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Advancing the State of the Art in Expansion Planning for the California Grid in Partnership with IDAES

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Presentation Overview

Provide details of the IDAES collaboration with California Energy Commission (CEC)

- What is Expansion Planning, why is it challenging, and why is IDAES working on it?
- Problems facing the CEC in meeting clean energy goals
- Case study of San Diego County

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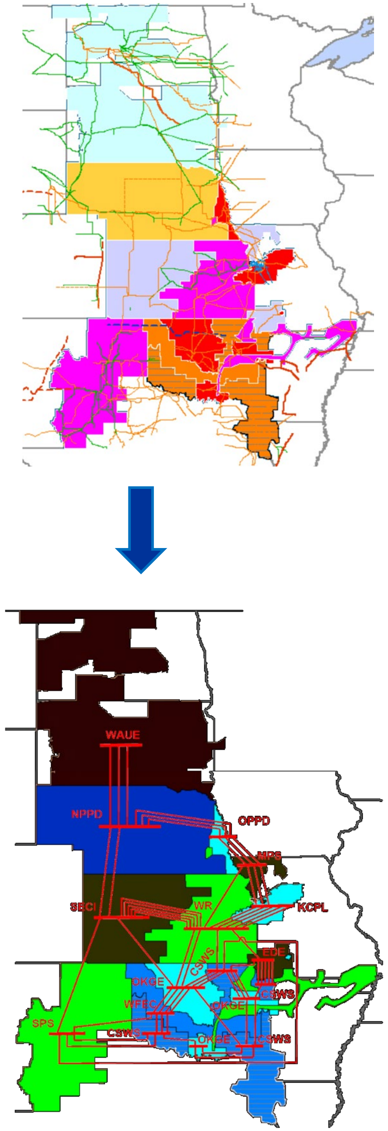
Expansion Planning and Why it is Hard

- **What is a capacity expansion model?** – Determining lease cost deployment of technologies to meet future load demand **over multi-decade horizons in a region** (state, ISO/RTO, nationwide)
  - What technologies/ designs **deployed, when and where?**
  - What generators will be **retired, renewed** and what technologies are **phased out**?

- At the core, an expansion planning model considers
  - Systems with **>10^2** generators, **>10^3** transmission lines,
  - Balancing loads over each of **10^6 time periods**,
  - With numerous opportunities to install, extend, and retire assets,
  - And significant uncertainty in all parameters (generator costs, available technology, load growth and patterns, renewable resources),

- **Too large to "directly solve"**

- Numerous **simplifications and approximations to develop "tractable" models** which **will impact accuracy**
  - ACOFP → DCOPF → Transshipment
  - Full network → "skeletonized" network → "copper plate"
  - Individual generators → generator clusters
  - Full time horizon → representative days → representative loads
  - Discrete decisions → continuous relaxations



Why is IDAES Developing Expansion Planning Models?

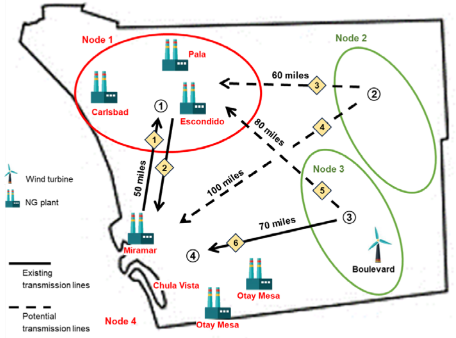
- Integrated Energy Systems must be designed for the *system*
  - Designing in isolation (e.g., “max efficiency”) does not guarantee participation / revenue from the market

- Existing expansion planning models focus primarily on *capacity*
  - Operability (e.g., the role of **dynamics, flexibility, and uncertainty**) is not explicitly included, leading to results that overvalue LCOE and undervalue dispatchability and flexibility
  - New and diverse set of technologies **needed to reach decarbonization goals**
  - **Advanced algorithms required** to solve new, challenging problems

- Extending expansion planning models is more than just adding features
  - Scaling up the model requires exploring new algorithmic approaches to solving the model. **Model is open, allowing for customization for the problem you are interested in addressing**

Solving Problems that Represent Today’s Challenges

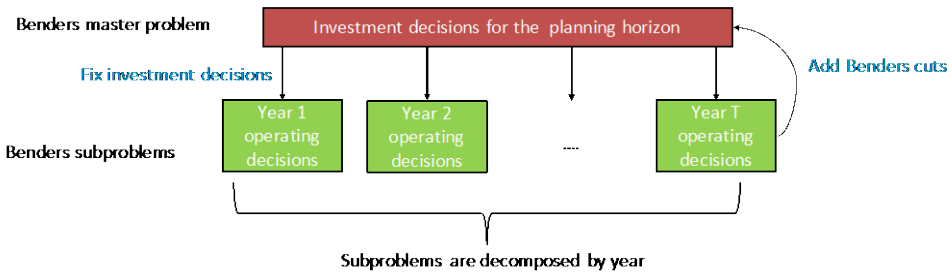
San Diego County Case Study



Improved capabilities in models (e.g. reliability)

Begin with smaller, **less complex models** (smaller regions/ time-scales)

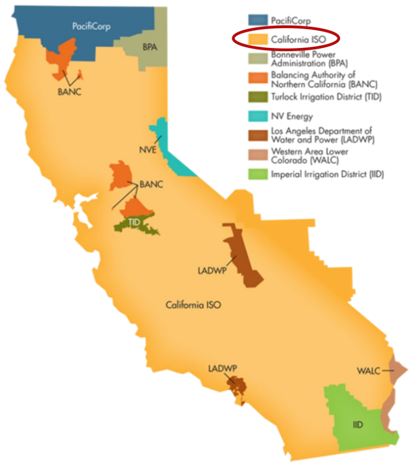
Advanced Algorithms



Higher Complexity

Improve/ develop new algorithms to address convergence challenges

ISO/RTO Scale Problem



Improved capability to address challenging problems on complex models

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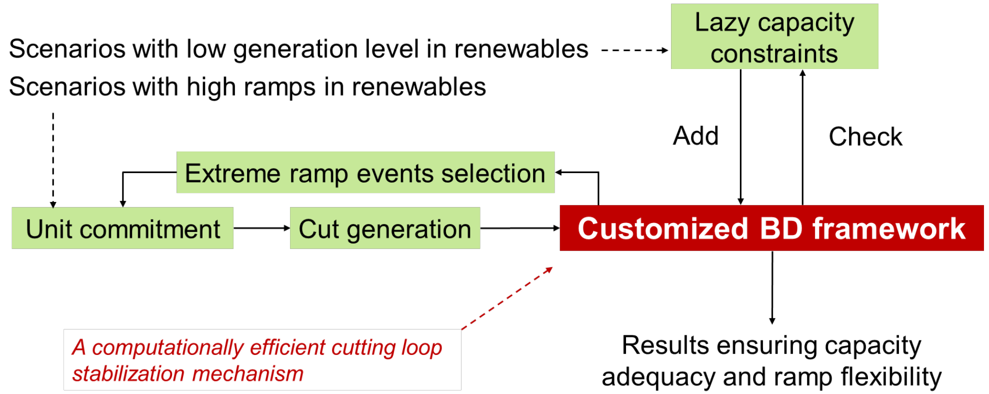
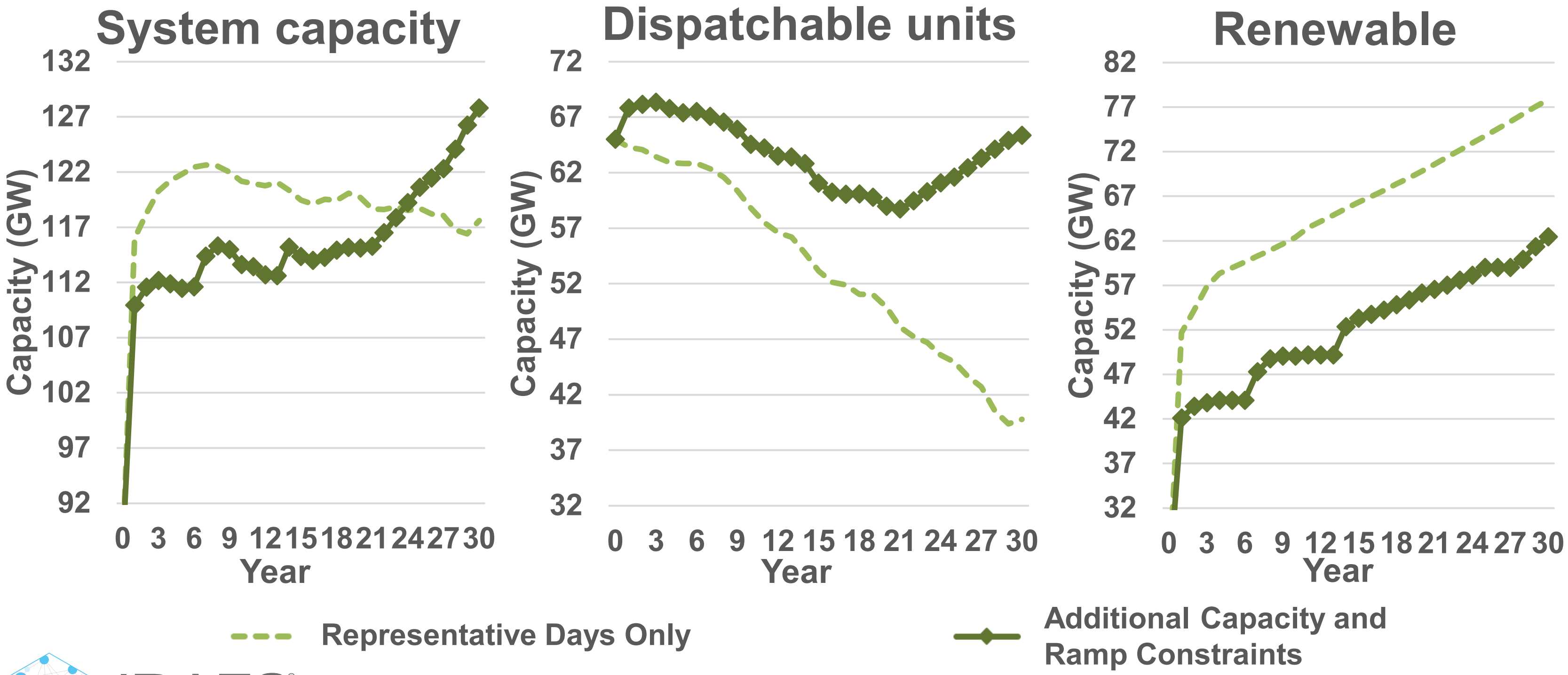
Accounting for Intermittency and Volatility

- "Non-representative" capacity and ramp scenarios critical in understanding dispatchable unit requirements
- Modified algorithm provides insights into low renewable capacity and/or rapid dispatchable ramp scenarios
  - Lazy capacity constraints
  - Extreme ramp events





- "Representative Days Only" underestimates total required capacity
- More dispatchable capacity required with additional capacity constraints and ramp events

* SPP scenarios under high carbon tax

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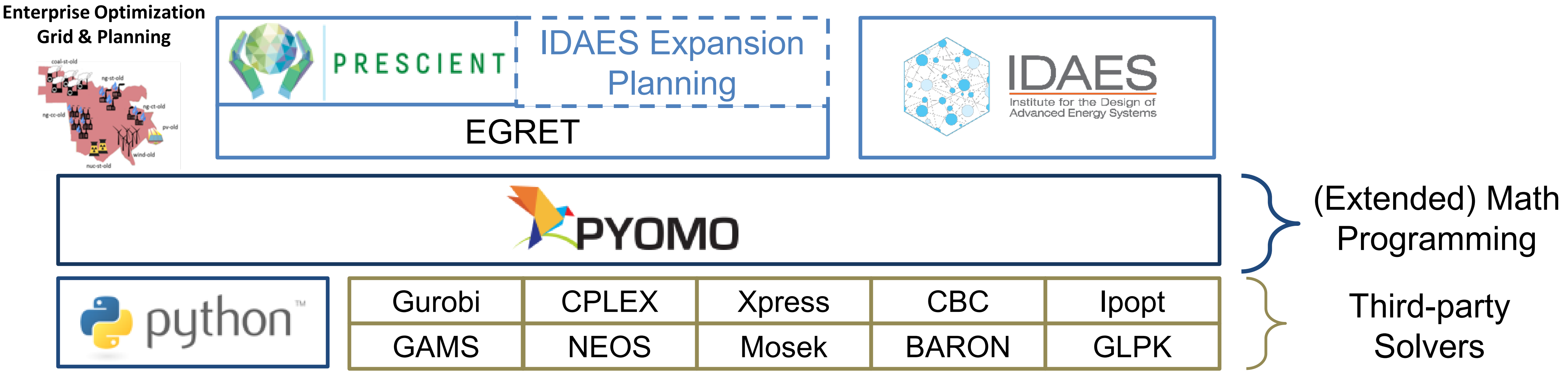
Current IDAES Expansion Planning Activities

- Develop reliability models and algorithms (Carnegie Mellon University, Seolhee Cho and Ignacio E. Grossmann)
  - Improve valuation of **flexibility**
  - Incorporate **resilience with reliability**
  - Expand to new case studies (partnering with California Energy Commission)



- Model maturation (Sandia National Laboratory)
  - **Generalizing / standardizing the models**, leveraging standardizing modeling components from **EGRET**
  - **Generalizing / standardizing algorithms** (remove explicit ties to case studies)

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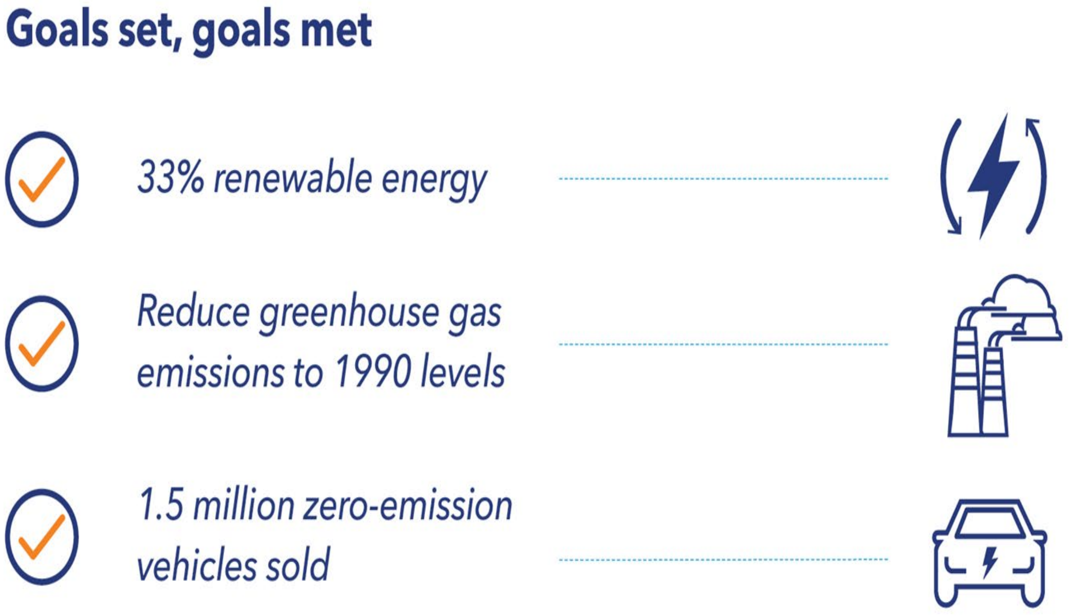
Planning California's Clean Energy Future

California is leading the clean energy revolution:

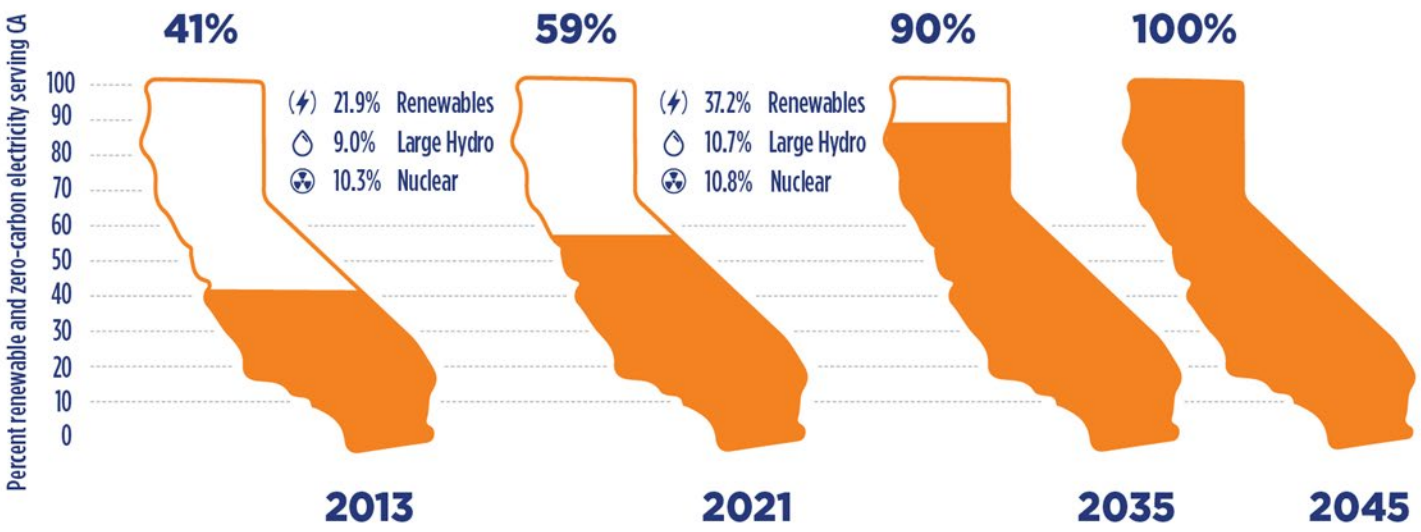
- California has a plan to manage the transition to clean energy
- Changing climate driving more frequent and extreme weather events
- California is creating modern rules to build a modern electrical grid



ENERGY COMMISSION

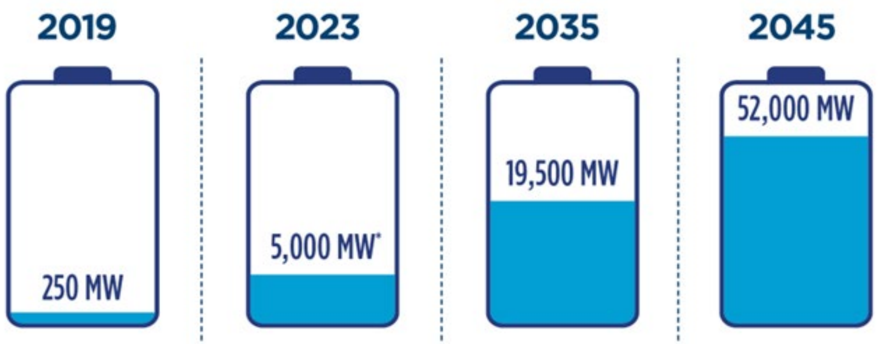
California is on track to achieve 100% clean electricity

with 59% of the state's electricity already coming from renewable and zero-carbon resources



California's growing battery storage capacity

captures the state's abundant renewable resources



*Projected as of June 1, 2023 based on California ISO interconnection queue.

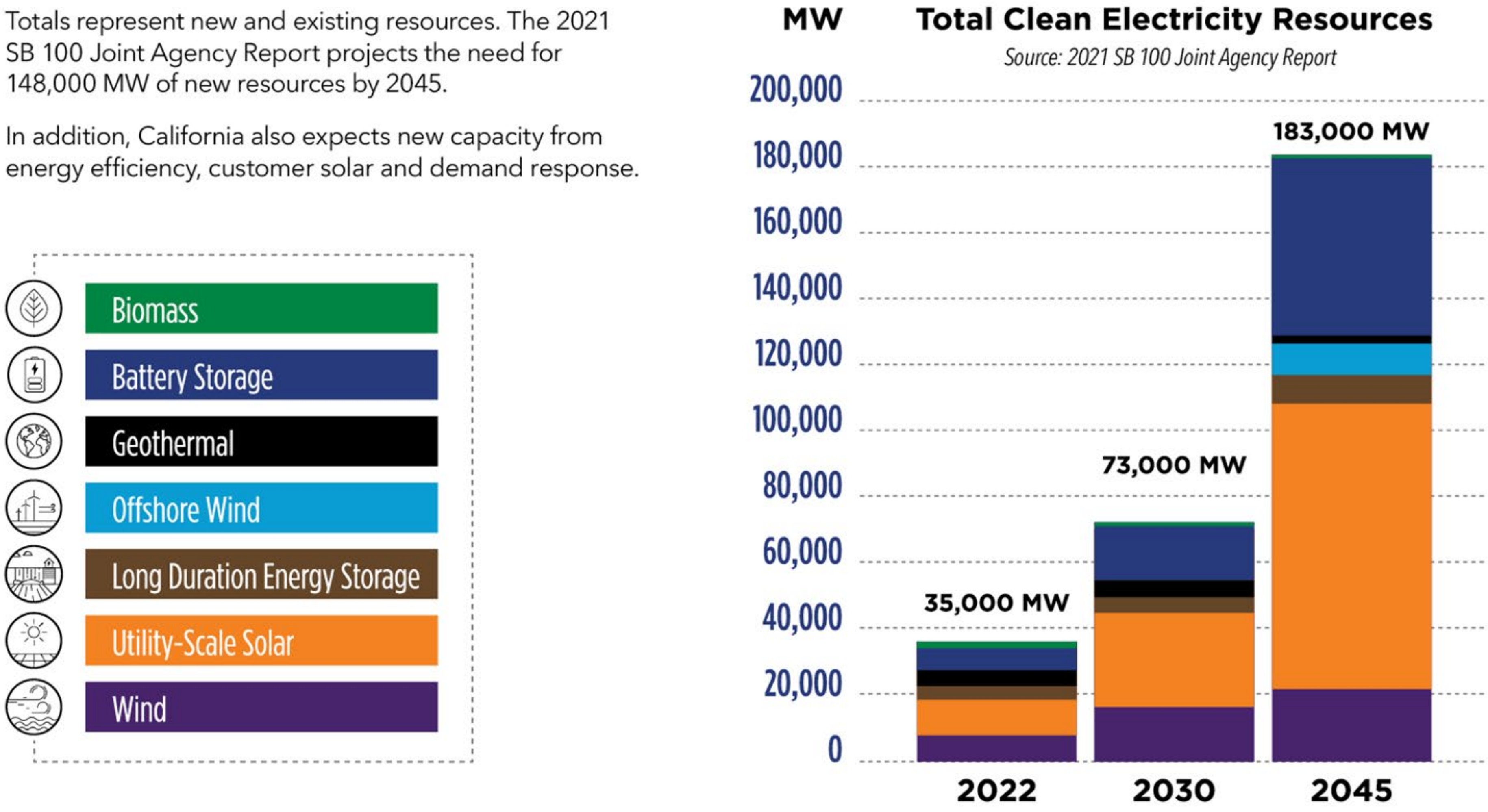
ENERGY COMMISSION

To provide 100% clean electricity by 2045,

California will build an unprecedented amount of new utility-scale clean energy resources

Totals represent new and existing resources. The 2021 SB 100 Joint Agency Report projects the need for 148,000 MW of new resources by 2045.

In addition, California also expects new capacity from energy efficiency, customer solar and demand response.



California's Clean Energy Future Depends Upon State of the Art Tools

The IDAES collaboration is delivering this much needed tooling.

Challenges with the available Capacity Expansion Modeling (CEM) tools commonly found in use:

- Ignore battery state-of-charge, diurnal and multi-period storage value dynamics
- Static network representations
- Fixed loads

Enhanced CEM capabilities will meet critical needs, especially around these modeling objectives:

- Advanced storage technology representations, across broader time scales
- Transmission availability / expansion; dynamic network topologies
- Flexible load representations; incorporating drivers of load uncertainty
- Explicit modeling of System Reliability and resilience.

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How to Improve Reliability in Expansion Planning

- ***Reliability*** An ability to supply uninterrupted power to customers to satisfy the load demand.
- Adding extra generators, batteries, and transmission lines can improve the reliability of power systems.
- In case some facilities fail, other connected facilities can replace the workload of failed facilities to minimize power loss.
- It should optimize where, when, and what type and size of facilities should be added to satisfy the load demand while improving reliability at a minimum cost.

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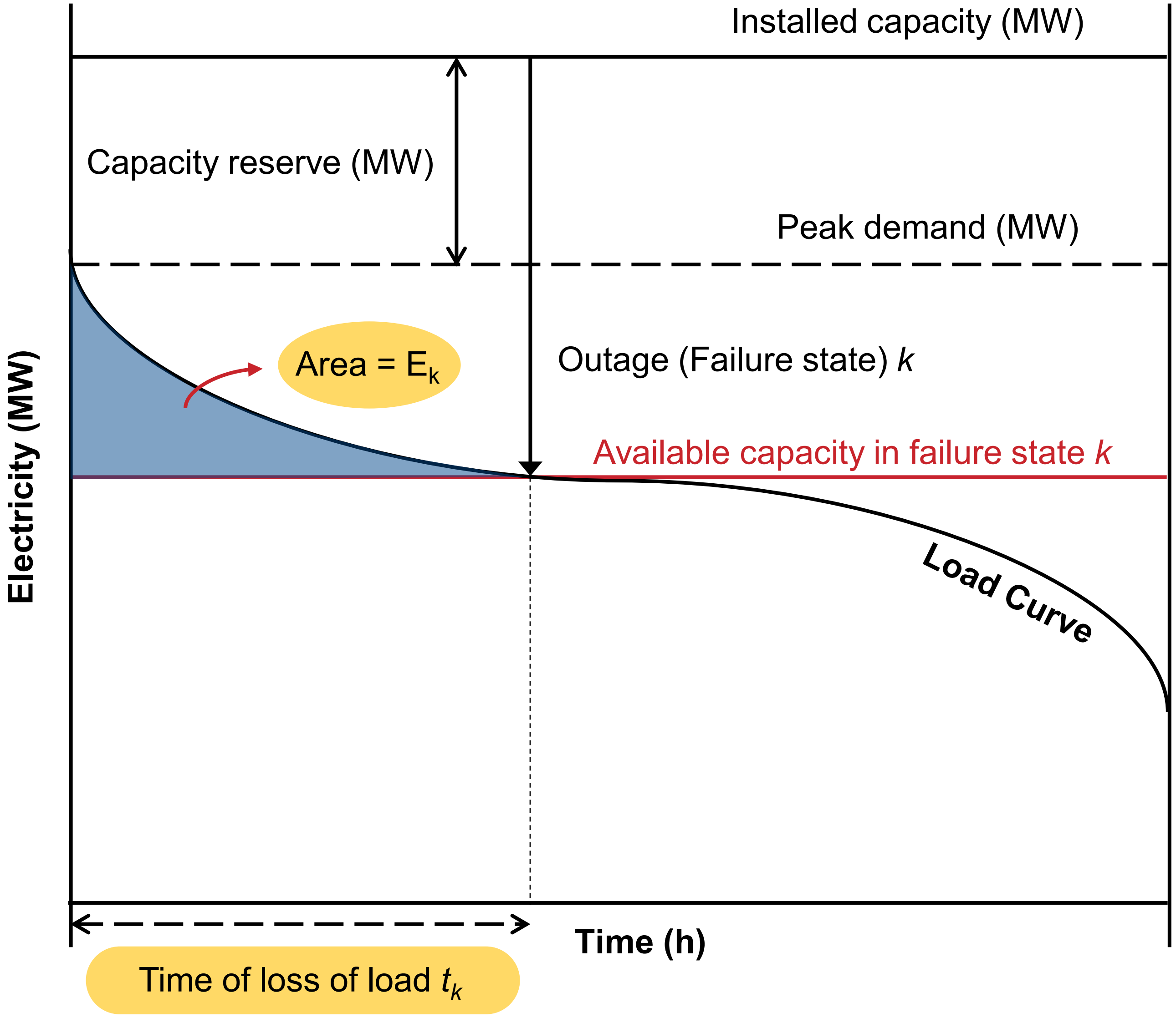
How to Evaluate Reliability – This work



1) **LOLE**# (Loss of Load Expectation, unit: ***hours***): **time** of not satisfying the load demand

$$LOLE = \sum_{k=1}^{n} p_k t_k$$

p_k: Probability of capacity failure state *k*
t_k: Outage time of capacity failure state *k*

2) **EENS*** (Expected Energy Not Served, unit: ***MWh***): **the amount of demand** that the system cannot satisfy

$$EENS = \sum_{k=1}^{n} p_k E_k$$

E_k: Unserved energy in capacity failure state *k*

LOLE & EENS ↓ → Power System Reliability ↑

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[3] R. Medjoudj et al., "Power system reliability: mathematical models and applications", IntechOpen, 2017

Overview of optimization model

Generalized Disjunctive Programming (GDP) model

Min Cost = CAPEX + OPEX + Load shedding penalty

s.t.

Investment constraints

- Installation/lifetime extension of dispatchable generators
- Installation/capacity expansion of **renewable generators and battery**
- Installation of **transmission lines**

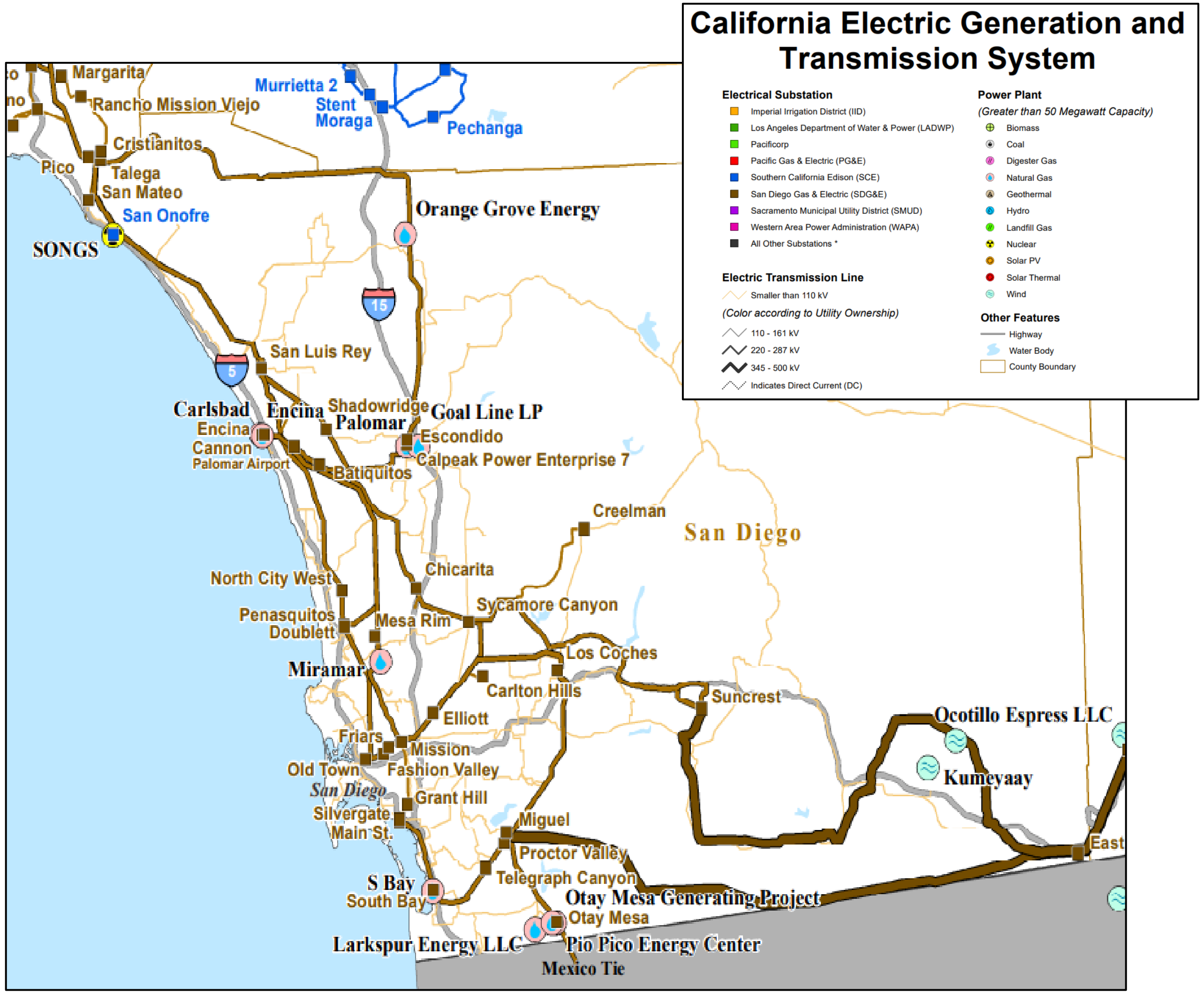
Operation constraints

- Ramping up/down, start-up/shut-down, and **unit commitment**
- **Charging/discharging levels** of storage
- **DC power flow and power balance**
- Fuel consumption and CO_2 emission estimation
- Simplified loss of load expectation (LOLE) and expected energy not served (EENS) estimation
- CO_2 emission limit
- Minimum share of renewable generation

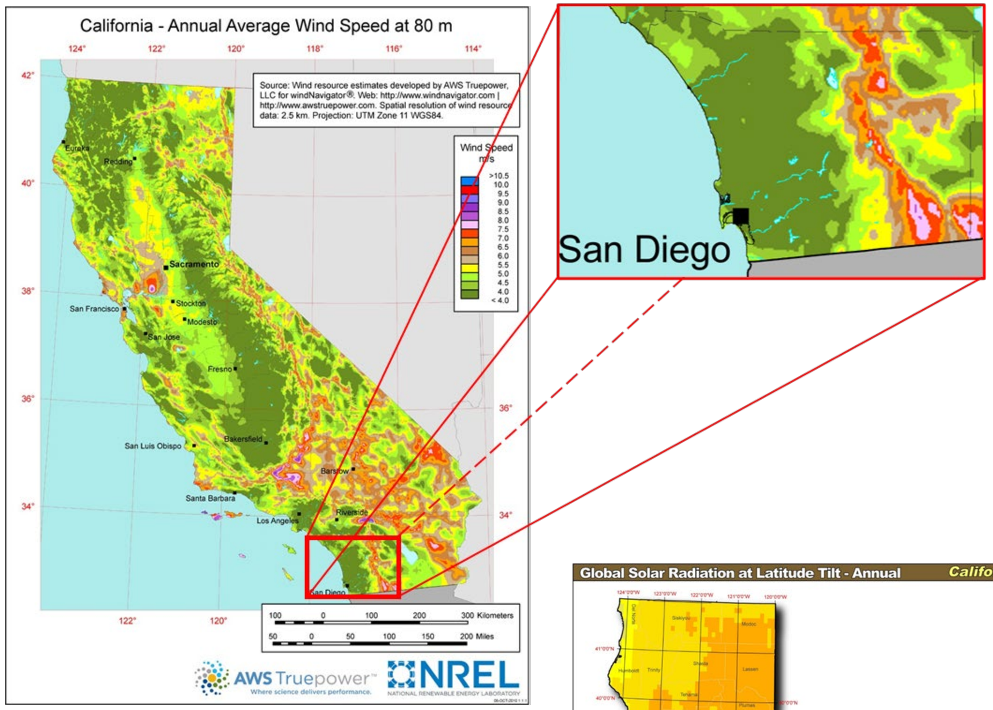
PYOMO GDP

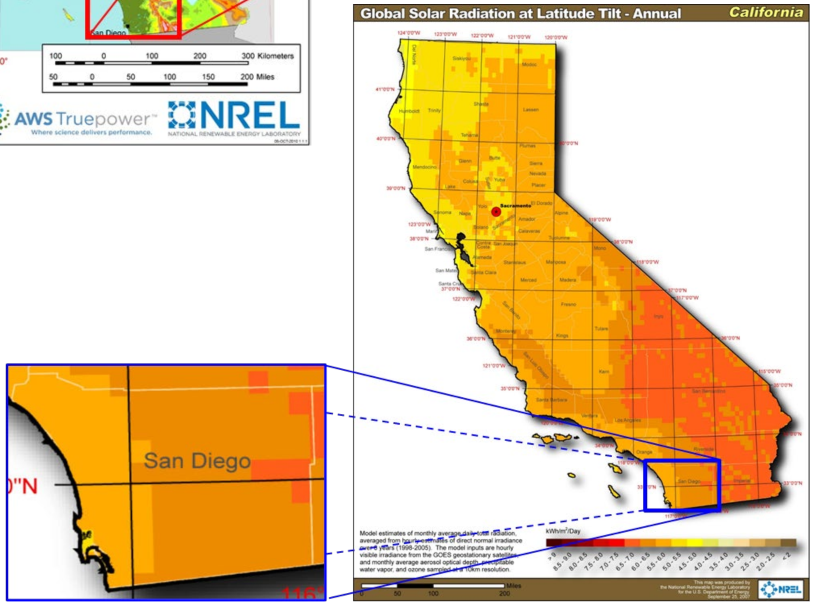
Python 3.10.12, Pyomo 6.6.2

Resource & Technology Status of San Diego County in 2021



< Generation and transmission network in 2021 >





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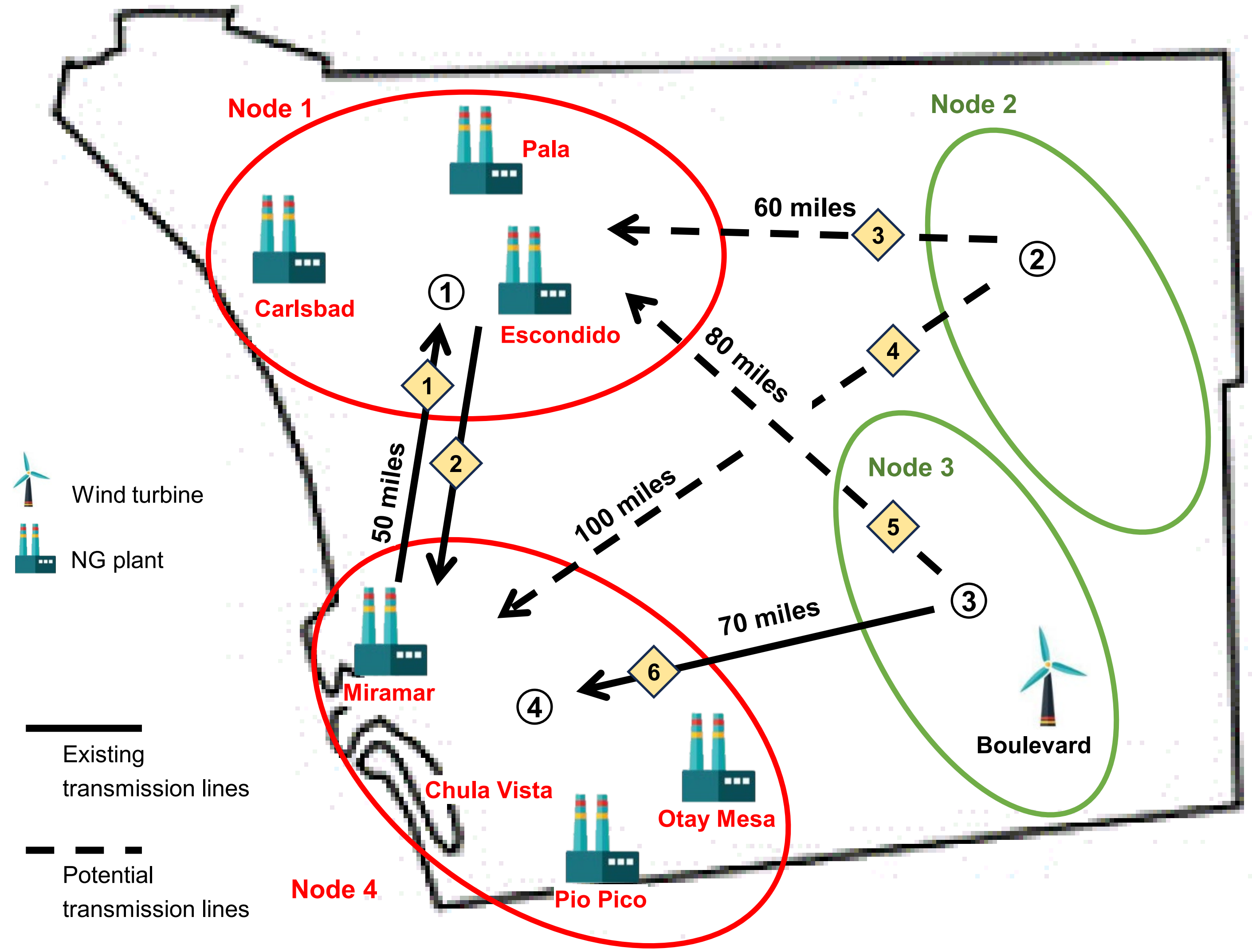
[4] Figure: https://cecgis-caenergy.opendata.arcgis.com/documents/CAEnergy::california-electric-generation-and-transmission-system-part-2-of-2, modified 2021-12-14

Case Study: Representation of San Diego County



Latitude/Longitude
① 32.210880 / -117.190754 ② 33.232716 / -116.320088
③ 32.702726 / -116.270649 ④ 32.590562 / -116.802113

- ✓ Horizon: **10-year planning**
- ✓ 3 representative days and 24 hours for each day
- ✓ Size: **4 nodes**
  - ◯ Demand and supply nodes
  - ◯ Supply-only nodes

Assumptions

- ✓ Generator types: NG (Simple cycle), NGCC (w/o CCS), NGCC (w/ CCS), Wind turbine, PV, and Li-ion battery.
- ✓ **Supply-only nodes (green circle)** can only install **renewable generator** and **batteries.**
- ✓ **Dispatchable generators in demand and supply nodes (red circle)** can be extended, dispatchable generators (w/ and w/o CCS) can be installed, and renewable generators can be installed.
- ✓ Distance between nodes is estimated by measuring the distance between centers of each node.

Technology data (investment and operating costs, size, emission rate) is obtained from NETL and NREL, IRENA report.

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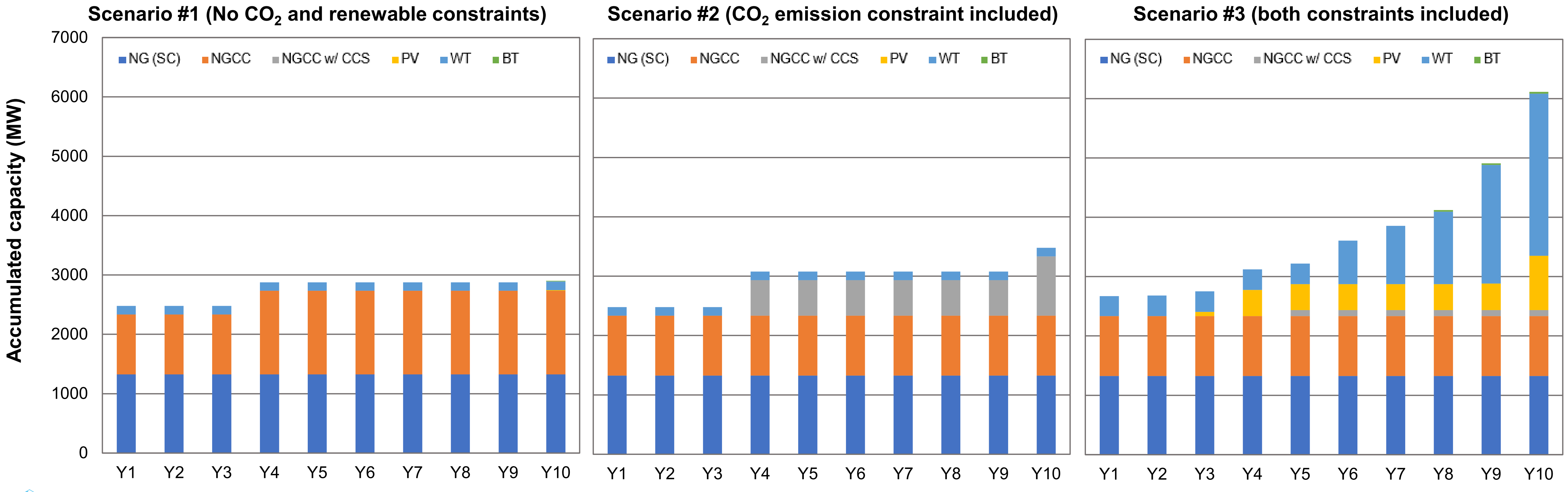
CEC Case Study: Reliable and Carbon-neutral Power Systems

California Policy and Regulatory Environment[6,7]	Scenario #1	Scenario #2	Scenario #3
CO_2 emission limits (30% reduction by Y10)	X	O	O
Renewable generation (60% of the total generation by Y10)	X	X	O

** All scenarios are forced to satisfy the target reliability level.*



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[5] California Peaker Power Plants: Energy Storage Replacement Opportunities, PSE Healthy Energy, 2020
[6] Greenhouse Gas Emission Tracking Report December 2021, California ISO, 2021

Future Work

- Continue collaboration with the California Energy Commission
  - Examining impacts of different methods of representing energy storage in expansion planning models, specifically in how it impacts reliability
  - Improve algorithms to increase tractability in solving more complex problems (spatially and temporally) while considering reliability

- Advancing capabilities in Expansion Planning Models
  - Improving integration with EGRET, generate plausible future detailed grids for validation
  - Enhance technology selection, centralized around determining least-cost paths to decarbonization (CDR technologies, renewables, point-source CCS)

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