Energy+Environmental Economics

Practical Considerations for Application of Effective Load Carrying Capability

PJM Capacity Capability Senior Task Force Meeting

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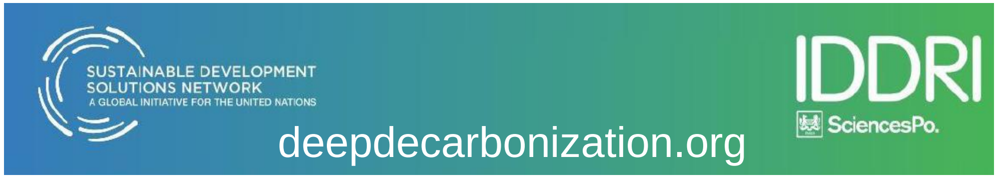
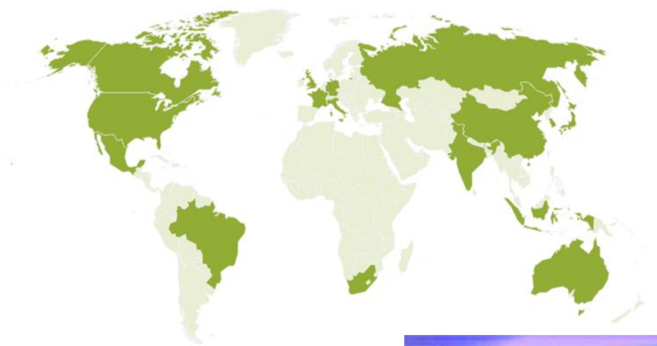
Outline

+ Role of Effective Load Carrying Capability (ELCC) in Capacity Markets
+ ELCC Interactive Effects
+ Accrediting ELCC to Individual Resources
+ The “Delta Method” Approach

About E3

- E3 is a San Francisco-based consulting firm founded in 1989 specializing in electricity economics with approximately 70 staff
- E3 consults extensively for utilities, developers, government agencies, and environmental groups on clean energy issues
- Services for a wide variety of clients made possible through an analytical, unbiased approach
- Our experts provide critical thought leadership, publishing regularly in peer reviewed journals and leading industry publications





Evolving Electricity System

- Policy and economics are driving a transition toward low-carbon electricity systems
- These systems will increasingly rely on intermittent (wind, solar) and energy-limited (storage, demand response) resources to provide essential grid services
- Capacity markets must evolve to appropriately value the resource adequacy contributions of these resources

Background and Role of ELCC in Capacity Markets

- Effective load carrying capability ("ELCC") has been increasingly recognized by the industry as the preferred method for measuring the resource adequacy contribution of these resources
- ELCC is a technology-neutral measurement of the equivalent 'perfect' capacity of intermittent and energy-limited resources
- *Example: if solar has an ELCC of 50%, an electricity system with 100 megawatts of solar would achieve the same reliability as a system with 50 megawatts of a perfect firm resource*
- Fits in nicely with the planning reserve margin framework where all resources are counted on their equivalent firm ELCC or UCAP basis

ELCC Calculation Process

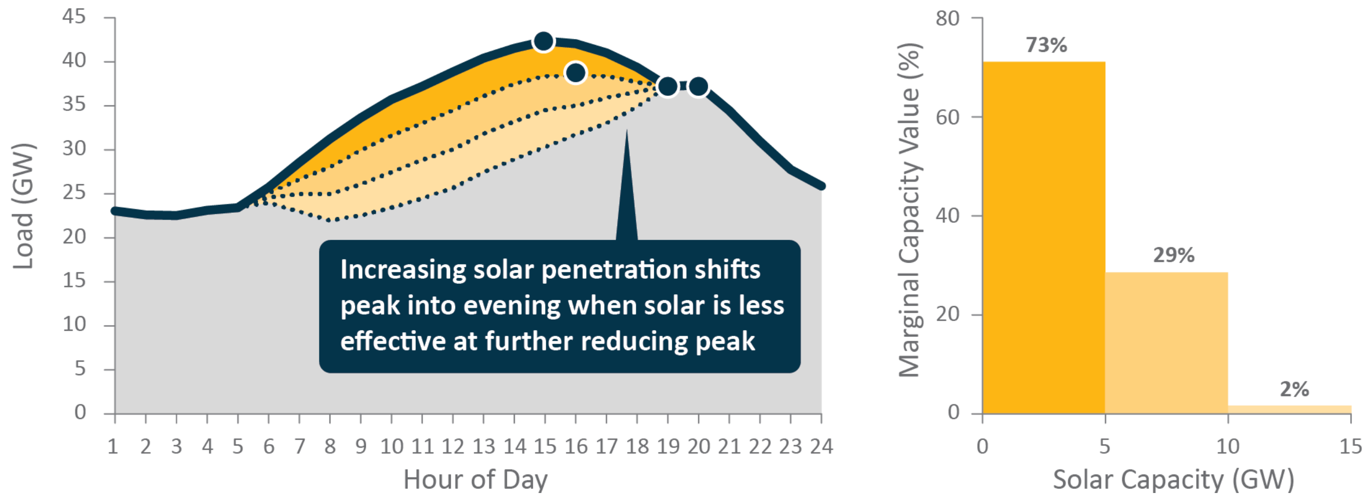
Calculate reliability of system with desired intermittent or energy-limited resource

Remove intermittent or energy-limited resource from system and add firm capacity until system reliability equals step 1

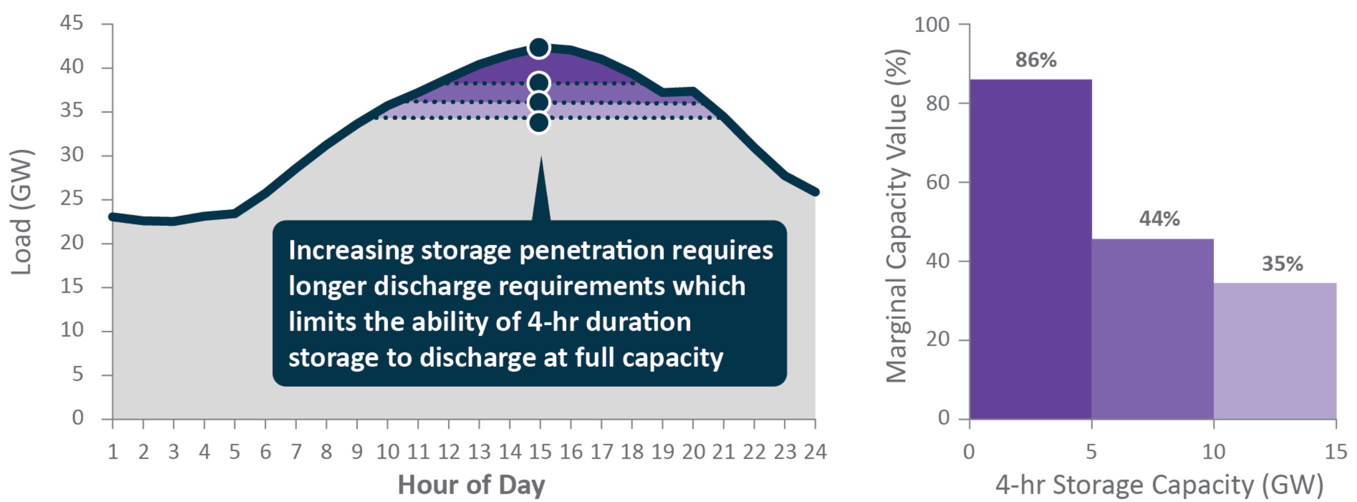
The ELCC of the intermittent or energy-limited resources is the amount of firm capacity added in step 2

ELCC Captures Interactive Effects of Resource Penetration

Diminishing Capacity Value of Solar

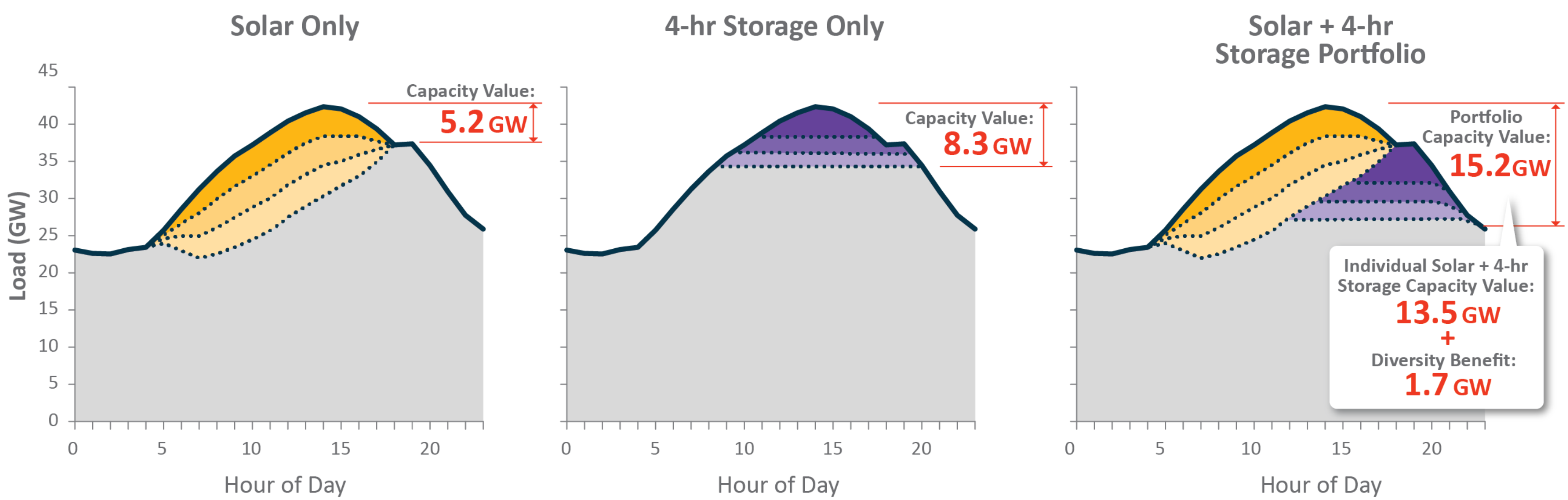


Diminishing Value of 4-hr Storage ELCC



ELCC Captures Synergistic Interactive Effects Between Resources

- **Resources with complementary characteristics produce the opposite effect, synergistic interactions**
  - Has been described as a "diversity benefit"



Common Examples of Synergistic or Antagonistic Pairings

- **ELCC captures interactions between different resources which are an inherent feature of a decarbonized electricity system and will grow to be of profound importance**
  - This is what makes the calculation complex, but also what makes it valuable

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

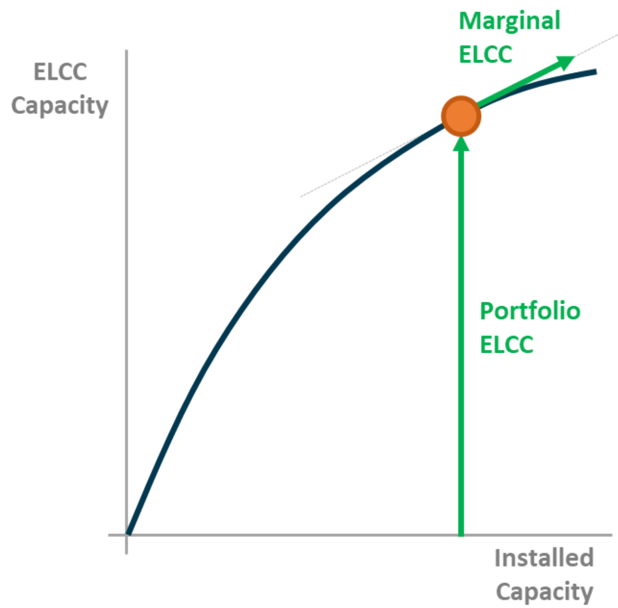
Common Examples of Antagonistic Pairings

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

Measuring ELCC of a Portfolio and Individual Resources

- **In reality, an electricity system is comprised of multiple resources that are all interacting with one another, making interactions difficult to disentangle**
- **As penetrations of intermittent and energy-limited resource grow, these interactive effects will grow significantly and cannot be ignored or rounded away**
- **The ability of ELCC to capture interactive effects, leads to the observation that ELCC is a property of a portfolio of resources, not of individual resources themselves**
  - It is not a straightforward exercise to calculate the ELCC of an individual resource
- **There are two measurable types of resources**
  - **Portfolio ELCC:** the combined capacity contribution of a combination of intermittent and energy-limited resources. This method inherently captures all interactive effects
  - **Marginal ELCC:** the incremental capacity value of a resource (or a combination of resources) measured relative to an existing portfolio



Accrediting ELCC to Individual Resources

- **The very feature of ELCC that makes it the preferred metric to measure the capacity contributions of resource adequacy needs creates challenges for implementation**
- **Centralized capacity markets must assign a ELCC credit to individual resources**
- **There are many options to do this, but no single scientifically correct approach due to portfolio effects**
- **The following principles are useful to consider in designing an approach**
  - In many ways, these parallel principles that must be balanced in electricity ratemaking
  - Like with rate design, these principles sometimes conflict with one another

1 Reliability

The sum of all ELCC credits to individual resources should equal the total resource portfolio ELCC

2 Fairness

ELCC credits should be technology-neutral and properly reward resources for their characteristics

3 Efficiency

Credits should send signals that encourage economically efficient planning and procurement decisions

4 Acceptability

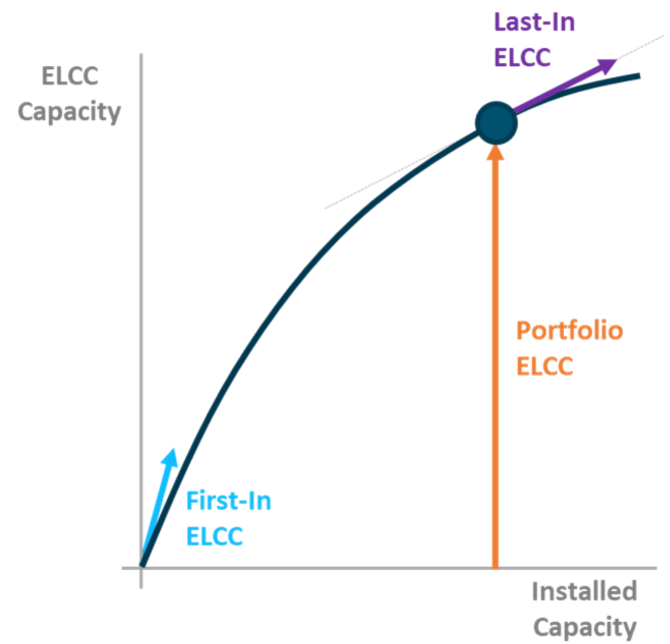
Credits should be transparent, tractable, understandable, and implementable for planners and market participants

Multiple frameworks have been considered for accreditation of ELCC to individual resources

Framework	Description	Pros	Cons
Vintaged Marginal	Assigns each resource a credit based on the marginal ELCC at the time it is added to the system	Yields correct total ELCC across all resources Provides correct marginal signal for procurement of new resources	Distinction between otherwise identical resources undermines fair competition and isn't a feature of other electricity market products (even though the same factors apply) ELCC "lock-in" can become intractable based on resource lives and potential for upgrades or partial retirements
Marginal	All resources are attributed an ELCC based on their marginal contribution to resource adequacy	Temporarily provides correct marginal signal for procurement of new resources	Does not appropriately credit a portfolio of resources for its total contribution to resource adequacy
Adjusted Class Average	1) Calculate Portfolio ELCC 2) Calculate average[1] ELCC for each group of resources (e.g. wind, solar) 3) Apply uniform adjustment to each class average ELCC so that the sum of all classes matches Portfolio ELCC	Yields correct total ELCC	Increasingly segmented classes to capture distinctions between resources (renewable geography, storage duration, hybrid resource configuration, etc.) leads to inconsistent treatment in classes of different sizes. Small classes have an ELCC much closer to marginal where larger classes have an average ELCC much different from marginal Uniform adjustments to all resource classes to account for interactive effects does not faithfully capture nature of interactions. In a portfolio with positive synergy, adjustments should only be applied to the resources that are providing that synergy

Add note about average

Delta Method: A New Approach to ELCC Accreditation

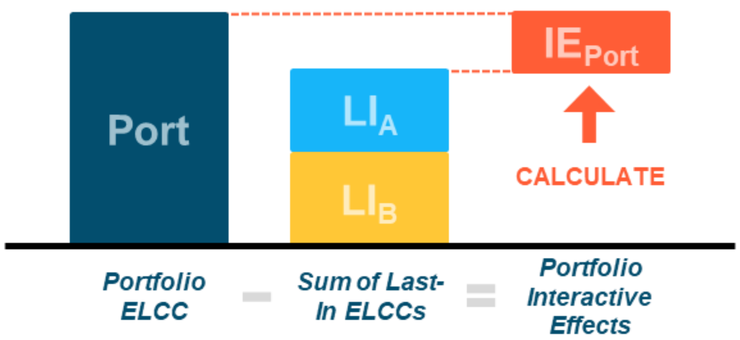


- **An accreditation approach is needed that**
  - Does not exhibit sensitivity to the definition of resource classes
  - Allows for accurate accreditation of ELCC to a portfolio of resources
- **The proposed method relies on three ELCC values**
  - **Portfolio ELCC:** total ELCC provided by a combination of variable and use-limited resources
  - **First-In ELCC:** the marginal ELCC of each individual resource in a portfolio with no other variable or use-limited resources
  - **Last-In ELCC:** the marginal ELCC of each individual resource when taken in the context of the full portfolio
- **None of the above metrics alone can appropriately credit resources, but they can characterize the synergistic and antagonistic interactions within a portfolio**
  - Resources whose Last-In ELCC exceeds First-In ELCC are **synergistic**
  - Resources whose Last-In ELCC is less than First-In ELCC is **antagonistic**
- **The "Delta Method" adjusts each resource's First-In ELCC upward or downward based on its synergistic or antagonistic interaction with the portfolio**
- **This approach can simultaneously account for synergistic, antagonistic, and neutral reactions within a single portfolio**

Delta Method: Calculation Approach

STEP 1 — Calculate Portfolio Interactive Effects

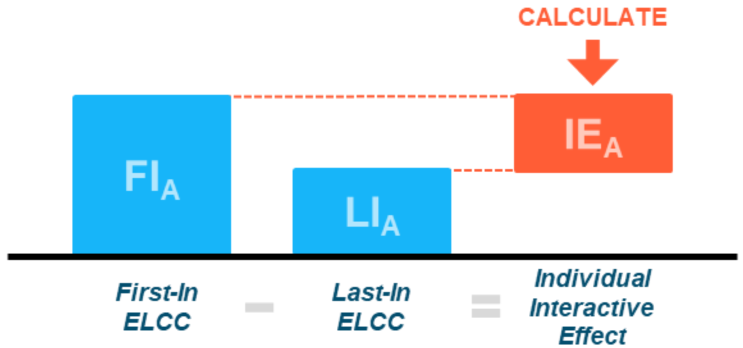
Calculated as the difference between the **Portfolio ELCC** and the sum of the **Last-In ELCCs** for all individual resources



STEP 2 — Calculate Individual Interactive Effects

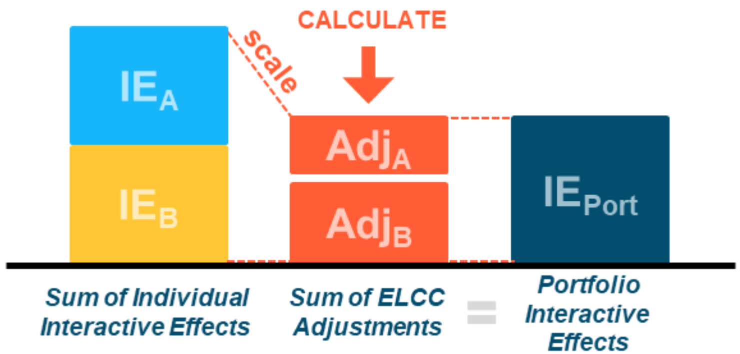
for each resource

Calculated as the difference between the **First-in ELCC** and **Last-In ELCC** for each individual resource



STEP 3 — Calculate Individual ELCC Adjustments

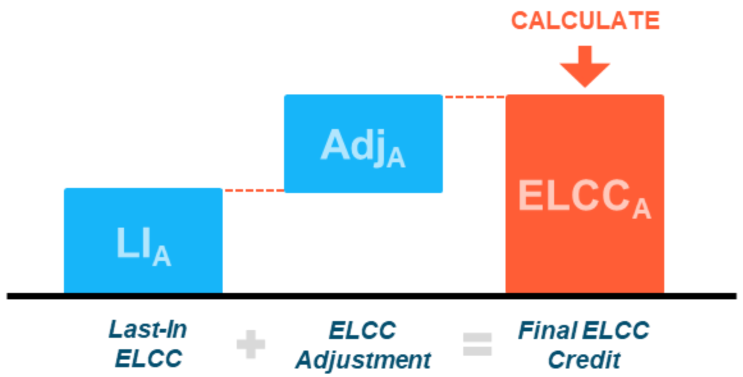
Calculated by scaling all *Individual Resource Diversity Impacts* to match the *Portfolio Diversity Impact*



STEP 4 — Calculate ELCC Accreditation

for each resource

Add *Individual Resource ELCC Adjustment* to **Last-In ELCC** for each individual resource



Evaluating Accreditation Methods

+ **The Delta Method offers several improvements over prior applications of ELCC accreditation, namely**
  - ✓ ELCC credits are based on individual resource characteristics and not uniform across a technology class
  - ✓ Approach is technology neutral and does not rely on the potentially arbitrary definitions of technology classes, which could be come problematic over time and unduly differentiate between similar resources that fall into different classes
  - ✓ ELCC credits attributed to individual resources reflect the synergistic, antagonistic, or neutral interactions with the portfolio

	Reliability	Fairness	Efficiency	Acceptability
Vintaged Marginal	+	○	+	○
Marginal	−	○	+	+
Adjusted Class Average	+	−	−	+
Delta	+	+	○	+

Market Considerations

+ **While the Delta Method presents a theoretical framework for resource-specific ELCCs, there are practical issues associated with implementing this method**
  - **Computational Burden and Simplicity**
    - **Problem:** Running ELCC calculations for thousands of individual resources will likely be too computationally intensive given existing modeling techniques
    - **Consideration:** A pre-defined library of ELCC values could be used to assign an ELCC to a resource with similar characteristics. This application to individual resources should not be confused with class-based approach which calculates the ELCC of an entire class instead of individual resources
  - **Certainty and Risk Mitigation**
    - **Problem:** ELCC accreditation may reduce transparency and predictability of a capacity value
    - **Consideration:** PJM could conduct forward-looking studies under a variety of resource portfolios, provide a locked-in ELCC or a guaranteed ELCC floor for a limited period of time

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Thank You

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Appendix

Delta Method: Mathematical Representation

The Delta Method: Doing the Math

Consider a system with resources $r_1, r_2 \ldots r_n$ with installed capacities of $C_1, C_2 \ldots C_n$, respectively. The ELCC function for this system is given by $f(r_1, r_2 \ldots r_n)$. Then:

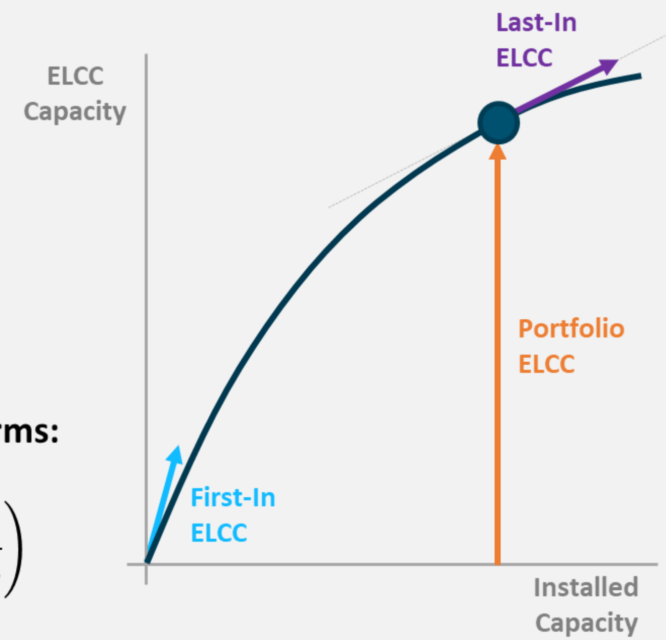
Portfolio ELCC: $P = f(C_1, C_2 \ldots C_n)$

First-In ELCC: $FI_i = C_i \cdot \frac{\partial f}{\partial r_i}(0, 0 \ldots 0)$

Last-In ELCC: $LI_i = C_i \cdot \frac{\partial f}{\partial r_i}(C_1, C_2 \ldots C_n)$

The ELCC attributed to each resource is calculated from these terms:

Resource ELCC: $ELCC_i = LI_i + \left(P - \sum_{j=1}^{n} LI_j\right)\left(\frac{LI_i - FI_i}{\sum_{j=1}^{n} LI_j - FI_j}\right)$



Delta Method: Numerical Example

- The following represents a simple and illustrative numeric example demonstrating how ELCC credits would be calculated using the proposed methodology on a system with solar, wind, and storage resources
- The illustrative portfolio is representative of the current California electricity system, which has a peak load of approximately 50,000 MW

Item	Units	Solar	Wind	Storage	Notes
# of Plants	#	200	50	10	
Representative Plant Size	MW	100	100	100	
Total Capacity	MW	20,000	5,000	1,000	Plant size * # of plants
First-In ELCC for Representative Plant	MW	50	30	80	
	%	50%	30%	80%	
Last-In ELCC for Representative Plant	MW	10	20	90	
	%	10%	20%	90%	
Portfolio ELCC	MW	8,000			
Portfolio Interactive Effects	MW	4,100			Portfolio ELCC – Sum of Last-In ELCCs for All Resources 8,000 – (200 * 10 + 50 * 20 + 10 * 90)
Individual Interactive Effect	MW	+40	+10	-10	First-In ELCC MW – Last-In ELCC MW for Representative Resources Solar: 50 - 10 Wind: 30 - 20 Storage: 80 - 90
Sum of Individual Interactive Effects	MW	8,400			200 * 40 + 50 * 10 + 10 * -10
Individual Resource ELCC Adjustments	MW	20	5	-5	Individual Interactive Effect / Sum of Individual Interactive Effects * Portfolio Interactive Effects Solar: 40 / 8,400 * 4,100 Wind: 10 / 8,400 * 4,100 Storage: -10 / 8,400 * 4,100
Individual Resource ELCC Credit	MW	30	25	85	Last-In ELCC + Individual Resource ELCC Adjustment Solar: 10 + 20 Wind: 20 + 5 Storage: 90 – 5
Individual Resource ELCC Credit	%	30%	25%	85%	