HECO Resource Adequacy Workplan

Inputs, Assumptions, and Modeling Framework

Mar 2, 2023

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Energy+Environmental Economics

Agenda

- Overview and Goals of Resource Adequacy Workplan
- Initial Findings from E3's Resource Adequacy Planning Survey
- RA Workplan Modeling Methodology
- Appendix: Modeling inputs, assumptions, and methodology

RA Workplan Overview and Goals

Workplan Purpose and Motivation

- **In 2022, the Commission instructed Hawaiian Electric to explore an ELCC-based resource adequacy criteria for use in future rounds of IGP and develop a workplan in consultation with the TAP and Parties.**
- **The workplan must explain:**
  - How Hawaiian Electric intends to solicit and incorporate stakeholder feedback
  - How long Hawaiian Electric expects the process to take
  - How and in what dockets and other efforts Hawaiian Electric uses ERM and HDC as resource adequacy criteria
  - How Hawaiian Electric could begin transitioning from using ERM and HDC to ELCC in IGP and elsewhere
  - How long it would take to compute ELCC for all resource types evaluated in PLEXOS as part of Hawaiian Electric's stochastic reliability modeling in the current round of IGP
- **In coordination with the TAP, HECO + E3 will explore whether ELCC is a superior alternative to the current methodology (ERM+HDC) or proposed improvements to the current methodology (ERM+HEC)**

Resource Adequacy Frameworks to Test

ERM + HDC
Energy Reserve Margin + Hourly Dependable Capacity

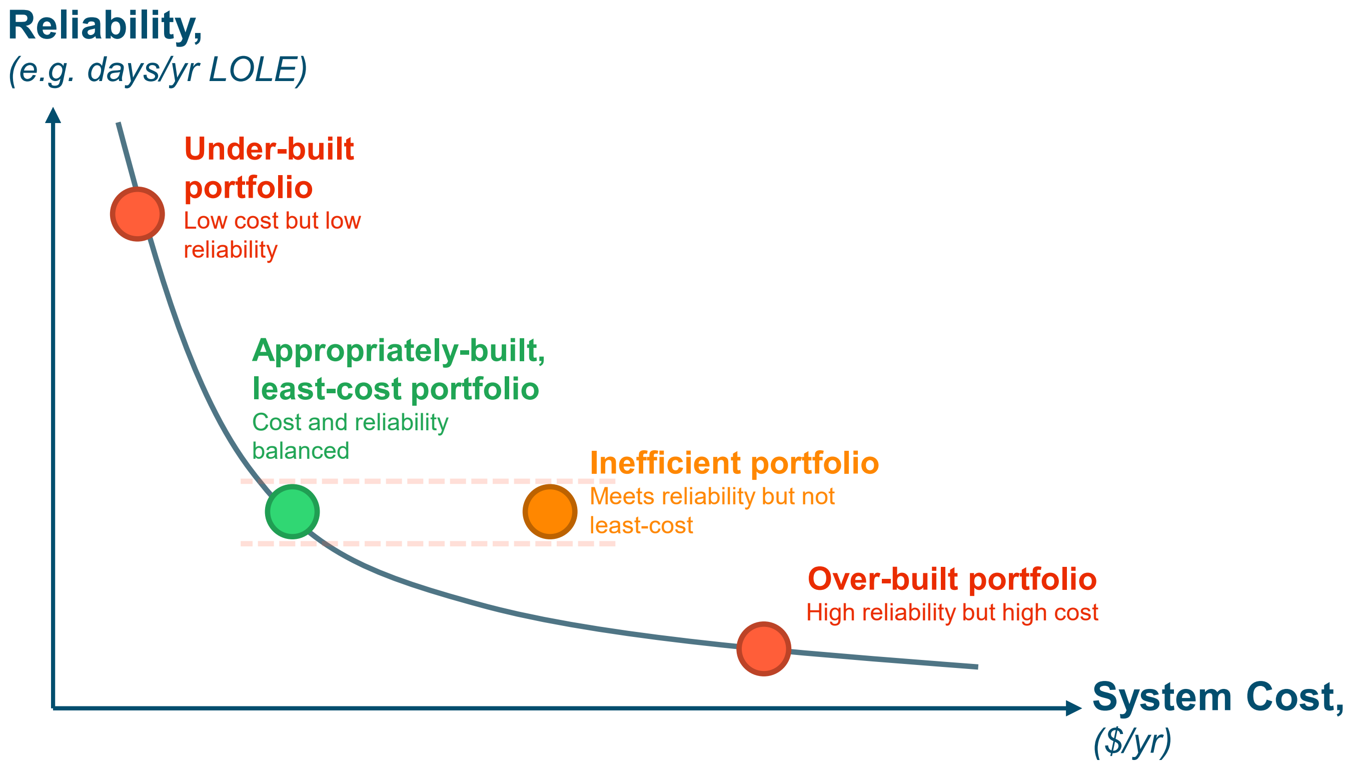
ERM + HEC
Energy Reserve Margin + Hourly Expected Capacity

PRM + ELCC
Planning Reserve Margin + Effective Load Carrying Capability

Key Questions to Address in This Workplan

<u>Three questions to address in this workplan:</u>

1. **What resource adequacy framework sends the correct marginal investment signals for RESOLVE to meet reliability at least cost?**
2. **How do these frameworks balance accuracy vs complexity and transparency?**
3. **Do these frameworks meet both near-term and long-term system planning challenges to maintain system reliability through the transition to 100% renewables?**



What RA planning framework results in a least-cost and sufficiently reliable portfolio?

Overview of Proposed Workplan

Industry Review

Produce a resource adequacy methodology survey

- *Review of RA planning frameworks in other jurisdictions*
- *Review of Hawai'i-specific considerations*
- *Pros and cons of different methods*

Development of Reliability Need and Resource Capacity Values

E3 Workstream

Develop a LOLP model + comprehensive stochastic dataset

Determining reliability need and resource capacity value for *PRM + ELCC*

Joint Workstream with HECO, TAP, and E3

Use HECO-calculated ERM + HDC values

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Capacity Expansion Modeling

Perform capacity expansion in RESOLVE using each framework

- *Adjust inputs to reflect reliability need and resource capacity value*
- *Develop least-cost optimal portfolios with RA planning frameworks*

Evaluation + Final Report

Provide a final report with recommendation for RA framework

- *Final report describing modeling results for HDC, HEC, and ELCC*
- *Quantitative and qualitative evaluation of each method*
- *Recommended method for future IGP cycles*

Timeline

TAP Meeting #1	TAP Meeting #2	TAP Meeting #3	TAP Meeting #4
Today	Apr 13	May 25 or July 6	July 6 or Aug 17

Methodology, Inputs and Assumptions

- In this kickoff meeting, E3 will present the motivation and goals for the RA Workplan
- E3 will present its methodology to assess and compare the various resource adequacy planning techniques
- TAP will provide feedback on the workplan's inputs, assumptions, and modeling

Draft Results and Discussion

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Report and Final Recommendation

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Inputs & Model Dev → **Results Refinement & Updates** → **Report**

Initial Findings from E3's RA Survey

E3 performed an initial survey of resource adequacy frameworks across jurisdictions

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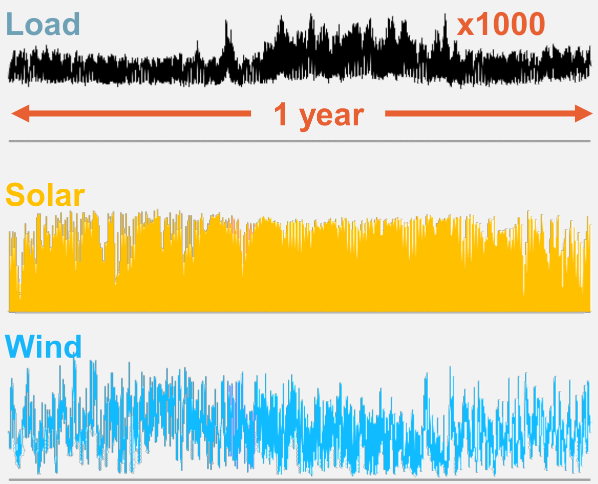
Key Steps for a Reliability Planning Framework

Step 1: Model + Data Development

Develop a robust dataset of the loads and resources, typically in a loss of load probability (LOLP) model

LOLP modeling evaluates resource adequacy across all hours of the year under a broad range of weather conditions

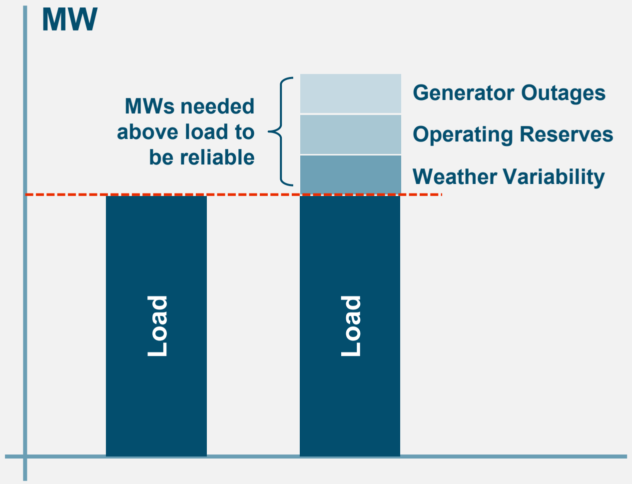


Robust probabilistic models + datasets are the foundation of any resource adequacy analysis

Step 2: Need Determination

Identify the Total Reliability Need to achieve the desired level of reliability

Factors that impact the amount of effective capacity needed include load & weather variability, operating reserve needs

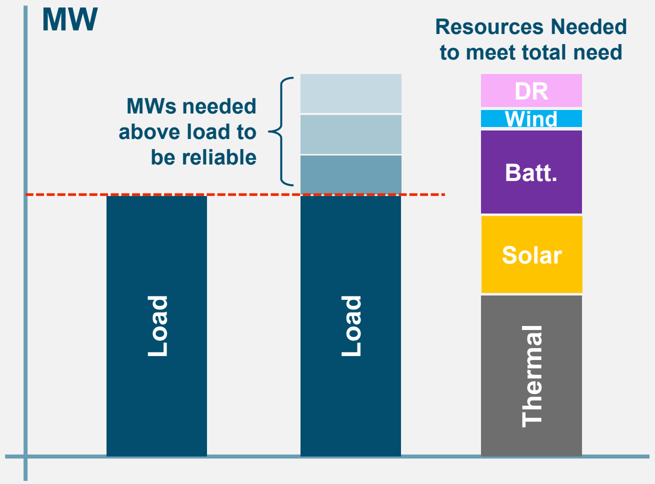


The total reliability need is calculated to meet a target reliability standard (e.g. 0.1 LOLE)

Step 3: Resource Accreditation

Calculate resource capacity contributions

Measures a resource's contribution to reliability needs relative to target reliability, accounting for performance across all hours



Resource accreditation determines how much each resource counts towards the total reliability need

Jurisdictional Survey Results: Reliability Metrics

Jurisdiction / Utility	Reliability Metric(s)	Metric Value	Notes
ISO-NE	LOLE	0.1 days/year	Multiple LOLE targets are used tested, but 0.1 LOLE used for demand curve requirement (ICR)
MISO	LOLE	0.1 days/year	LOLE working group process also oversees ELCC calculations
NYISO	LOLE	0.1 days/year	LOLE is used to set capacity market demand curve
PJM	LOLE	0.1 days/year	LOLE modeling also used in capacity market demand curve
SPP	LOLE	0.1 days/year	PRM for LSEs with at least 75% hydro-based generation is 9.9%
ERCOT	Total cost & market equilibrium	N/A	Purely informational PRM of 15.75% achieves 0.1 events/yr; Economically optimal (min. cost incl value of lost load) = 11.0%; Market equilibrium (cost vs. value of new entry) = 12.25%
AESO	N/A	N/A	AESO operates an energy-only market with no capacity requirement; 26% PRM achieved in 2020 w/o imports
CAISO	PRM	~17%	<0.1 days/year LOLE is used in IRP planning but not historically used to update RA PRM
Florida Power and Light	LOLE	0.1 days/year	15% PRM required in addition to ensuring LOLE is met
Nova Scotia	LOLE	0.1 days/year	20% PRM to meet 0.1 LOLE standard
PacifiCorp	N/A	N/A	13% PRM selected by balancing cost and reliability; Meets 0.1 LOLE
Hawaii (Oahu)	LOLP	0.22 days/yr	Relatively small system size and no interconnection results in 45% PRM (2016 PSIP)
Australia	EUE	0.002%	System operator monitors forecasted reliability and can intervene in market if necessary
Great Britain	LOLH	3 hours/year	5% (Target PRM 2021/22) 11.7% (Observed PRM 2018/19)

Jurisdictional Survey Results: Accreditation Methods

	Bilateral Markets			Centralized Capacity Markets				No Capacity Market	No Market
Resource Type	CAISO	SPP	WRAP	MISO	PJM	ISO-NE	NYISO	ERCOT	HECO
Renewable Accreditation Period	Monthly	Summer + Winter	Summer + Winter	Summer + Winter	Annual	Summer + Winter	Annual	Summer + Winter assessments (not accreditation)	Annual
Thermal	ICAP (considering UCAP)	ICAP + UCAP	UCAP	UCAP	UCAP	ICAP (seasonal)	UCAP	ICAP (summer capacity)	Weighted equivalent availability factor
Solar	ELCC	ELCC	ELCC	ELCC	ELCC	Median Historical Output During Reliability Hours	MRI*	Historical Output	HDC (80% probability of exceedance)
Wind	ELCC	ELCC	ELCC	ELCC	ELCC	Median Historical Output During Reliability Hours	MRI*	Historical Output	HDC (80% probability of exceedance)
Energy Storage	4-hr equivalent MW	ELCC	5-hr equivalent MW	Historical output and testing	ELCC	Full capacity credit for 2-hr+ duration	Capacity value analysis	n/a (~300 MW assumed to be 0 in recent studies)	Full capacity credit
DR	Statistical protocol	Testing & measurement	Operational testing and historical performance	Testing & measurement	Rule of Thumb	Various	Testing & measurement	Installed MW	Full capacity credit
Hydro	Historical output	Median historical conditions, post EFOR	NWPP-specific modeling	Median historical summer output	Historical summer head and/or streamflow	Median historical summer + winter output	Average historical summer + winter output	Installed capacity	HDC (80% probability of exceedance)
Notes	CPUC RA program considering hourly "slice of day" method CPUC IRP program uses ELCCs for all resources		Will reconsider energy storage capacity value as adoption increases	Class avg. forced outage rates	PJM model using E3's delta allocation method to calculate average ELCCs	**Exploring ELCC or MRI** No UCAP MW for thermal, but pay-for-performance incentives for availability	Class avg. forced outage rates **ELCC studies have been performed** by GE	ERCOT uses historical output for wind/solar to calculate its reserve margin, but considering new approaches like **ELCC** by Astrape	HDC calculations use NREL NSRDB data for solar, historical data for wind and hydro

*the Marginal Reliability Impact (MRI) is a method like ELCC, but measures the incremental impact of its 'last' MW on system reliability

Summarizing reliability planning methods

+ **E3 plans to create a comparison table of planning methods surveyed, qualitatively considering:**
  - Accuracy, complexity, transparency, robustness

	Pros	Cons
Historical Output (mean or exceedance)		
Effective load carrying capability (ELCC)	?	
Hourly energy-based methods (like "slice of day")		
Other methods?		

What other outcomes would you like to see from this survey to inform Hawaiian Electric reliability planning methods?

What is unique about reliability planning for Hawaiian Electric grids?

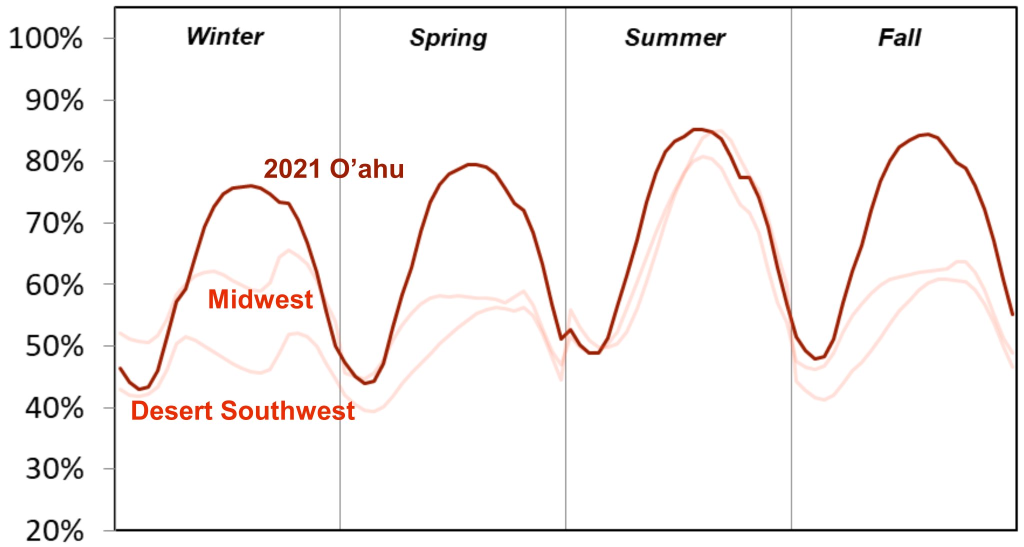
+ **Planning for Hawaii is unique relative to mainland grids (like RTO or large utility resource adequacy programs):**
  - Smaller, isolated grids (no neighbor support, resource/load diversity, higher impact on LOLE of plant outages)
  - Generally mild year-round weather
  - Limited inter-annual weather extremes
  - Uniqueness of the integrated grid planning process (vertical integration, transmission planning, etc.)

Hawaii vs. Other Summer Peaking Systems

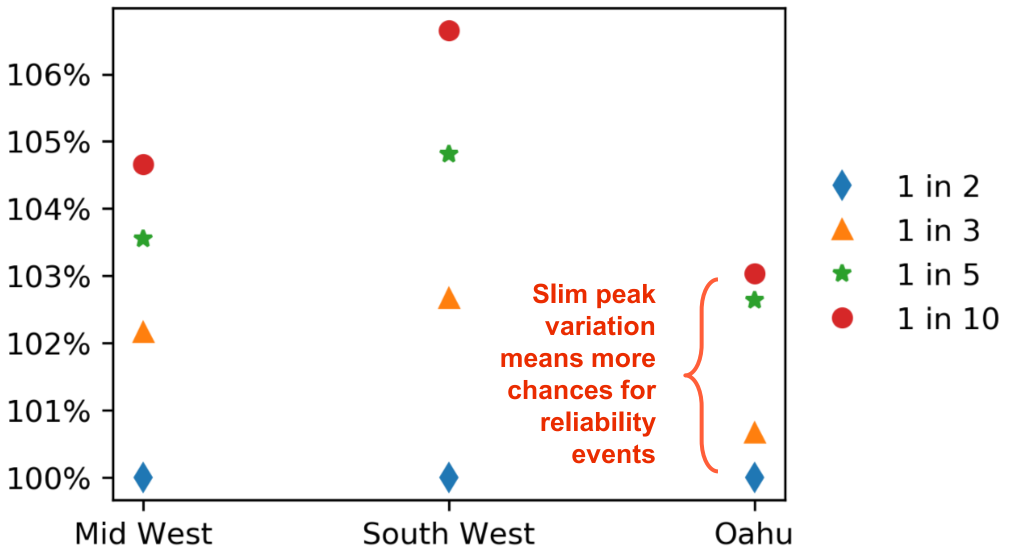
How sensitive is reliability in a system with very low seasonal and interannual load variability?

+ **Low intra-year variability:** Unlike many mainland systems, Hawaii's uniform temperatures year-round leads to high load periods for all seasons within the year, spreading out reliability risk
+ **Low inter-year variability:** Across weather years, peak to peak variations are also narrower than many mainland systems
+ These two factors make Hawaiian Electric's system more sensitive to reliability risk than mainland grids driven by seasonal peaks and infrequent extreme weather conditions

Normalized Season-Hour Load,
Percent of Median Peak Load



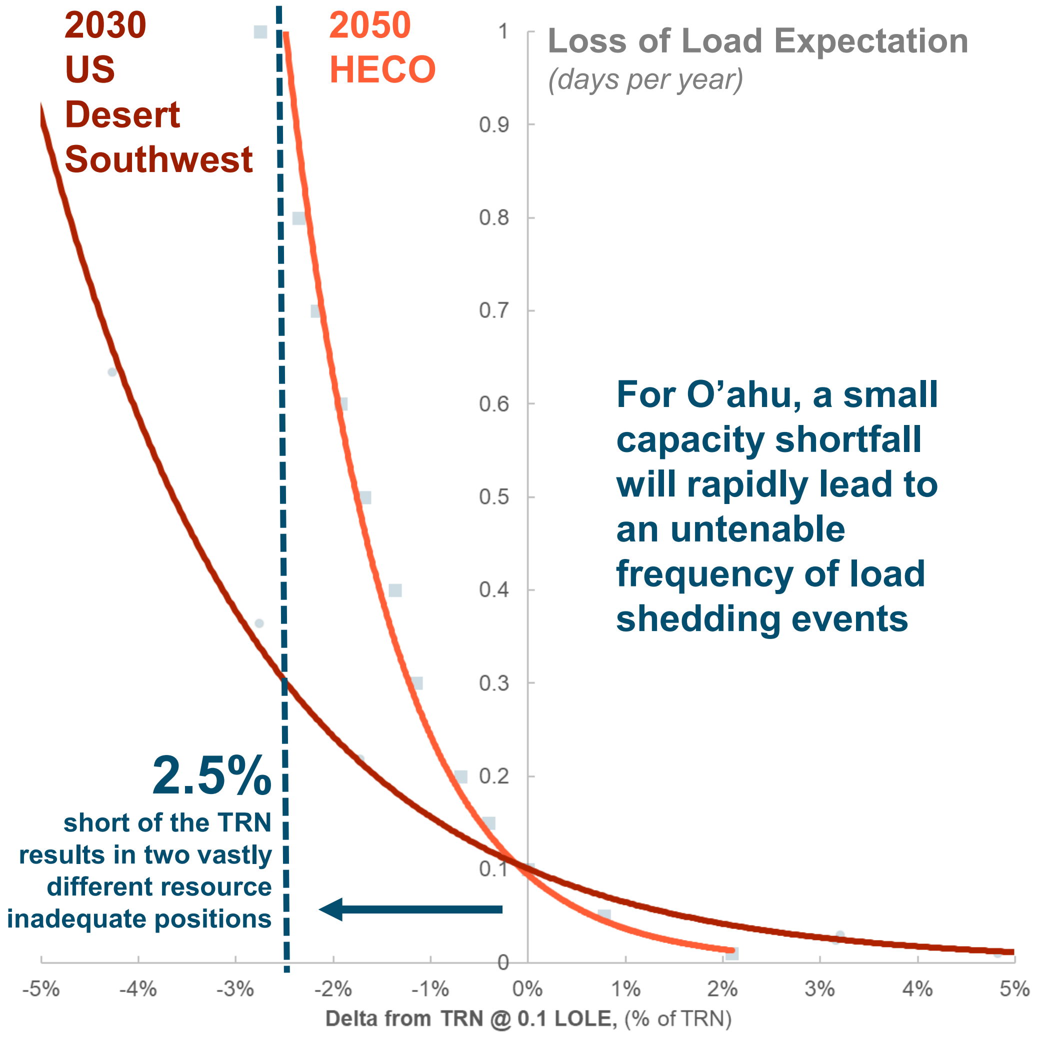
1-in-X peak load relative to 1-in-2,
(%)



Hawaii vs. Other Summer Peaking Systems

How sensitive is reliability in a system with very low seasonal and interannual load variability?

- **Preliminary LOLP analysis confirms that HECO's loss of load expectation is more sensitive to small capacity changes than larger mainland grids**
  - This is due to low seasonal and inter-year load variability
- **This means that uncertainties compound in their impact and may warrant some conservatism in reliability procurement**
  - E.g. relative to a 0.1 days/yr LOLE standard, missing the targeted reliability need by 2.5% on O'ahu leads to 1 day/yr of lost load vs. 0.3 days/yr for the Desert Southwest



RA Framework Testing Methodology

E3 and HECO will compare RA frameworks through capacity expansion and LOLP modeling

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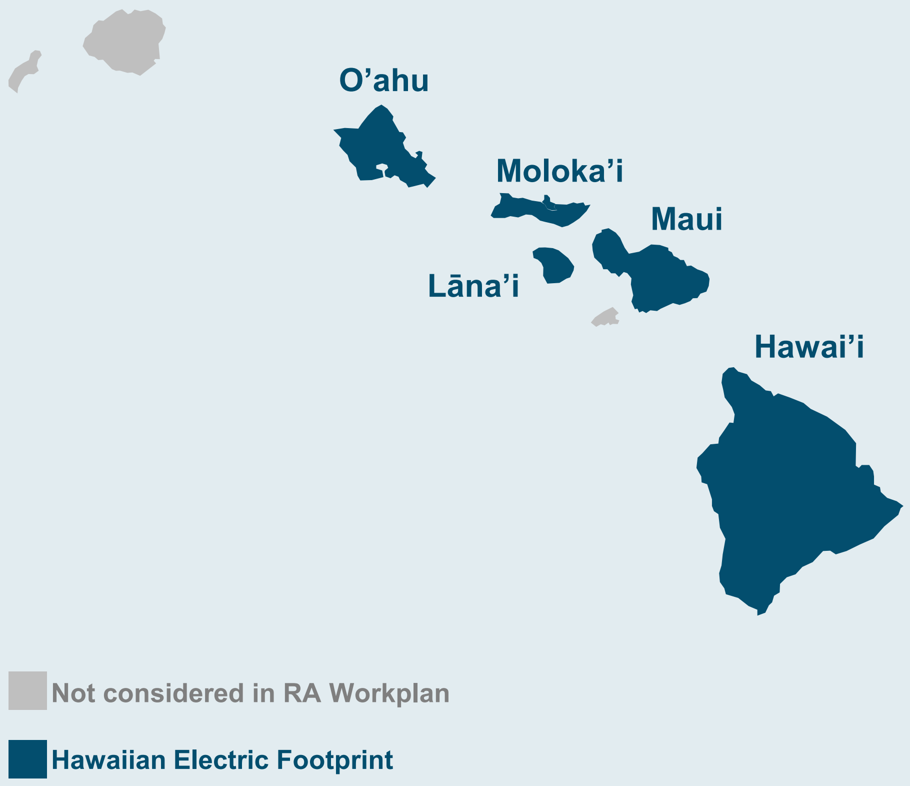
Modeling scope and horizon

- To measure RA framework performance, E3 will develop least-cost portfolios using Hawaiian Electric's capacity expansion model, RESOLVE, and develop a loss of load probability (LOLP) model, RECAP, to perform a detailed system reliability assessment
- E3 will examine RA frameworks for O'ahu, Hawai'i, Maui, Lāna'i, and Moloka'i
- E3 will model a near-term and long-term system based on IGP reference assumptions for load, policy, and resource availability
  - Sensitivities may be considered depending on scenario and relevance to RA workplan

Study Footprint



Resource Adequacy Frameworks to Test

Resource Adequacy Framework		Need Determination Method	Capacity Accreditation Method
Energy Reserve Margin + Hourly Dependable Capacity	***ERM+HDC***	The **Energy Reserve Margin (ERM)** is the percentage of system load by which the system capacity must exceed the system load in each hour. The ERM is 30% or 60%* above load **for every hour** depending on the island. **ERM may be recalibrated in this study to align loss of load expectation across frameworks**	Firm resources are counted on its unforced capacity. Variable resources use the **Hourly Dependable Capacity (HDC)** methodology, counted hourly based on their **historical production with an 80% probability of exceedance**. Accreditation implemented directly in RESOLVE.
Energy Reserve Margin + Hourly Expected Capacity	***ERM+HEC***	The **Energy Reserve Margin (ERM)** is the percentage of system load by which the system capacity must exceed the system load in each hour. The ERM is 30% or 60%* above load **for every hour** depending on the island. **Due to the increased accreditation for variable resources with HEC, ERM target will be different than the ERM established with HDC; need to discuss with TAP.**	Firm resources are counted on its unforced capacity. Variable resources the **Hourly Expected Capacity (HEC)** methodology, counted hourly based on their **mean historical production.** **Details still TBD; need to discuss with TAP.** Accreditation implemented directly in RESOLVE.
Planning Reserve Margin + Effective Load Carrying Capability	***PRM+ELCC***	First, **a reliability target must be established** (e.g., 0.1 LOLE or 0.0005% EUE). Then, the probabilistic **Total Reliability Need (TRN in ELCC MW) needed to meet the reliability standard is calculated** and can be converted into a **Planning Reserve Margin (PRM in %)** relative to annual median peak demand. The PRM is an output from loss of load probability modeling and **is defined annually.**	All resources (including firm resources) are measured using the **Effective Load Carrying Capability** methodology (ELCC). All resources are measured against perfect capacity and accredited based on their ability to reduce system reliability risk. Accreditation parameterized using RECAP LOLP modeling to generate RESOLVE inputs.

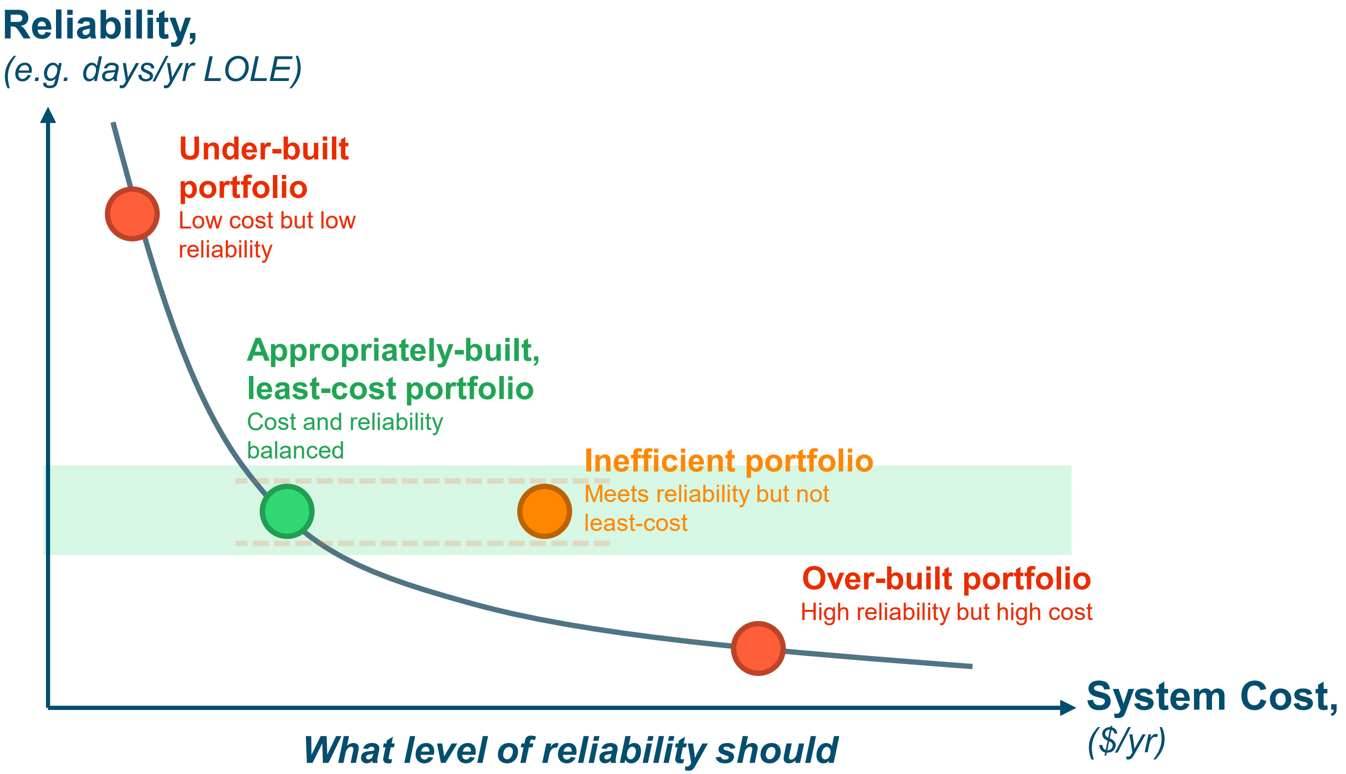
*30% for O'ahu, Hawai'i, and Maui; 60% for Lana'i and Moloka'i

Pre-requisites for Need Determination: Reliability Standard

+ To perform reliability planning, a system needs a reliability standard
+ A standard, like 1-day-in-10 LOLE or others, is needed for implementing this workplan

Questions for TAP Members

1. *What reliability target should Hawaiian Electric adopt?*
2. *Should targets be different across islands?*
3. *Do we need to align the reliability target between the ERM and PRM methods?*

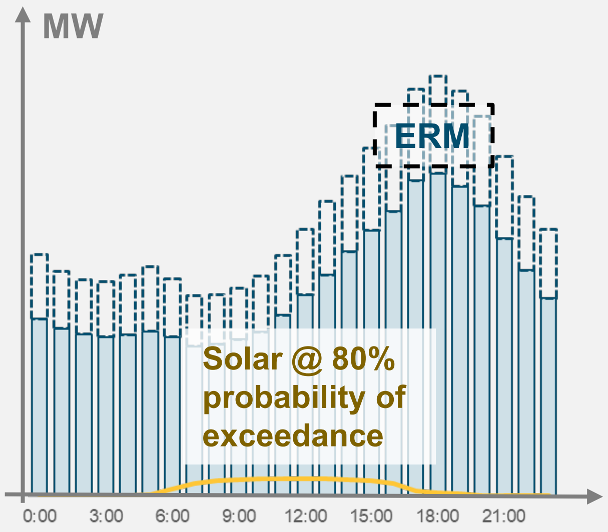


What level of reliability should Hawaiian Electric adopt and should we align target reliability across ERM and PRM targets?

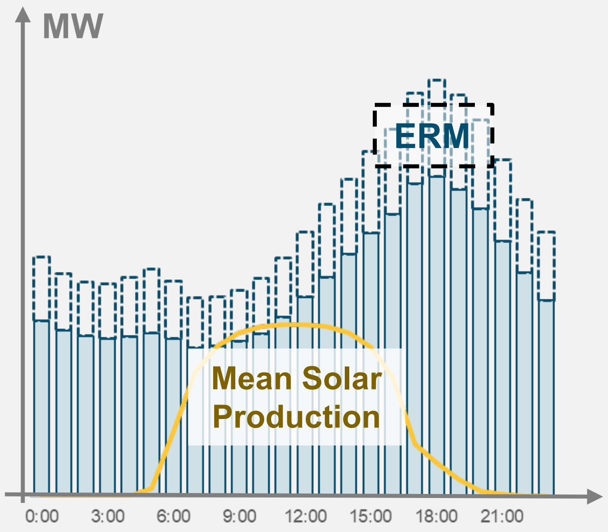
Expectations on Resource Accreditation Methods

HDC and HEC

Hourly Dependable Capacity (HDC)



Hourly Expected Capacity (HEC)



HDC and HEC applies to all variable resources

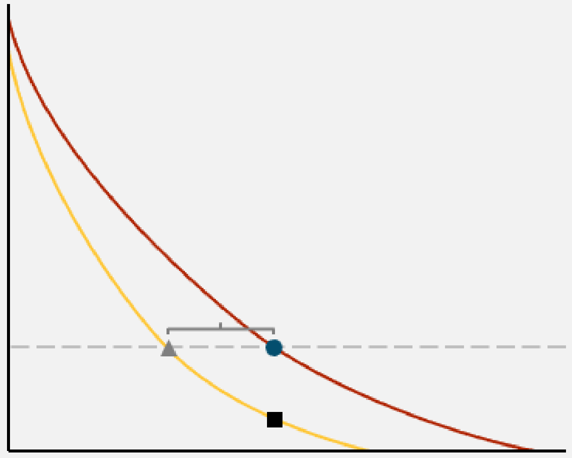
+ **Under the ERM construct, variable resources, like solar and wind, are accredited by HDC or HEC Methodology**
  - The Hourly Dependable Capacity ("HDC") is the minimum expected capacity from variable generation resources based on historical data,
  - Measured in MW output at 80% probability of exceedance per hour
+ **Thermal resources accredited by UCAP**
+ **Storage resources accredited by their ability to shift generation**
+ **Changes from HDC to HEC directly impacts variable resource capacity accreditation and may indirectly impact storage resource accreditation**

Expectations on Resource Accreditation Methods

ELCC

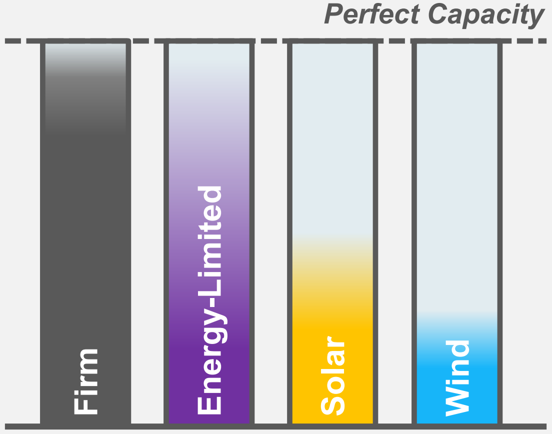
Effective Load Carrying Capability (ELCC)

Measures a resource's contribution to reliability needs relative to target reliability, accounting for performance across all hours



Calculate capacity contributions of different resources using effective load carrying capability

ELCC measures a resource's contribution to the system's needs relative to perfect capacity, accounting for its limitations and constraints



ELCC applies to all resources

+ **Under a PRM+ELCC construct, all resources will be accredited by the ELCC methodology**
  - Effective Load Carrying Capability (ELCC) represents the equivalent "perfect" capacity MW that a resource provides towards meeting the target reliability metric (e.g., 0.1 day/year LOLE)
+ **ELCC captures the coincidence of hourly and seasonal production variability, including historical correlations between renewable output and load**
+ **ELCC also captures interactive effects between all resources**
  - E3 proposes to develop a solar + storage "ELCC surface" to capture diversity benefits between solar and storage
+ **ELCC for firm resources can consider forced outages, maintenance outages, and portfolio effects**

E3 will compare portfolios across different RA frameworks and develop takeaways for HECO and TAP

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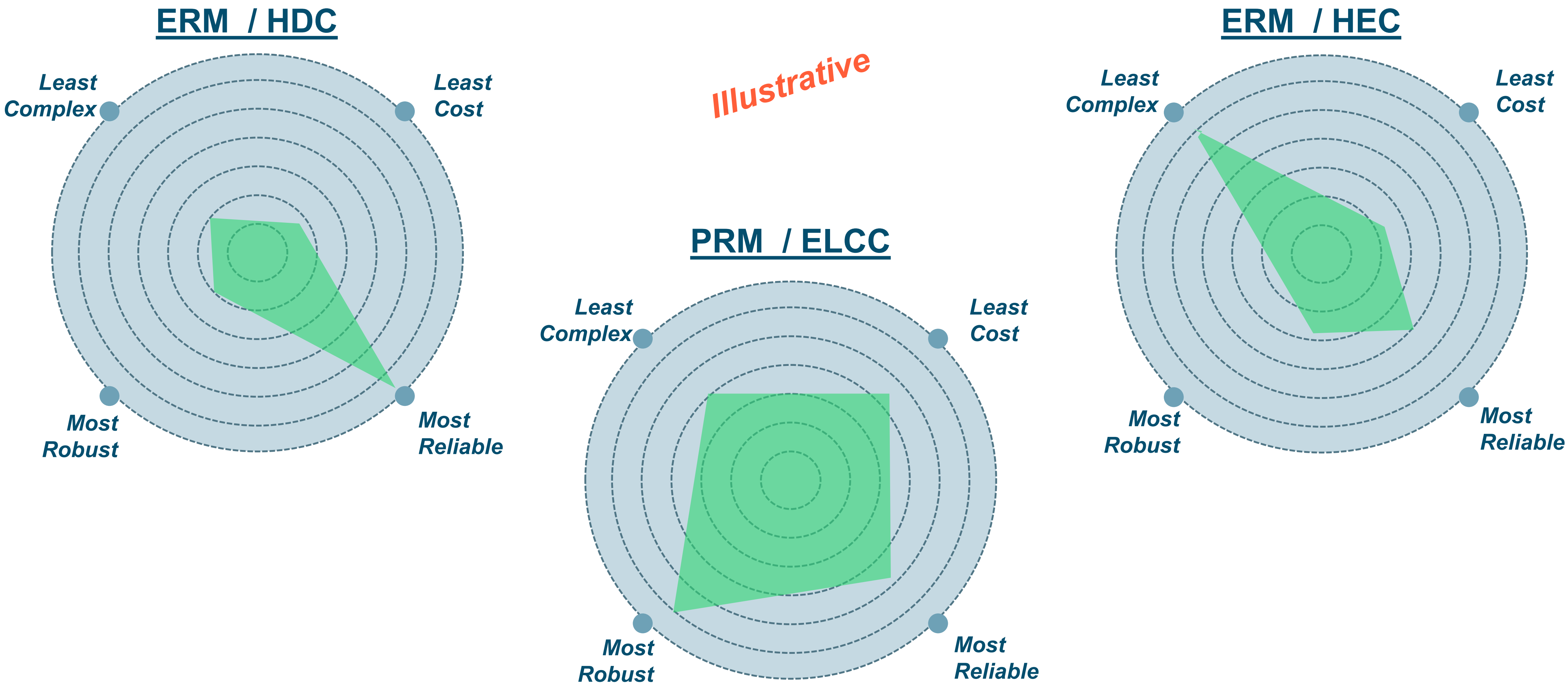
Resource Adequacy Framework Evaluation Criteria

Resource Adequacy Framework		Cost *How cost optimal are the portfolios produced by this framework?*	Reliability *How reliable are the portfolios produced under this framework?*	Complexity/ Transparency *How difficult would it be and how much time would be needed for Hawaiian Electric to implement this framework?*	Robustness *Would this framework work for today and tomorrow's electric system? Does it include interactive effects?*
Energy Reserve Margin + Hourly Dependable Capacity	*ERM+HDC*	Quantitative Metrics		Qualitative Metrics	
Energy Reserve Margin + Hourly Expected Capacity	*ERM+HEC*				
Planning Reserve Margin + Effective Load Carrying Capability	*PRM+ELCC*				

In the end, E3 will assess performance metrics and develop final takeaways



Question for the TAP

+ **Do you have feedback on the proposed approach to compare the methods using RECAP and RESOLVE?**
+ **Are the quantitative and qualitative evaluation metrics proposed appropriate?**
+ **Commissioners laid out 3 criteria for Hawaiian Electric's future resource adequacy planning framework: (1) be transparent (2) incorporate resource interactive effects and (3) show no bias for conventional generation. Does this workplan address the commission's concerns about Hawaiian Electric's resource adequacy planning framework?**
  - If not, what else should HECO and E3 include and address?
+ **What opportunities can you identify to enhance or improve the methods and assumptions used in this work?**

Next Steps

Bonus meeting

HEC Methodology
E3 and HECO would like to meet with a sub-group to finalize HEC Methodology

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Inputs & Model Dev → Results Refinement & Updates → Report

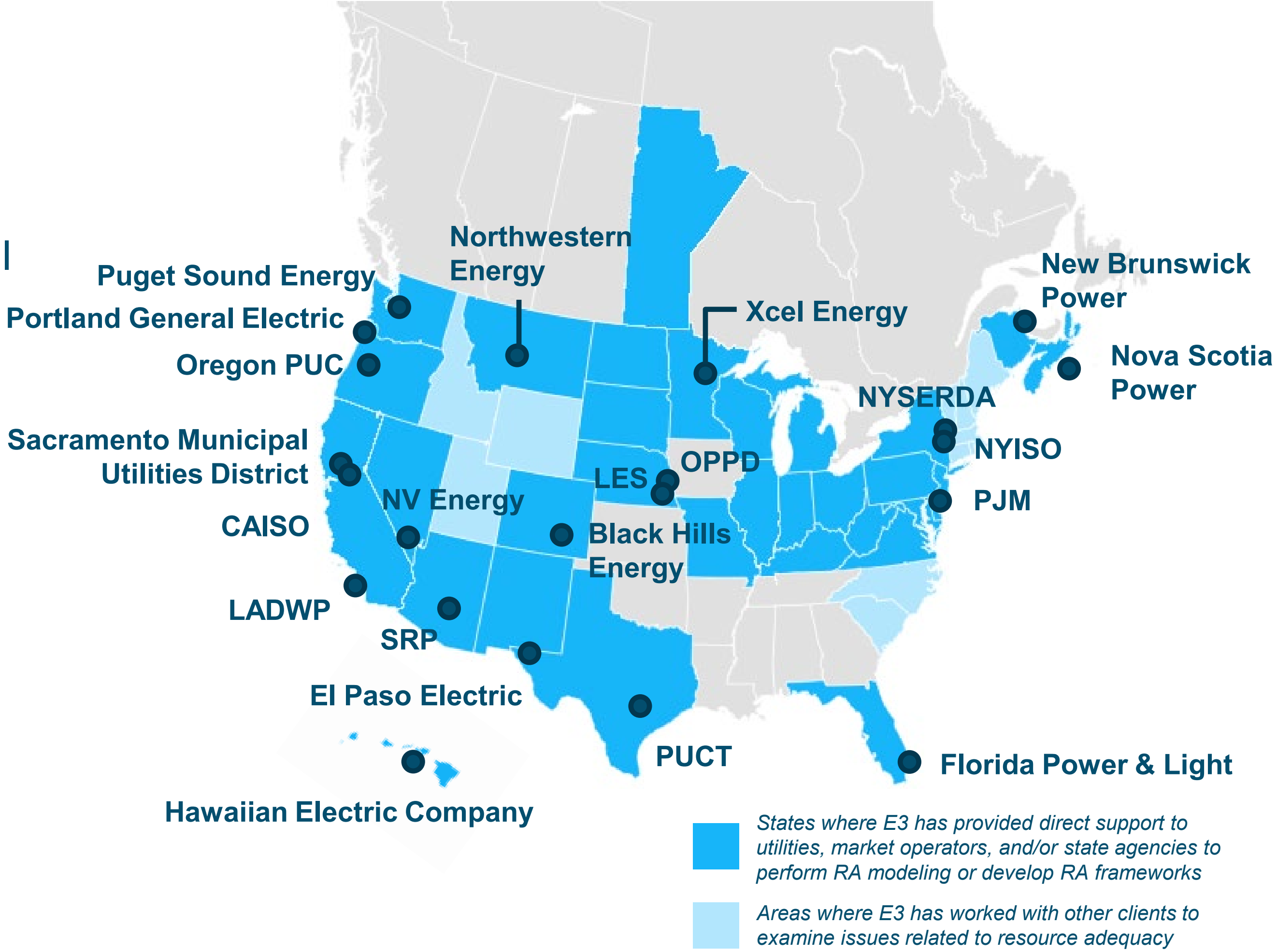
Appendix

RECAP Overview

RECAP Overview

+ **RECAP is a time-sequential, Monte Carlo-based model that evaluates hourly resource availability over thousands of simulated years**
  - In addition to summary statistics, RECAP produces hourly resource availability profiles for all simulated years
  - Time-sequential modeling allows for tracking of DR calls and storage state-of-charge
+ **RECAP uses historical weather, load, wind, and solar correlations as foundation of Monte Carlo simulation**
  - Additional uncertainty added via **stochastic forced and maintenance outages** for generation and transmission resources

E3 has worked directly with utilities across North America to study resource adequacy needs

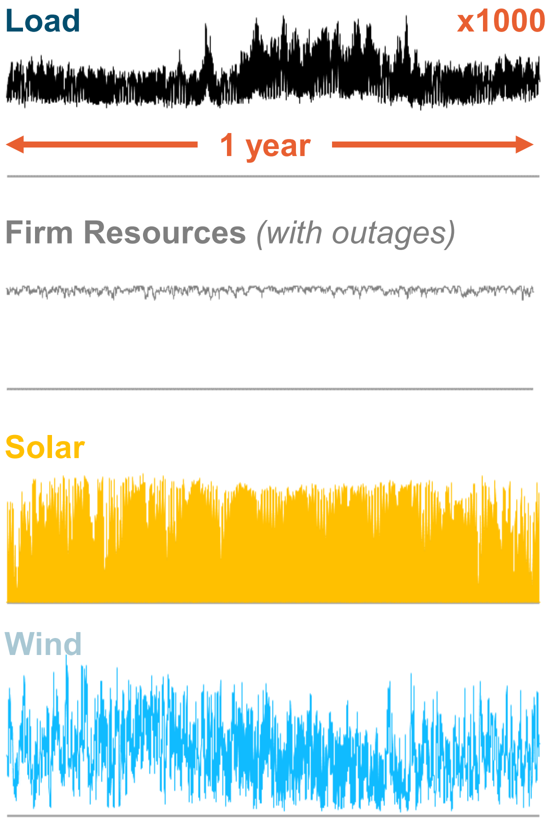


RECAP: Loss-of-Load-Probability Modeling for System Reliability

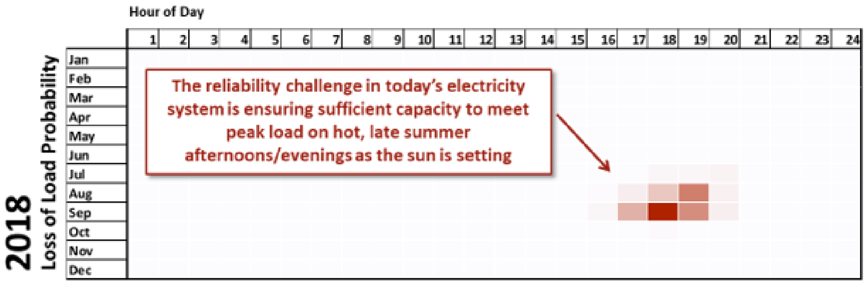
+ **RECAP provides a robust framework for evaluation of resource adequacy on systems with high penetrations of variable and energy-limited resources**

+ **Results of simulation can be used on a standalone basis to support resource adequacy program design or can be used in conjunction with other modeling tools (e.g. RESOLVE) to inform long-term portfolio development**

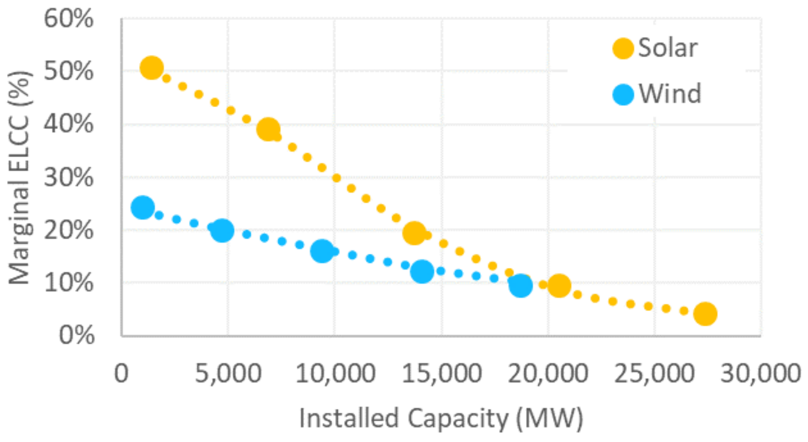
Monte Carlo simulation of loads, renewable profiles, and generator outages used to simulate 1,000 years of plausible system conditions



System reliability measured relative to "one day in ten year" standard; periods of high loss of load probability identified



Effective load carrying capability (ELCC) for a wide range of types of resources evaluated



Example RECAP result from *Long-Run Resource Adequacy under Deep Decarbonization Pathways for California* (Calpine, 2019)

RECAP Inputs and Outputs

+ **RECAP evaluates resource adequacy through time-sequential simulations over hundreds or even thousands of years**

Inputs

Load
- *Hourly load for many weather years*

Dispatchable Generation
- *Capacity*
- *FOR*
- *Maintenance*

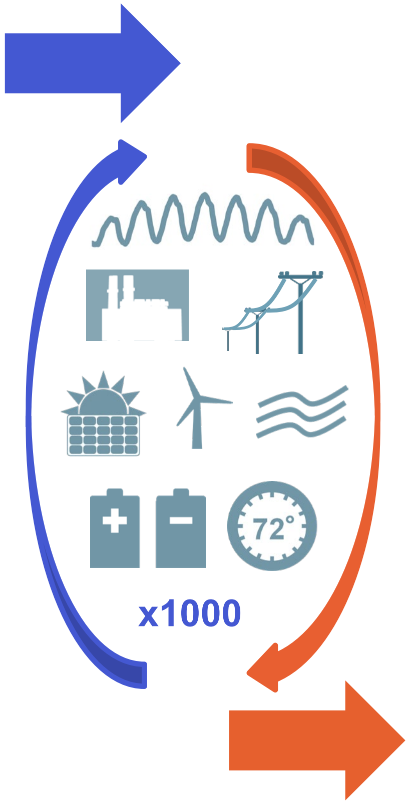
Renewables
- *Capacity*
- *Hourly generation profiles for many weather years*

Hydro
- *Hydro availability for many hydro years*
- *Max/min constraints*

Storage
- *Capacity*
- *Duration*
- *Roundtrip efficiency*
- *FOR*

Demand Response
- *Capacity*
- *Max # of calls*
- *Duration of each call*

Flexible Load
- *Capacity*
- *Max hours of shift*



Outputs

LOLH
- *Loss of load hours*
- *Hrs/yr of total expected lost load per year*

LOLE
- *Loss of load expectation*
- *Days/yr of total expected lost load per year*

ALOLP
- *Annual loss of load probability*
- *% probability of having a single loss of load in any given year*

EUE
- *Expected unserved energy*
- *MWh/yr of energy that cannot be served*

ELCC
- *Effective load carrying capability*
- *Equivalent quantity of 'perfect capacity' for a variable or energy-limited resource*

TPRM
- *Target planning reserve margin*
- *PRM required to achieve a specified reliability threshold (i.e. LOLH, LOLE, ALOLP, or EUE)*

Developing a library of hourly load & renewable profiles

Profile	Primary Source(s)	Weather Conditions Captured	Notes
Loads	**HECO** Data request **ERA 5** Simulated Historical Weather Data	HECO: 2007 – 2022 ERA 5: 1979 – 2022	• Neural network regression used to simulate hourly load patterns under broad range of weather conditions using recent historical load data (2010-2019) and long-term weather data (1979-2019) • E3 leveraged European Centre for Medium-Range Weather Forecast's climate model for simulated hourly temperature data* • Shapes for load modifiers (e.g. transportation electrification) layered on top of neural network results
Wind	**NREL & HECO** WIND Toolkit	2015 – 2019	• Profiles for **existing wind resources** provided by HECO • Profiles for **future wind resources** provided by HECO through based on NREL simulations of locations across the state
Solar	**NREL & HECO** System Advisor Model	2015 – 2019	• Profiles for **existing utility-scale solar resources** provided by HECO • Profiles for **future utility-scale solar resources** provided by HECO through based on NREL simulations of locations across the state • Profiles for **behind-the-meter/distributed solar** provided by HECO

RECAP's endogenous day-matching algorithm extends shorter samples of wind and solar data to cover full historical period while preserving underlying correlations with load

[1]ERA5 Documentation

Neural Network Load Simulation

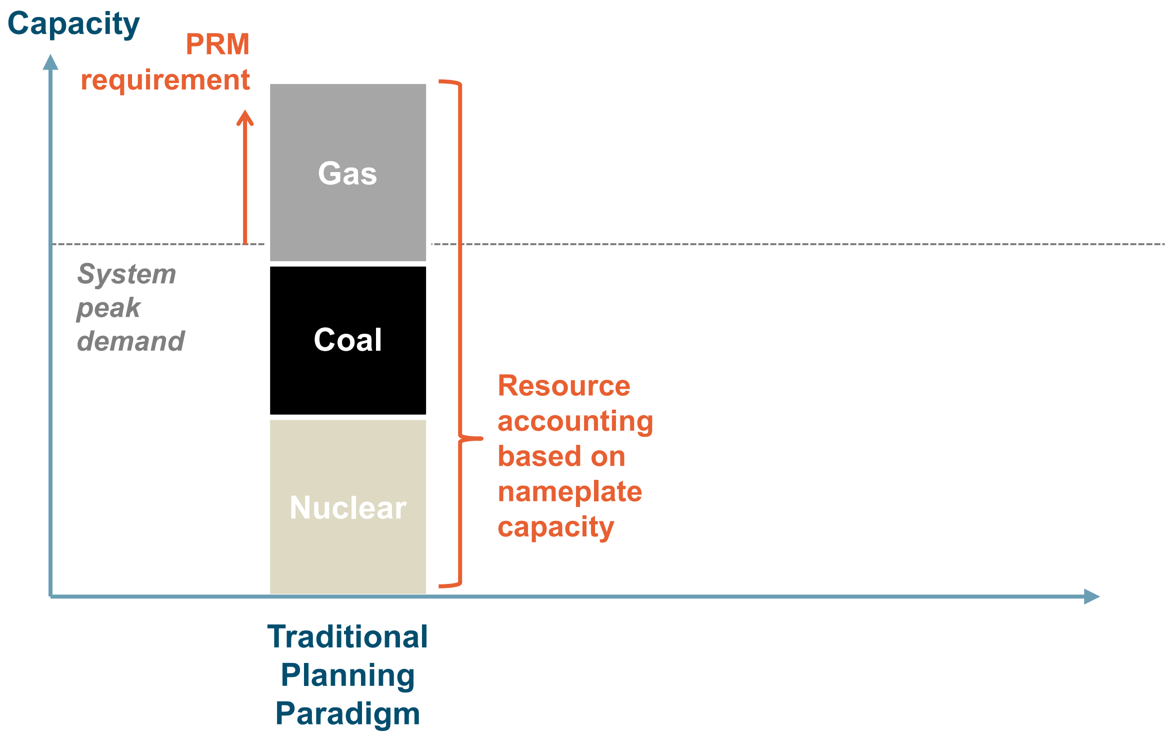
Goal: *Simulating a Longer Record of Historical Gross Load*

- **To capture weather variability, E3 uses a neural network model to simulate historical loads under different historical weather conditions**
- **Input: Historical load from 2007 to 2020**
- **Input: Weather and date information from 1979 to 2020 served as predictors**
  - Hourly maximum and minimum temperatures
  - Day of the week, month, and holiday variables
- **Output: Load simulation from 1979 to 2021**
  - 2022 daily load will be used to check the performance of the model

Adapting the PRM framwork and using ELCCs for future RA planning

Resource accreditation is simple in the traditional planning paradigm

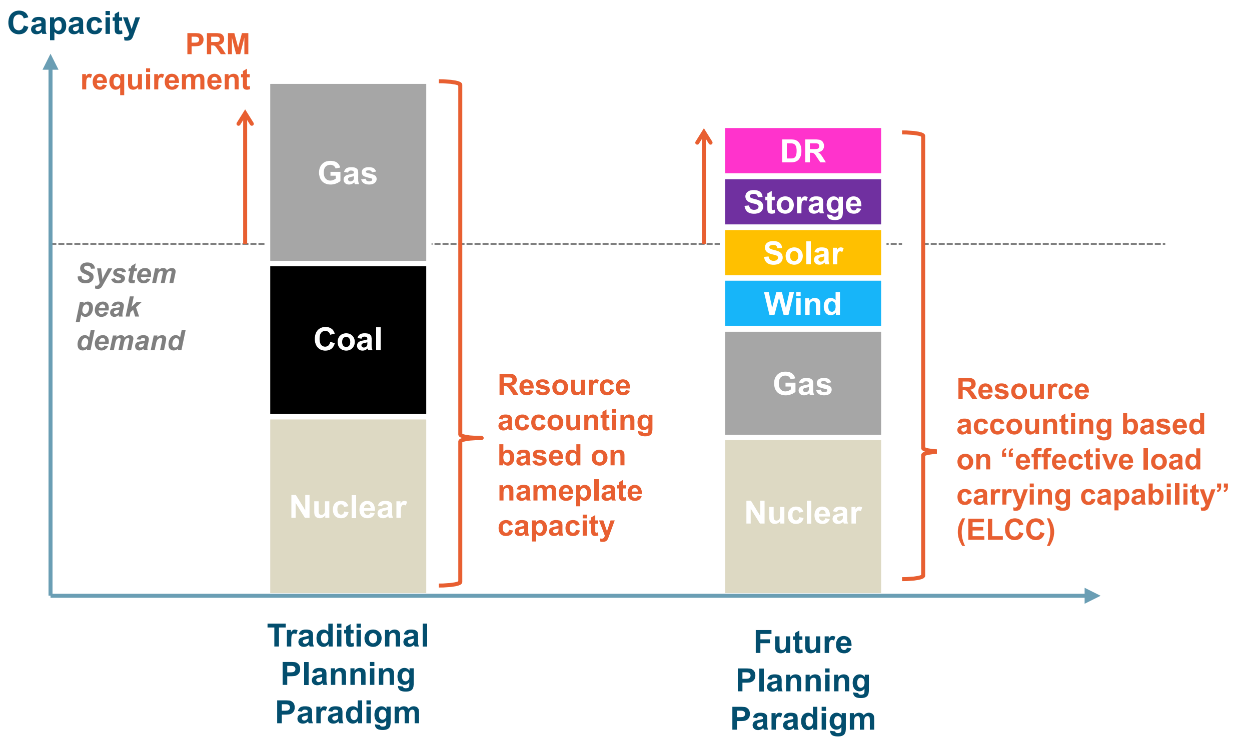
- **PRM defined based on Installed Capacity method (ICAP)**
  - Covers annual peak load variation, operating reserve requirements, and thermal resource forced outages
- **Individual resources accredited based on nameplate capacity**
  - Small differences in forced outage rates
  - No interactions among resources
  - Forced outages also incorporated through performance penalties



$$Installed\ Capacity = \sum_{i=1}^{n} G_i$$

Adapting the PRM framework for a high renewable future

- **PRM defined based on need for Perfect Capacity (PCAP)**
  - Covers annual peak load variation and operating reserves only; forced outages addressed in resource accreditation
- **Individual resources accredited based on ELCC**
  - Large differences in availability during peak
  - Significant interactions among resources
  - ELCC values are dynamic based on resource mix



$$Portfolio\ ELCC = f(G_1, G_2, \ldots, G_n)$$

ELCC is calculated using loss-of-load-probability modeling

+ **Effective Load Carrying Capability (ELCC) represents the equivalent "perfect" capacity that a resource provides in meeting the target reliability metric (e.g., 0.1 day/year LOLE)**
  - **Derived from LOLP modeling**, building on foundation for resource adequacy analysis
  - Captures **complex interactive effects**, e.g., saturation effects and diversity benefits
  - **Agnostic to technology** and can be applied to all resources

1 → **2** → **3**

1. Calculate existing system reliability and tune the system to the target

2. Add desired resource to portfolio

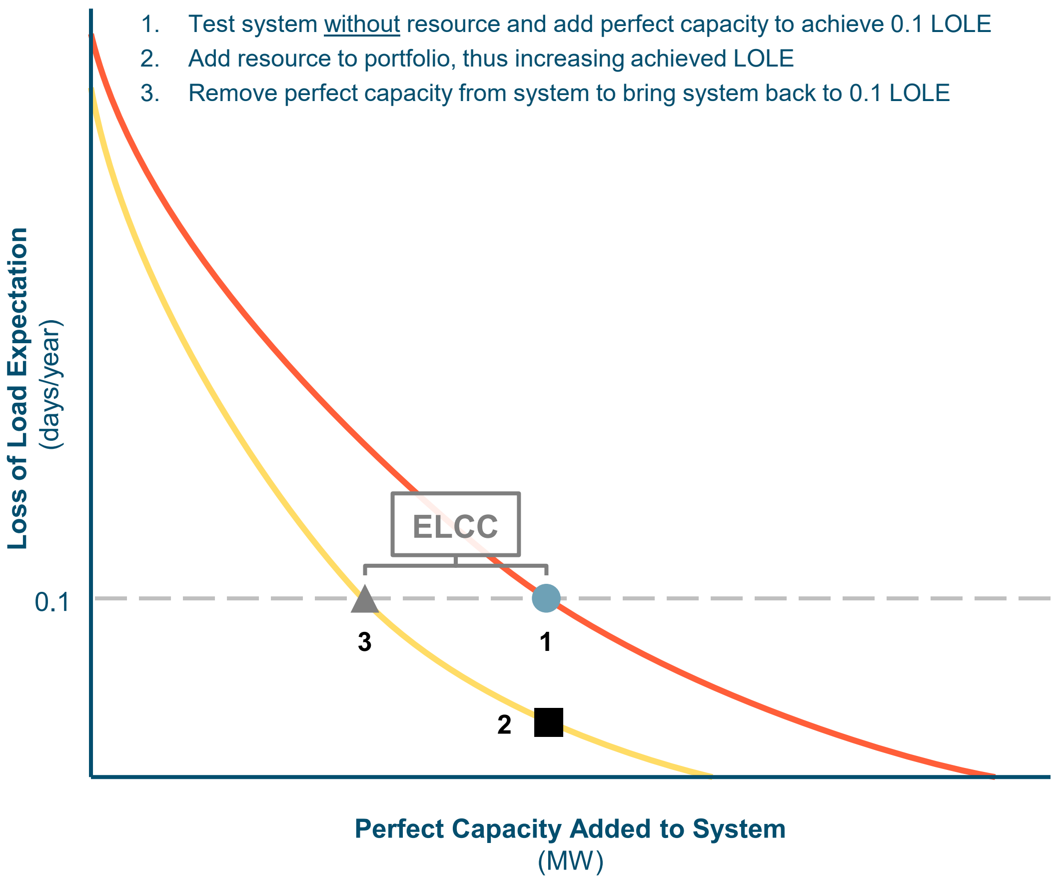
Addition of new source of generation will increase reliability relative to measurement in Step 1

3. Remove perfect capacity until target reliability is restored

Removal of perfect capacity results in decrease in reliability until original target is met

A resource's ELCC is equal to the amount of perfect capacity removed from the system in Step 3

Illustration of ELCC Calculation Approach



Measuring ELCC of a portfolio and individual resources

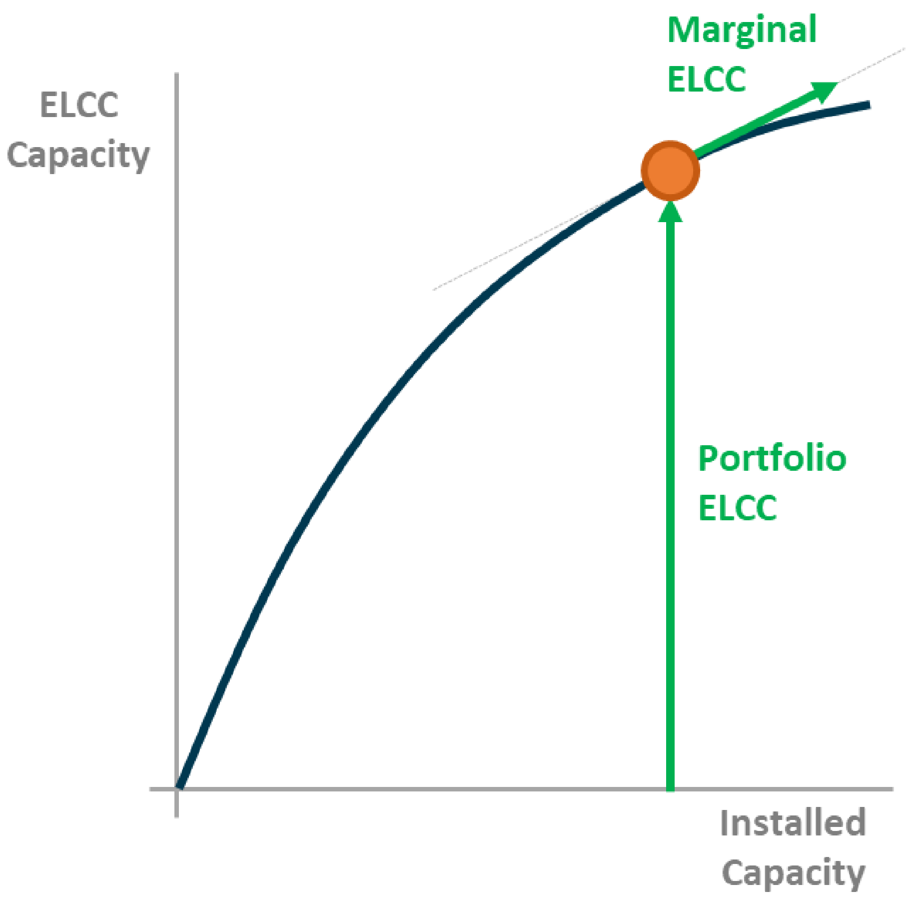
- **ELCC is a function of the portfolio of resources**
  - The function is a surface in multiple dimensions
  - The Portfolio ELCC is the height of the surface at the point representing the total portfolio

$$Portfolio\ ELCC = f(G_1, G_2, \ldots, G_n)\ (MW)$$

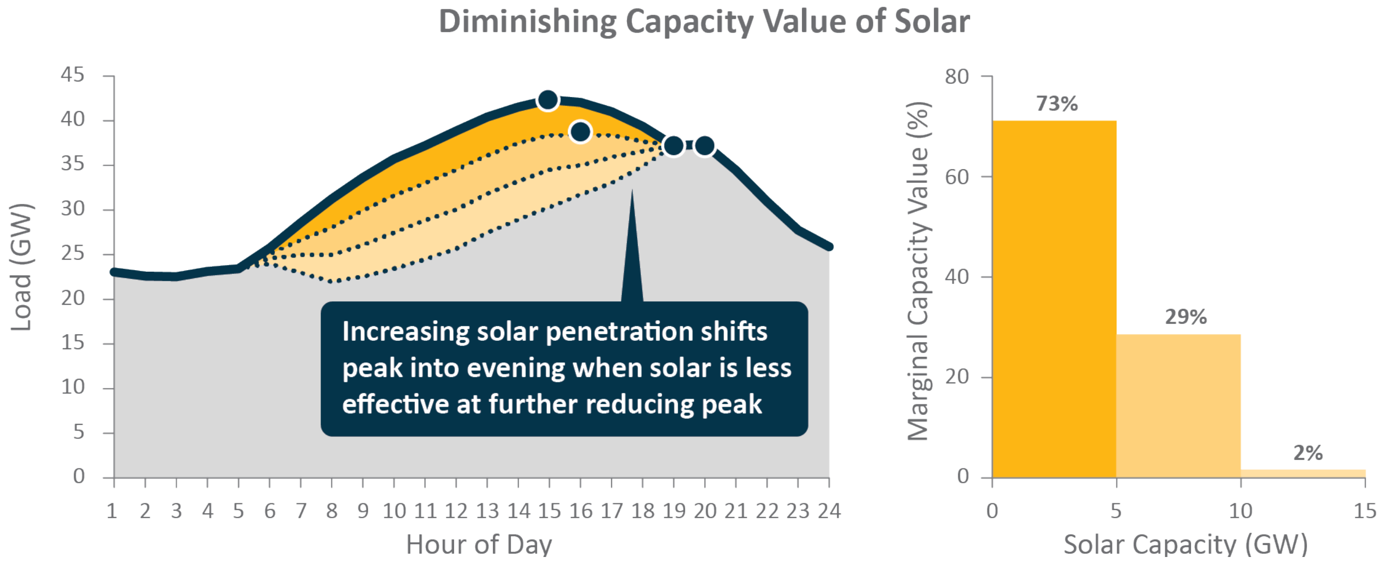
  - The Marginal ELCC of any individual resource is the gradient (or slope) of the surface along a single dimension – mathematically, the partial derivative of the surface with respect to that resource

$$Marginal\ ELCC_{G_1} = \frac{\partial f}{\partial G_1}(G_1, G_2, \ldots G_n)\ (\%)$$

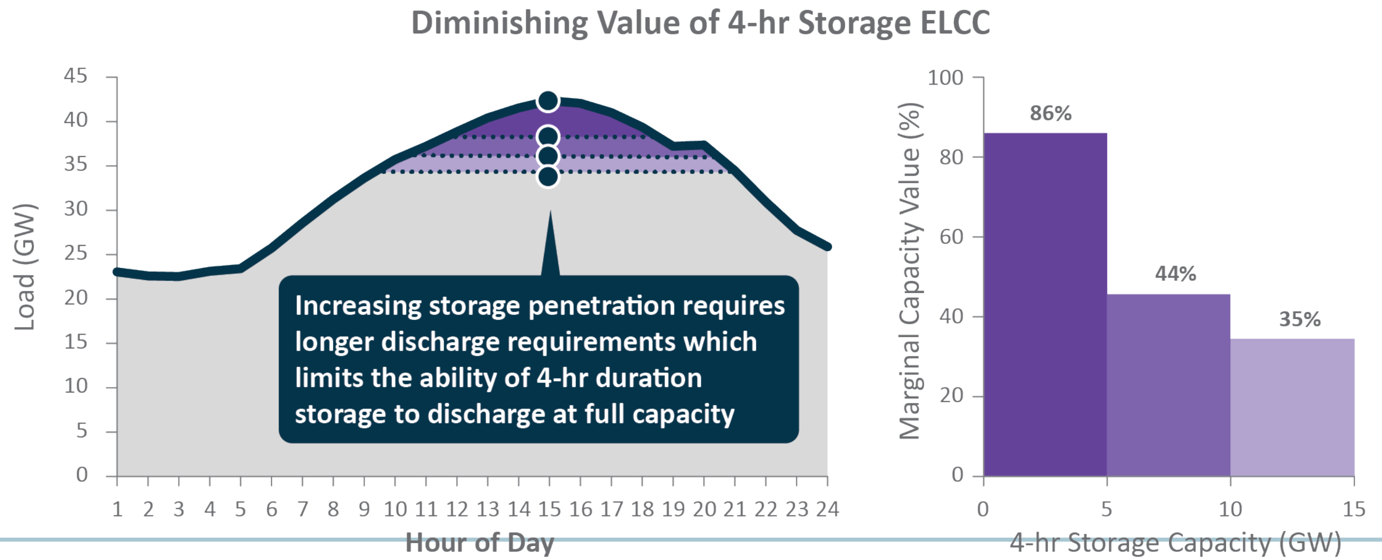
- **The functional form of the surface is unknowable**
  - Marginal ELCC calculations give us measurements of the contours of the surface at specific points
  - It is impractical to map out the entire surface



The capacity contribution of variable and dispatch-limited resources diminishes at higher penetrations



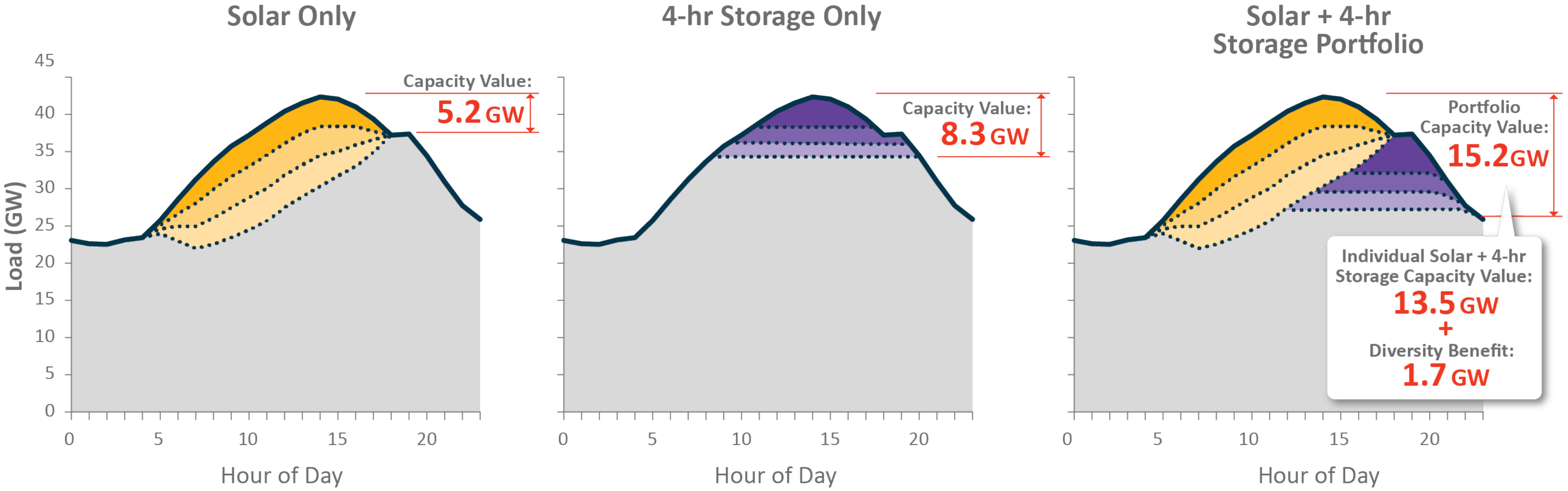
Solar and other **variable resources** (e.g. wind) exhibit declining value due to variability of production profiles



Storage and other **energy-limited resources** (e.g. DR, hydro) exhibit declining value due to limited ability to generate over sustained periods

The capacity contribution of a dispatch-limited resource depends in part on the other resources in the portfolio

+ Resources with complementary characteristics produce the opposite effect, synergistic interactions (also described as a "diversity benefit")
+ As penetrations of intermittent and energy-limited resource grow, the magnitude of these interactive effects will increase and become non-negligible



Resource interactions: synergistic or antagonistic pairings

Common Examples of Synergistic Pairings

Solar + Wind
The profiles for many wind resources produce more energy during evening and nighttime hours when solar is not available

Solar + Storage
Solar and storage each provide what the other lacks – energy (in the case of storage) and the ability to dispatch energy in the evening and nighttime (in the case of solar)

Solar/Wind + Hydro
Hydro is an energy-limited resource so increasing penetrations of solar or wind allows hydro to save its limited production for the most resource constrained hours

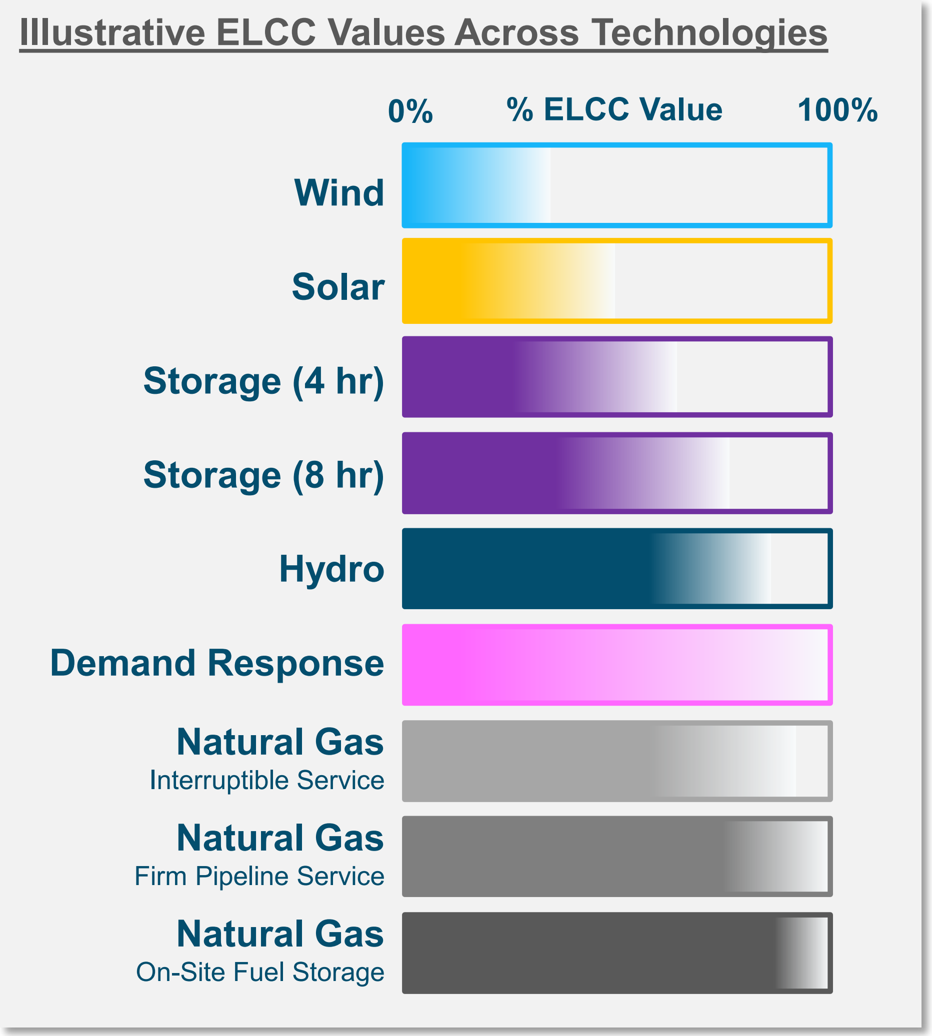
Common Examples of Antagonistic Pairings

Storage + Hydro
Energy limitations on both storage and hydro require longer and longer durations after initial penetrations

Storage + Demand Response
Energy limitations on both storage and hydro require longer and longer durations after initial penetrations

No resource is "perfect" – ELCC can and should be applied to all resources

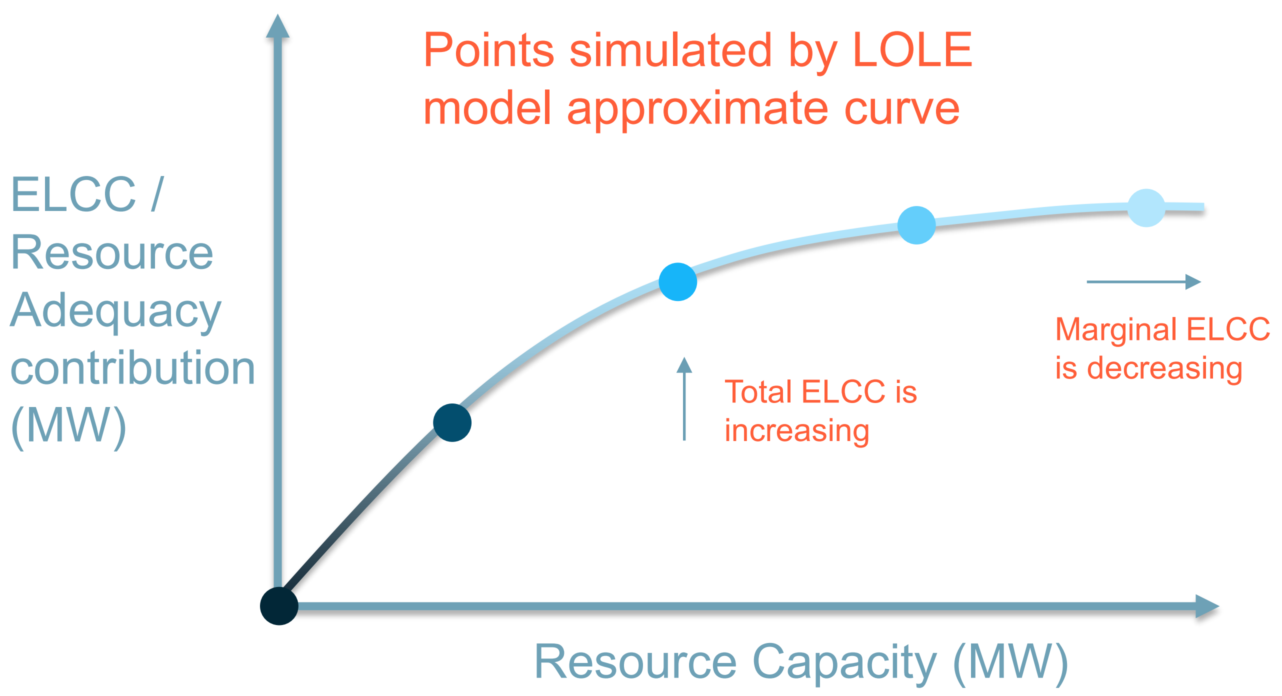
+ **ELCC creates level playing field by measuring all resources against perfect capacity**
+ **Can account for all factors that can limit availability:**
  - Hourly variability in output
  - Duration and/or use limitations
  - Seasonal temperature derates
  - Temperature-related outage rates
  - Forced outages
  - Energy availability
  - Fuel availability
  - Correlated outage risk, *especially under extreme conditions*
+ **Use Perfect Capacity (PCAP) accounting as opposed to ICAP or UCAP**



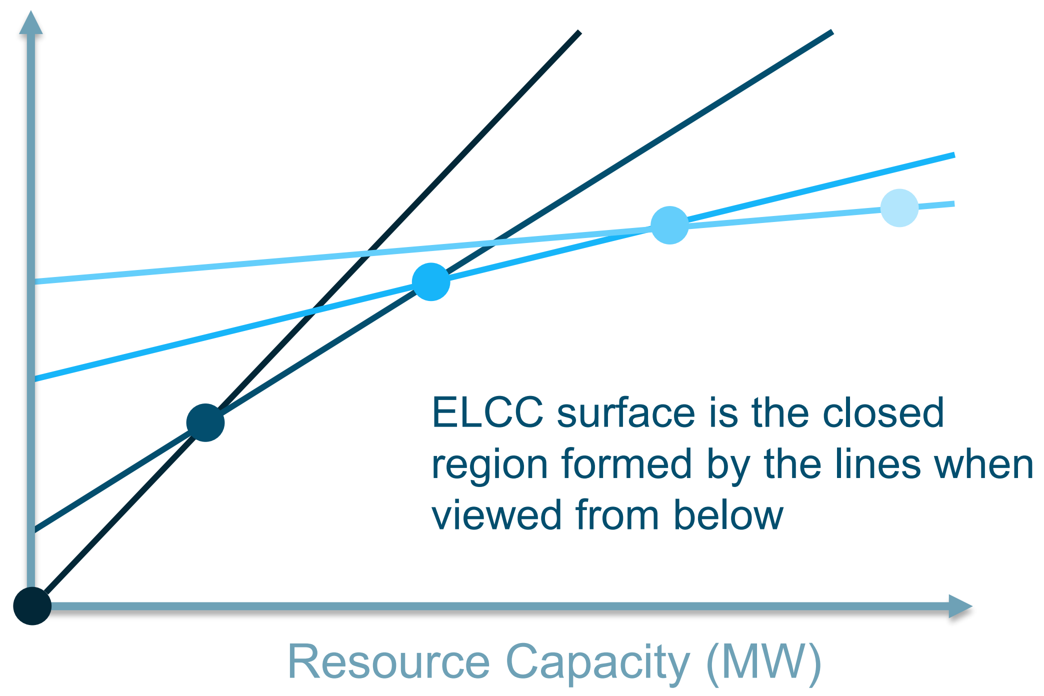
ELCCs in Capacity Expansion

Building an ELCC surface in one dimension

Calculate ELCC at Different Levels of Penetration



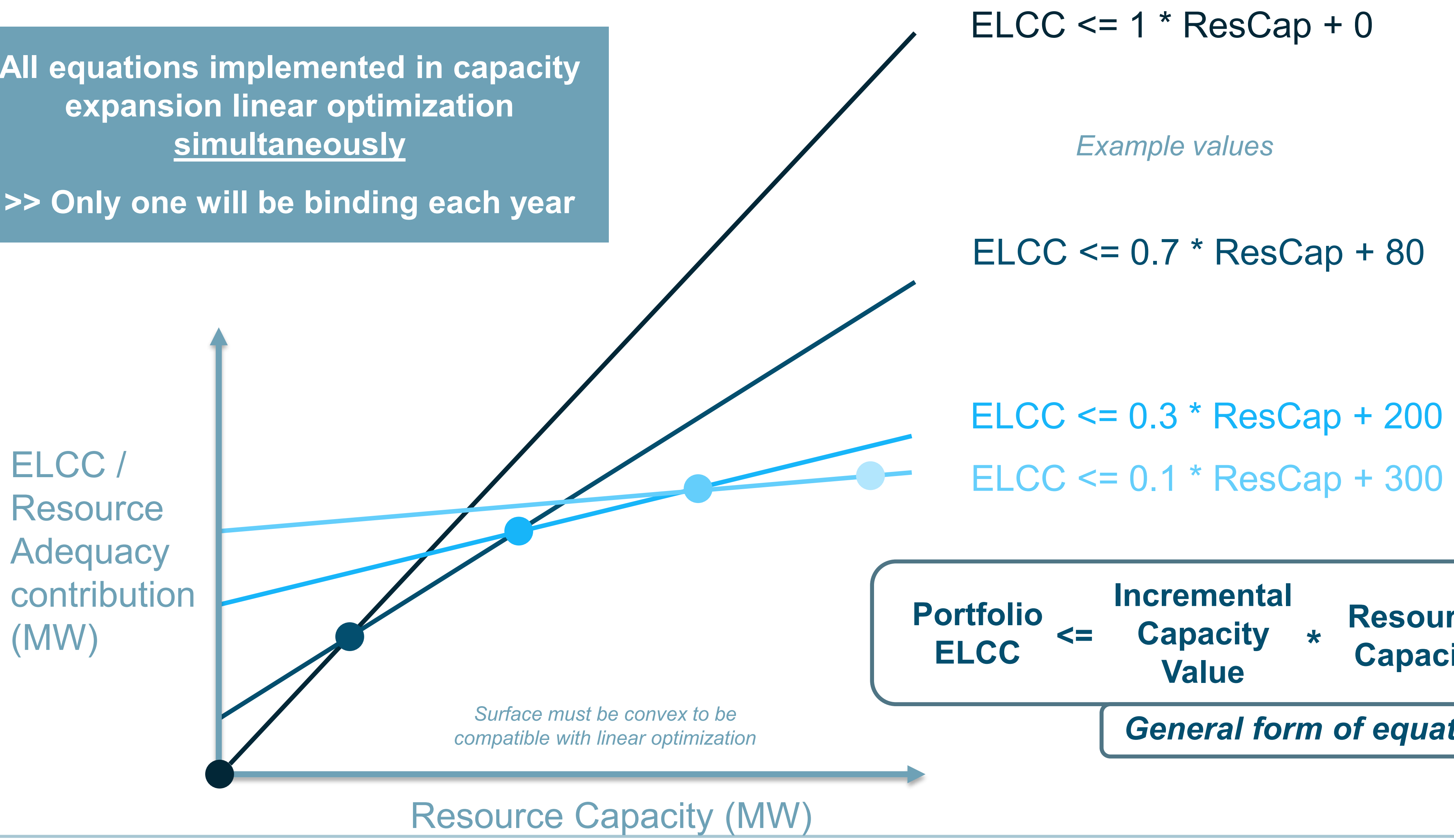
Linear equations to approximate ELCC curve



Implementing in capacity expansion model

All equations implemented in capacity expansion linear optimization <u>simultaneously</u>

>> Only one will be binding each year

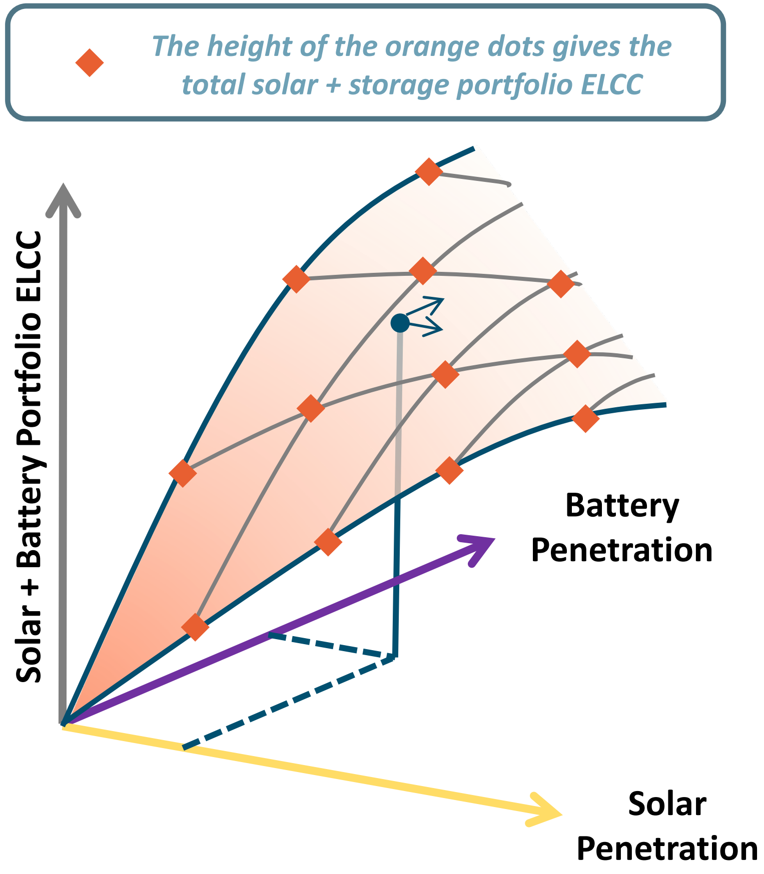


Portfolio ELCC <= Incremental Capacity Value * Resource Capacity + Line Intercept

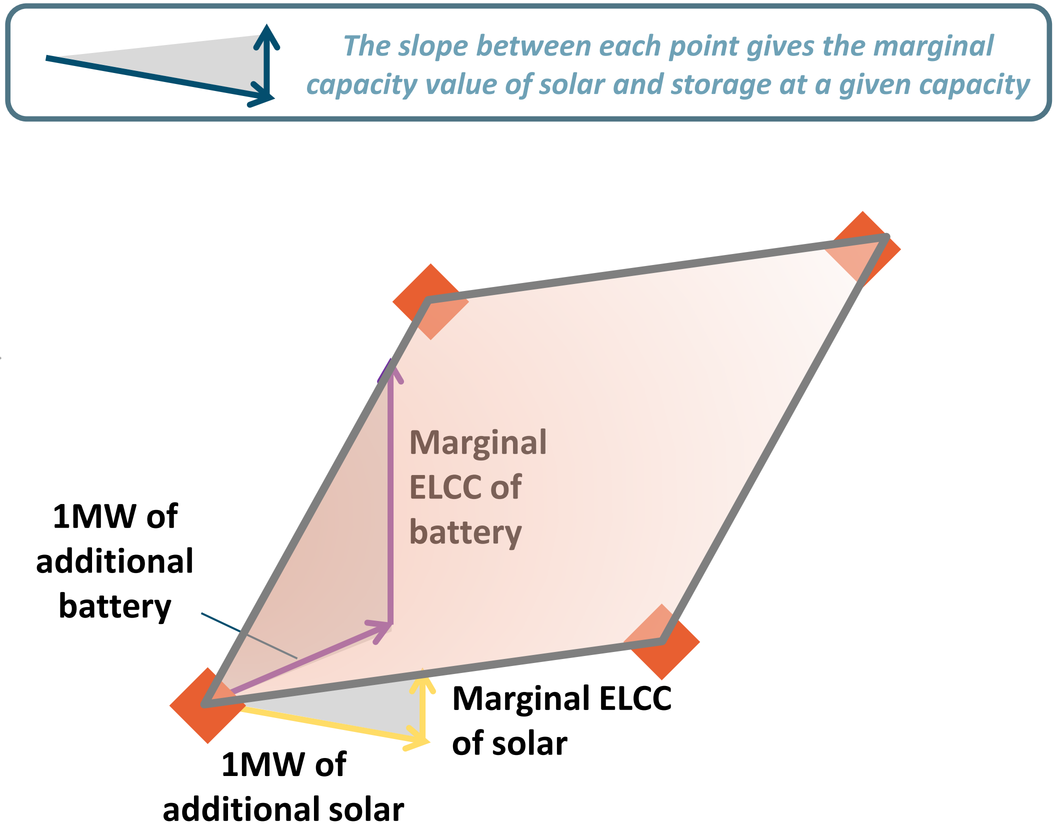
General form of equation

Now in two dimensions….

+ A two-dimensional ELCC surface can capture both diminishing returns and diversity benefits between resources

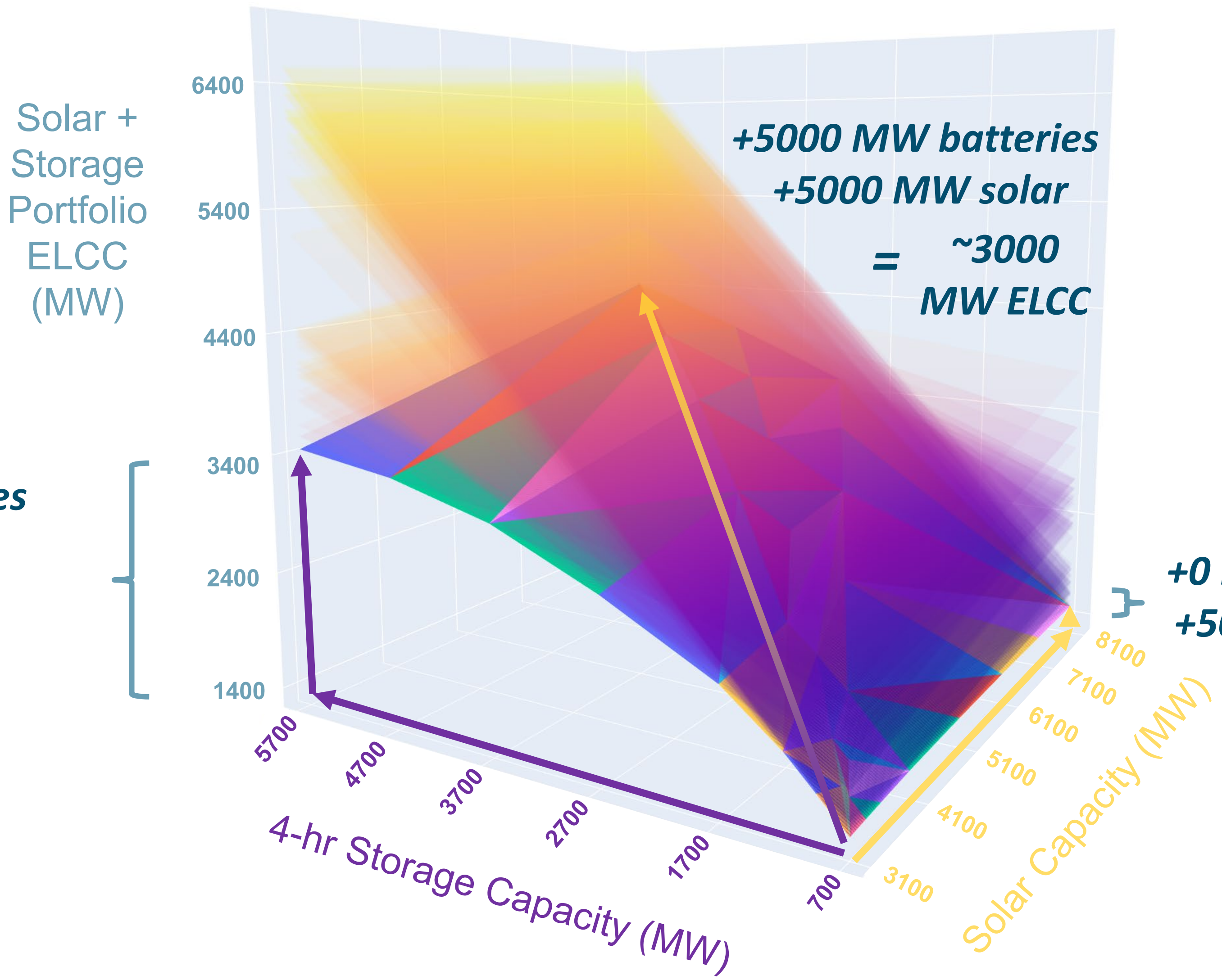


For any plane on the surface:



Surface shows interactive effects of solar and storage

Rotate



+5000 MW batteries
+0 MW solar
=
~2000 MW ELCC

+0 MW batteries
+5000 MW solar
=
~100 MW ELCC

Solar (MW)	Storage (MW)	ELCC (MW)
5000	0	**100**
0	5000	**2000**
5000	5000	**3000**

2100

900 MW ELCC from diversity

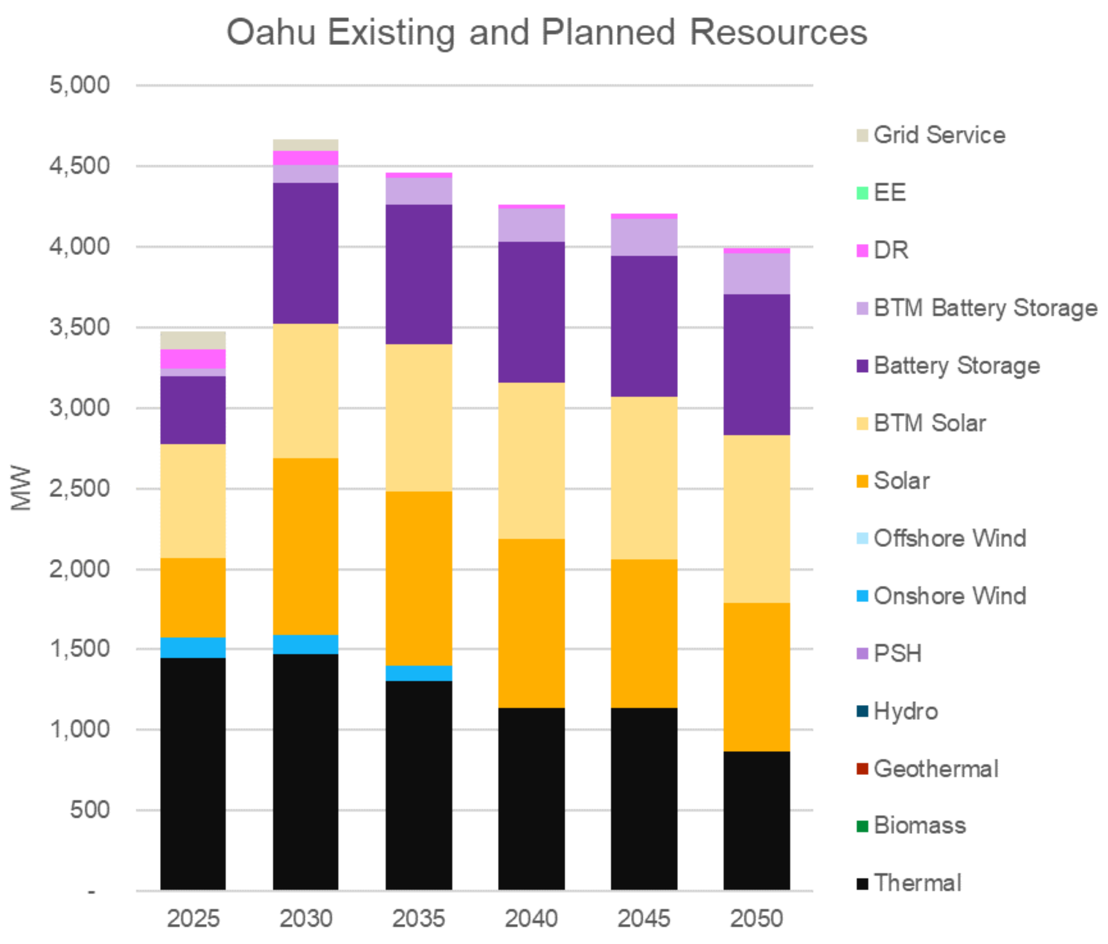
Resource and Annual Energy Forecast

O'ahu

Existing and Planned Resources

- **Of the five islands, O'ahu has the largest peak demand and resources (5x higher peak than the 2nd largest island, Hawai'i)**
- **In the near-term, the island will retire ~40% of its firm capacity due to age and policy targets**
- **Significant solar and storage additions are slated to come online in the next decade**

	Load Data
Historical Metered Peak Load	1,213 MW
Historical Avg. Annual Energy	7210 GWh
Historical Avg Load Factor	68%

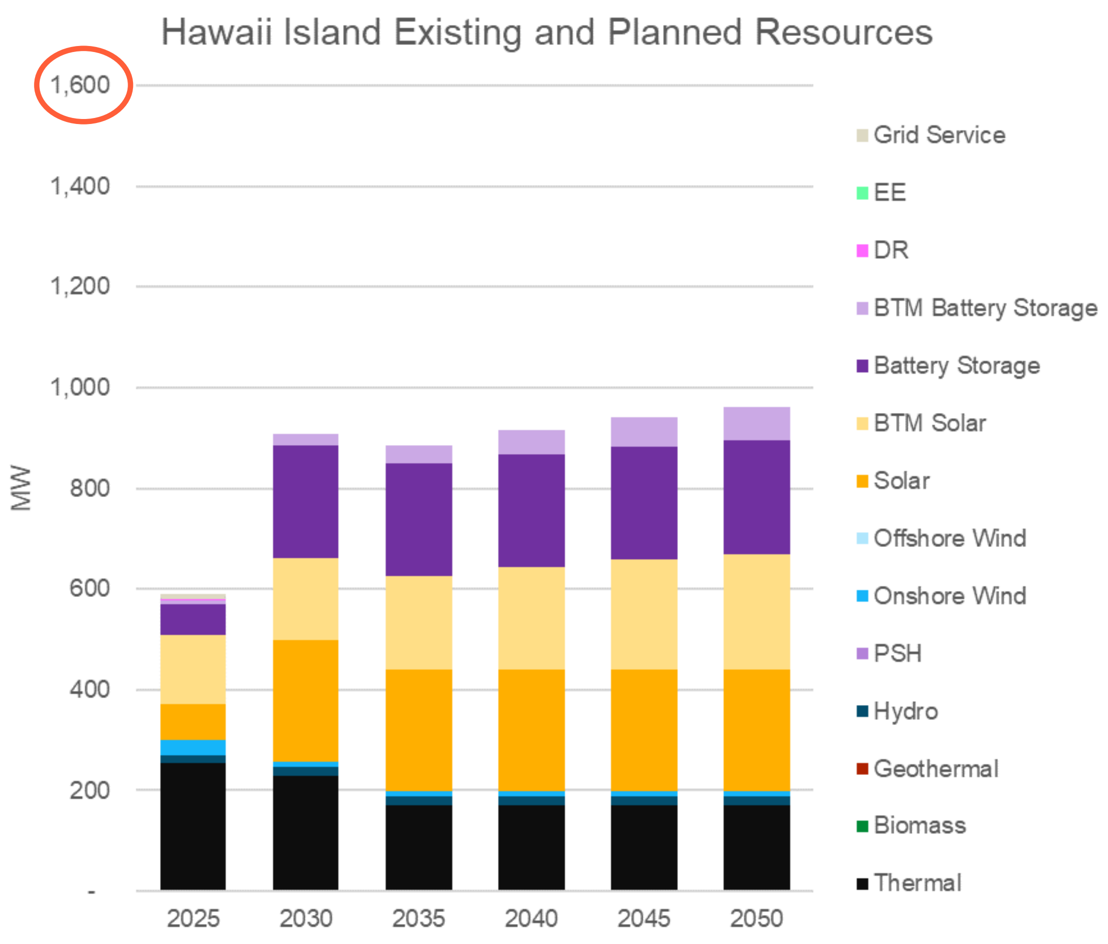


Hawaii Island

Existing and Planned Resources

- **Hawai'i Island is the 2nd largest island by peak load**
- **Hawai'i has the largest resource potential due to its large island footprint and geothermal potential**
- **In the near-term, the island will retire ~35% of its firm capacity due to age and policy targets**

	Load Data
Historical Metered Peak Load	209 MW
Historical Avg. Annual Energy	1,142 GWh
Historical Avg Load Factor	62%

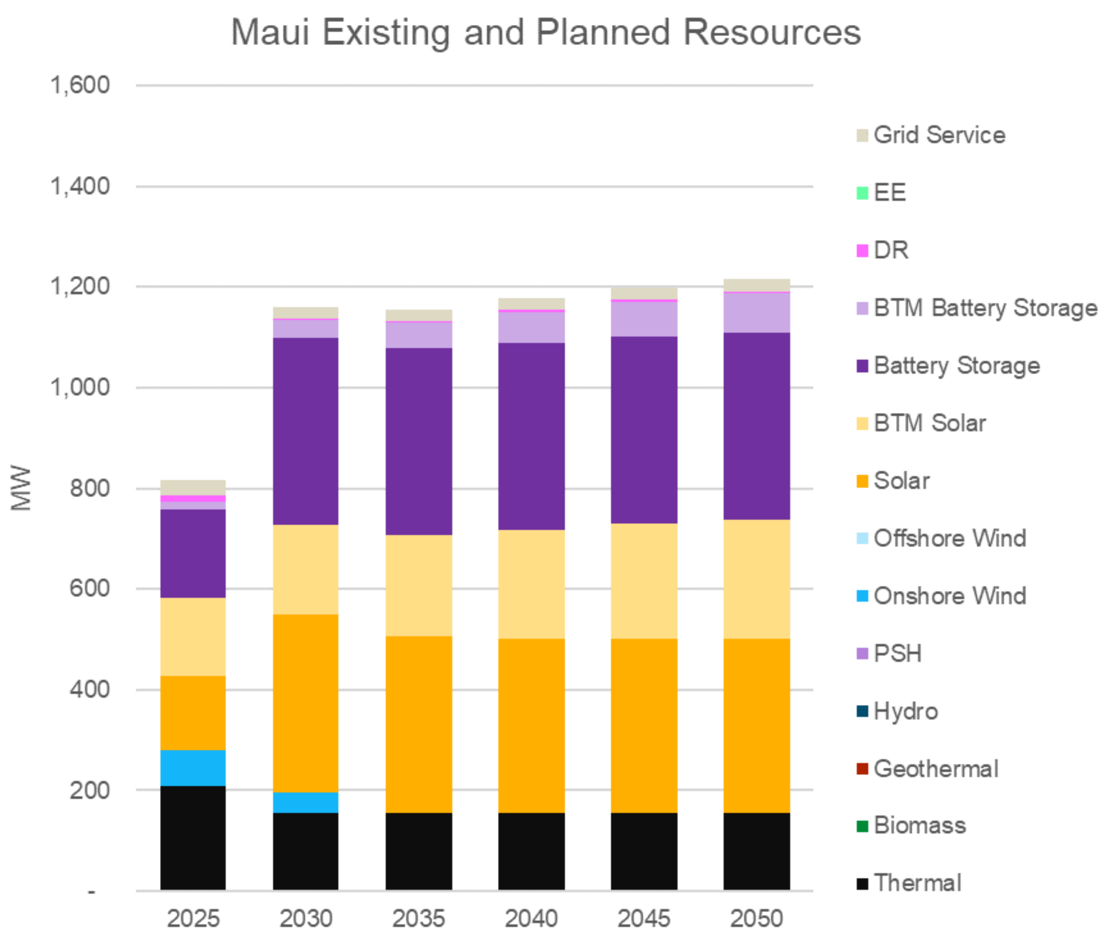


Maui

Existing and Planned Resources

- **Maui is the 3rd largest island, ranked by peak load**
- **Currently, Maui is the one of the two islands with wind generation, but wind contracts are set to expire by 2032**

	Load Data
Historical Metered Peak Load	206 MW
Historical Avg. Annual Energy	1,165 GWh
Historical Avg Load Factor	65%

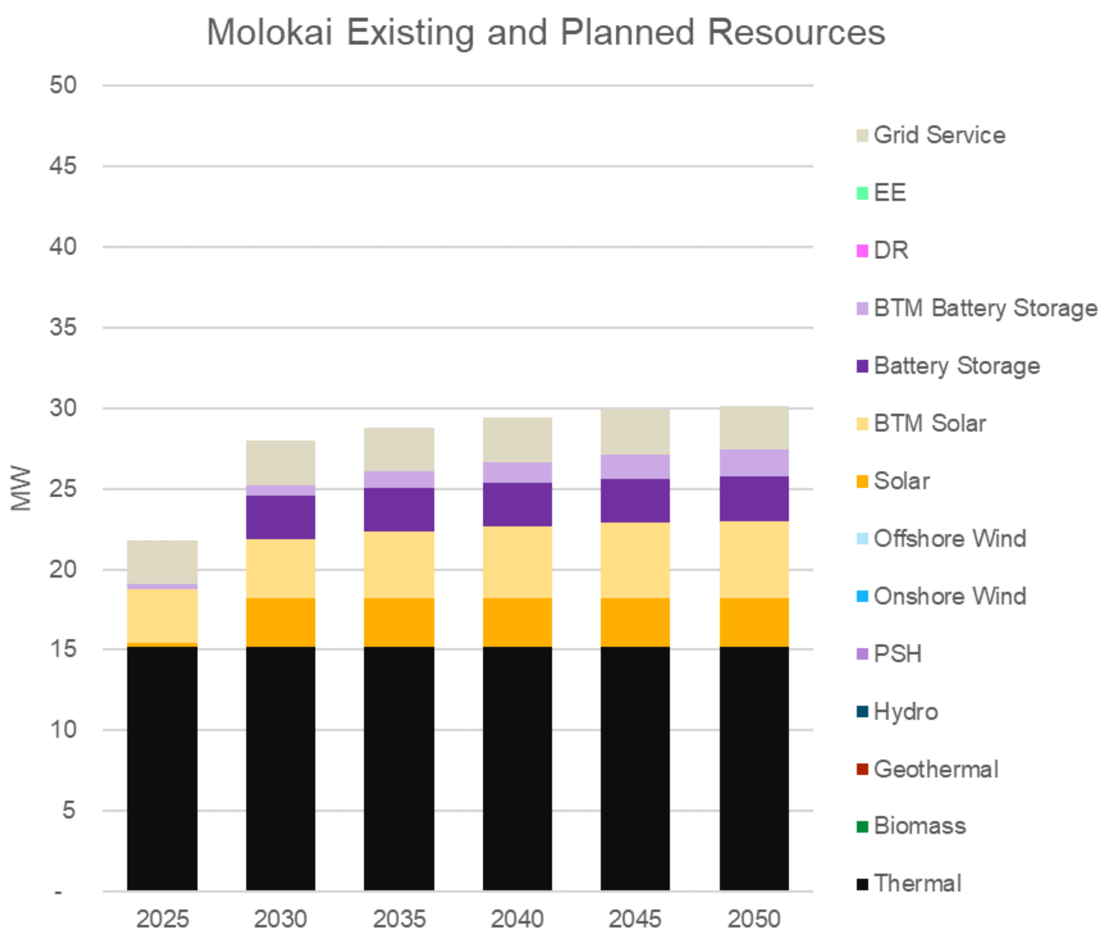


Molokai

Existing and Planned Resources

- **Moloka'i is one of two smaller islands within Hawaiian Electric's service territory**
- **Most of the island depends is currently powered by firm generation**
- **Solar and storage, both utility and distributed, are forecasted to grow year over year**

	Load Data
Historical Metered Peak Load	6 MW
Historical Avg. Annual Energy	32 GWh
Historical Avg Load Factor	62%

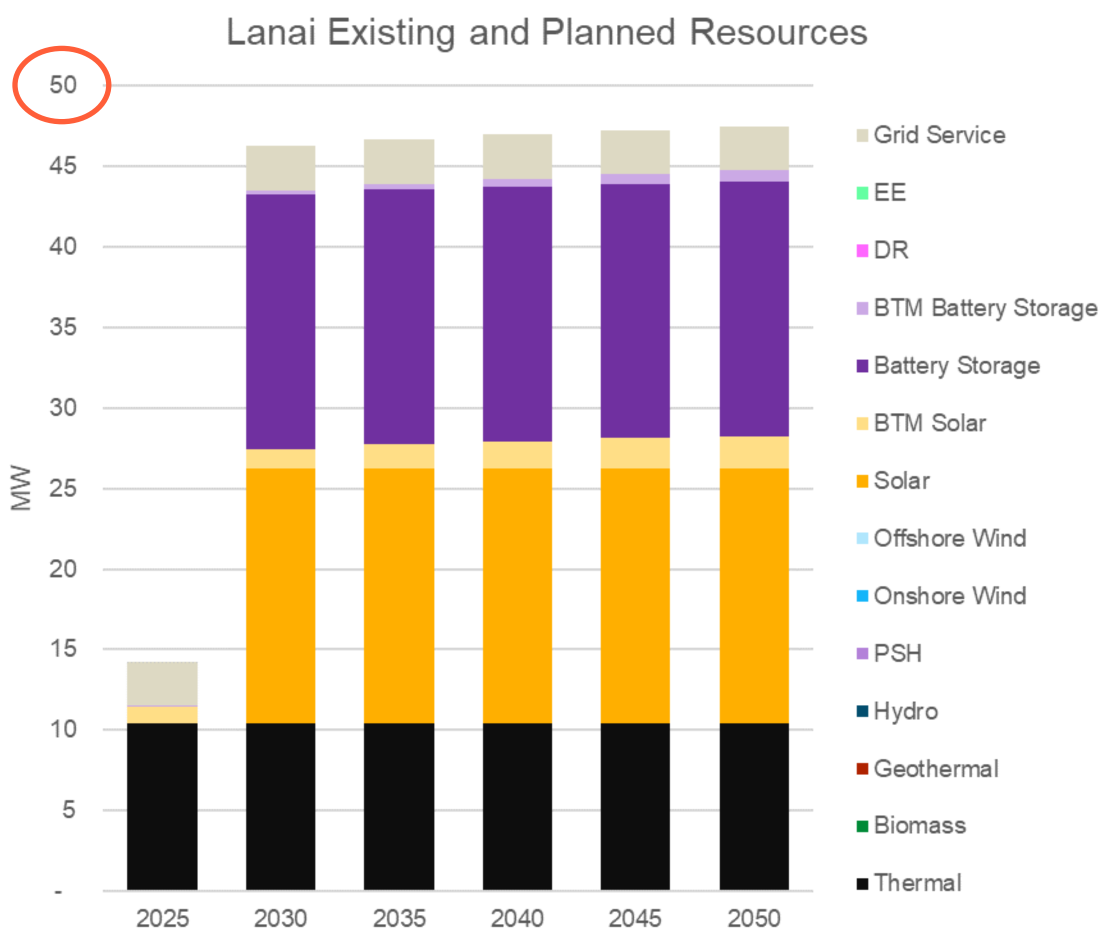


Lanai

Existing and Planned Resources

- **Lanai is the smallest island by peak load**
- **One of two large customers on the island set a 100% renewable goal, leading to large solar and storage installations within the decade**

	Load Data
Historical Metered Peak Load	6 MW
Historical Avg. Annual Energy	33 GWh
Historical Avg Load Factor	62%



Deterministic Energy Reserve Margin + Hourly Dependable Capacity

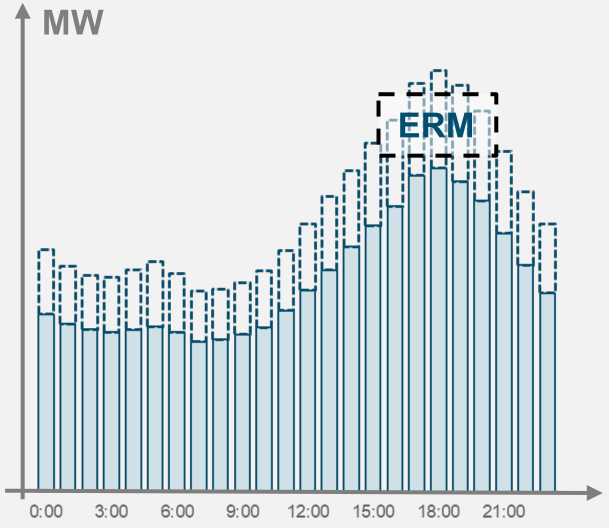
HECO-Specific

Methodology Survey
Is there a reliability target? *No*
How is the need calculated/determined? Determined by rule of thumb like single largest contingency
At what frequency is the need defined? *Hourly*
Are resources accredited based on contribution to any reliability target? *No*
How is resource accreditation determined? *Firm resources are counted on its unforced capacity using weighted equivalent availability factor; Variable resources are counted hourly based on their historical production with an 80% probability of exceedance for each hour*

Need Determination

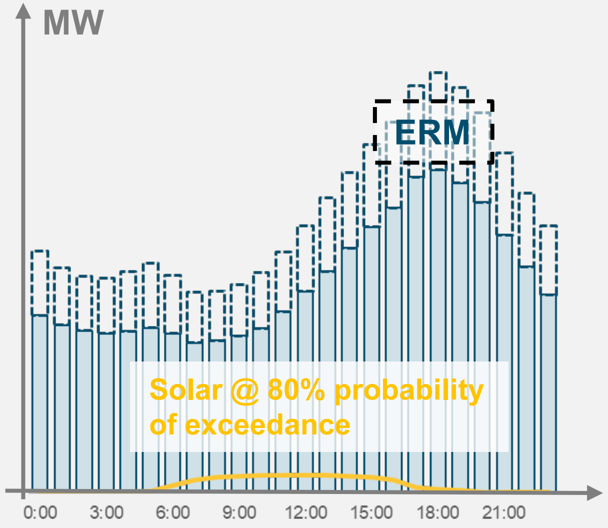
Deterministic
Hourly Reserve Margin (ERM)

A need determination is defined hourly and is set to meet an annual target level of reliability (e.g. 0.1 LOLE)



Resource Accreditation

Hourly Dependable Capacity (HDC)



Deterministic Energy Reserve Margin + Hourly Expected Capacity

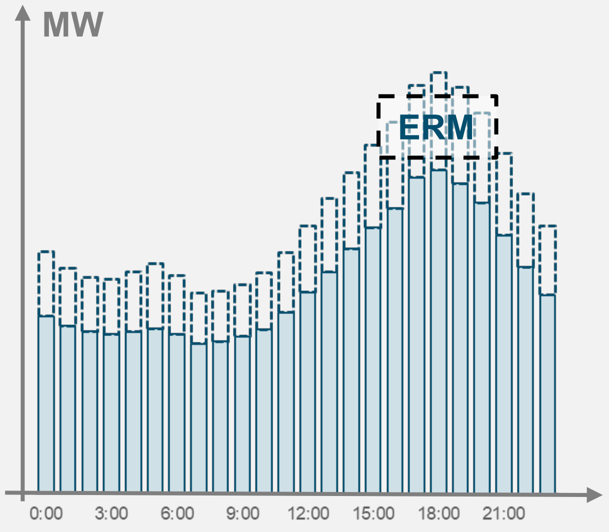
Not Used Yet

Methodology Survey
Is there a reliability target? *No*
How is the need calculated/determined? Determined by rule of thumb like single largest contingency
At what frequency is the need defined? *Hourly*
Are resources accredited based on contribution to any reliability target? *No*
How is resource accreditation determined? *Firm resources are counted on its nameplate or unforced capacity; Variable resources are counted hourly based on their mean historical production during each hour*

Need Determination

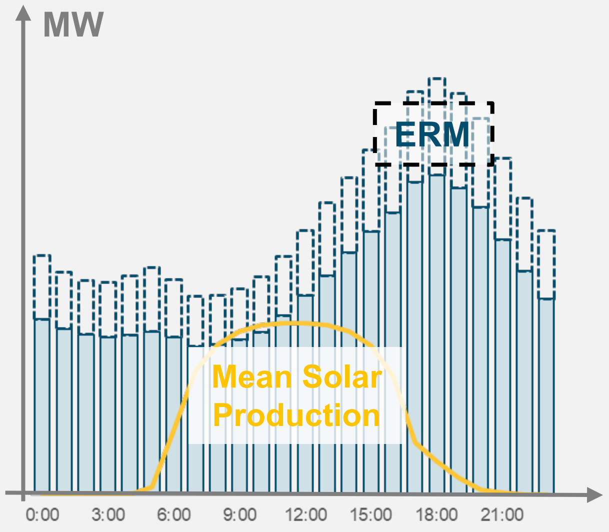
Deterministic
Energy Reserve Margin (ERM)

A need determination is defined hourly and is set to meet an annual target level of reliability (e.g. 0.1 LOLE)



Resource Accreditation

Hourly Expected Capacity (HEC)



Probabilistic Planning Reserve Margin + Effective Load Carrying Capability

Gaining-Traction

PRM + ELCC are coupled through the same reliability target

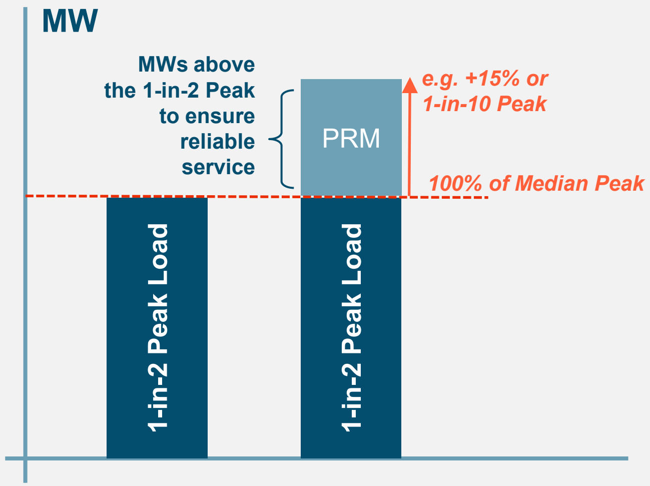
Methodology Survey

Methodology Survey
Is there a reliability target? *Yes*
How is the need calculated/determined? An output of LOLP modeling, determined by how much perfect capacity* is needed to meet reliability target
At what frequency is the need defined? *Annually*
Are resources accredited based on contribution to any reliability target? *Yes*
How is resource accreditation determined? *Each resource is measured against how much additional load the system can take on with each resource*

Need Determination

Probabilistic Planning Reserve Margin (PRM)

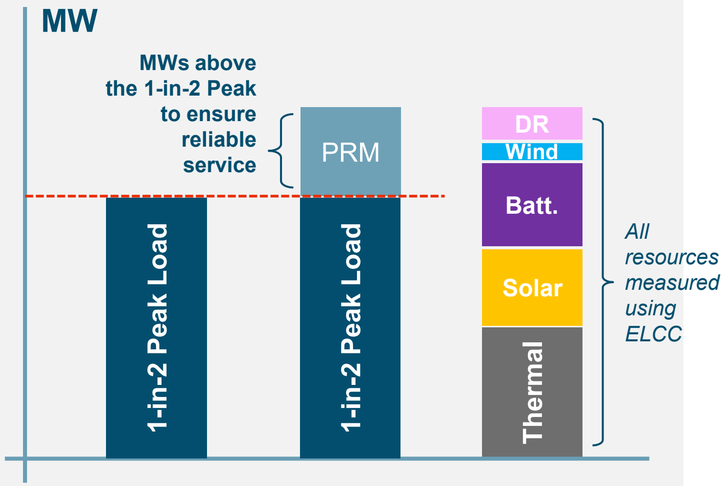
A need determination sets the total requirements for reliability resource procurement to meet a target level of reliability (e.g. 0.1 LOLE). The Probabilistic PRM is measured in effective or perfect capacity.



Resource Accreditation

Effective Load Carrying Capability (ELCC)

All resources (firm resources and dispatch-limited resources) are measured using the Effective Load Carrying Capability methodology (ELCC). All resources are measured against perfect capacity and accredited based on its ability to meet the median peak + PRM



~~Need determination is not coupled to capacity accreditation using a reliability target~~