inodú
energy & sustainability

CHALLENGES DETERMINING THE CAPACITY VALUE BY USING THE EFFECTIVE LOAD CARRYING CAPABILITY IN POWER SYSTEMS TRANSITIONING TO NET-ZERO CARBON EMISSIONS

Prepared for:

AIEE ASSOCIAZIONE ITALIANA ECONOMISTI DELL'ENERGIA

7th AIEE Energy Symposium
Current and Future Challenges to Energy Security

December 16th, 2022

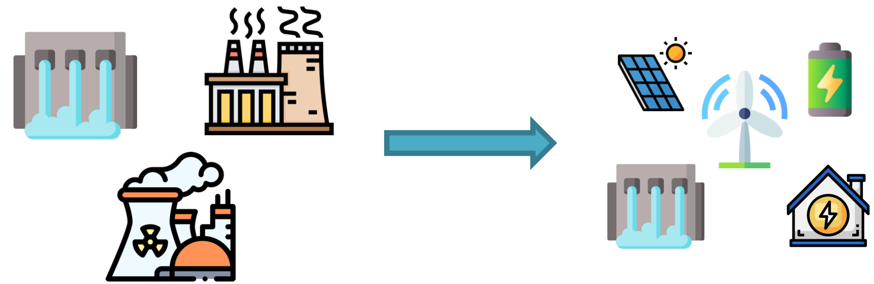
Agenda

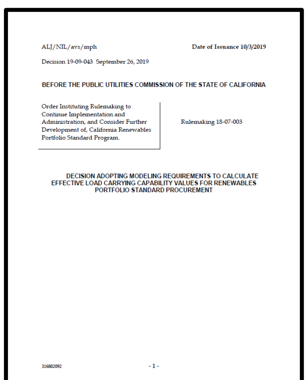
1) **Effective Load Carrying Capability (ELCC)**
2) Cases studied
3) Load adaptation to reach the reliability target
4) Effect of the evaluation conditions
5) Challenges with storage and energy availability
6) Conclusions

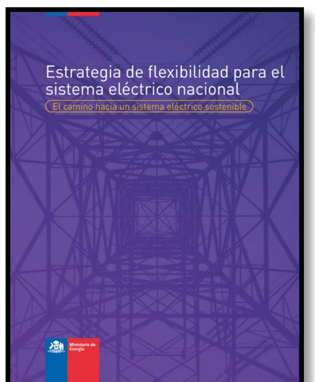
Different approaches to quantify the contribution to system reliability

Regulators, system operators and utilities need to understand future reliability challenges in order define the right market signals to create the conditions to deploy the infrastructure needed.

The structure of power systems is changing







How can capacity contributions to the system reliability be quantified?

One approach is to use the

Effective Load Carrying Capability (ELCC)

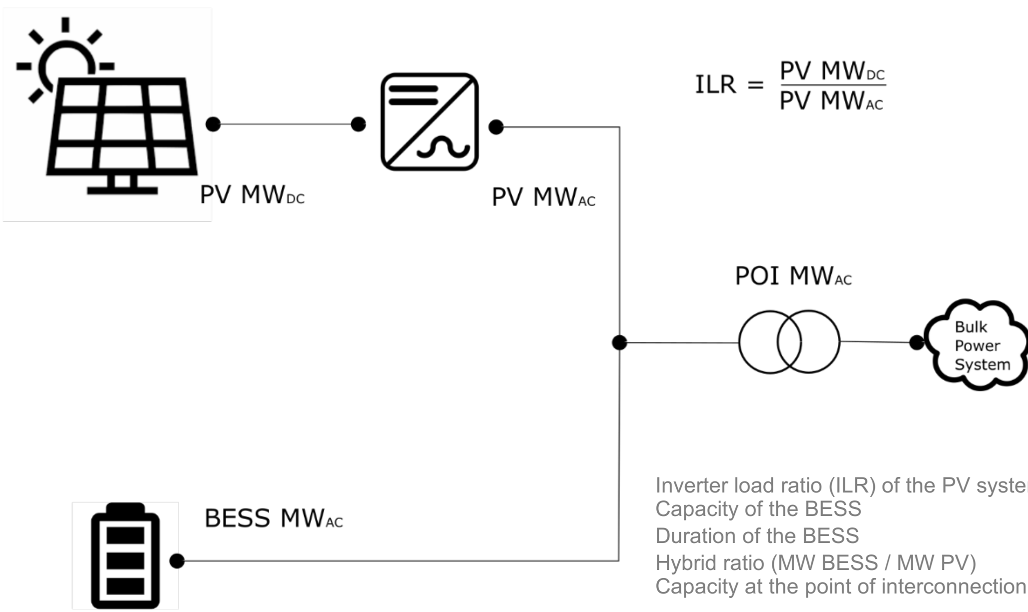
- **Average** – By changing technology
- **Incremental** – By changing units

How will modeling requirements be balanced with the objectives of manageable complexity and reasonable efficiency in capacity allocation?

ELCC type	Average vs Marginal
Dispatch considerations	Economic dispatch, security constraints, water use contraints in systems with important hydro resources
Time granularity	8760 hours, one representative day per month, etc.
Transmission & nodes	Simplified (no transmission, 3 – 5 zones, + 5 zones)
LOLE Metric	0.1; 0.7; etc
Number of resource classes and resource class subtypes	a.) All generators treated as one category in portfolio ELCC; b.) # resources classes (wind, solar PV, storage, hydro, etc); c.) # resource class subtypes (fixed axis PV, trancking PV, trancking PV with storage, wind, wind paired with storage, hydro with reservoir (5 hours, several days or months),
Number of locations	# of locations (renewable resource pattern)
Etc.	

A simplification of the number of resource class subtypes can hidden the effect of design variables that have significant implications in the performance of hybrid systems (renewable + storage)

Case: PV + BESS AC coupled system



Inverter load ratio (ILR) of the PV system
Capacity of the BESS
Duration of the BESS
Hybrid ratio (MW BESS / MW PV)
Capacity at the point of interconnection (POI)

How many subclasses of hybrid systems should be evaluated?

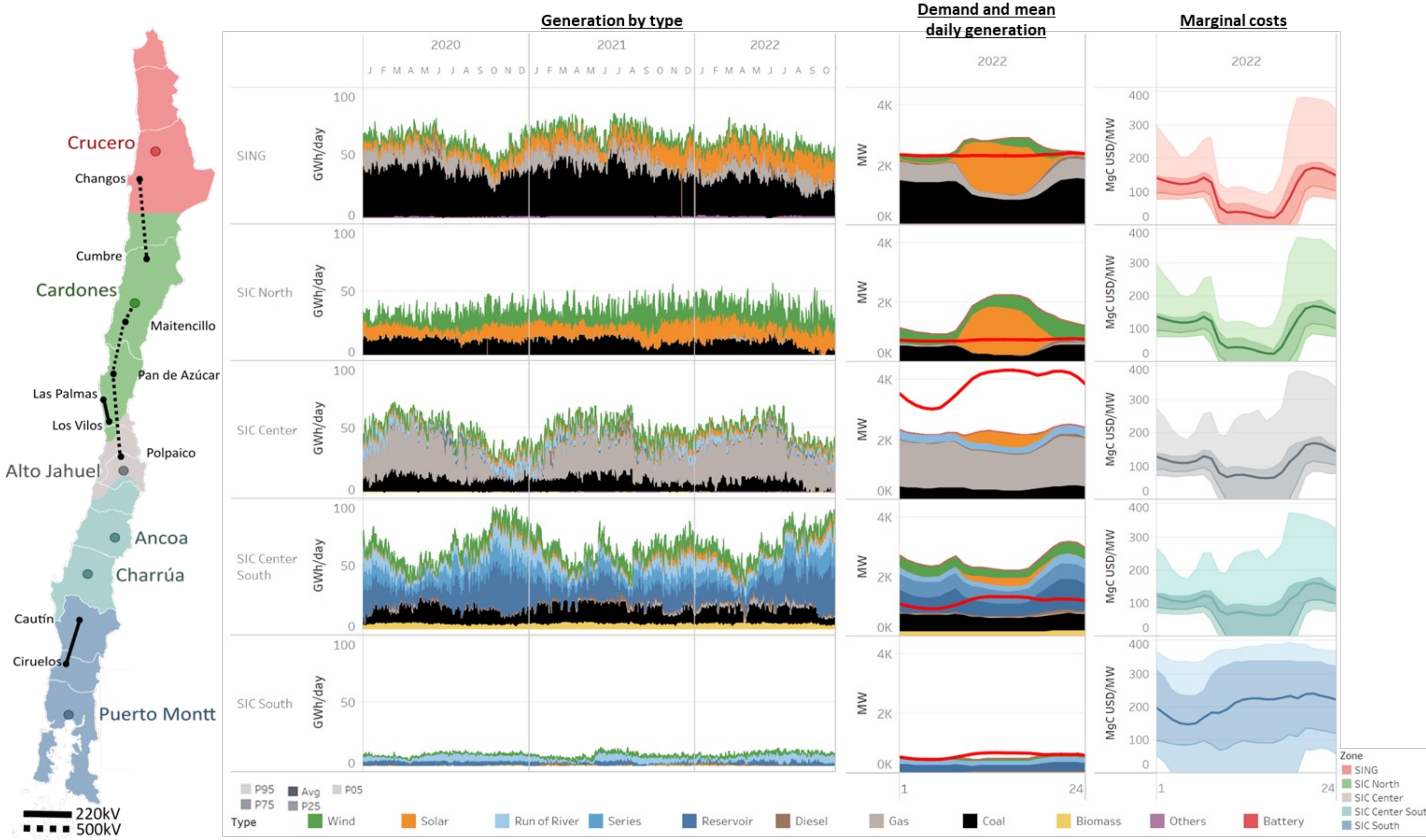
A combined approach to define ELCC values of hybrid systems should be defined (ELCC calculation + heuristic method)

Agenda

1) **Effective Load Carrying Capability (ELCC)**
2) **Cases studied**
3) Load adaptation to reach the reliability target
4) Effect of the evaluation conditions
5) Challenges with storage and energy availability
6) Conclusions

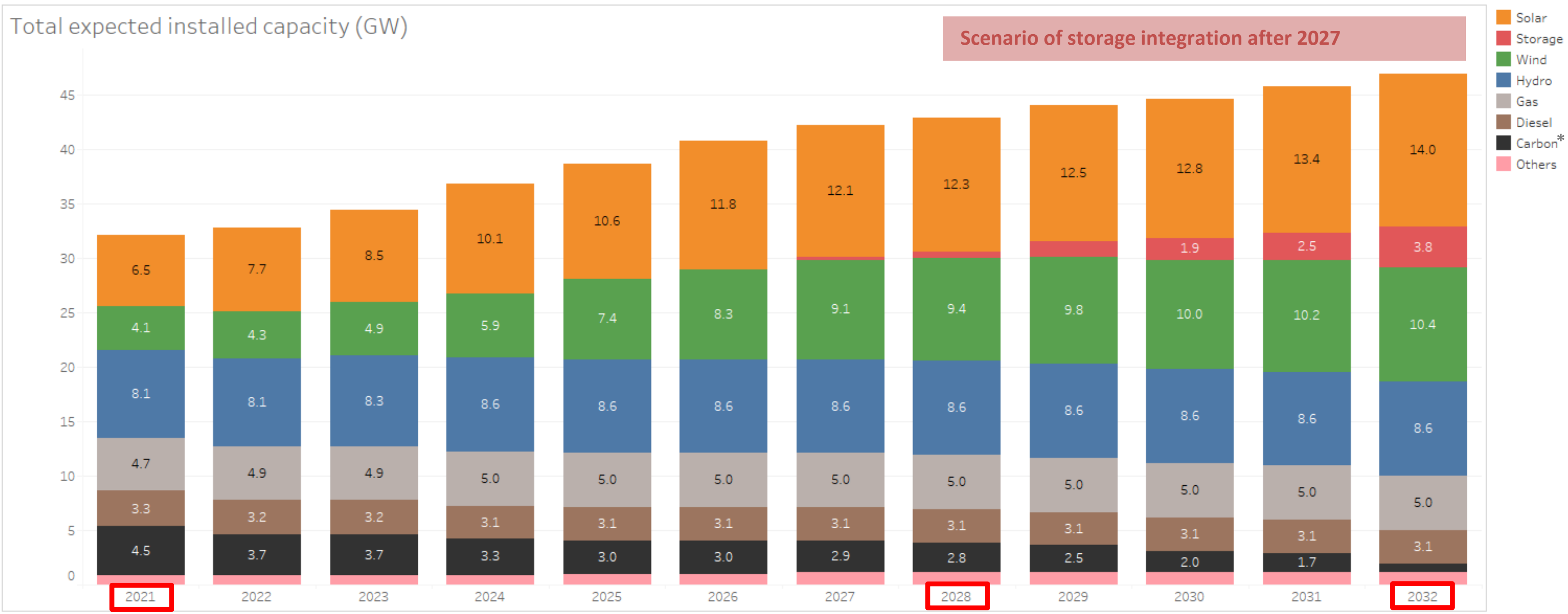
The Chilean NES: National Electricity System

Chilean National Electric System (“SEN”) has been primarily a hydrothermal system, which over the past few years has integrated significant levels wind and solar generation. Recently, the government and utilities have subscribed voluntary commitments to retire coal facilities which could lead to adequacy and flexibility challenges.



Challenges in the transition to net-zero carbon emissions system

The retirement of coal power plants, aging CCGT units, failures of thermoelectric facilities, and a sequence of dry years (driven by climate change) are affecting adequacy of the system and its capacity to operate efficiently, creating opportunities for renewables and energy storage.



Today, reservoirs can store hydro resources and complement renewables. The system doesn't have long duration energy storage systems (BESS or other type of storage).

*This retirement plan was used in evaluation; however, it does not include recent announcements made by AES in July.

The ELCC was calculated using an hourly security constrained economic dispatch model

The short-term operational restrictions were considered. To reduce the calculation time a two-stage process was developed. In the first stage 10 samples were executed to approach the defined reliability level with a certain level of confidence. In the second stage the number of samples are increased to guarantee a confidence level of 95%.

System
Base installed capacity

→

Base load calculation

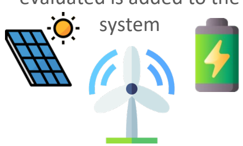
Calculation of how much load can be supplied for at a specific reliability target.

PLEXOS BY ENERGY EXEMPLAR

→

D_0
Base demand that can be supplied

System
+
Resource
The additional resource to be evaluated is added to the system



→

Load with additional resource calculation

Calculation of how much load can be supplied for at a specific reliability target when a new resource is added to the system.

PLEXOS BY ENERGY EXEMPLAR

→

D_n
Demand that can be supplied with additional resource

The contribution of the new resources toward the system capacity is defined as the difference between the demand that can be supplied with an additional resource and the base demand.

$$ELCC = D_n - D_0$$

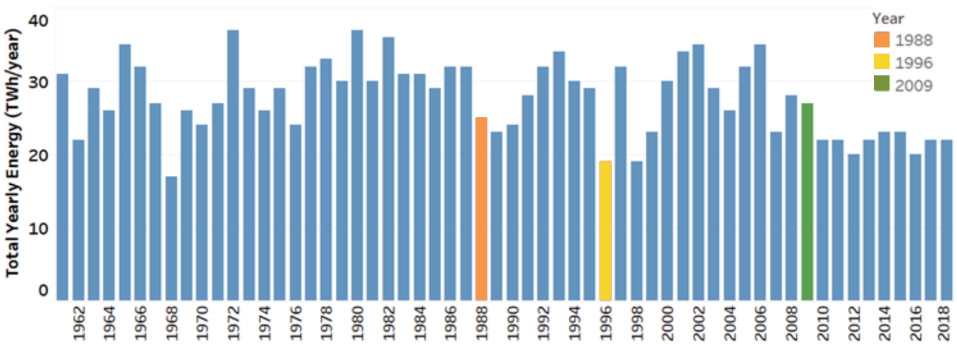
ELCC cases – PV, Wind, and stand alone storage

The cases consider renewable portfolios (solar & wind) and energy storage systems (5 and 10 hours of duration). Sensitivities were performed considering different hydrological conditions, reliability targets, renewable energy integration levels, storage integration levels and decarbonization paths.

Evaluated resources

Technology	Type	Removal of
Solar	Average	Full solar portfolio
	Average	80% solar portfolio
	Average	120% solar portfolio
Wind	Average	Full wind portfolio
Storage	Average	BESS 5h and 10h portfolio
	Average	BESS 5h portfolio
	Average	BESS 10h portfolio
	Incremental	300 MW of 5h BESS
	Incremental	340 MW of 10h BESS

Hydrological conditions



Reliability level

There are no international standards or metrics for reliability levels, criteria vary by country/grid operator

Simulated periods

Three years were simulated: 2021, 2028, and 2032. Each year considers a different generation and storage mix. For each year, the 8760 hours were considered.

The NES is highly dependent on the availability hydro resources. Three hydro scenarios were simulated according to their probability of exceedance P56 (wet), P67 (medium) and P97 (dry).

There is a strong interaction between the dispatch of reservoirs and the availability of renewables (solar and wind). Spot prices are affected by the energy available.

The potential impact of climate change on energy reliability is becoming more relevant. For example, long periods of low inflows and low availability of wind during winter can emerge.

Known historical patterns of inflows are being affected by significant changes in the accumulation of ice in the Andes.

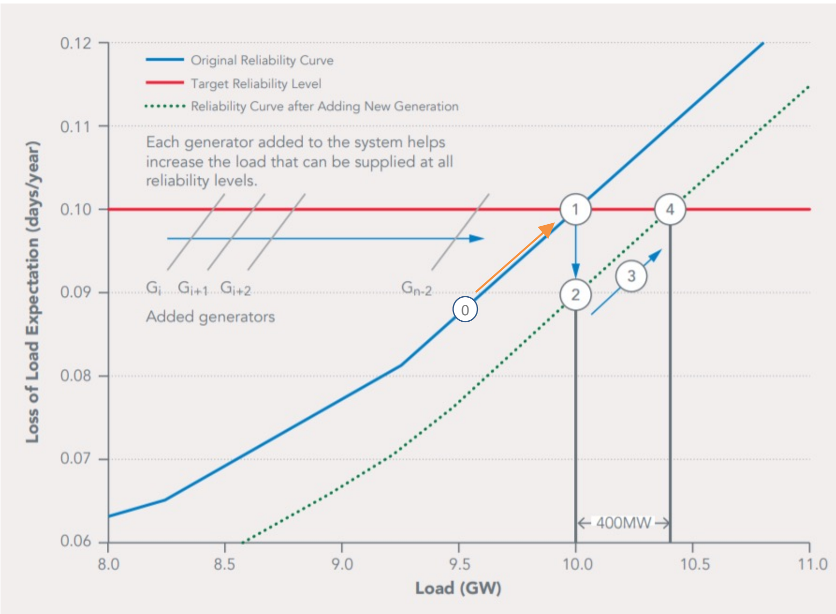
Agenda

1) **Effective Load Carrying Capability (ELCC)**
2) **Cases studied**
3) **Load adaptation to reach the reliability target**
4) Effect of the evaluation conditions
5) Challenges with storage and energy availability
6) Conclusions

To evaluate the ELCC at the target LOLE, the demand must be significantly increased, affecting the dynamics of the system and the interaction between resources

Increasing the demand to comply with the reliability target can significantly modify the operational dynamics of the system. The ELCC of a specific portfolio is conditioned by the operation of the system. For example, in Chile, a high demand scenario to evaluate the ELCC at the target LOLE requires the persistent dispatch of diesel units to complement renewables. This behavior is atypical for the Chilean system and is not aligned with decarbonization targets.

Recalling the ELCC methodology...

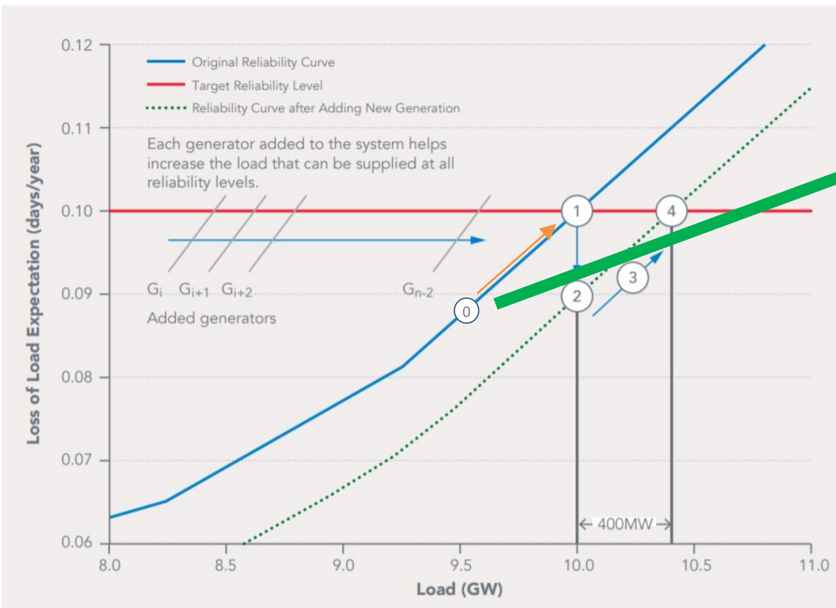


J. Katz, P. Denholm "Using Wind and Solar to Reliably Meet Electricity Demand, Greening the Grid".
Picture modified by Inodú.

To evaluate the ELCC at the target LOLE, the demand must be significantly increased, affecting the dynamics of the system and the interaction between resources

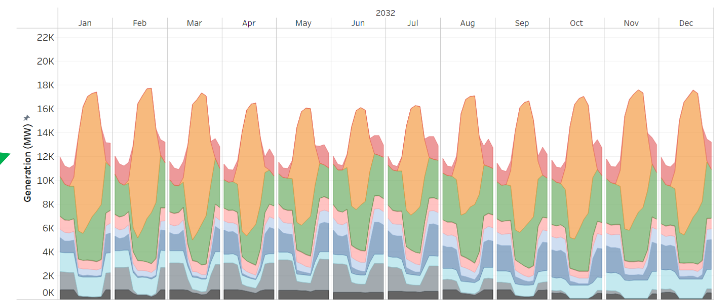
Increasing the demand to comply with the reliability target can significantly modify the operational dynamics of the system. The ELCC of a specific portfolio is conditioned by the operation of the system. For example, in Chile, a high demand scenario to evaluate the ELCC at the target LOLE requires the persistent dispatch of diesel units to complement renewables. This behavior is atypical for the Chilean system and is not aligned with decarbonization targets.

Recalling the ELCC methodology...



J. Katz, P. Denholm "Using Wind and Solar to Reliably Meet Electricity Demand, Greening the Grid".
Picture modified by Inodú.

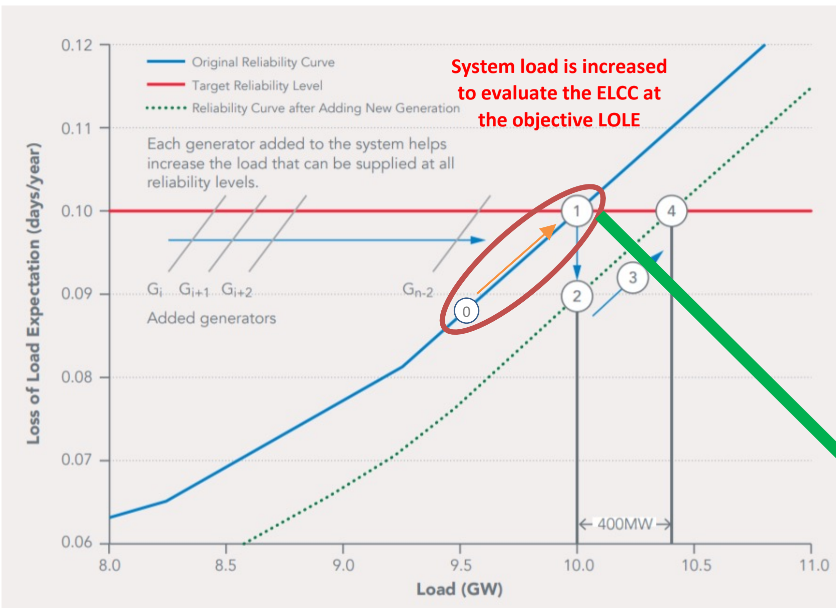
Expected system operation (0)



To evaluate the ELCC at the target LOLE, the demand must be significantly increased, affecting the dynamics of the system and the interaction between resources

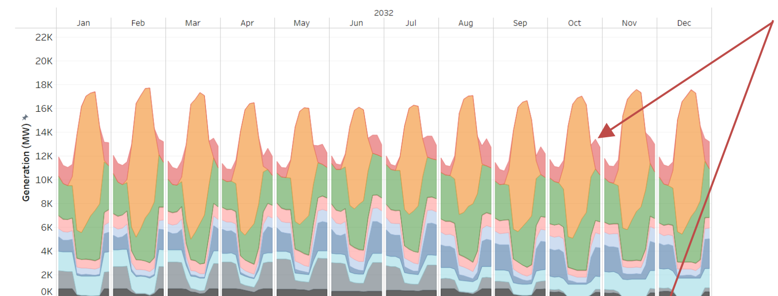
Increasing the demand to comply with the reliability target can significantly modify the operational dynamics of the system. The ELCC of a specific portfolio is conditioned by the operation of the system. For example, in Chile, a high demand scenario to evaluate the ELCC at the target LOLE requires the persistent dispatch of diesel units to complement renewables. This behavior is atypical for the Chilean system and is not aligned with decarbonization targets.

Recalling the ELCC methodology...

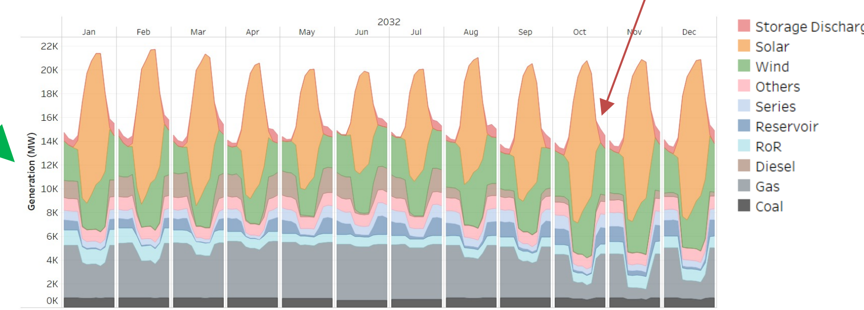


J. Katz, P. Denholm "Using Wind and Solar to Reliably Meet Electricity Demand, Greening the Grid".
Picture modified by Inodú.

Expected system operation (0)



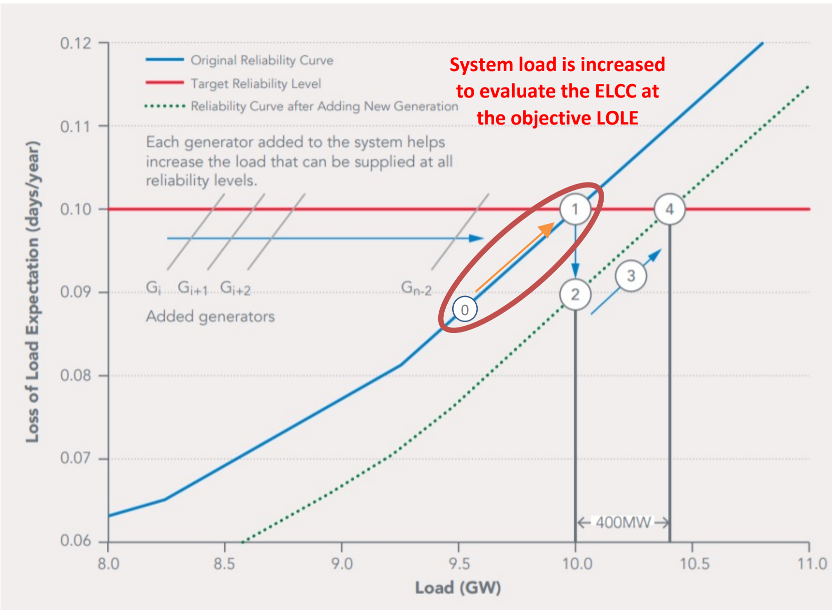
System operation at the reference LOLH (1)



To evaluate the ELCC at the target LOLE, the demand must be significantly increased, affecting the dynamics of the system and the interaction between resources

Increasing the demand to comply with the reliability target can significantly modify the operational dynamics of the system. The ELCC of a specific portfolio is conditioned by the operation of the system. For example, in Chile, a high demand scenario to evaluate the ELCC at the target LOLE requires the persistent dispatch of diesel units to complement renewables. This behavior is atypical for the Chilean system and is not aligned with decarbonization targets.

Recalling the ELCC methodology...



J. Katz, P. Denholm "Using Wind and Solar to Reliably Meet Electricity Demand, Greening the Grid".
Picture modified by Inodú.

Are the operations of thermoelectric facilities at the target LOLE consistent with meeting decarbonization goals and a reasonable future operation of the system?

Are the reliability parameters of units (EFOR) valid for new simulated operational conditions?

How do the operational dynamics of thermoelectric facilities at the target LOLE change the operational risk of the system?

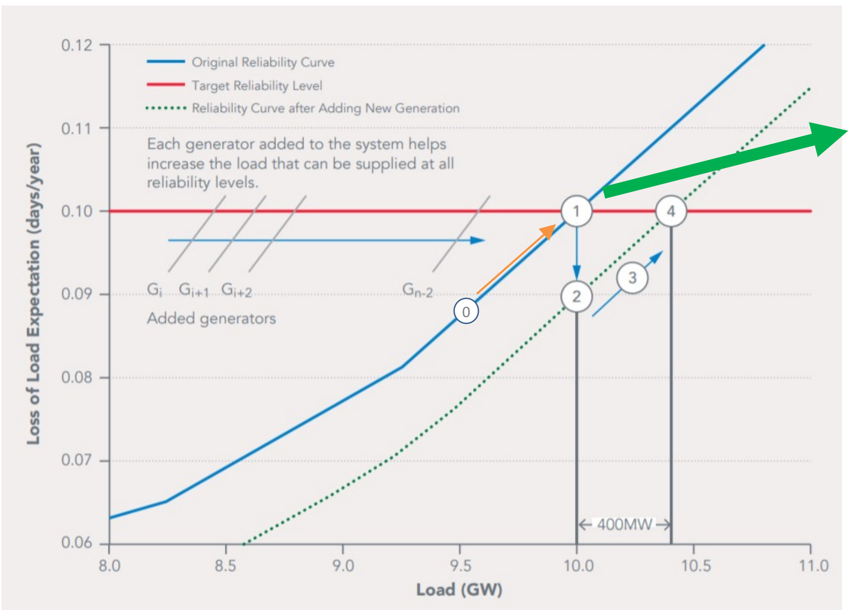
How is the operation of energy storage systems affected by the distortion of spot prices at the target LOLE?

Are the critical periods of the system shifted by the demand increase used to evaluate the system at the target LOLE?

To evaluate the ELCC at the target LOLE, the demand must be significantly increased, affecting the dynamics of the system and the interaction between resources

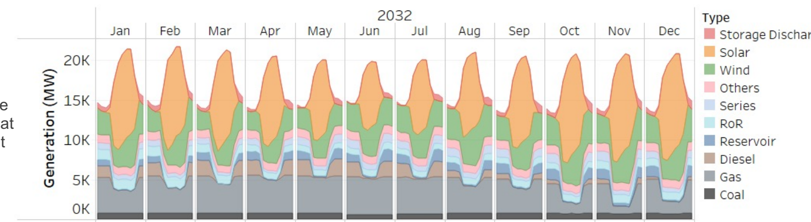
Increasing the demand to comply with the reliability target can significantly modify the operational dynamics of the system. The ELCC of a specific portfolio is conditioned by the operation of the system. For example, in Chile, a high demand scenario to evaluate the ELCC at the target LOLE requires the persistent dispatch of diesel units to complement renewables. This behavior is atypical for the Chilean system and is not aligned with decarbonization targets.

Recalling the ELCC methodology...



J. Katz, P. Denholm "Using Wind and Solar to Reliably Meet Electricity Demand, Greening the Grid".
Picture modified by Inodú.

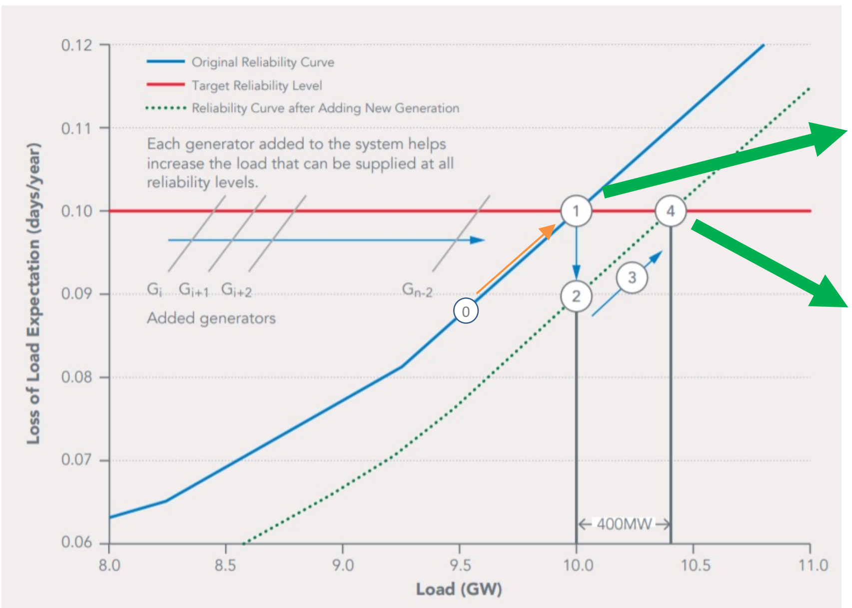
Reference operation at the target LOLE



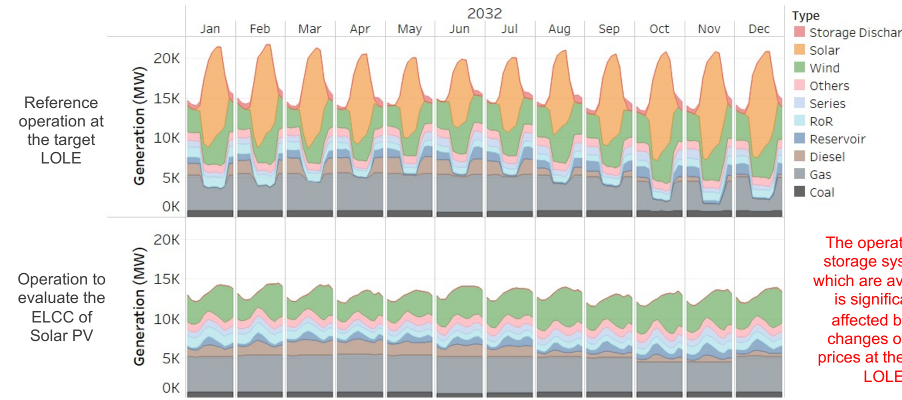
To evaluate the ELCC at the target LOLE, the demand must be significantly increased, affecting the dynamics of the system and the interaction between resources

Increasing the demand to comply with the reliability target can significantly modify the operational dynamics of the system. The ELCC of a specific portfolio is conditioned by the operation of the system. For example, in Chile, a high demand scenario to evaluate the ELCC at the target LOLE requires the persistent dispatch of diesel units to complement renewables. This behavior is atypical for the Chilean system and is not aligned with decarbonization targets.

Recalling the ELCC methodology...



J. Katz, P. Denholm "Using Wind and Solar to Reliably Meet Electricity Demand, Greening the Grid".
Picture modified by Inodú.

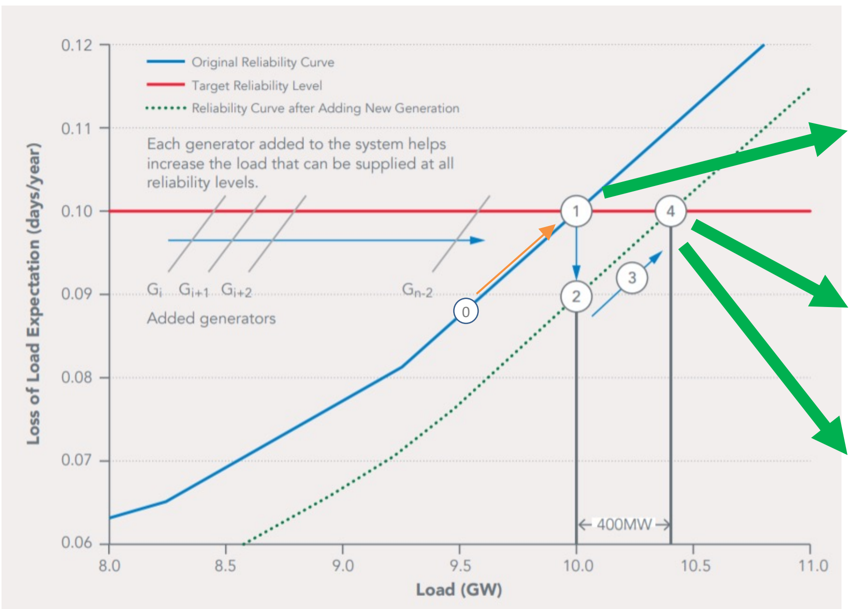


The operation of storage systems, which are available, is significantly affected by the changes of spot prices at the target LOLE

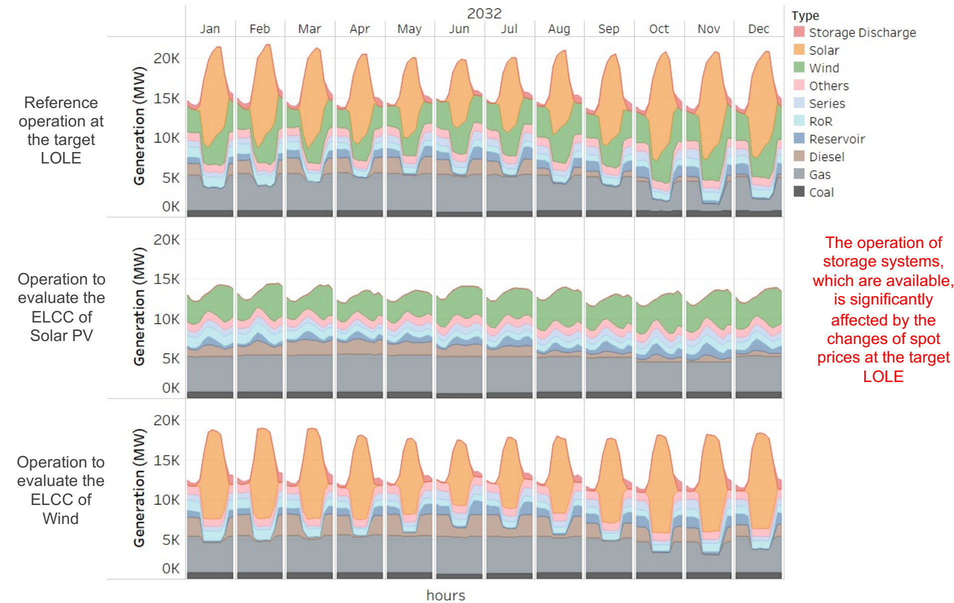
To evaluate the ELCC at the target LOLE, the demand must be significantly increased, affecting the dynamics of the system and the interaction between resources

Increasing the demand to comply with the reliability target can significantly modify the operational dynamics of the system. The ELCC of a specific portfolio is conditioned by the operation of the system. For example, in Chile, a high demand scenario to evaluate the ELCC at the target LOLE requires the persistent dispatch of diesel units to complement renewables. This behavior is atypical for the Chilean system and is not aligned with decarbonization targets.

Recalling the ELCC methodology...



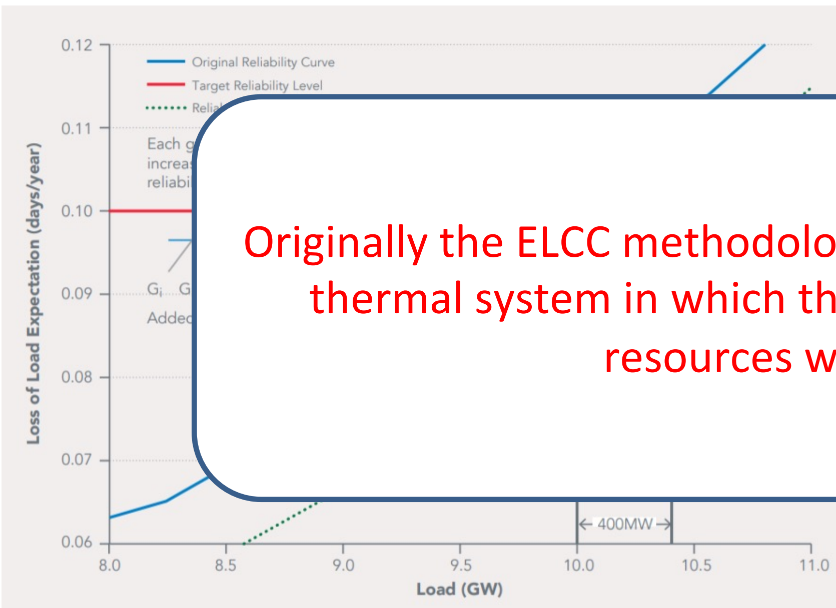
J. Katz, P. Denholm "Using Wind and Solar to Reliably Meet Electricity Demand, Greening the Grid".
Picture modified by Inodú.



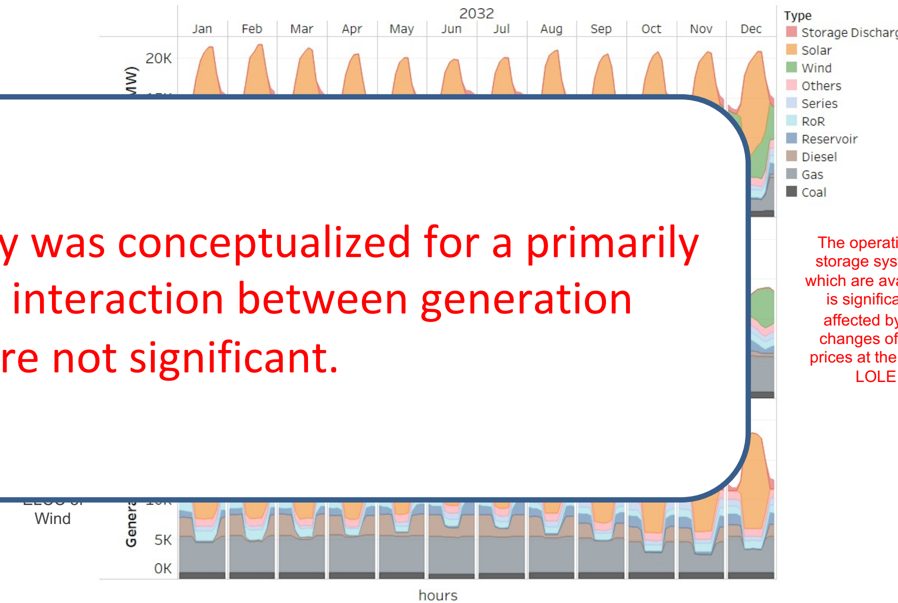
To evaluate the ELCC at the target LOLE, the demand must be significantly increased, affecting the dynamics of the system and the interaction between resources

Increasing the demand to comply with the reliability target can significantly modify the operational dynamics of the system. The ELCC of a specific portfolio is conditioned by the operation of the system. For example, in Chile, a high demand scenario to evaluate the ELCC at the target LOLE requires the persistent dispatch of diesel units to complement renewables. This behavior is atypical for the Chilean system and is not aligned with decarbonization targets.

Recalling the ELCC methodology...



J. Katz, P. Denholm "Using Wind and Solar to Reliably Meet Electricity Demand, Greening the Grid".
Picture modified by Inodú.



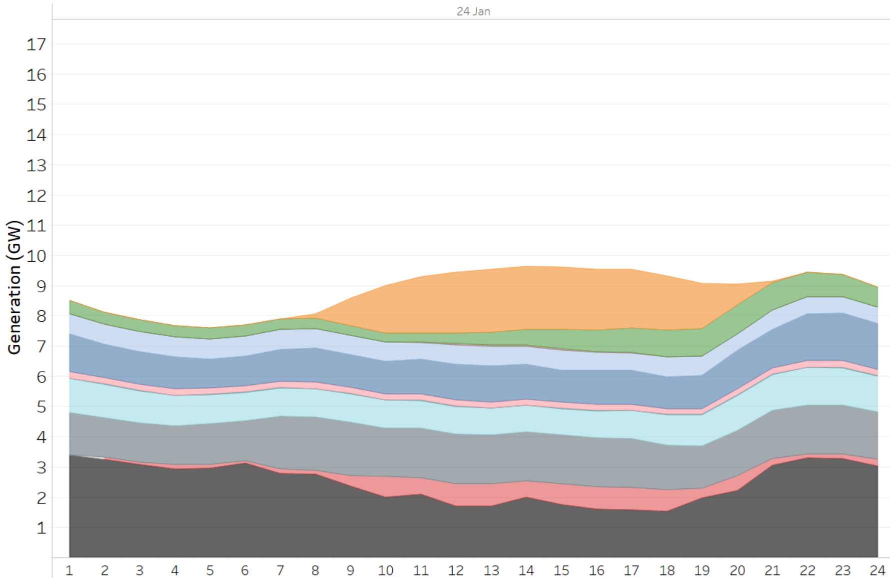
Originally the ELCC methodology was conceptualized for a primarily thermal system in which the interaction between generation resources were not significant.

The operation of storage systems, which are available, is significantly affected by the changes of spot prices at the target LOLE

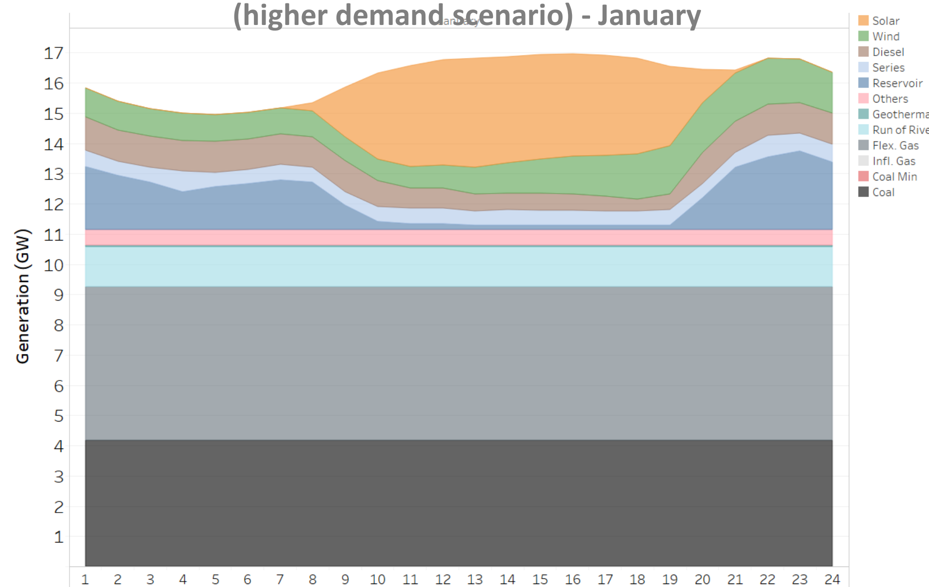
ELCC does not properly consider inflexibilities of power plants

Important parameters such as startup time, minimum operational time, fuel supply, ramping capability and startup costs are not being considered when evaluating the system at the desired reliability level, however they play a very important role in real operations.

Real Operations (2021) - January



Simulated Operations at the target LOLE (higher demand scenario) - January



The simulated operations does not consider relevant parameters which highly impact the real operations. Also to meet the new demand levels for target LOLE, units end up operating in ways which are unexpected in real operations.

Inflexible generation assets reduce the reliability of the system in high VRE. In order to properly address the contribution of legacy generation systems with reduced flexibility, the ELCC calculations shall be enhanced with the evaluation of a set of technical parameters such as startup time, ramp, and minimum up time. Even though minimum load is not directly related with the contribution of the generation asset to reliability of the system, it is desirable to define a mechanism to incentivize capacity with reduced minimum load.

Agenda

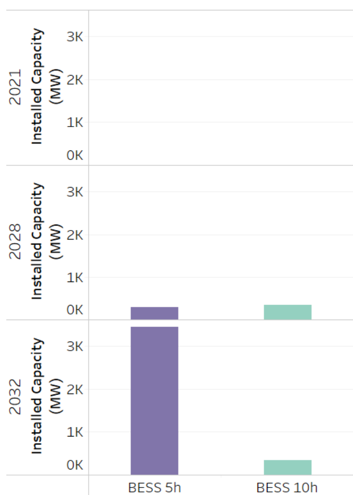
1) **Effective Load Carrying Capability (ELCC)**
2) **Cases studied**
3) **Load adaptation to reach the reliability target**
4) **Effect of the evaluation conditions**
5) Challenges with storage and energy availability
6) Conclusions

The impact of the reliability target on the portfolio's ELCC is conditioned by the generation mix in the system

In 2021, when the system does not have storage systems, the target LOLE greatly impacts the ELCC of solar PV – the interaction between solar PV and reservoir generation is critical and low inflow scenarios provides more flexibility for integration of PV generation.

However, in 2032 when the system has integrated more storage systems and coal facilities have been retired, the reliability target and the inflow conditions don't have a significant impact on the ELCC of solar PV.

BESS evolution



There is an important difference in the BESS installed between the simulated years.

Reliability target impact on solar ELCC

Case	Hidrology	LOLH* (h/year)	ELCC (%) 2021	ELCC (%) 2032
Solar	Medium	7.66	9	22
		0.1	2	20

The target LOLE has a larger effect on the ELCC of solar PV when less storage is available.

Hydrology impact on VRE ELCC

Case	LOLH*(h/year)	Hidrology	ELCC (%) 2021	ELCC (%) 2032
Solar	7.66	Wet	11	22
		Medium	9	22
		Dry	20	20
Wind	7.66	Wet	34	21
		Medium	32	21
		Dry	31	23

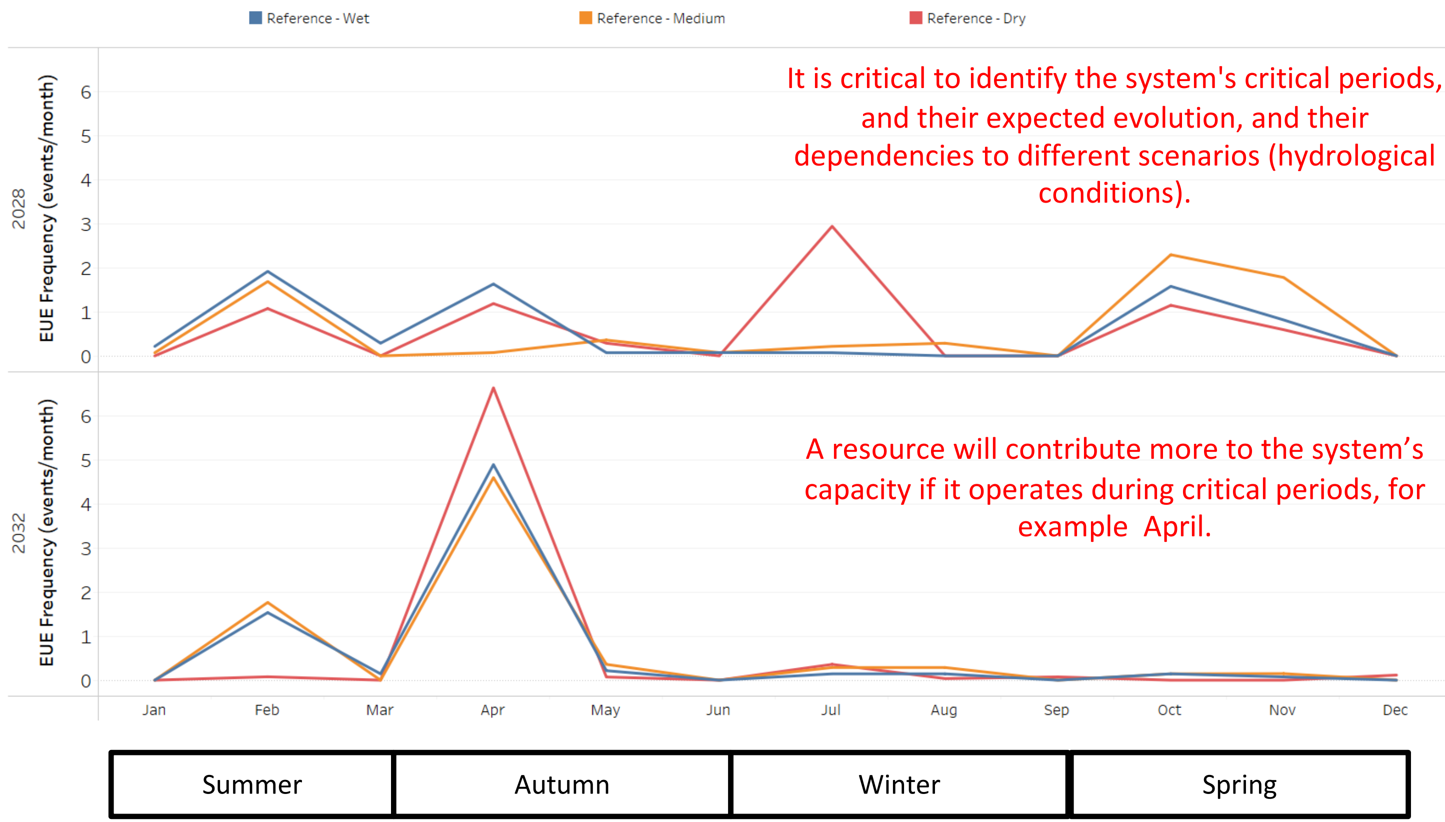
ELCC of solar and wind generation is affected by the integration of storage. In this context, the evaluation of the ELCC at the target LOLE significantly reduces the value of the interaction between wind generation and other resources.

Agenda

1) **Effective Load Carrying Capability (ELCC)**
2) **Cases studied**
3) **Load adaptation to reach the reliability target**
4) **Effect of the evaluation conditions**
5) **Challenges with storage and energy availability**
6) Conclusions

Critical periods change depending on the evolution of the system

Unserved energy hours change as the system evolves, which affects the contribution of the renewable portfolios. If a technology generates more during critical hours, its contribution will be higher.

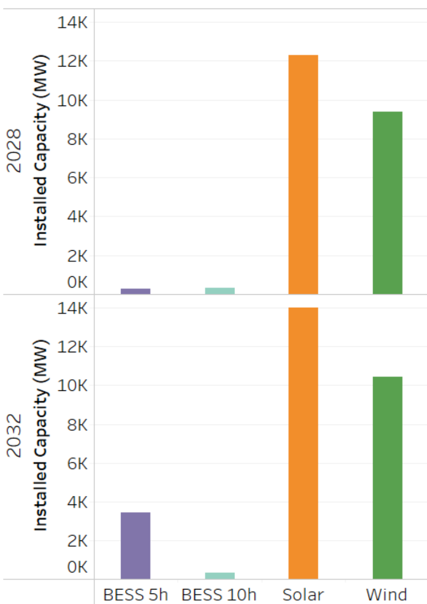


The ELCC of energy storage is highly conditioned by the **energy availability** (which in the future will be provided by VRE) during critical periods

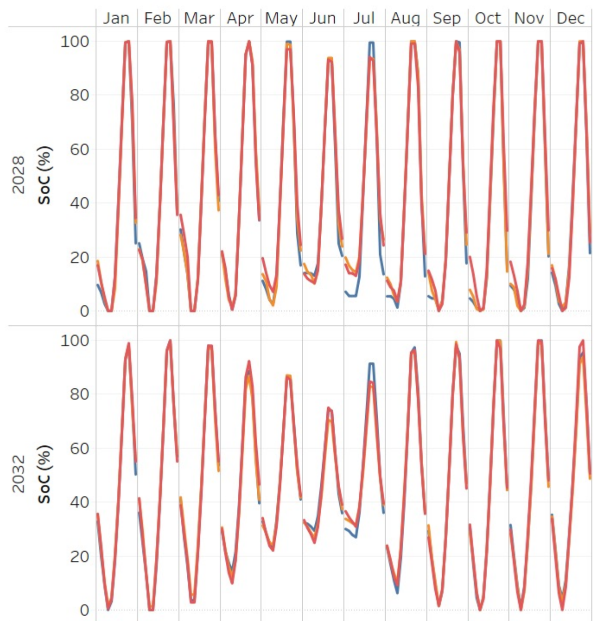
The state of charge (SOC) of 5 hr energy storage shows that, in the evaluated scenario, there is not enough energy to fully charge the energy storage systems between April and July 2032 -- the riskier hours occurs during April which coincides with SOC limitations.

In 2032 the ELCC for energy storage is lower than in 2028. The ELCC for 10 hours storage was higher than 5 hour storage, as expected.

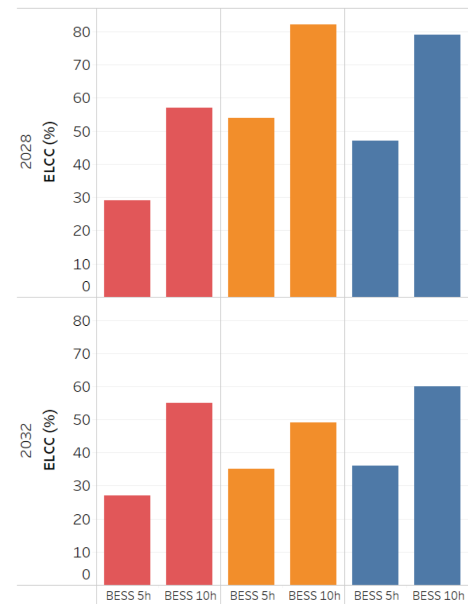
VRE and BESS integration



Monthly average state of charge



BESS capacity recognition



Agenda

1) Effective Load Carrying Capability (ELCC)
2) Cases studied
3) Load adaptation to reach the reliability target
4) Effect of the evaluation conditions
5) Challenges with storage and energy availability
6) Conclusions

To evaluate the ELCC at the target LOLE, the demand must be significantly increased, affecting the dynamics of the system and the interaction between resources

1. Each resource, especially renewable energy and flexible resources, could require different assumptions to ensure they operate in a reasonable manner and their interactions combined with other resources in the system is reasonable in the future scenario being evaluated, therefore applying the same assumptions to the evaluation of all resources could lead to an over or underestimated ELCC for a particular resource.

2. The operations of energy storage systems are affected by a spot price differential. Increasing the demand to evaluate the system at the target LOLE can affect the spot price differential and change battery operations. How will we ensure that the adjusted energy storage operations are reasonable, and therefore the ELCC for these energy storage units, or other resources which are affected, is fair?

3. When the ELCC methodology was conceptualized, increasing load to achieve a LOLE target on a generation mix that was heavily dependent on natural gas, coal and nuclear resources would lead to reasonable operations and interactions amongst these assets.

4. How should the methodology be adjusted to account for systems which are undergoing transformations due to decarbonization pressure and resources such as batteries and renewables which depend more on one another in their future operations? For example: All other things being equal, greater solar deployment leads to a higher ELCC for storage, however the ELCC of solar decreases. Similarly, more storage deployment leads to a higher ELCC of solar and a decrease in the ELCC of storage.

5. Can we ensure each resource has a reasonable capacity recognized based on viable operations and their contributions to system adequacy?

6. Clustering resources leads to sharing the value of capacity amongst them. For example, if a highly reliably hybrid system is clustered with other less reliable hybrid systems, the ELCC of the former will be reduced. Should we adjust how we cluster hybrid resources?

7. Low-capacity factor flexible resources can increase their capacity factor at the target LOLE. Are the EFORs used representative for such dispatch conditions?

Jorge Moreno
jmoreno@inodu.com
+56 9 5698 0920

Donny Holaschutz
donny@inodu.com
+1 512 587 3573
+56 9 9093 4427