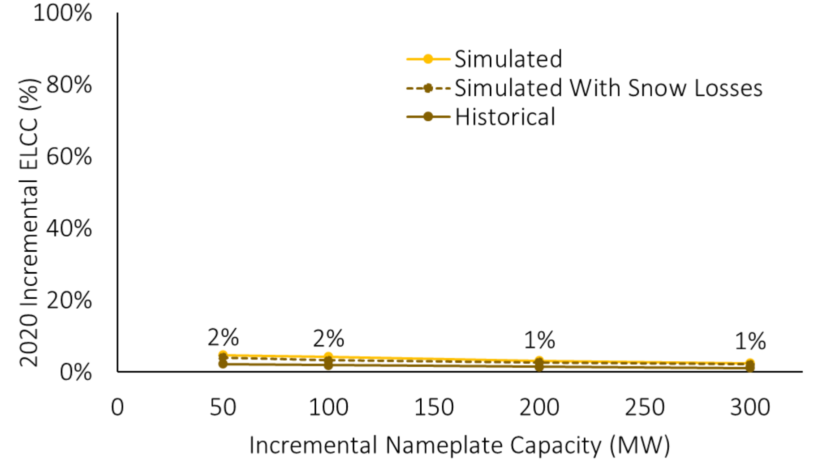


Solar Incremental ELCCs

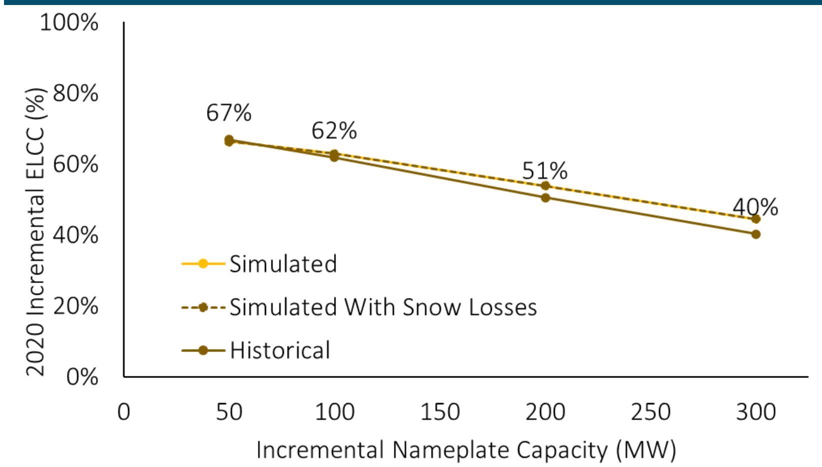
Simulated and Historical Shapes

- **Solar ELCCs calculated for both historical and simulated shapes (with and without a snow loss adjustment)**
- **Given the small differences in ELCCs, E3 recommends using the simulated PV without snow losses**
  - Historical shapes and simulated snow loss adjusted shapes are more likely to draw criticism as non-representative of new projects
  - Simulated shapes appropriately capture higher summer ELCCs due to tracking PV assumption, which also helps reduce snow cover losses

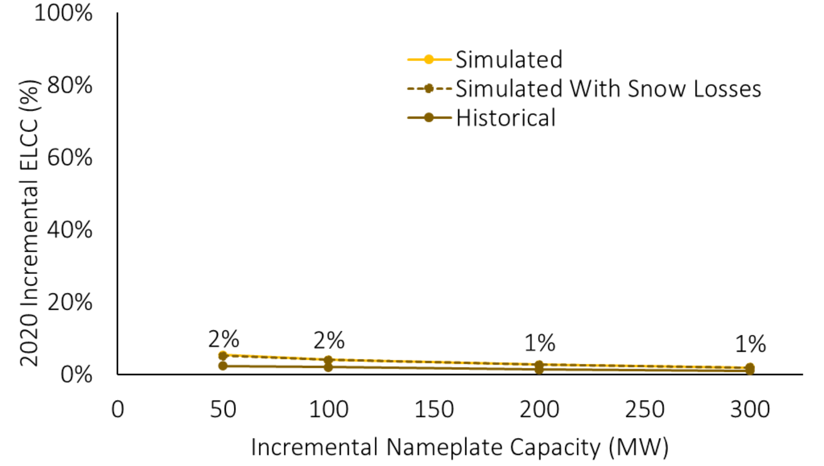
Annual ELCC Curve



Summer ELCC Curve



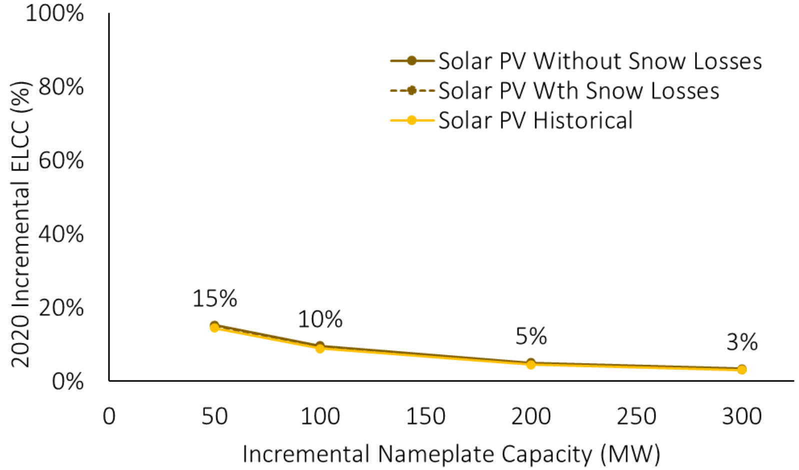
Winter ELCC Curve



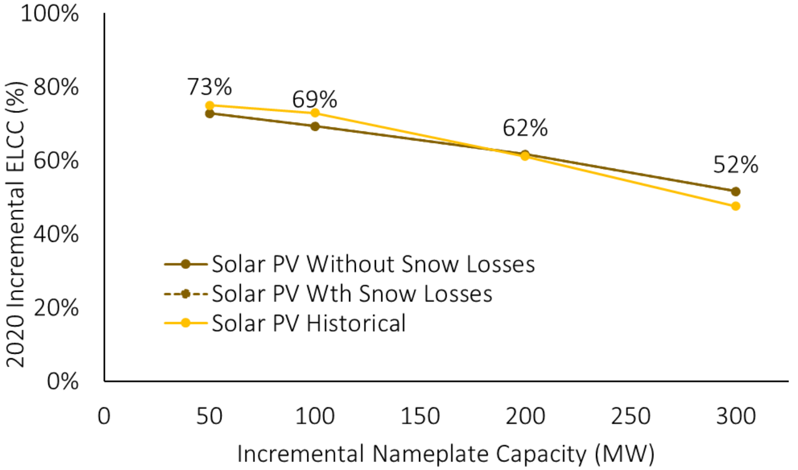
Solar Incremental ELCCs
10 Historical Weather Years Sensitivity

+ **Compared to last 50 years, the last 10 years show more frequent summer peaks than winter peaks**
  - Summer peaks drive higher annual capacity value for solar resources

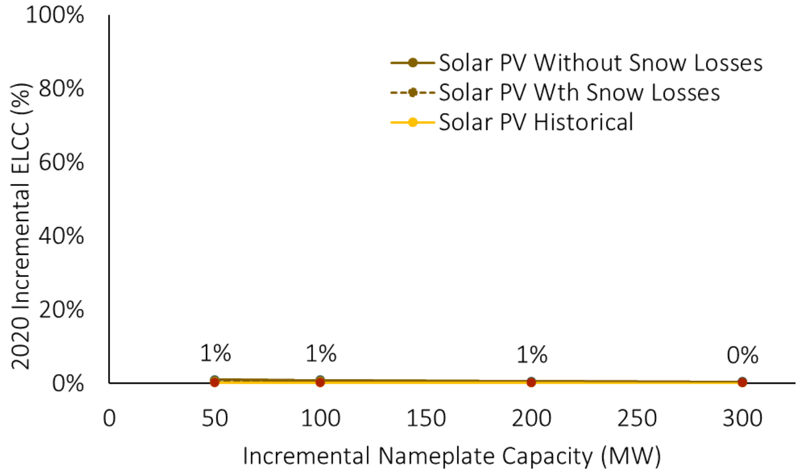
Annual ELCC Curve



Summer ELCC Curve



Winter ELCC Curve



Solar Incremental ELCCs

10-yr vs 50-yr Sensitivity

Annual

Average ELCC Provided by Different Resources, 2020								
Nameplate Capacity		25 MW	50 MW	100MW	200MW	300MW	400MW	500MW
Solar PV	Historical		2%	2%	1%	1%		
50 Year	Wth Snow Losses		4%	3%	3%	2%		
	Without Snow Losses		5%	4%	3%	2%		
Solar PV	Historical		14%	9%	5%	3%		
10 Year	Wth Snow Losses		15%	9%	5%	3%		
	Without Snow Losses		15%	10%	5%	3%		

More frequent summer peaks in the last 10 years leading to higher annual solar ELCCs

Winter

Average ELCC Provided by Different Resources, 2020									
Nameplate Capacity		Charging From	25 MW	50 MW	100MW	200MW	300MW	400MW	500MW
Solar PV	Historical			2%	2%	1%	1%		
50 Year	Wth Snow Losses			5%	4%	3%	2%		
	Without Snow Losses			5%	4%	3%	2%		
Solar PV	Historical			0%	0%	0%	0%		
10 Year	Wth Snow Losses			1%	1%	0%	0%		
	Without Snow Losses			1%	1%	1%	0%		

Summer

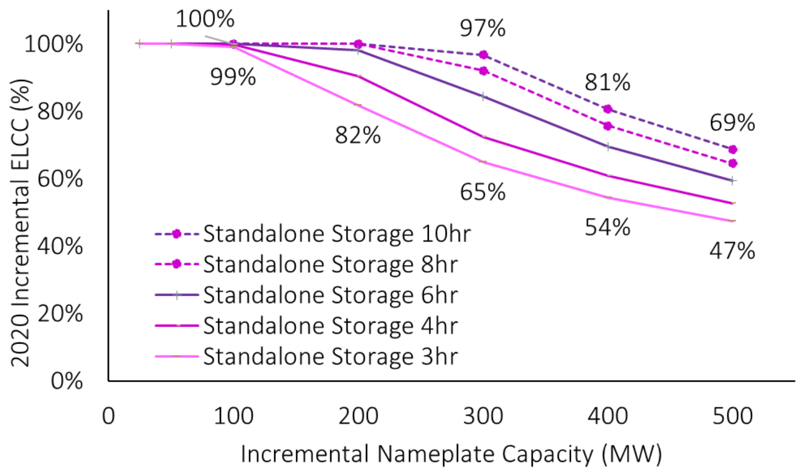
Average ELCC Provided by Different Resources, 2020									
Nameplate Capacity		Charging From	25 MW	50 MW	100MW	200MW	300MW	400MW	500MW
Solar PV	Historical			67%	62%	51%	40%		
50 Year	Wth Snow Losses			66%	63%	54%	45%		
	Without Snow Losses			66%	63%	54%	45%		
Solar PV	Historical			75%	73%	61%	48%		
10 Year	Wth Snow Losses			73%	69%	62%	52%		
	Without Snow Losses			73%	69%	62%	52%		

Storage Incremental ELCCs

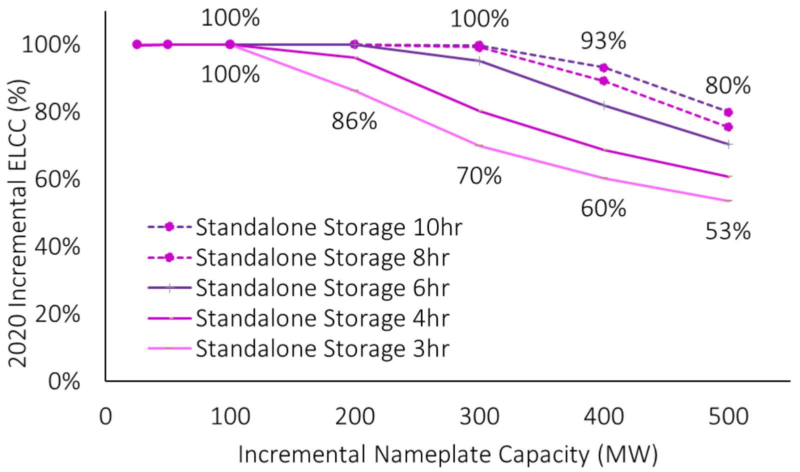
Stand-alone Storage

- Storage modeled at 3, 4, 6, 8, and 10-hour durations
- Saturation effects seen after ~100-200 MW of installed storage
  - Higher durations minimize saturation effects

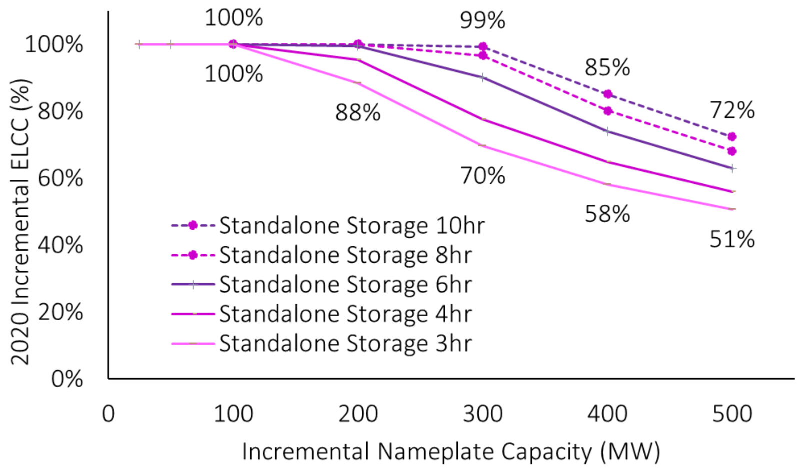
Annual ELCC Curve



Summer ELCC Curve



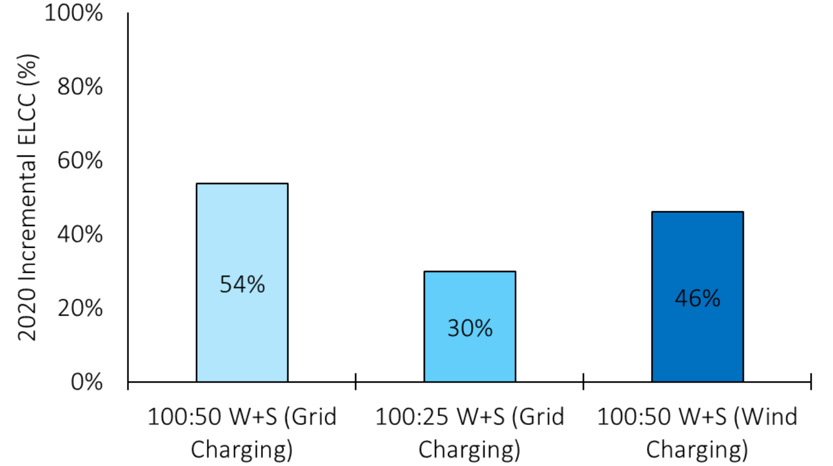
Winter ELCC Curve



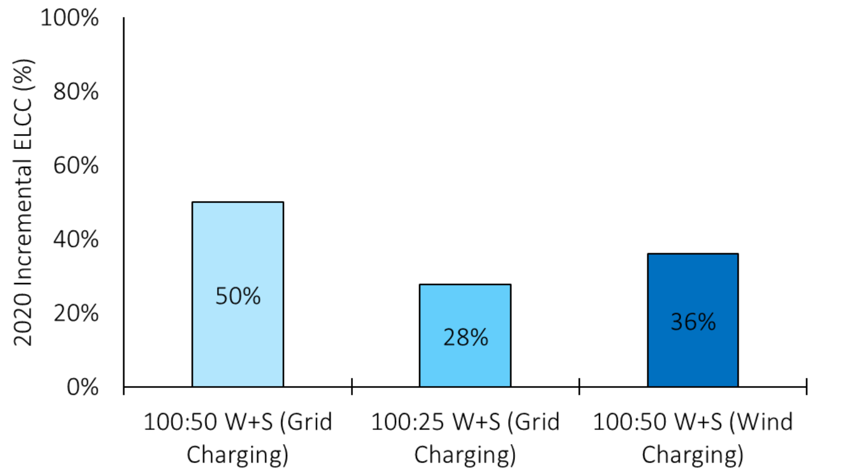
Wind Hybrid Incremental ELCCs

+ **Grid charging wind hybrids modeled as wind + storage additions**
  - Subject to an ELCC cap based on the interconnection limit (i.e. the RE nameplate capacity)
+ **Storage effectively gets full capacity credit, with a slight bump from the wind**

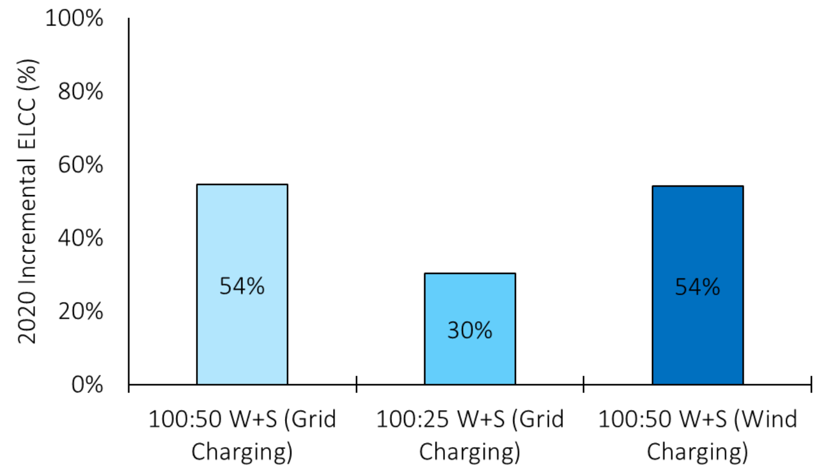
Annual ELCC Curve



Summer ELCC Curve



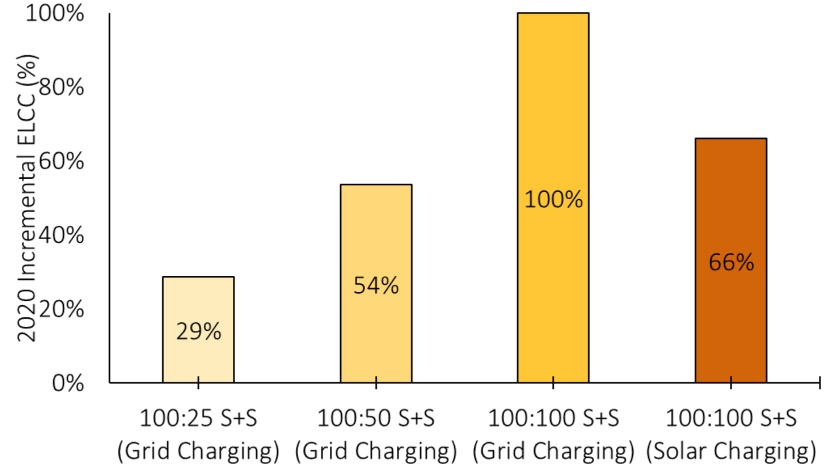
Winter ELCC Curve



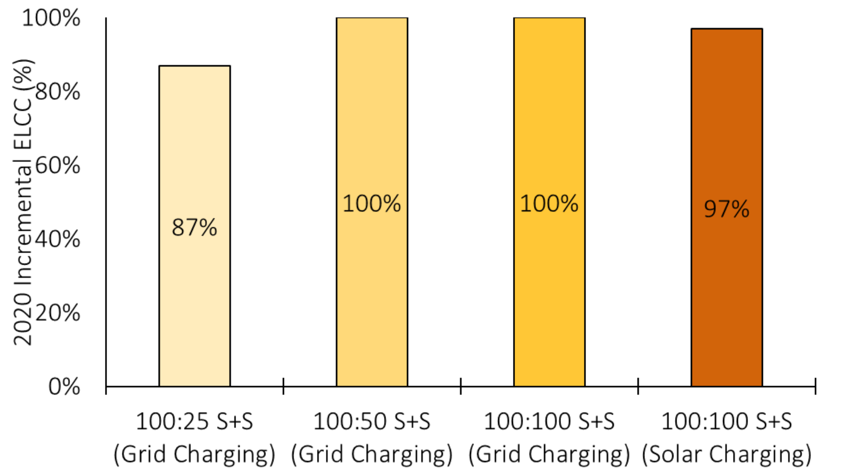
Solar Hybrid Incremental ELCCs

- **Grid charging solar hybrids modeled as solar + storage additions**
  - Subject to an ELCC cap based on the interconnection limit (i.e. the RE nameplate capacity)
  - 100:25, 100:50 are AC coupled w/ 1.3 ILR, 100:100 DC coupled w/ 1.7 ILR
- **In summer, storage "tops off" solar ELCCs**
- **In winter, hybrid ELCC is driven by the storage ELCC contributions**

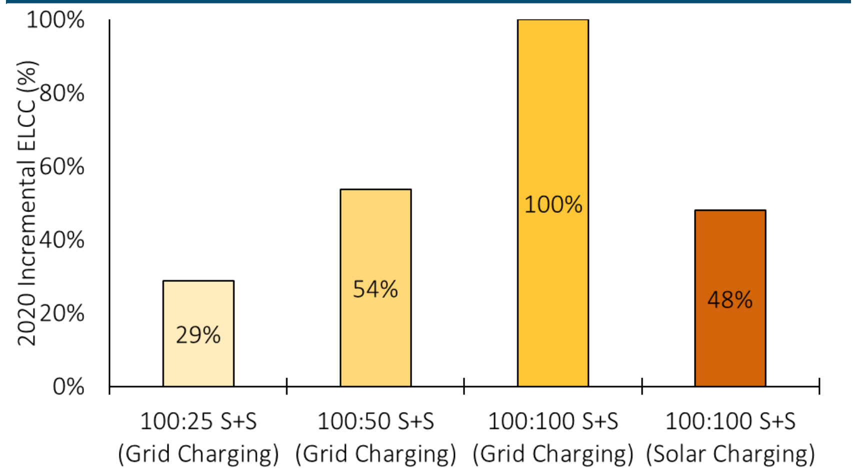
Annual ELCC Curve



Summer ELCC Curve



Winter ELCC Curve



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Utilization of Results

Incorporation into NWE's Capacity RFP

+ **Primary use: Determine incremental ELCC value for specific resource types**
  - E.g. 100 MW * 5% incremental ELCC value = 5 MW effective capacity
  - % incremental values apply to the nameplate capacity shown (e.g. 200 MW wind @ 5% incremental ELCC = 200 * 5% = 10 MW effective capacity)
+ **Key Considerations:**
  - Storage is shown at the "rated" capacity and duration
    - E.g. a 50 MW, 4-hour duration battery can output its Pmax of 50 MW for 4-hours, but must have >200 MWh of batteries to account for round-trip efficiency losses
  - Operational restrictions on hybrid resources
    - E3 considered different operational restrictions (RE vs. grid charging) but always capped ELCC at the interconnection limit (assumed to be the renewable nameplate MW)
    - Project specific restrictions may further impact actual ELCCs
  - Diversity impacts
    - Diversity impacts are explicitly accounted for when modeling hybrid resources, but not stand-alone resource additions, e.g. a solar + storage hybrid includes a diversity benefit while using separate stand-alone solar + stand-alone storage ELCCs does not
    - RECAP modeling of proposed portfolio of additions could capture diversity impacts
  - ELCCs are measured for a system tuned to 0.1 LOLE
    - Per standard industry practice, E3's ELCCs are calculated using a system tuned to 0.1 LOLE

Energy+Environmental Economics

Appendix

RECAP evaluates the availability of energy supplies to meet loads using an 8-step calculation process

Step 1
Calculate Hourly Load

Step 2
Calculate Renewable Profiles

Step 3
Calculate Available Dispatchable Generation

Step 4
Hydro Dispatch

Step 5
Calculate Available Transmission

Step 6
Dispatch Storage

Step 7
Dispatch Demand Response

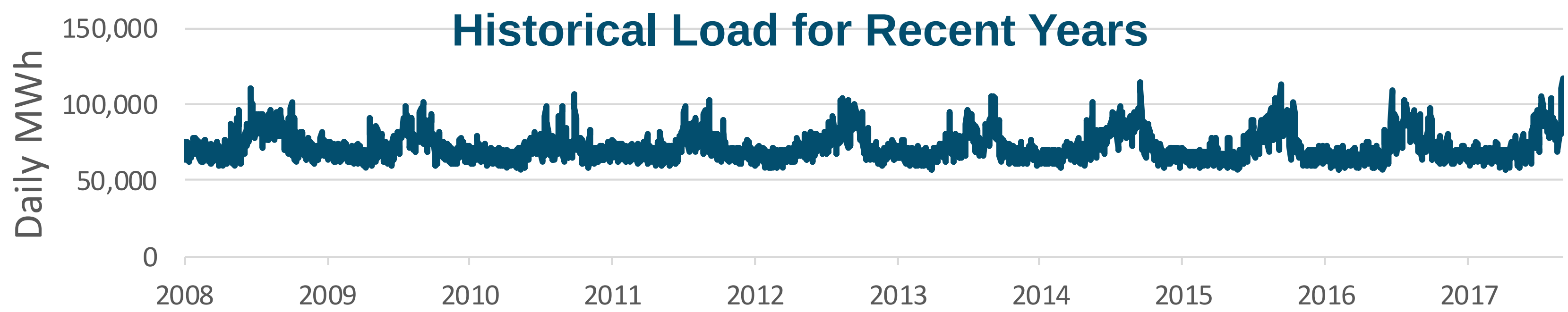
72°

Step 8
Calculate Loss of Load

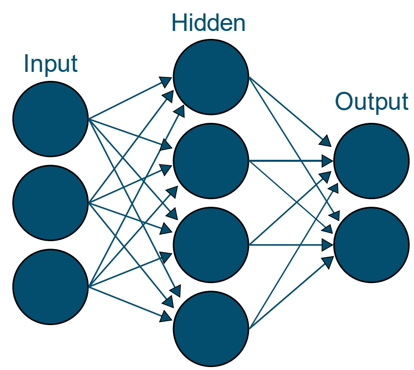
RECAP calculates a number of metrics that are useful for resource planning

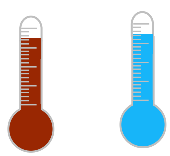
- **Annual Loss of Load Probability (aLOLP) (%):** is the probability of a shortfall (load plus reserves exceed generation) in a given year
- **Annual Loss of Load Expectation (LOLE) (days/yr):** is total number of days in a year with at least one event wherein load plus reserves exceeds generation
- **Annual Expected Unserved Energy (EUE) (MWh/yr):** is the expected unserved load plus reserves in MWh per year
- **Effective Load Carrying Capability (ELCC) (%):** is the additional load met by an incremental generator while maintaining the same level of system reliability (used for dispatch-limited resources such as wind, solar, storage and demand response)
- **Planning Reserve Margin (PRM) (%):** is the resource margin above 1-in-2-year peak load, in %, that is required in order to maintain acceptable resource adequacy

RECAP Load Profile Development



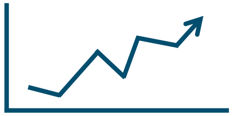
Run neural network model to establish relationship between daily gross load for several recent years and the following factors





Max & Min Daily Temp

Month & Day-Type



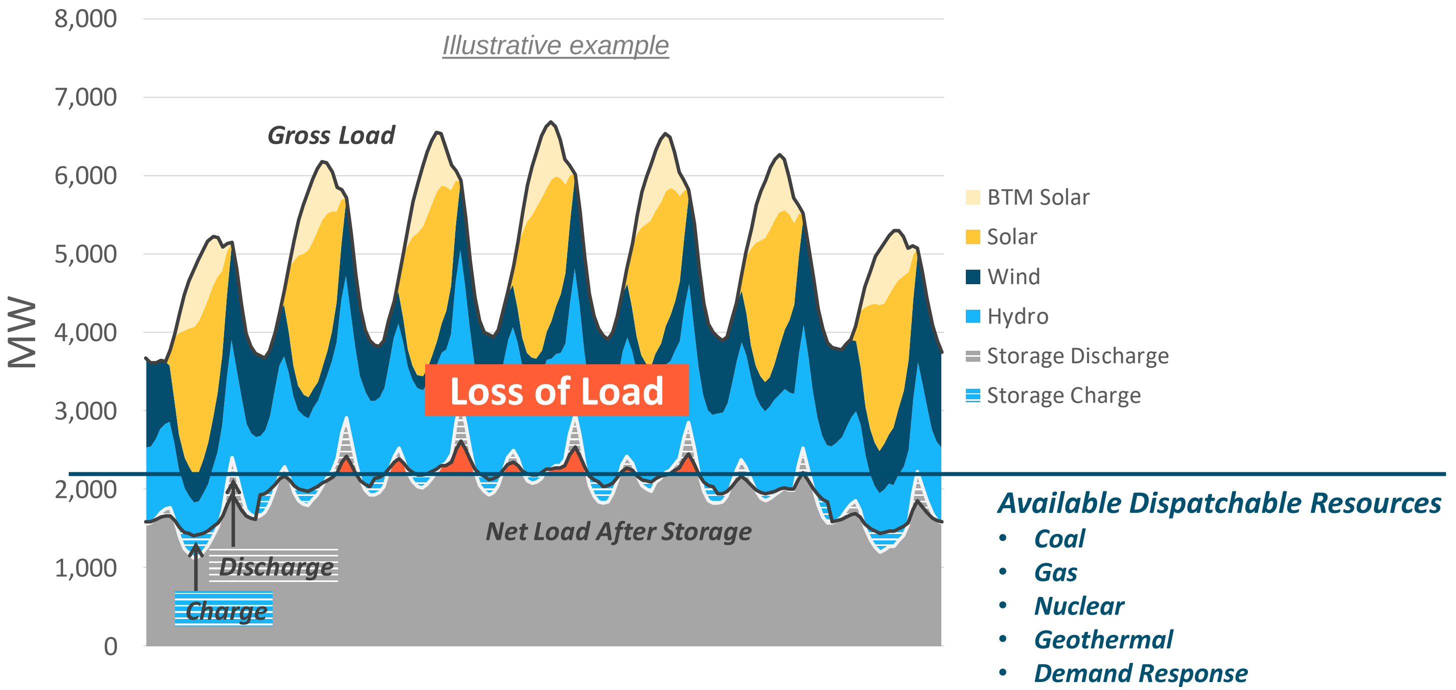
Day Index for Economic Growth

RECAP Inputs for Load

- **Actual historical NWE BA hourly load from 2010 to 2018**
  - Neural network reads firm load from 2010 to 2017 for training and validation purposes
  - 2018 load data are used for testing the performance and are not the inputs of the neural network model
- **Weather and date information from 1950 to 2018 served as predictors**
  - Daily maximum and minimum temperatures for Butte, Fort Assiniboine, Great Falls
  - Day of the week, month, and Canadian holiday dummy variables

Calculating Loss of Load in RECAP

- Any residual load that cannot be served from all available resource is counted as lost load
- Loss of load expectation (LOLE) is the number of days with at least one loss of load event per year



Hybrid Resources: Key Variables

+ Key variables for modeling hybrid resources in RECAP

Variable	Options	Recommended Scenario(s)
Renewable Technology	Wind or solar	Wind and Solar
VER to Storage Ratio	Solar: typically ~3:1 to 1:1 Wind: typically ~10:1 to 4:1	Solar: 4:1, 2:1, 1:1* Wind: 4:1, 2:1
Storage Duration	Solar: typically 1-4 hours Wind: typically 1-2 hours	Solar: 4 hours Wind: 4 hours**
Shared Inverter	Solar: AC or DC coupled	AC and DC coupled scenarios
ITC Charging Limits	Charge from VER or can charge from grid	Can charge from grid + RE charging sensitivity
Inverter Loading Ratio	Solar: 1.3 to 1.7	1.7 for DC-coupled, 1.3 for AC-coupled

* While a 1:1 ratio with a high ILR is becoming more common in solar saturated grids like Hawaii and the Southwest, it is less likely to be economic in higher latitudes like MT with more limited solar to charge batteries during many parts of the year.
** While most existing wind hybrids have lower duration, E3 recommends 4 hours, which will maximize RA value and is the duration for the MT Caithness Beaver Creek project (320 MW wind, 160 MW / 640 MWh storage).
*** NOTE: charging from the grid does not necessarily revoke the ITC. If >75% of battery charging is from the solar facility, project is eligible for pull or partial ITC. If not grid charging constraints, stand-alone ELCCs can be used, subject to inverter limits if DC coupled solar.

Hybrid vs. Stand-alone ELCCs

+ **Hybrid resources should have equal or lower ELCCs to stand alone resources for similar capacity + storage duration**
+ **Charging constraints (e.g. requiring the storage to charge from renewables for the solar ITC) likely to further reduce hybrid ELCCs**

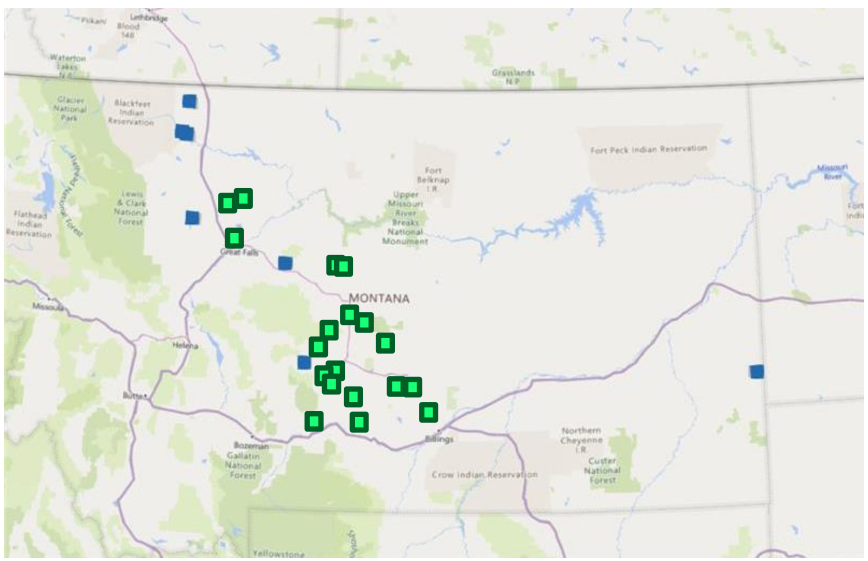
Stand-alone VER + Storage ELCC ≥ Hybrid VER + Storage ELCC (no RE charging constraints) ≥ Hybrid VER + Storage ELCC (w/ RE charging constraints)

Interconnection and/or inverter limits (for DC-coupled projects) may further limit maximum project ELCCs

Simulated Wind + Solar Sites

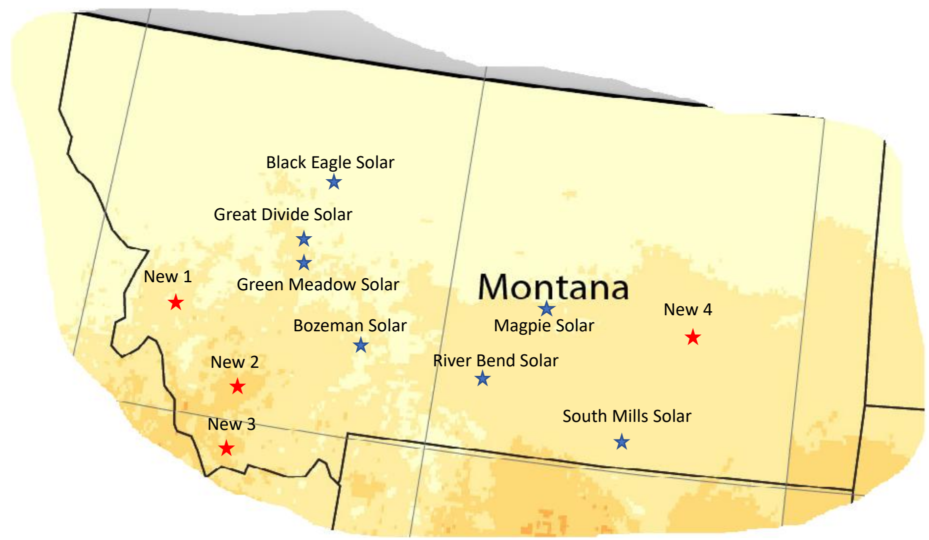
+ **Simulated wind and solar shapes utilize NREL datasets (Wind Toolkit + NSRDB) combined with E3 scripts to develop multi-year hourly simulated renewable output shapes**

Simulated Wind Sites



Existing sites (approximate)   New resource sites

Simulated Solar Sites



Existing sites (approximate)   New resource sites