

*Visions for integrated planning across
Generation-Transmission-Distribution-Customer:
Integration across T&D scales*

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National Renewable Energy Laboratory*

*ESIG Virtual Workshop on System Expansion Modeling
Nov. 18, 2024*

Silos of Excellence

Least cost generation, RA

Generation
(Resources)

Stability, congestion,
interconnection

Transmission
(Bulk Grid)

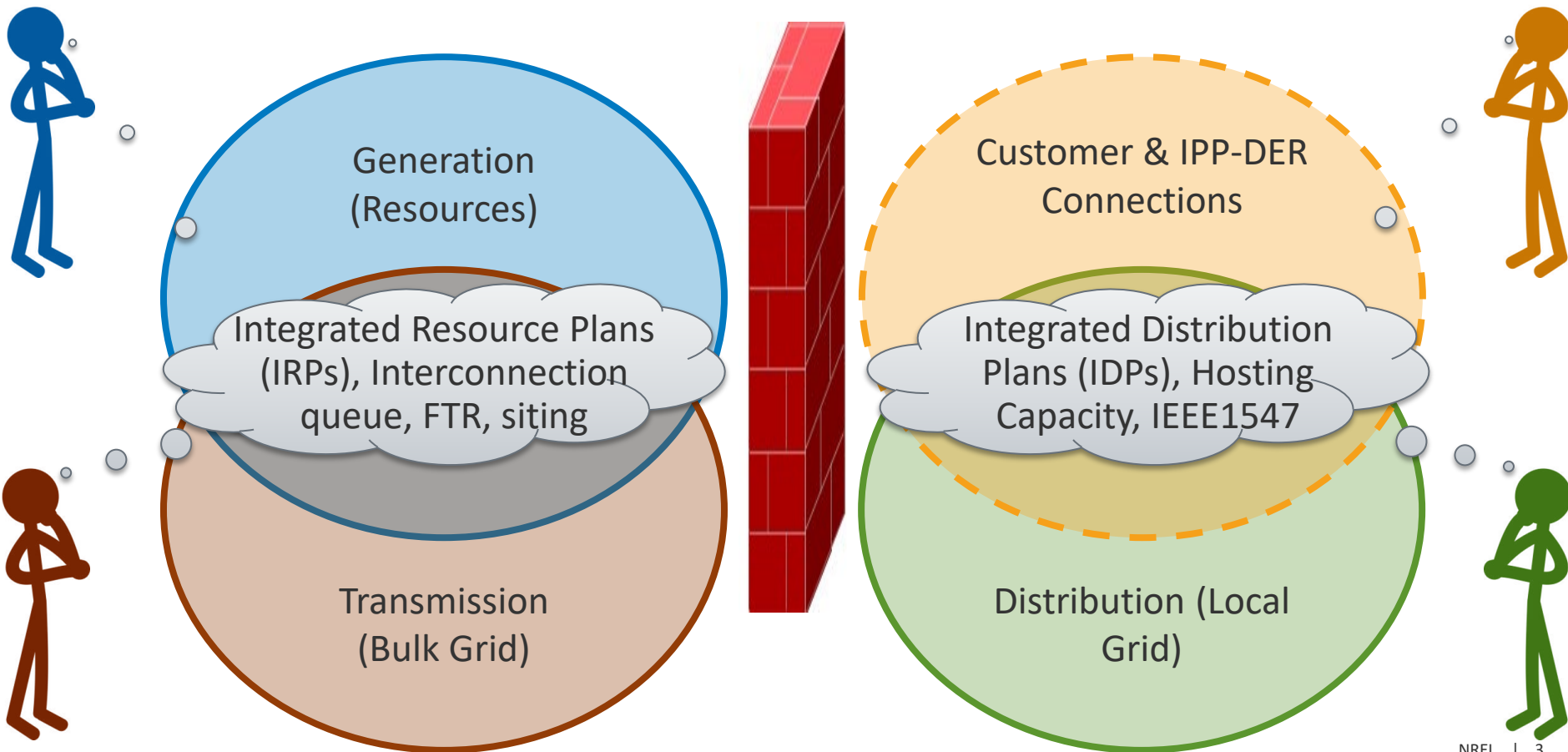
Minimize my bill, DER
interconnect?, 24/7, CCA

Customer & IPP-DER
Connections

Circuit/sub. capacity, Voltage,
reliability, rate of return

Distribution
(Local Grid)

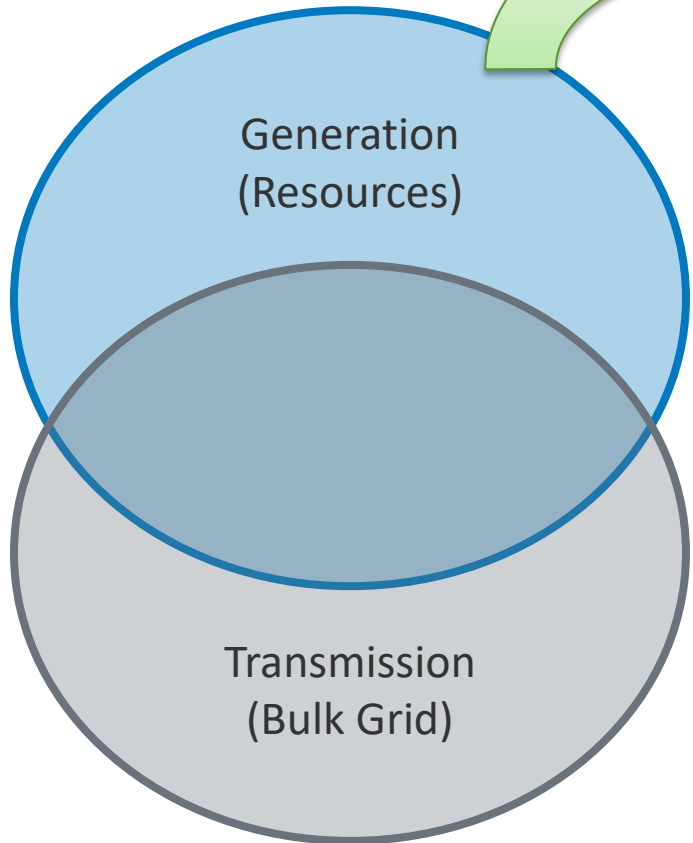
(Partial) Integration and the T-D wall



Partial bridges



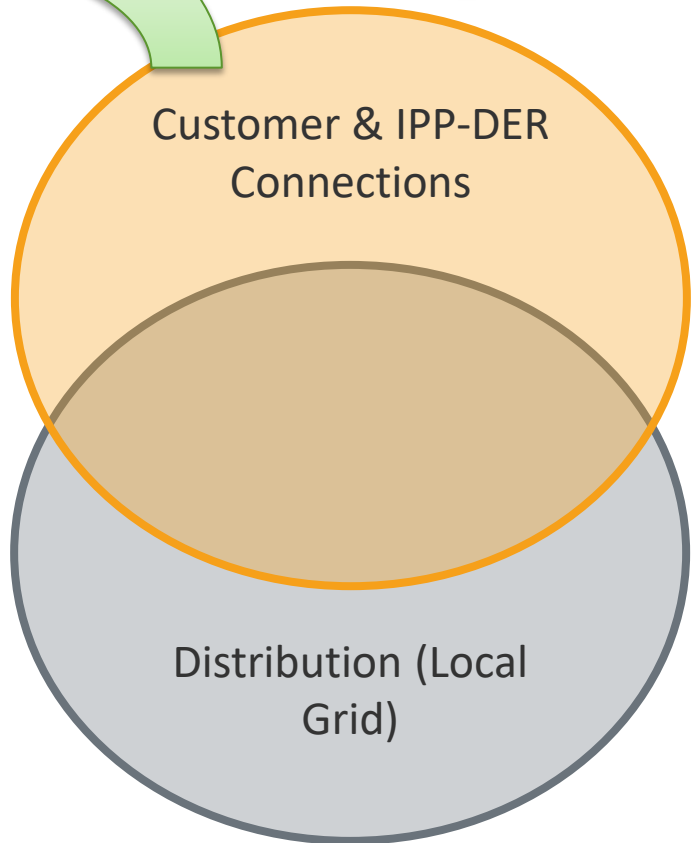
How can I include DERs?



DR? DERs in IRPs?



You gonna pay me for that?



G-T-D-C Planning

What services can DERs provide? Adequacy?

What are other value streams for my resources?

Generation (Resources)

Customer & IPP-DER Connections

By working together across G-T-D-C we can accelerate the grid transition, at lower costs and with enhanced customer reliability

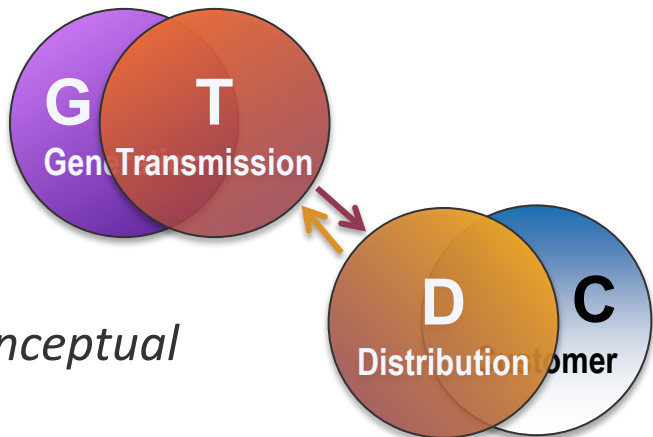
Transmission (Bulk Grid)

Distribution (Local Grid)

Can distribution help expansion needs? Stably?

Can controls/DERs offset distribution upgrade needs?

Modeling T&D (scales) together



 *Conceptual*

Distribution

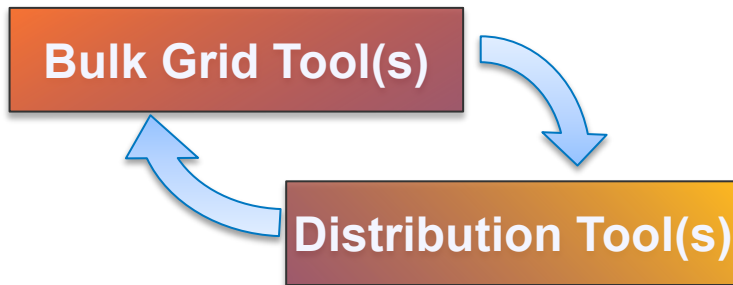


Bulk Grid

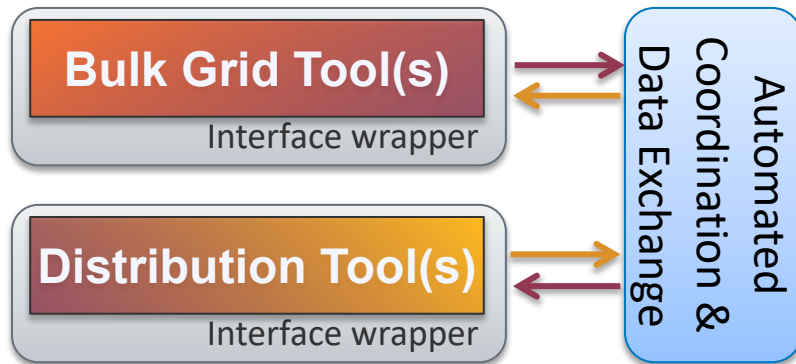
1 *Once-through workflow*

D
Bulk Grid

2 *Co-model (mini-D)*



3 *Iteration (semi-manual)*



4 *Co-optimize, Co-simulate*



The Los Angeles 100% Renewable Energy Study

More at <https://maps.nrel.gov/la100>

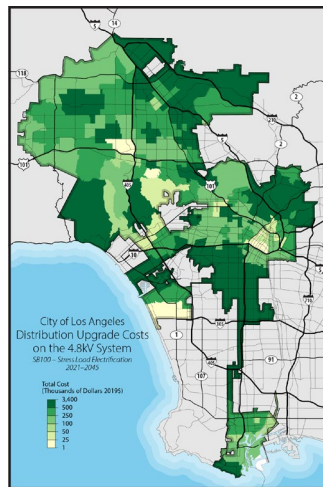
The most **comprehensive** study ever done

to model a grid as **complex** as LA's

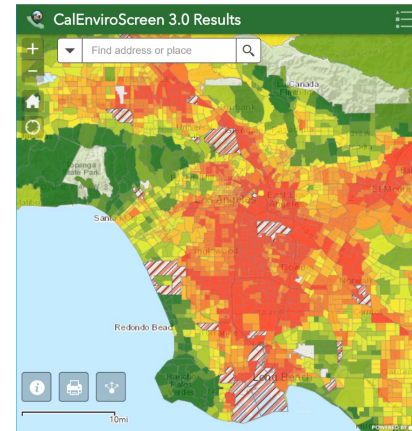
LA100: A deep dive on many fronts



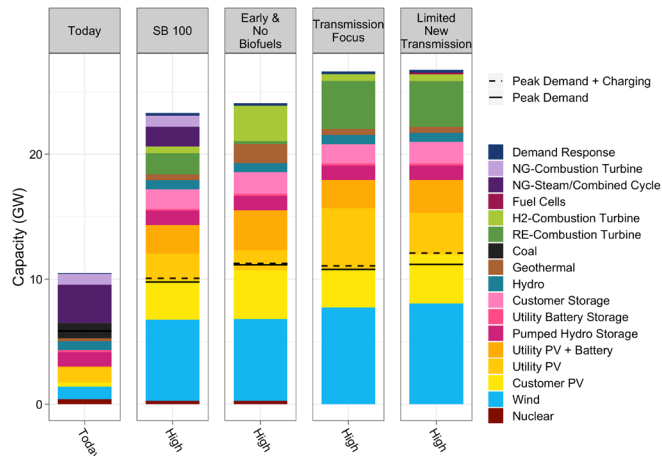
Granular Building, EV, load & DER Models



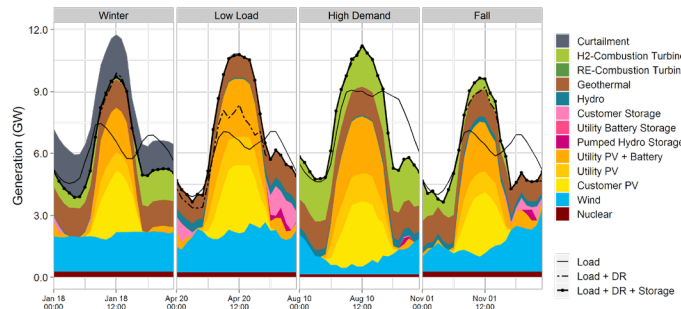
High-resolution Distribution Upgrades



Air quality, Jobs, & more



Multi-scenario Bulk Capacity Expansion



Detailed production cost

Over 100 million simulations

High-level Results Across All Scenarios



Electrification
Efficiency
Flexible Load



Customer
Rooftop Solar



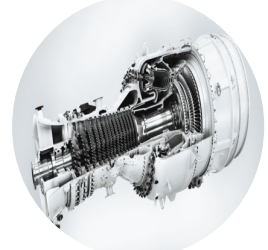
Renewable
Energy



Storage
(including coupled
with solar)
+ >2,700 MW



Distribution,
Transmission



Renewably Fueled
Combustion
Turbines
+>2,600 MW
(in basin)

Much More

New

Natural gas



Biofuel/ hydrogen

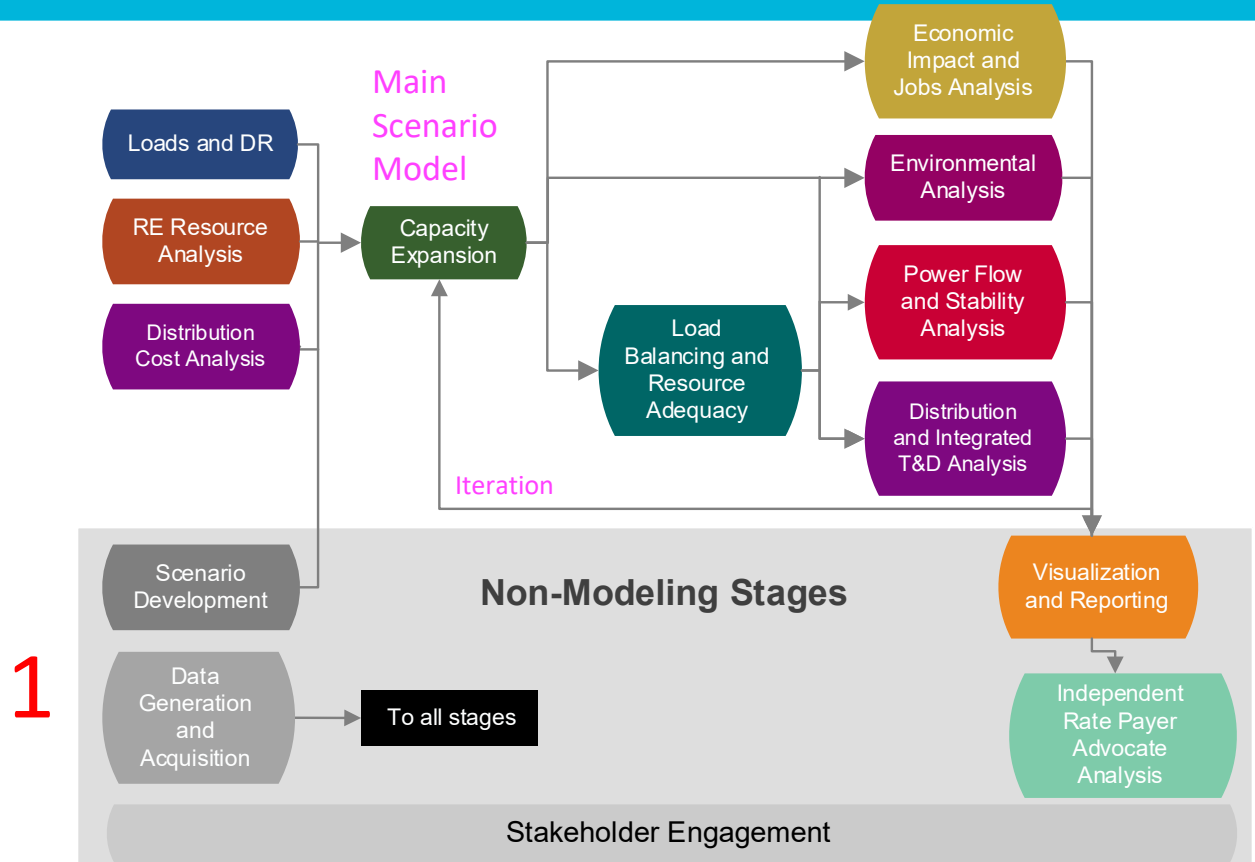
Today:
Daily

Future:
Infrequently

(Lots) more results at <https://maps.nrel.gov/la100>

Steps of the LA 100% Renewable Energy Study

1. Data collection and scenario development

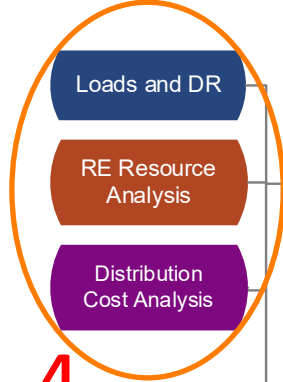


Steps of the LA 100% Renewable Energy Study



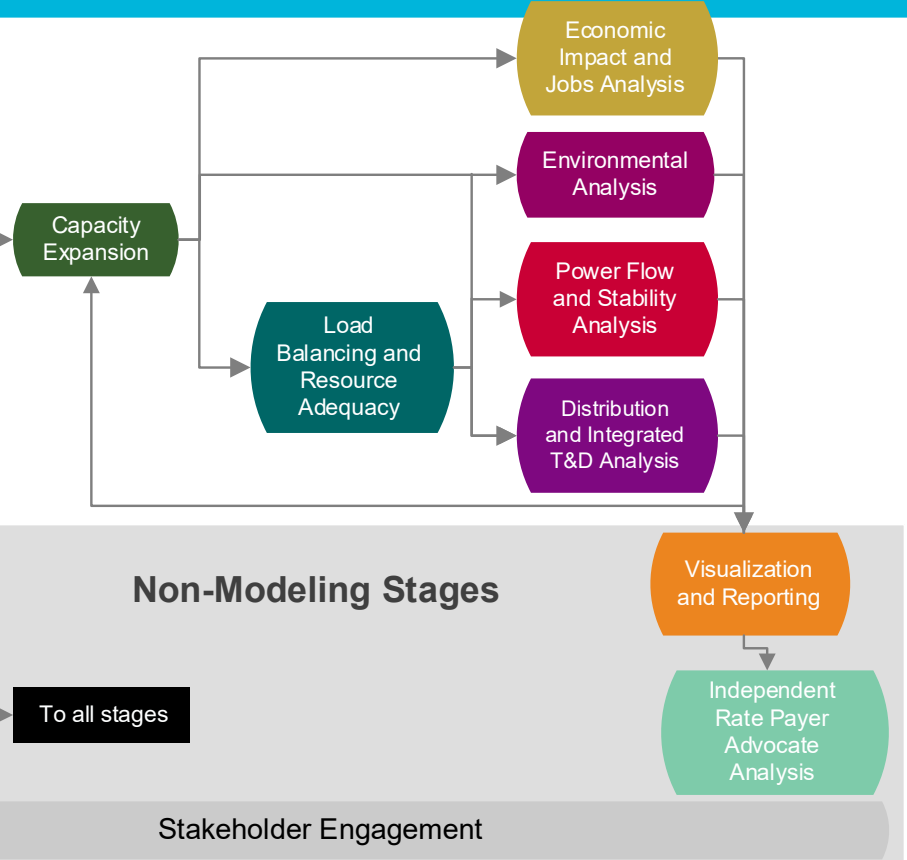
2. Estimate load growth and demand profiles
3. Determine renewable resource availability and generation profiles
4. Estimate distribution system hosting capacity and upgrade costs

Input Models



2-4

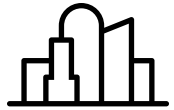
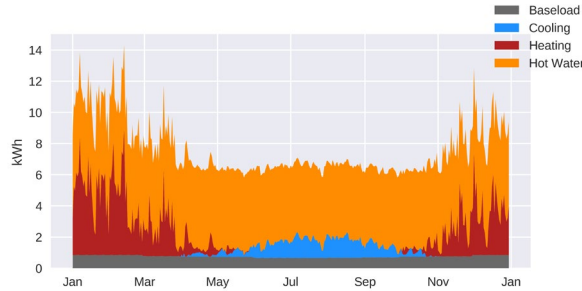
1



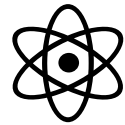
Step 2: (Lots of) Load modeling



Buildings



Building stock characteristics database

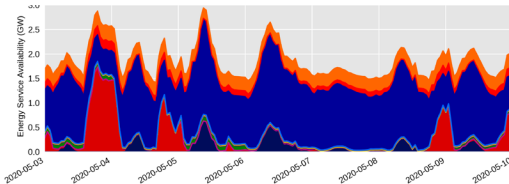


Physics-based computer modeling



High-performance computing

Demand Flexibility



Transportation

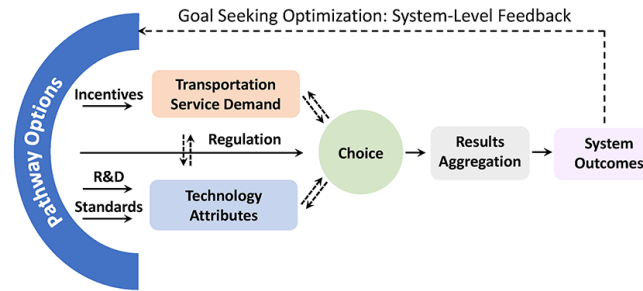
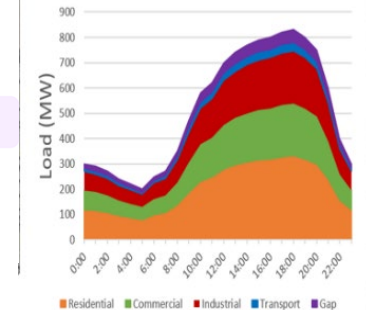


Industrial:

- Key individual facilities
- AMI data
- Water loads

Other/Gap loads:

- Match Data



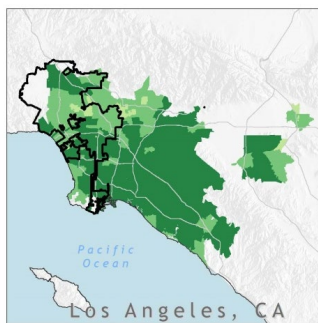
Step 2: Distributed Technology Diffusion (dGen)



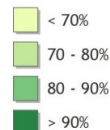
Capacity Expansion does not estimate (BTM) DG adoption.
A separate model (dGen) is used.



- Representative agent based, demographics and (multi-sample) parcel data matching
- Forecasts customer adoption of distributed generation technologies (solar, storage, wind, geothermal) for residential, commercial, and industrial entities, given assumptions about future electricity costs, technology cost and performance, policy and regulation, and customer behavior
- High geographic resolution enables state, utility, or city-specific analysis with overlay of multiple spatial layers

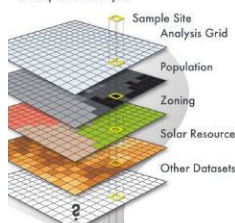


Percent of small buildings that are suitable



City Boundary

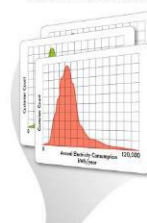
Geospatial Analysis



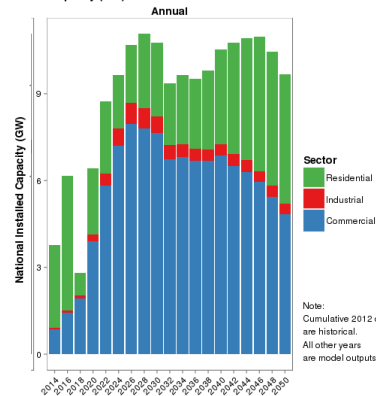
Results

Agent Profile	
1	Sample No. 100
2	Sample No. 200
3	Sample No. 300
4	Sample No. 400
5	Sample No. 500
6	Sample No. 600
7	Sample No. 700
8	Sample No. 800
9	Sample No. 900
10	Sample No. 1000

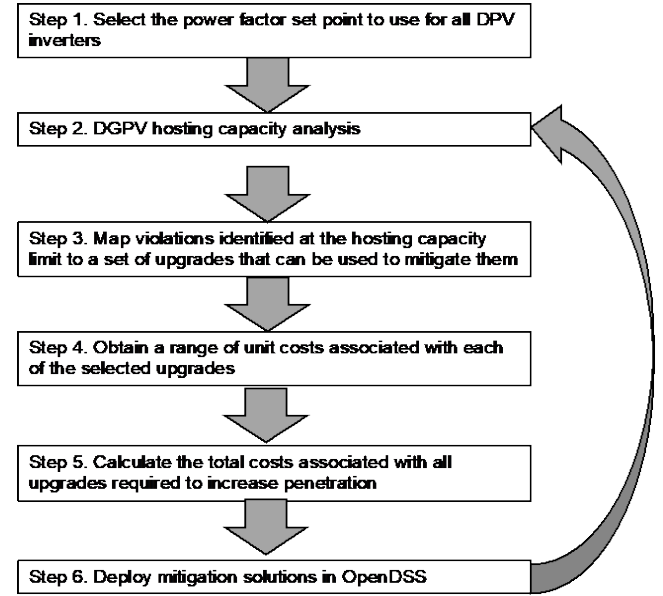
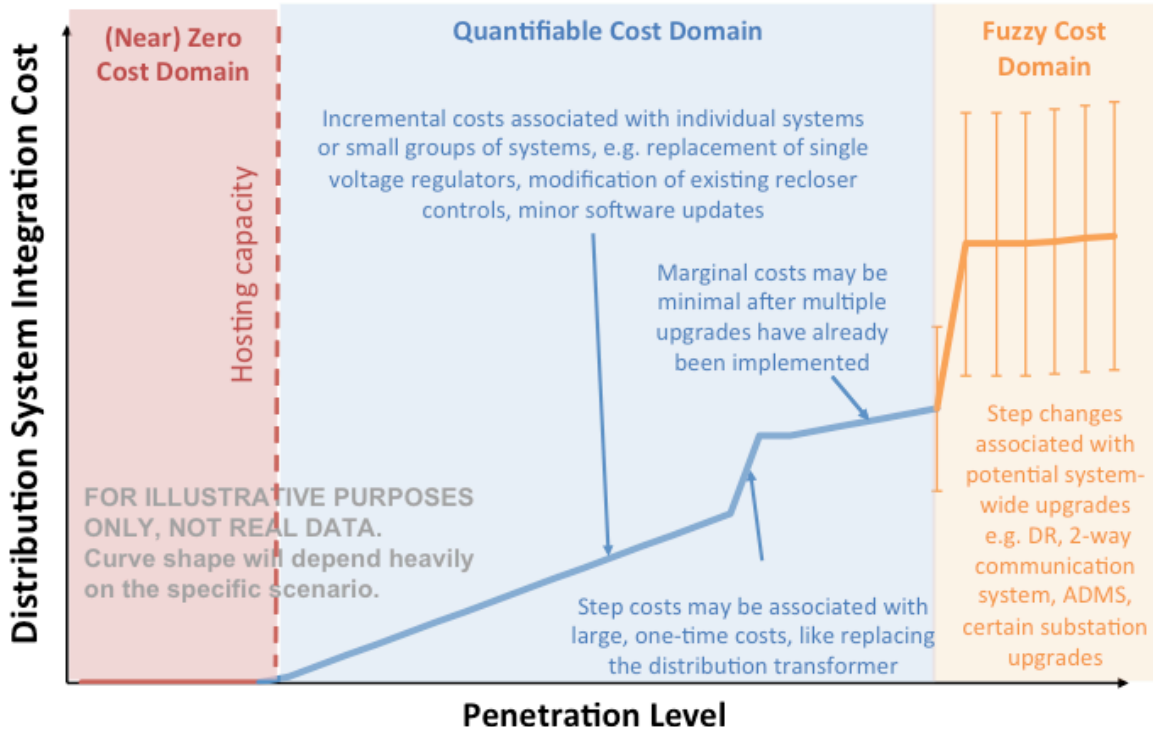
National Data Trends



led Capacity (GW)



Step 4 – Distribution System Cost Analysis

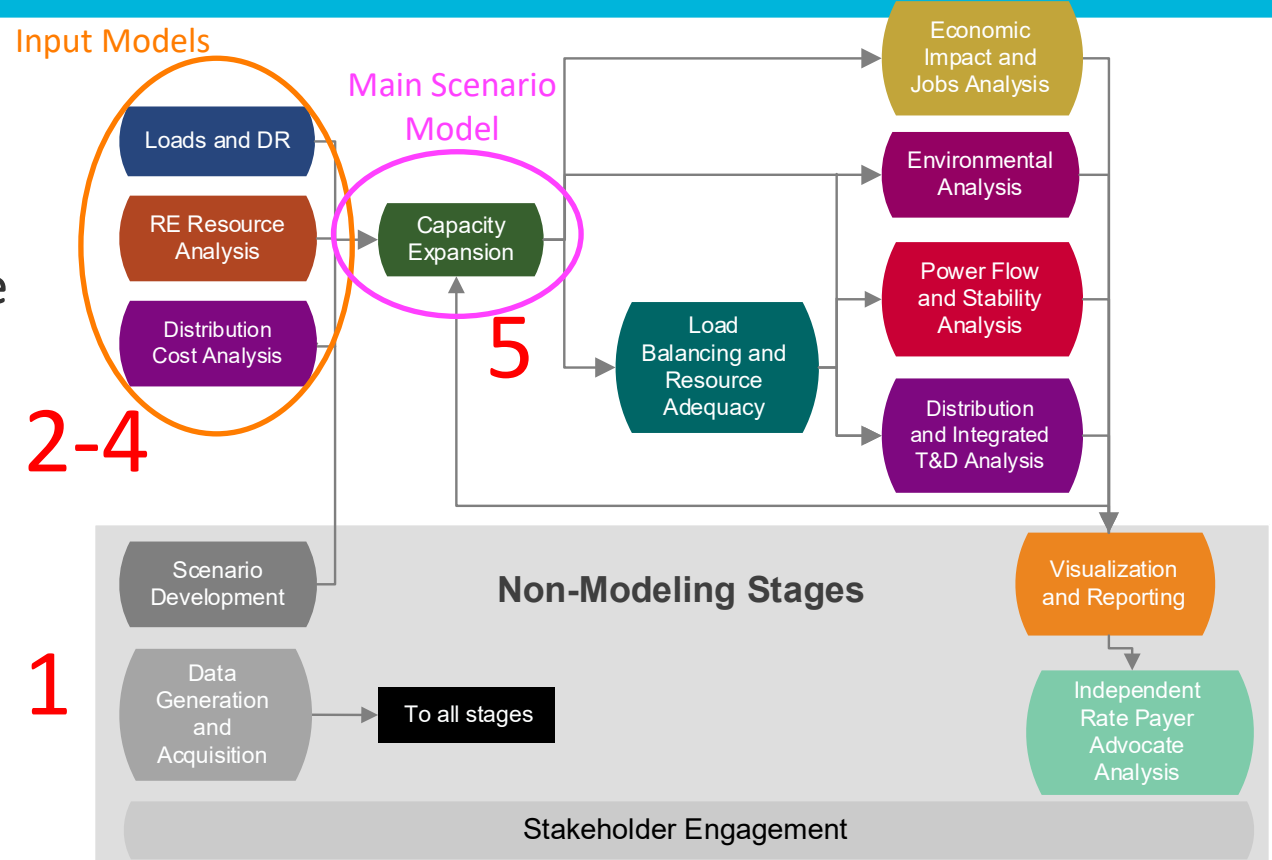


Distribution grid Integration Solution Cost

Steps of the LA 100% Renewable Energy Study

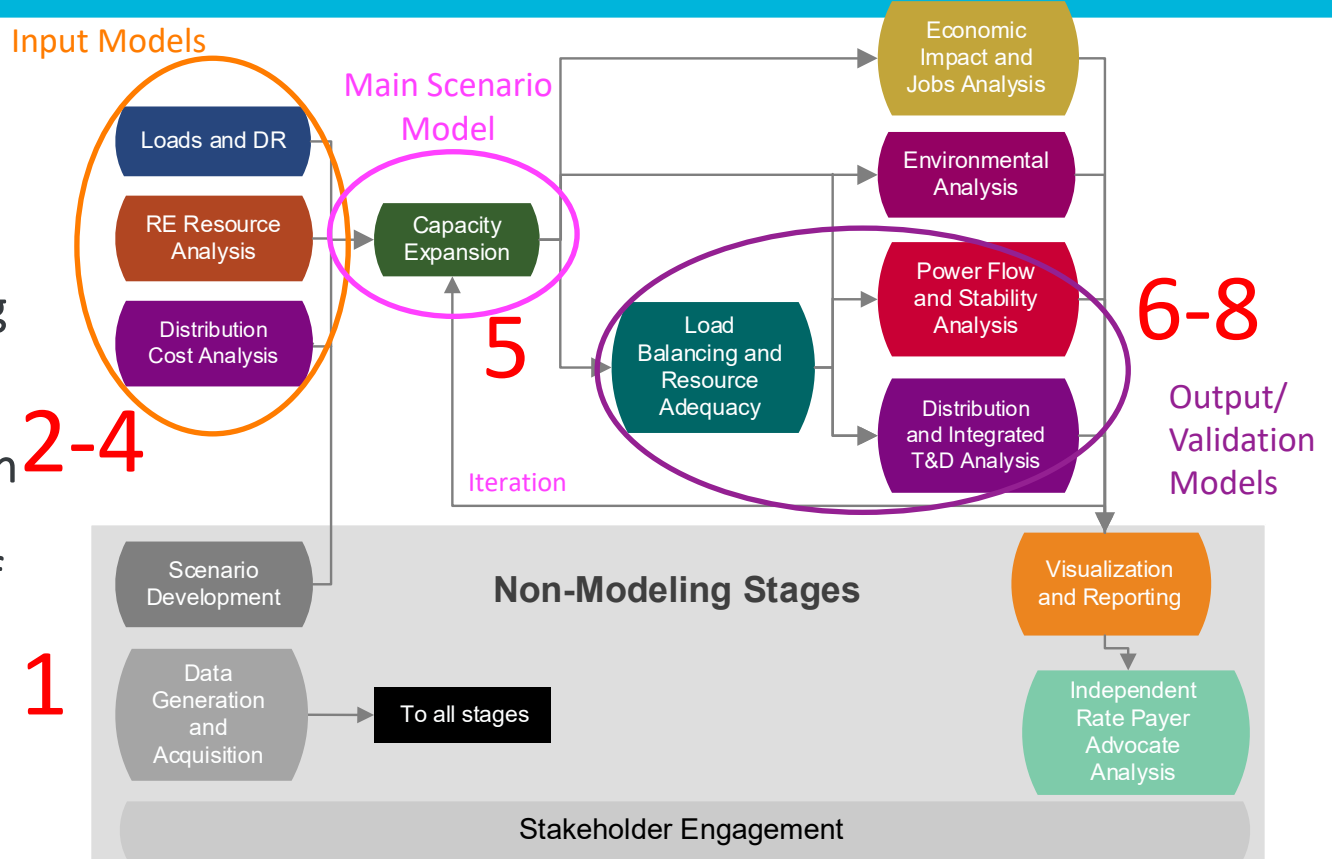


5. Develop optimal expansion plan and distributed resource adoption scenario

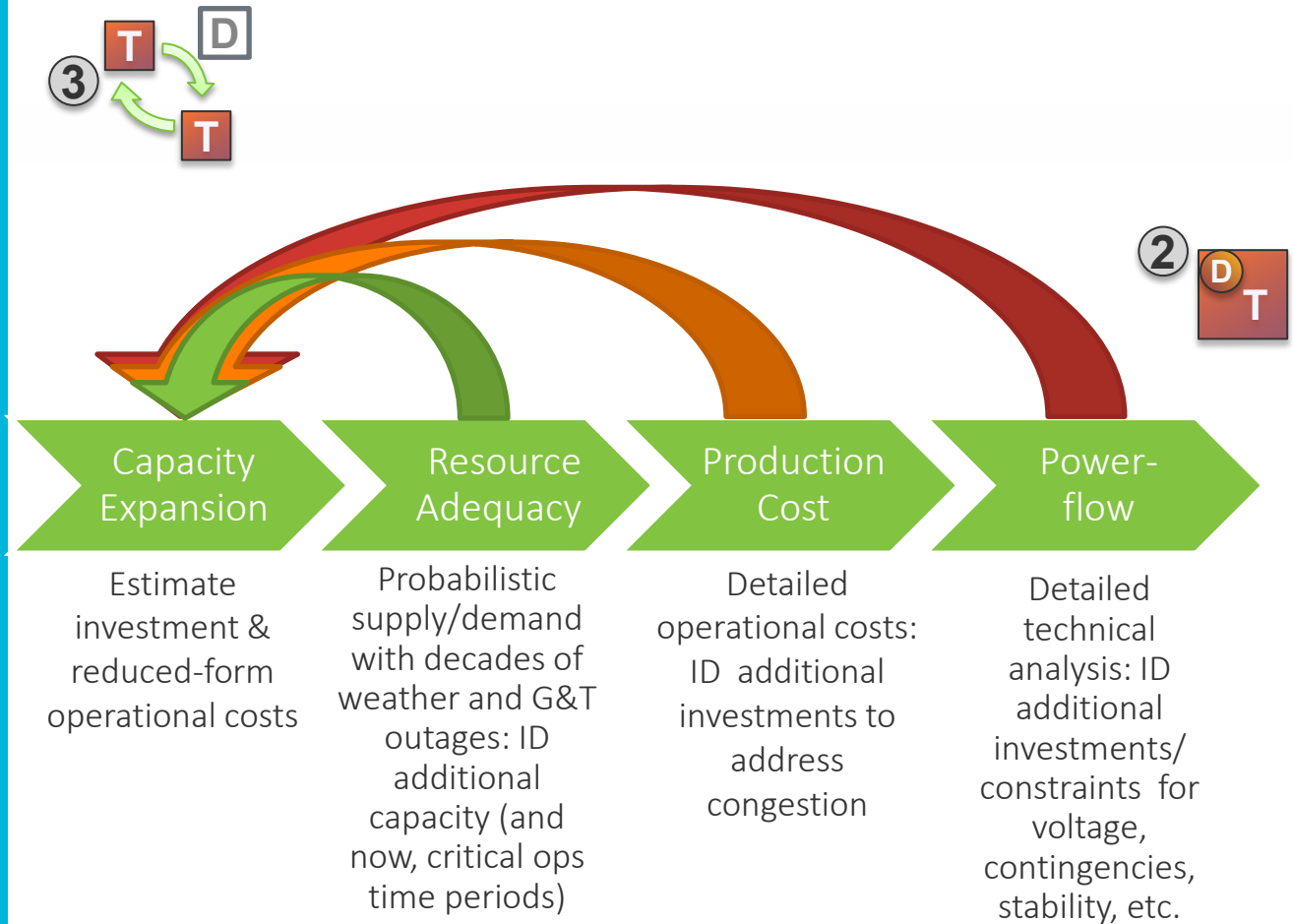


Steps of the LA 100% Renewable Energy Study

6. Simulate grid operations and performance including load balancing, operating reserves, and resource adequacy
7. Evaluate transmission system reliability
8. Validate operation of integrated transmission and distribution system

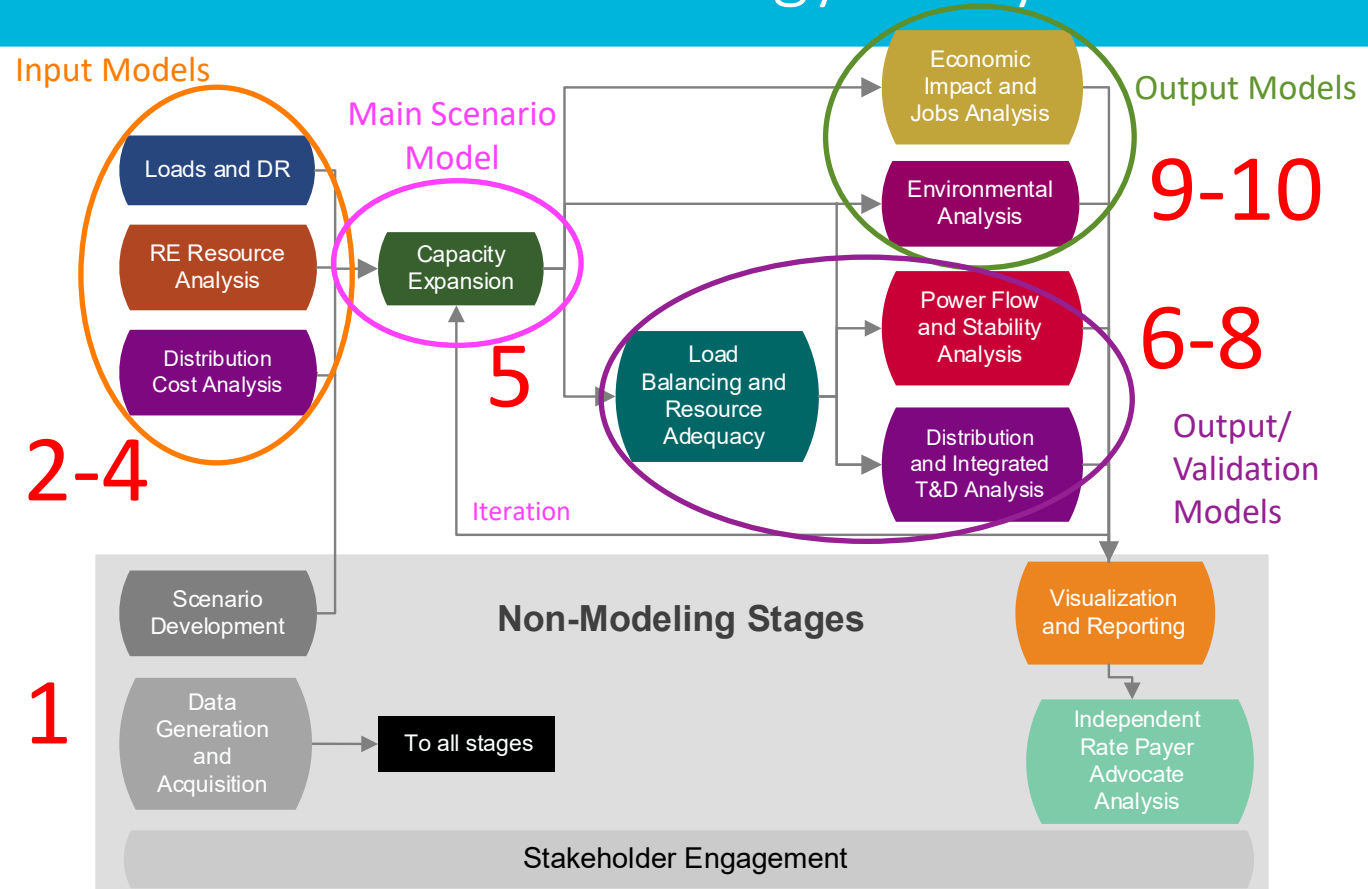


General Bulk Analysis Approach: Estimate, Then Refine



Steps of the LA 100% Renewable Energy Study

- 9. Evaluate environmental benefits and impacts
- 10. Evaluate local job and economic development impacts



Controls



Demand

and

by Demand Projection

Resolution

ers

Layer Specific Settings

ion to view

period

mer)

Delivery Losses

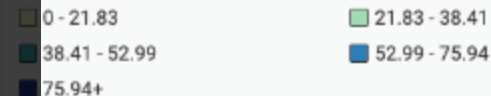
2045

2030 2035 2040 2045



Data Legend

Peak Demand (MW) at Load Centers



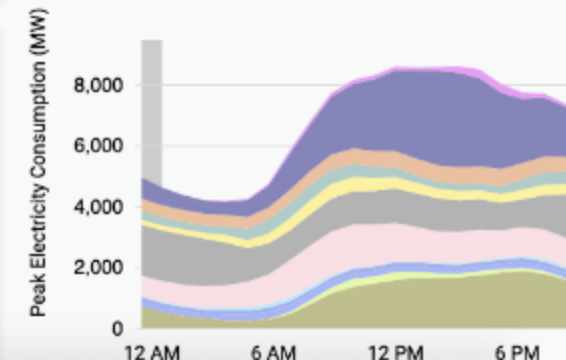
Peak Demand (MW) by Sector



Peak Demand by End Use

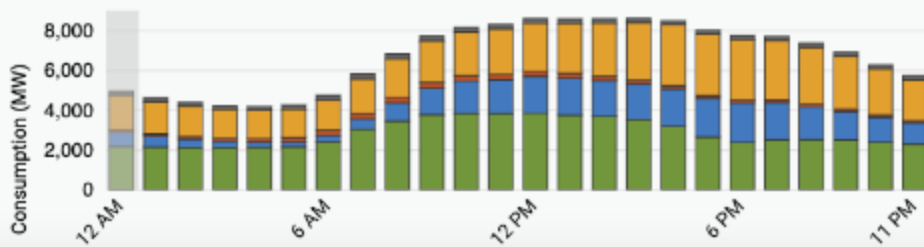


Peak Demand by End Use - Friday, 8/11/2045



Dive into the full LA100 and LA100-Equity Strategies findings at <https://maps.nrel.gov/la100>

Peak Demand (MW) by Sector - Friday, 8/11/2045



Selected additional Integrated Planning Highlights

National Transmission Planning Study

Better understand the role, value, and opportunities for transmission across the U.S.

Identify **interregional and national strategies** to accelerate cost-effective **decarbonization** while maintaining system reliability

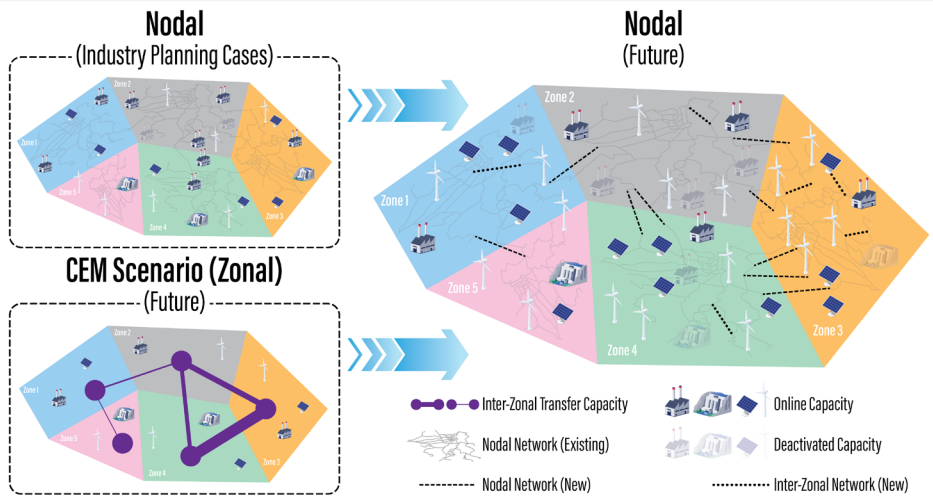
Inform regional and interregional transmission planning processes, particularly by **engaging stakeholders** in dialogue

Develop **methods for national-scale transmission planning** that are applicable for industry

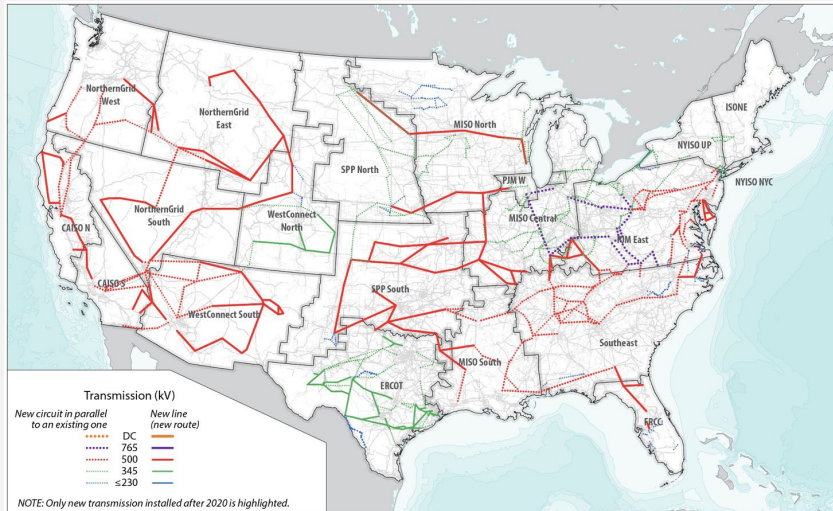
<https://www.energy.gov/gdo/national-transmission-planning-study>



Process for zonal-to-nodal translation



Nodal transmission expansion for the AC scenario for the model year 2035



Zonal to nodal translations of future transmission portfolios allows detailed operational analysis

Emerging Distribution Capacity Planning Tool: CADET

Advancing Integrated Distribution Planning

Partners: Duquesne Light Company, PEPCO Holdings, Xcel Energy, PGE, Hawaiian Electric



DER Allocation Planning Horizon

Disaggregated Growth + Existing Peak Load

Feeder/Substation Projected Peak Load by Year

Feeder ID	Year 1	Year 2	Year 3	Year 4
Substation A	10	20	30	40
Substation B	20	30	40	50
Substation C	30	40	50	60
Substation D	40	50	60	70
Substation E	50	60	70	80
Substation F	60	70	80	90

Existing Peak Load

Feeder / Substation Peak Load + New Service Requests

SCADA Data / Past Performance

Scenarios

OBJECTIVES & METRICS

- ✓ N-1 Reliability
- ✓ Capital Expense
- ✓ Budget Constraints

KEY CHARACTERISTICS

- Historical Load & DER Trends Drive Future Forecasts
- Deterministic Model
- Single / Limited Scenarios
- Manual Spreadsheet Process

Deterministic approach

KEY BENEFITS

- Probabilistic / Scenario Planning
- Cost-Allocation / Cost-Causation
- Captures Uncertainty
- Stakeholder Engagement
- Alignment with Long-Term Policy Goals

Probabilistic approach

OBJECTIVES & METRICS

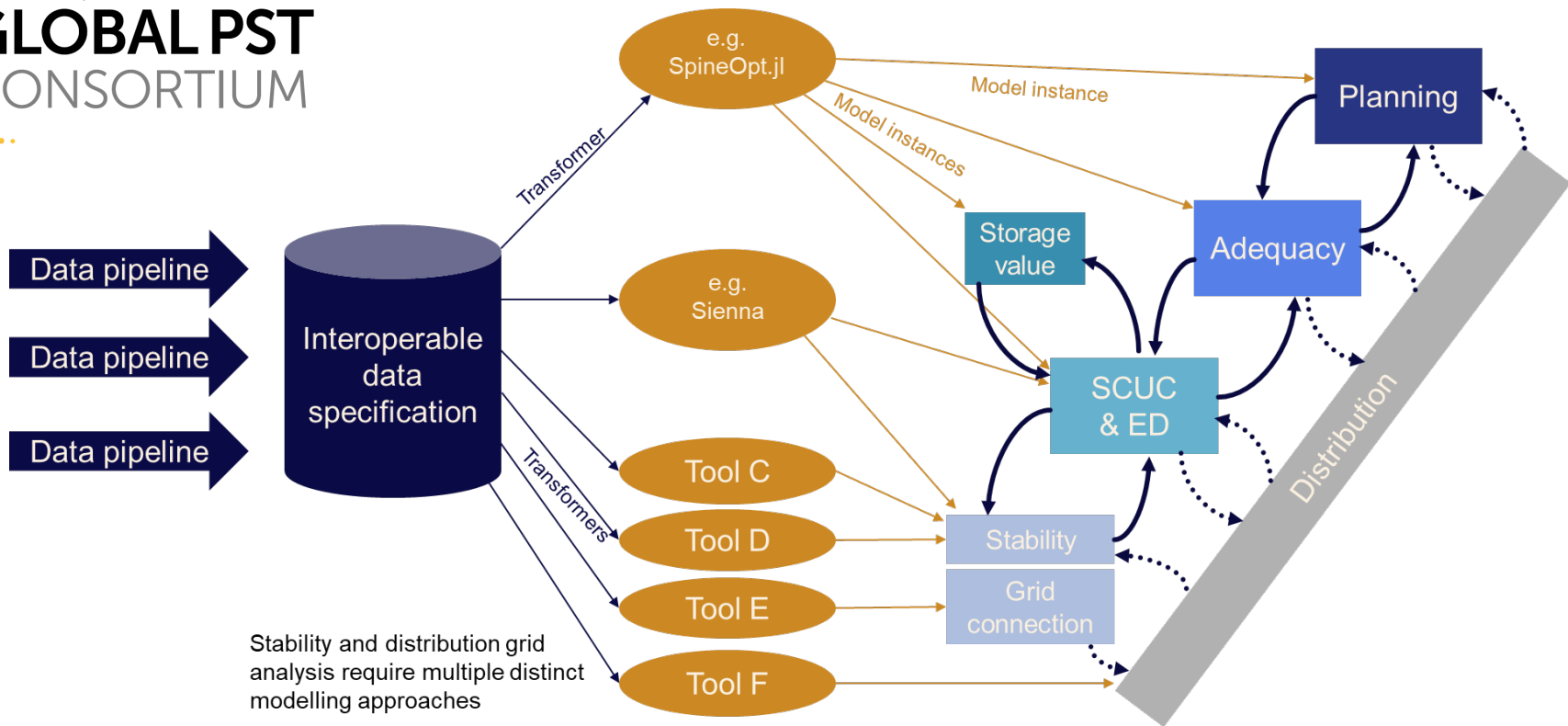
- ✓ N-1 Reliability
- ✓ Capital Expense
- ✓ Avoided Costs
- Resilience
- Equity
- Energy Efficiency
- Carbon Emissions



Objectives

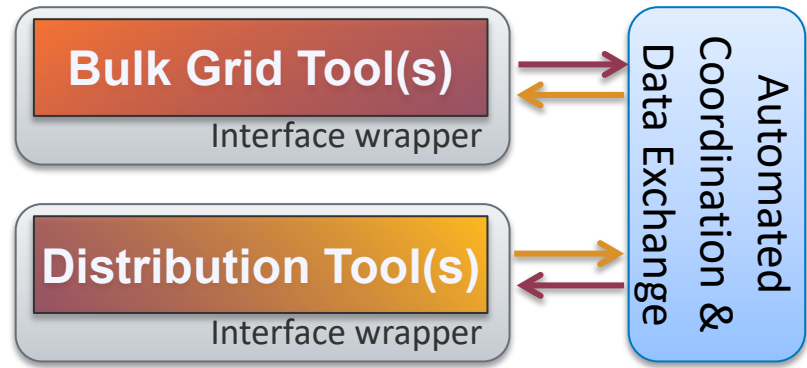
J. Keen *et al.*, "Distribution Capacity Expansion Planning: Current Practice, Opportunities, and Decision Support," National Renewable Energy Laboratory (NREL), Golden, CO (United States), NREL/TP-6A40-83892, Nov. 2022. <https://www.nrel.gov/docs/fy23osti/83892.pdf>.

Interoperable Data can enable expanded integrated planning workflows



Multi-model Frameworks

“But wait, didn’t you forget one of your T&D linkage types...”



④ *Co-optimize, Co-simulate*

PIPES

Pipeline for Integrated Projects in Energy Systems

Distribution

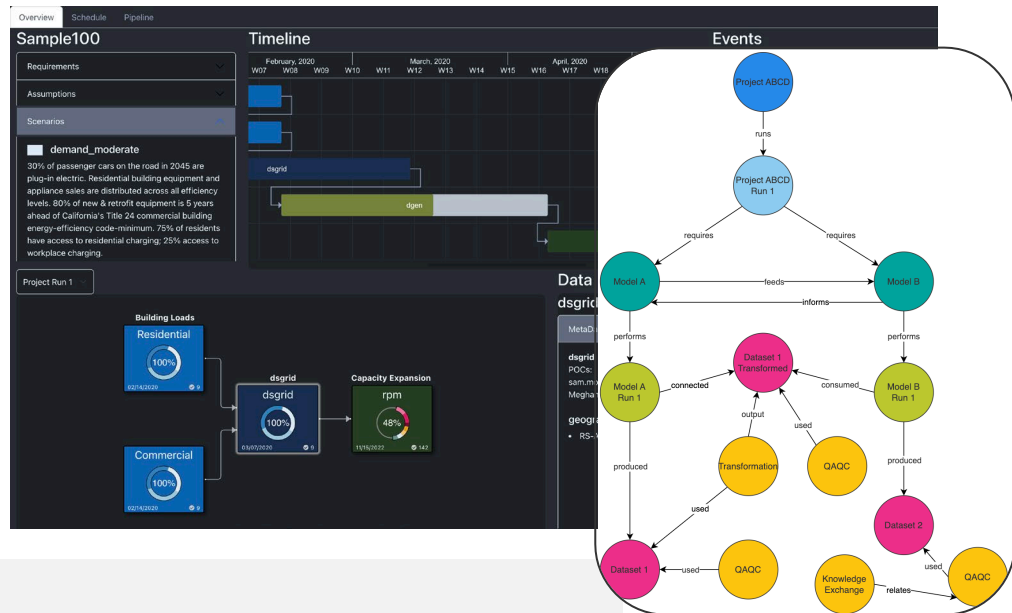
Bulk Grid

1 (Complex) Workflows

A new high-impact tool for scaling NREL analysis projects

[PIPES Documentation](#)

[PIPES UI](#)



PIPES is project management + data management + workflow management for integrated modeling teams

Tested in PR100 and DECARB

Backend: Graph Database and PIPES API

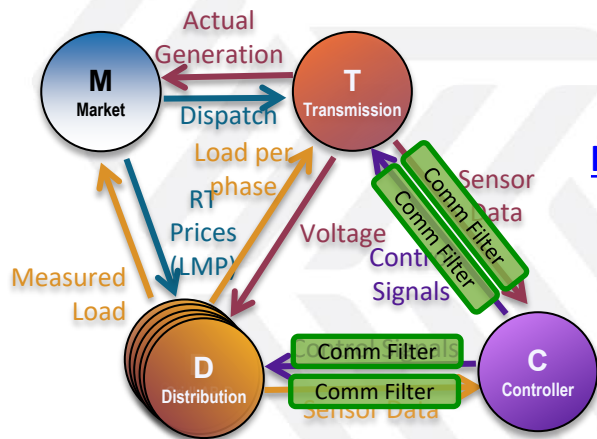
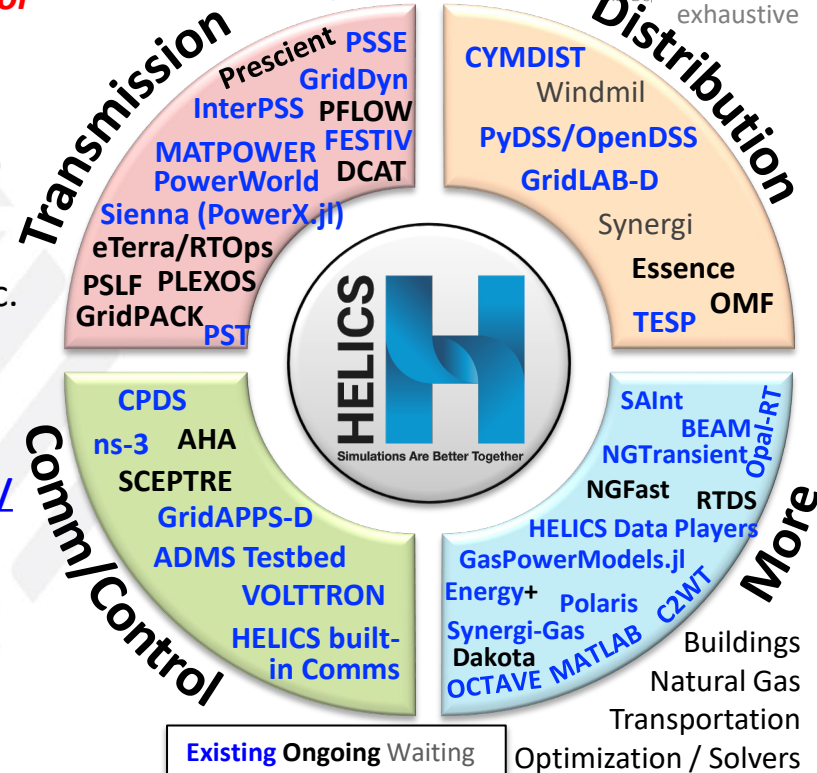
Front End: Web User Interface and Command Line Interface

HELICS™: Hierarchical Engine for Large-scale Infrastructure Co-Simulation



High-performance co-simulation to combine best-in-class tools for breakthrough integrated energy analysis

- **Scalable:** 2-10,000,000+ Federates, **Open Source:** BSD 3-clause
- **Unique Features:**
 - Physical Data (Values) vs. Market/Controller Data (Messages)
 - Multiple “brokers” for hierarchical multi-site performance
- **Cross-platform:** HPC (Linux), Cloud, Windows, OSX
- **Modular:** mix and match tools. **APIs:** Python, C++, Julia, FMI, etc.

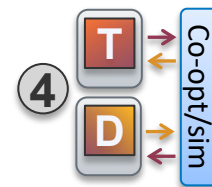


v3.5.x and details at
<https://helics.org/introduction/>
<https://github.com/GMLC-TDC/HELICS/releases>
 or via `pip install helics`

Existing Ongoing Waiting Optimization / Solvers

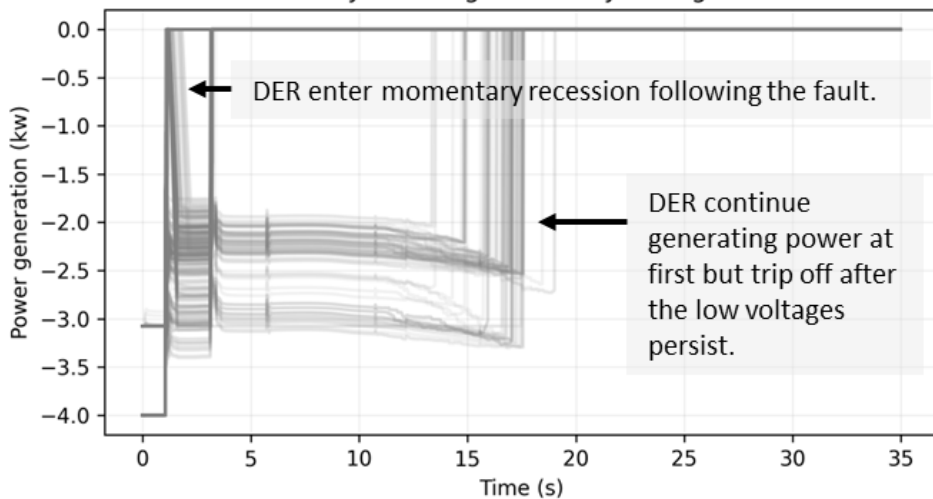
T. D. Hardy, B. Palmintier, P. L. Top, D. Krishnamurthy, and J. C. Fuller, “HELICS: A Co-Simulation Framework for Scalable Multi-Domain Modeling and Analysis,” *IEEE Access*, vol. 12, pp. 24325–24347, 2024, doi: 10.1109/ACCESS.2024.3363615.

Example T&D Co-simulation (Engineering Analysis): High DER affects transmission stability

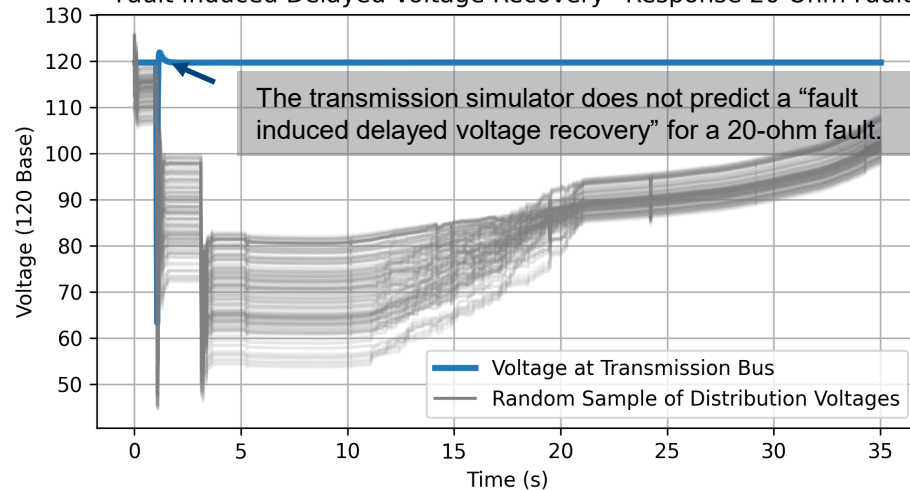


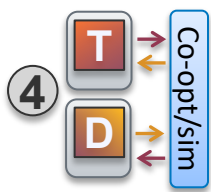
- PSS/e with multiple feeders in OpenDSS using HELICS
- Real System Data from Puerto Rico as part of PR100

Detailed Distributed Energy Resource Generator Response to “Fault Induced Delayed Voltage Recovery” using T&D Cosimulation

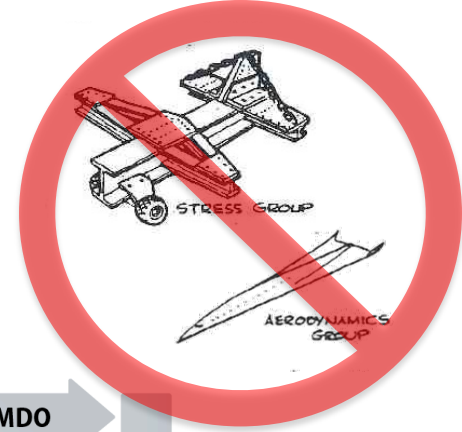


Transmission and T&D Cosimulation
“Fault Induced Delayed Voltage Recovery” Response 20 Ohm Fault





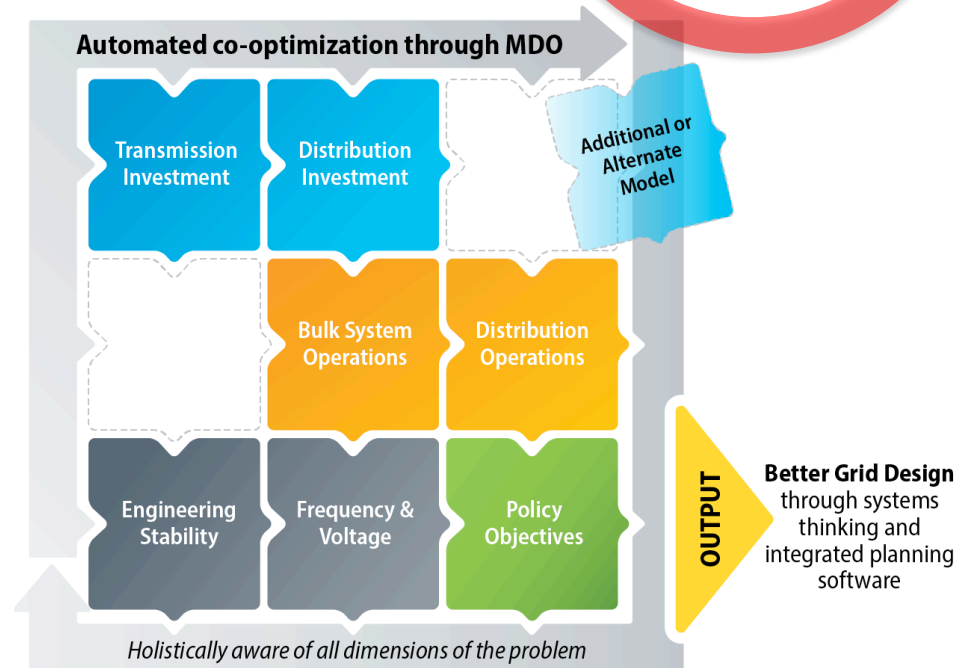
Imagine if you could integrate existing tools into a co-optimization

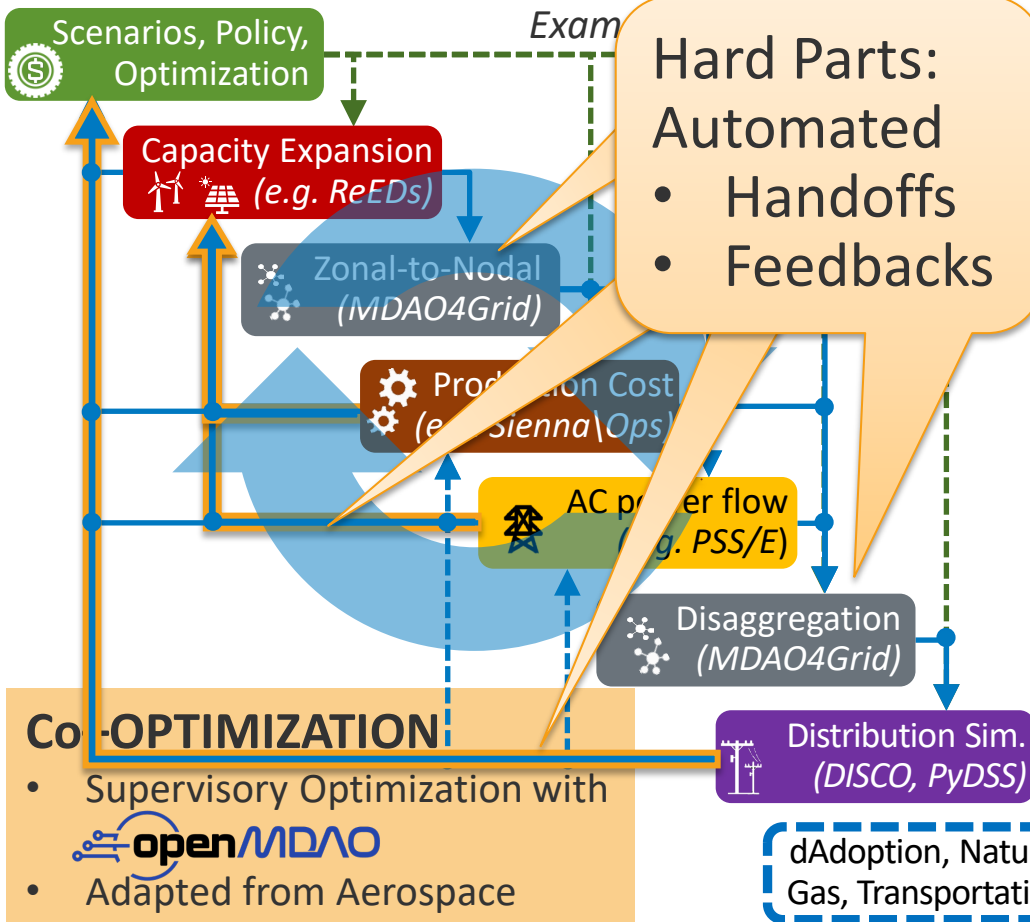


This is exactly what NREL is doing in collaboration with NYSERDA

MDO4Grid

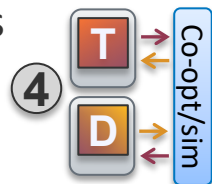
- Adapt aerospace-developed multi-disciplinary design and analysis optimization (MDO/MDAO) for the grid
 - Integration at Conceptual Design Phase
 - Automated supervisory optimization
 - Modular: mix-and-match existing trusted analysis tools
 - Technical, economic, and social considerations in one framework





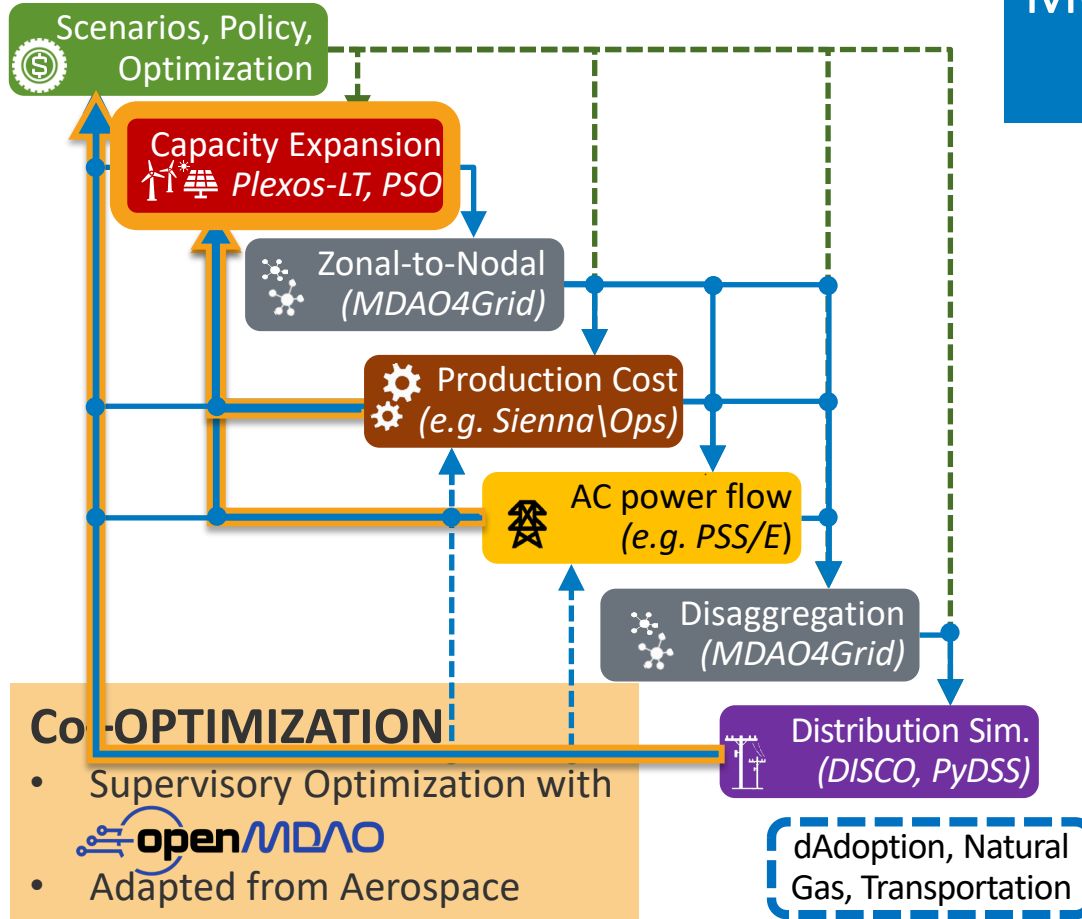
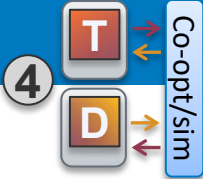
Automated conceptual design phase framework to endogenously capture multi-domain interactions and *feedbacks*

- Combine existing design tools
 - Investment, Policy
 - Operations, Markets
 - Engineering Assessments
- Reconfigure for different analyses:
 - Transmission-Distribution
 - Investment, markets, services
 - DER Adoption
 - High-IBR investment
 - Grid+X (transport, buildings, gas)
- Mix and match tools & Flow



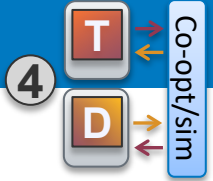
B. Palmintier, R. Henriquez-Auba, N. Panossian, P. Brown, J. D. Lara, and A. Latif, "Toward Multidisciplinary Design, Analysis, and Optimization (MDO) for Co-Designed Transmission & Distribution Electric Grid Planning," (In Review)

Modularity & Configurability



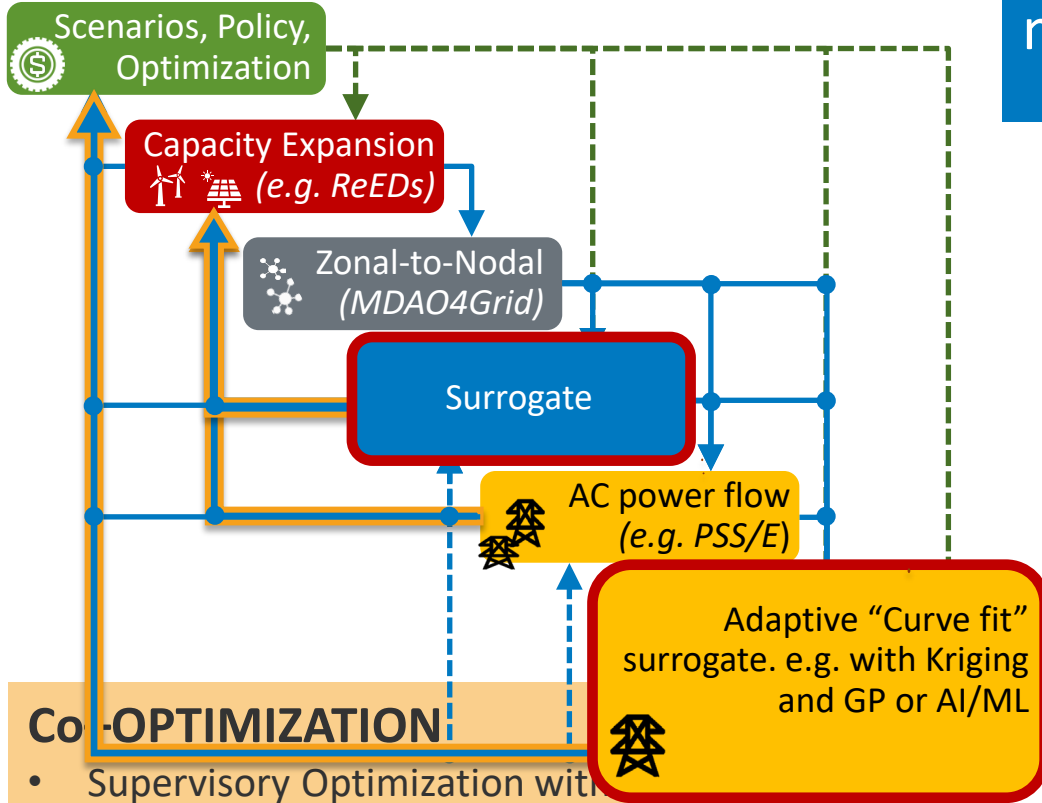
- Replace tools without changes to any others
- Restructure as needed
 - Add/subtract domains
 - Reorder
 - Change data exchange

Avoiding running complex models or blocks



Approaches:

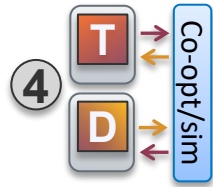
- Memoization (results cache)
- Surrogate models:
 - Nearby estimates
 - On-the-fly generation
 - AI?
- Multi-fidelity models
 - Simple, even data look up when needed
 - Full models later



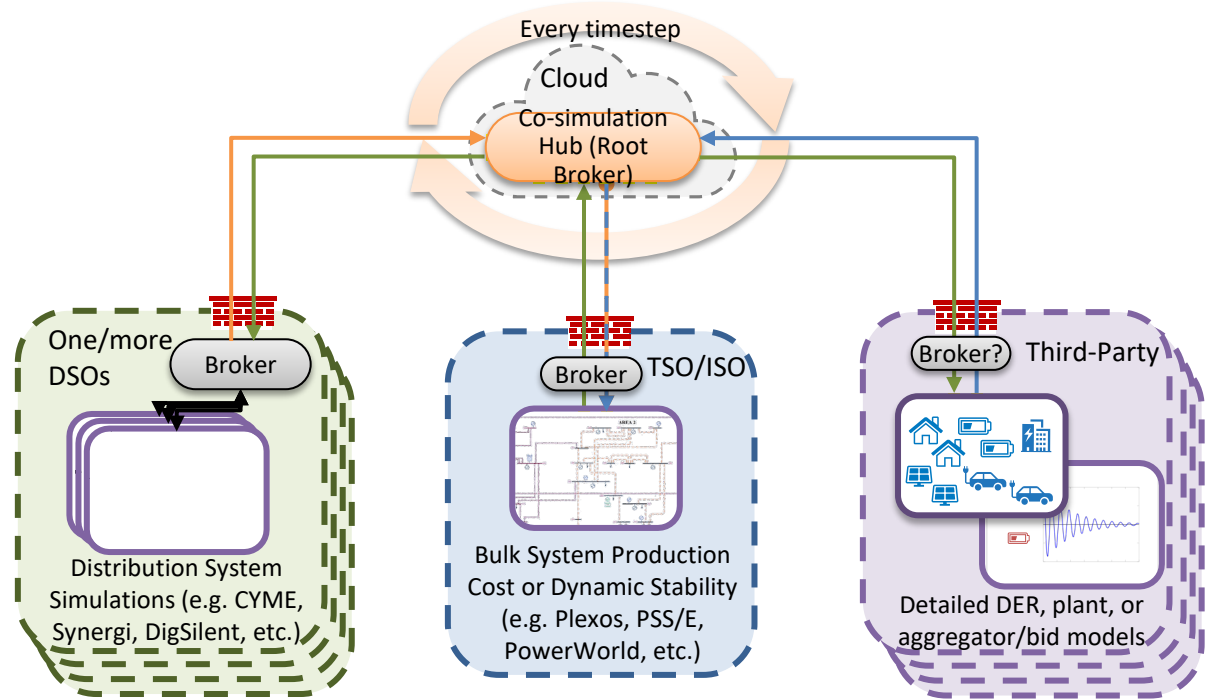
• Adapted from Aerospace



Multi-model frameworks also enable multi-organization G-T-D-C analysis without full model data exchange

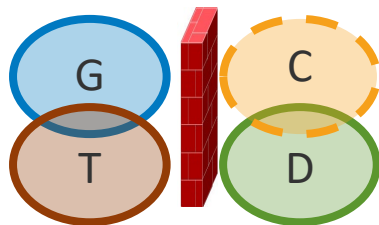


- Run a combined simulation across multiple sites/organizations
- Only exchange interface data
 - Avoid detailed/sensitive model exchange
- Example frameworks:
 - HELICS
 - MDO4Grid



Summary and Closing Thoughts

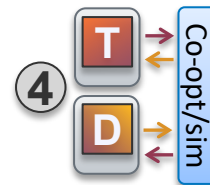
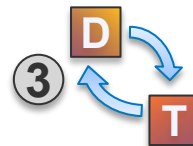
- The T&D divide requires care to overcome well



- Multiple Approaches for T&D:

- Simpler approaches may miss key interactions or perpetuate assumptions

- E.g. existing hosting capacity ignores on-going D upgrades & values
- E.g. Once-through workflows may miss value stacking



- Iteration & Co-optimization can capture more cross-value

- All of these need lots of data

- Distribution hardest, simplified (but still multi-node) models could offer a sweet spot
- Multi-model frameworks could reduce data exchange

- Other key gaps:

- Interchangeable interfaces (analog to “USB”)
- Data: mid-scale (1-10+MW) distribution/sub-transmission solar/storage

Questions? Discussion?



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