Current Modeling Capabilities and Practices for Integrated Planning

Review of Select Modeling Tools and Prominent Studies

January 2024

DISCLAIMER OF WARRANTIES AND LIMITATION OF LIABILITIES

THIS DOCUMENT WAS PREPARED BY THE ORGANIZATION(S) NAMED BELOW AS AN ACCOUNT OF WORK SPONSORED OR COSPONSORED BY THE ELECTRIC POWER RESEARCH INSTITUTE, INC. (EPRI). NEITHER EPRI, ANY MEMBER OF EPRI, ANY COSPONSOR, THE ORGANIZATION(S) BELOW, NOR ANY PERSON ACTING ON BEHALF OF ANY OF THEM:

(A) MAKES ANY WARRANTY OR REPRESENTATION WHATSOEVER, EXPRESS OR IMPLIED, (I) WITH RESPECT TO THE USE OF ANY INFORMATION, APPARATUS, METHOD, PROCESS, OR SIMILAR ITEM DISCLOSED IN THIS DOCUMENT, INCLUDING MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE, OR (II) THAT SUCH USE DOES NOT INFRINGE ON OR INTERFERE WITH PRIVATELY OWNED RIGHTS, INCLUDING ANY PARTY'S INTELLECTUAL PROPERTY, OR (III) THAT THIS DOCUMENT IS SUITABLE TO ANY PARTICULAR USER'S CIRCUMSTANCE; OR

(B) ASSUMES RESPONSIBILITY FOR ANY DAMAGES OR OTHER LIABILITY WHATSOEVER (INCLUDING ANY CONSEQUENTIAL DAMAGES, EVEN IF EPRI OR ANY EPRI REPRESENTATIVE HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES) RESULTING FROM YOUR SELECTION OR USE OF THIS DOCUMENT OR ANY INFORMATION, APPARATUS, METHOD, PROCESS, OR SIMILAR ITEM DISCLOSED IN THIS DOCUMENT.

REFERENCE HEREIN TO ANY SPECIFIC COMMERCIAL PRODUCT, PROCESS, OR SERVICE BY ITS TRADE NAME, TRADEMARK, MANUFACTURER, OR OTHERWISE, DOES NOT NECESSARILY CONSTITUTE OR IMPLY ITS ENDORSEMENT, RECOMMENDATION, OR FAVORING BY EPRI.

EPRI PREPARED THIS REPORT.

NOTE

For further information about EPRI, call the EPRI Customer Assistance Center at 800.313.3774 or e-mail askepri@epri.com.

Together…Shaping the Future of Energy®

Acknowledgments

EPRI prepared this report.

Principal Investigators
G. Adams
J. Bukenberger
S. Dutta
N. Goteti
N. Santen
Q. Zhu

Contributors
P. de Mello

This report describes research sponsored by EPRI.

We would like to acknowledge Daniel Brooks, Vice President of Integrated Grid and Energy Systems, as the executive sponsor of this EPRI Board of Directors initiative.

Feedback from and peer-review by the following EPRI staff is also gratefully acknowledged: Erik Ela, Anish Gaikwad, and Devin Van Zandt.

This publication is a corporate document that should be cited in the literature in the following manner: *Current Modeling Capabilities and Practices for Integrated Planning: Review of Select Modeling Tools and Prominent Studies.* EPRI, Palo Alto, CA: 2024. 3002028537.

Abstract

Electric companies are searching for new modeling approaches and tools to support strategic resource planning and asset investment across generation, transmission, and distribution systems, with an aim to identify cost-effective, resilient, and technologically-robust decarbonization resource strategies. Studying the capabilities of existing power system modeling tools and current practices is critical to understanding and advancing an integrated planning framework. This work reviews the objectives, features, and capabilities of various capacity expansion planning tools, production cost model tools, resource adequacy tools, and network reliability modeling tools; and provides an overview of select studies that have been completed over the past few years in the integrated electricity and energy system modeling space.

EPRI's Integrated Strategic System Planning (ISSP) Initiative develops a new resource planning framework and supporting analytical toolbox. This framework uses a series of soft-linked existing power system modeling tools, selected based on the review of modeling tools enlisted in this work. The new framework is tool-agnostic however, and may be used for more comprehensively planning reliable, low-carbon resource portfolios across electric power system supply, delivery, and end-use.

Keywords

Integrated system planning; capacity expansion, production cost, resource adequacy, network reliability

Executive Summary

Deliverable Number: 3002028537
Product Type: Technical Update
Product Title: Current Modeling Capabilities and Practices for Integrated Planning: Review of Select Modeling Tools and Prominent Studies

Primary Audience: Electric company staff engaged in long-term generation portfolio resource planning, transmission planning, distribution planning, end-use technology planning, integrated resource planning, decarbonization planning, and/or corporate strategy and risk management.

Secondary Audience: Regulators, policy makers, ISO/RTO staff, reliability organization staff, and others who are interested in integrated system planning strategy and novel modeling approaches for decarbonization planning.

RESEARCH OVERVIEW

This research provides a review of capabilities of modeling tools for capacity expansion, production cost modeling, resource adequacy, and network reliability modeling. The review consists of a summary of select existing power system modeling tools, as well as overviews and highlights from various prominent studies implementing integrated energy system modeling frameworks over the last few years.

Executive Summary

Deliverable Number: 3002028537
Product Type: Technical Update
Product Title: Current Modeling Capabilities and Practices for Integrated Planning: Review of Select Modeling Tools and Prominent Studies

KEY FINDINGS

- A review of capacity expansion modeling tools shows that the tools differ along many different dimensions, including spatial resolution, temporal resolution, transmission representation, foresight (myopic, perfect, stochastic), endogenous inputs, representation of dispatch, renewable profiles/uncertainty, technology choices, and policy design.
- A review of production cost modeling tools shows that the tools similarly differ along many different dimensions, including database resolution, ease of linking to other tools, markets and revenue modeling, temporal resolution, spatial resolution, storage and demand response capability, capability to include neighboring regions, transmission and distribution representation, emissions details, and reporting.
- A review of resource adequacy modeling tools shows that the tools mainly differ along the following: representation of probabilistic outages (e.g., convolution, Monte Carlo), distributions of outages and repair time (e.g., exponential, Weibull), metrics and reporting timeframes, temporal resolution, transmission representation and import/export availability, storage representation, interaction with adjacent systems (e.g., natural gas, hydrogen, hydro), and weather related disruptions and other common mode outages.
- Network reliability modeling tools use detailed transmission simulation during stressful conditions and the seconds surrounding disruptive events, for which they require high resolution transmission network representation and AC power flow to focus on electrical stability of system. All tools generally model the same phenomena; the main consideration for integrated planning is ease of linking with other tools and existing databases.

Executive Summary

Deliverable Number: 3002028537
Product Type: Technical Update
Product Title: Current Modeling Capabilities and Practices for Integrated Planning: Review of Select Modeling Tools and Prominent Studies

KEY FINDINGS (continued)

- None of the studies reviewed address low-carbon resource planning across generation, transmission, and distribution systems, or explicitly consider potential impacts on system reliability deficiencies from increasing renewables and DERs. Efforts to improve methods for integrated energy systems planning focus on either incorporating more operational reliability analysis into capacity-expansion planning or expanding the set of resources considered for long-range planning (e.g., transmission, distributed energy resources), but not both.
- Most prominent studies did not consider stakeholders' (utilities, ISOs, etc.) planning processes and how they may be integrated within actual utility business practices. For new integrated planning methods to be most valuable to the industry at large, utilities need guidance on how approaches align with their own established practices.
- Most studies focus on answering policy, economic, or engineering questions, not on instructing future integrated modeling studies. Study reports emphasize modeling results and technology insights, not the modeling approaches or their validation. There is a general lack of availability of detailed documentation about how to link different processes and modeling tools for a coordinated analysis. For example, how do assumptions from one tool map to another? What processes can be used to link two tools with different spatial or temporal resolution? Transferability of integration approaches differs among studies; few studies describe configurable tools.

Executive Summary

WHY THIS MATTERS

This research reviewed capabilities of select power system modeling tools and current practices used for integrated energy planning, which is helpful for individuals and organizations interested in exploring the choices of the analytical tools and procedures that may be used for integrated planning across generation, transmission, distribution, and end-use systems.

HOW TO APPLY RESULTS

Individuals or organizations interested in further exploring any power system modeling tool capabilities are encouraged to speak with the respective software vendors to assess the models' capabilities, or follow-up with the EPRI contacts below for a customized model road-mapping assessment.

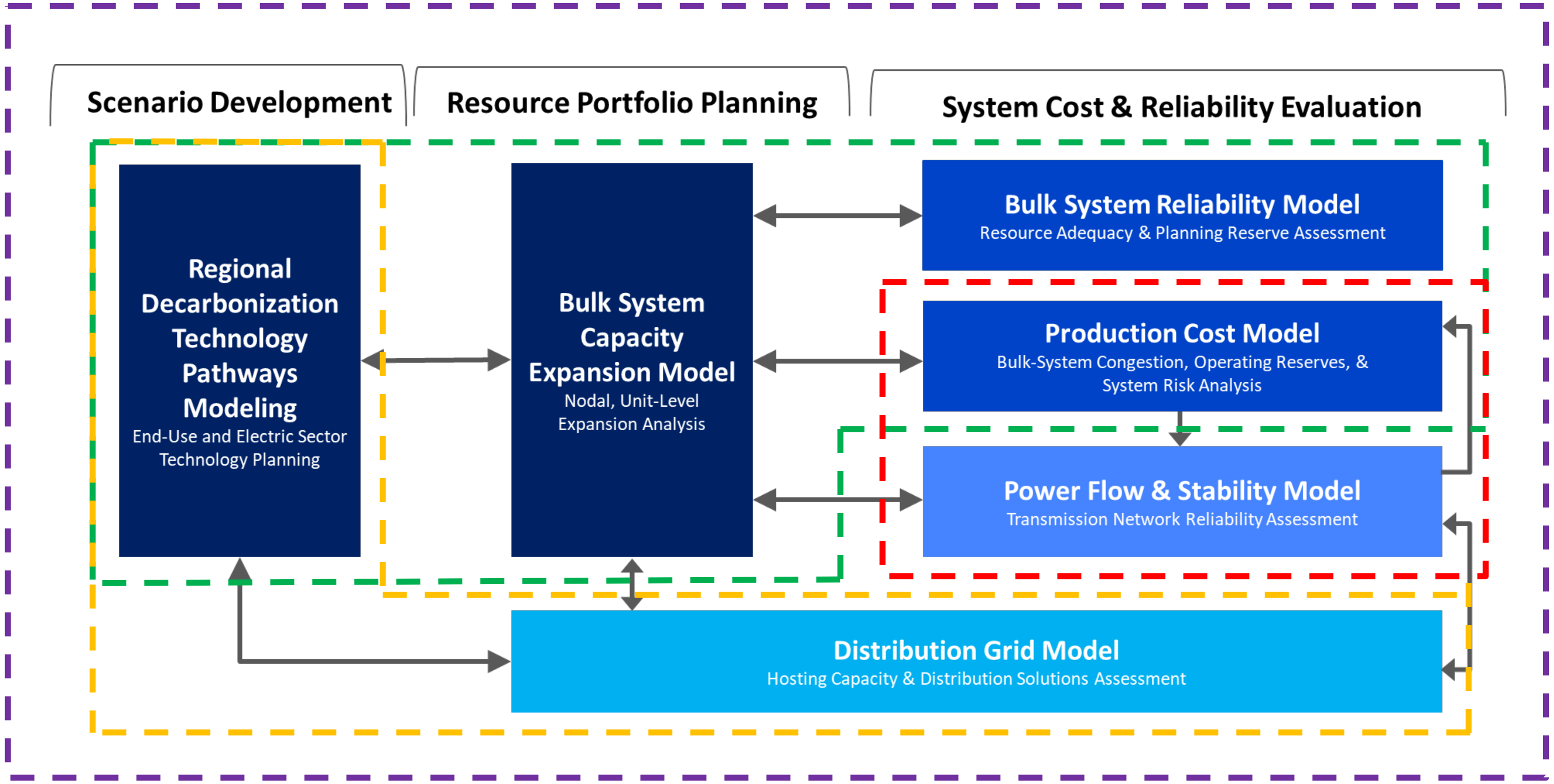
LEARNING AND ENGAGEMENT OPPORTUNITIES

- Implementing Integrated System Planning (ISP) Interest Group. EPRI Contact: Nidhi Santen, nsanten@epri.com
- Climate READi (REsilience and ADaptation initiative). https://www.epri.com/research/sectors/readi. EPRI Contact: Morgan Scott, mmscot@epri.com

EPRI CONTACTS: Anish Gaikwad, Sr. Program Manager (agaikwad@epri.com); Nidhi Santen, Program Manager (nsanten@epri.com); Devin Van Zandt, Sr. Program Manager (dvanzandt@epri.com)

PROGRAMS: Transmission Planning (P40), Bulk System Integration of Renewables and Distributed Energy Resources (P173), DER Integration (P174), Resource Planning for Electric Power Systems (P178), Distribution Operations and Planning (P200), and Energy, Environmental, and Climate Policy Analysis (P201); Electricity Market Design and Operation (P246)

EPRI Integrated Strategic System Planning (ISSP) Initiative Technical Report Series



Integrated Strategic System Planning Initiative: Modeling Framework, Demonstration Study Results, and Key Insights (Product ID 3002028640)

Linking Capacity Expansion, Resource Adequacy, and Production Cost Modeling Tools for Integrated Strategic System Planning (Product ID 3002028534)

Guidelines for Linking Power Flow Analysis with Production Cost Modeling Tools for Integrated Strategic System Planning: Needs, Screening Methods, and Best Practices (Product ID 3002028535)

Wide-Area Distribution Assessments for Integrated Strategic System Planning (Product ID 3002028536)

Other Reports:

- Current Modeling Capabilities and Practices for Integrated Planning: Review of Select Modeling Tools and Prominent Studies (Product ID 3002028537)
- A Distribution Perspective of Process, Capabilities, and Data for Integrated Planning (Product ID 3002028538)

Table of Contents

1

Introduction to EPRI's ISSP Initiative

Background and Analytical Framework

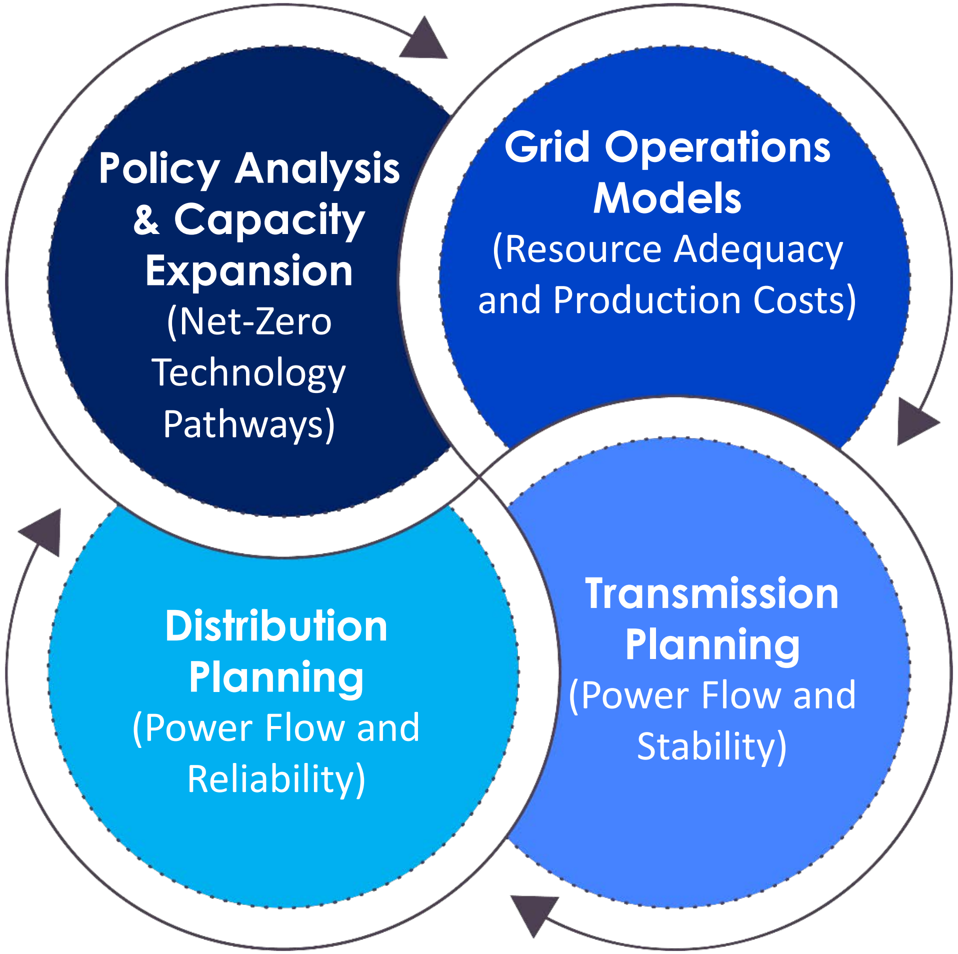
EPRI's Integrated Strategic System Planning (ISSP) Initiative

Integrated Planning for Strategic Questions

Least-cost pathway to electric sector decarbonization?

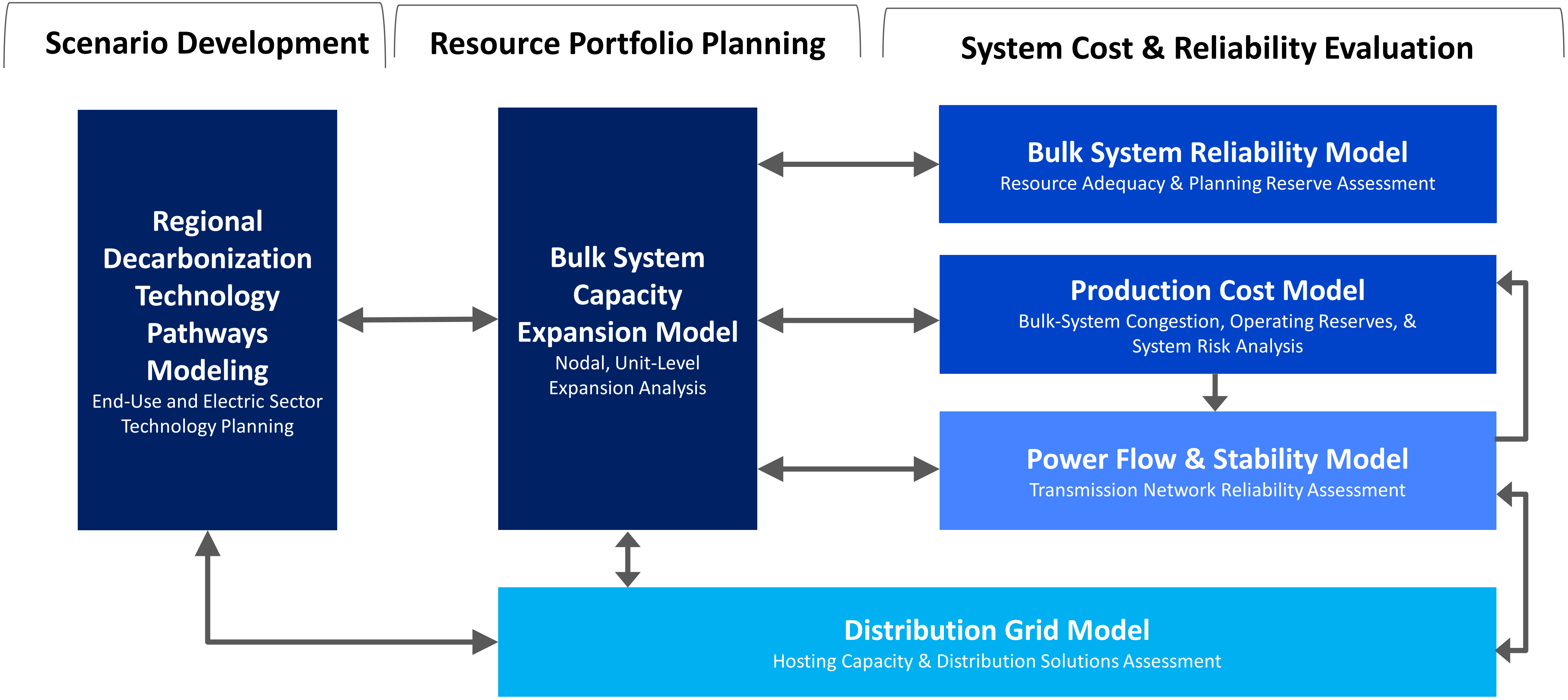
Sufficient capacity, energy, and flexibility to reliably balance supply and demand?

T&D investments for reliability/resiliency for a distributed, inverter-based supply mix?



Develops a generalizable analytical framework to assess future expansion plans across supply (G) and delivery (T&D) & ensures reliability

ISSP Analytical Framework & Modeling Toolbox



2

Review of Select Modeling Tools

Background

- This report briefly examines four categories of tools, their purpose, differentiating features, and select examples in each category.

- Four categories of tools are reviewed:
  1. Capacity expansion planning (CEP) tools
  2. Production cost modeling (PCM) tools
  3. Resource adequacy (RA) tools
  4. Network reliability modeling (NRM) tools

1. Capacity Expansion Planning (CEP) Tools

- Performs big-picture optimization for
  - long-term generation investments,
  - transmission investments, and
  - Retirement plans.

- Returns a course outline of what is optimal to build, when, and where

- Tools often come with many optional features, but computational limits mean system size, resolution, and advanced features must be balanced with one-another

- Tools with more options allow planners to answer specific questions without reworking entire frameworks

1. Capacity Expansion Planning (CEP) Tools (continued)

CEP tools differ along the following dimensions:

- Spatial resolution (none, zonal, nodal)
- Temporal resolution (load blocks, chronological hours)
- Transmission representation (copper plate, transport, DC-OPF, AC-OPF)
- Foresight (myopic, perfect, stochastic)
- Endogenous components (fuel prices, heat rates, demand levels)
- Dispatch (economic dispatch, unit commitment)
- Renewable profiles/uncertainty
- Included technologies (storage, demand response, adv. nuclear, carbon capture, hybrid generation/storage)
- Adjacent systems (gas network, hydro system)
- RPS and carbon policy

Selected Capacity Expansion Planning (CEP) Tools

Tool*	Owner	Spatial Res.	Trans. Flow	Planning Horizon	Long-Term Foresight	Dispatch	Operation Timestep
JHSMINE	Johns Hopkins	Zonal, Nodal	DC-transport hybrid	2+ stages	Stochastic Adaptive	ED – UC flexible	Hourly Chron.
WIS:DOM-P	Vibrant Clean Energy	Zonal	DC-OPF	2020-2050 (5-year step)	Myopic	ED – UC flexible	Hourly Chron.
RPM	NREL	Hybrid Zonal-Nodal	AC-DC	20-years	Myopic	Reduced order dispatch	Hourly Chron. Day-Week
SWITCH	UC Berkeley (Open Source)	Zonal	Transport	2+ stages	Perfect Foresight	ED-UC	Hourly Chron.
RESOLVE	E3	Zonal	Transport	2015-2030 5-year step	Perfect Foresight	Linearized UC	Hourly Chron.
PLEXOS-LT	Energy Exemplar	Regional-Nodal	Transport, DC-OPF	2+ years, overlapping segments option	Options for myopic, perfect, and stochastic foresight	ED-UC	Load Duration, Hourly Chron. Day-Month

** Source: Tool column names are linked to the respective websites*

Special Features of Select Reviewed CEP Tools

- RPM
  - High-spatial resolution for renewable resources
  - Individual generator and line detail capable for focus regions
  - Analytics for resource value such as storage revenue
  - Soft links to PCM, RA, and NRM tools
- JHSMINE
  - Fully stochastic adaptive decision process (multistage branching scenario tree)
- WIS:DOM-P
  - Distribution infrastructure modeled with “grid edge” interface for utility-observed peak distribution demand, generation, and consumption at 69kV and above
  - PCM mode included
- SWITCH
  - Modular user control options allow for customizable models and advanced optional features such as fuel markets, contingency reserves, and hydro systems
  - Hydro system option to represent stream flow network and and reservoir management constraints

Special Features of Selected CEP Tools (continued)

- RESOLVE
  - Focus on investments driven by renewable energy targets
    - Tracks both renewable generation and zone where renewable credits are contracted, so RPS targets can be met with generators in different regions
    - Uses day selection and weighting method based on ridge regression
  - Pairs with RECAP resource adequacy model
- PLEXOS-LT
  - Many options including integer/linear expansion variables, endogenous heat rates, and alternative depreciation methods
  - Overlapping horizon option lets users solve larger problems by breaking long time horizons into smaller overlapping segments, solved sequentially

  Results transfer within PLEXOS to resource adequacy and production costing modes

2. Production Cost Modeling (PCM) Tools

- Performs detailed operations simulation of a given system

- Typically, PCMs simulate
  - Dispatch,
  - Pricing, and
  - market behavior for thorough examination of candidate plan

- CEP outputs often give inputs for PCMs
  - Confirm or compare viability of expansion plans under anticipated operating conditions and alternative market/regulatory policies
  - Opportunity for feedback from PCM to CEP with updated prices/demand based on consumption

2. Production Cost Modeling (PCM) Tools (continued)

PCM tools differ along the following dimensions:

- Included Databases (regional coverage, resolution)
- Linking to other tools
- Markets and revenue modeling
- Time resolution (hourly, sub-hourly)
- Spatial resolution (nodal, bus)
- Storage and demand response capability
- Ability to model neighboring regions
- Transmission and distribution representation
- Emissions detail and reporting

Selected Production Cost Modeling (PCM) Tools

Tool*	Owner	Sub-hourly Timestep	Bus Level Resolution	Ancillary Markets Simulation	Transmission Congestion Pricing	Security Constrained UC&ED	Emissions Tracking & Trading Costs	Forecast Uncertainty	Regional Data	Links
PLEXOS	Energy Exemplar	✓	✓	✓	✓	✓	✓	✓	North America, Europe, parts of Latin America and Pacific	Other PLEXOS modes
GridView	Hitachi	✓	✓	✓	✓	✓	✓	✓	WECC, EI, ERCOT	PSLF, PSS/E
MAPS	General Electric	✓	✓	✓	✓	✓	✓	✓	WI, EI, ERCOT, and several countries	MARS, PSLF
PSO	Polaris	✓	✓	✓	✓	✓	✓	✓	WECC, ERCOT	

** Source: Tool column names are linked to the respective websites*

3. Resource Adequacy (RA) Tools

- Performs detailed checks of whether system has
  - sufficient energy,
  - capacity, and
  - flexibility resources to reliably meet demand

- Focus is on stressful periods and random unplanned outages to ensure system operating rules are sufficient for any probable contingencies

- CEP and PCM outputs often provide inputs to RA tools
  - Capacity from CEP and generator dispatch from PCM give RA operating conditions
  - Adequacy shortfalls can be addressed with operating reserve/dispatch changes or capacity additions
  - Return to CEP with updated assumptions if major capacity changes are needed

3. Resource Adequacy (RA) Tools (Cont.)

Tools differ along the following dimensions:

- Framework for representing probabilistic outages (convolution, Monte Carlo)
- Distributions of outages and repair time (exponential, Weibull)
- Metrics and reporting timeframes (Hourly/daily loss of load expectation, expected unserved energy, durations)
- Simulation timescale (hourly, sub-hourly)
- Transmission representation and import/export availability
- Storage representation (hydro reservoirs, fuel inventory, batteries, thermal)
- Span of modeled resources (demand response, DER, hybrid gen/storage, hydrogen)
- Interaction with adjacent systems (natural gas, hydrogen, hydro)
- Weather related disruptions and other common mode outages

Selected Resource Adequacy Tools

Tool*	Owner	Probability Framework	Dispatch	Neighboring Regions	Storage	Demand Response
PLEXOS	Energy Exemplar	PLEXOS-PASA: convolution PLEXOS-ST: Monte Carlo	ED-UC flexible	Many regions, up to security constrained OPF	Prior dispatch-price responsive dispatch, flexible	Supply side resource or price responsive load, flexible
SERVM	ASTRAPE Consulting	Monte Carlo	ED-UC flexible	Transport flow, same resolution as main system	Revenue or Reliability based dispatch, flexible	Stochastic response magnitude, fatigue with frequent calls, flexible
MARS	General Electric	Monte Carlo	None, Import from MAPS	Power pools with reserve sharing contracts	Prior dispatch from MAPS, or as needed	Constrained number of DR calls, flexible
RECAP	E3	Monte Carlo	Reliability Dispatch Heuristic	Limited	Load flattening heuristic	As needed dispatch
PRAS	NREL (Open Source)	Convolution-Monte Carlo	None	Transport flow, time-varying capacity with outages	Duration sorted as needed dispatch	None

** Source: Tool column names are linked to the respective websites*

Network Reliability Modeling (NRM) Tools

- Performs detailed transmission simulation during stressful conditions and the seconds surrounding disruptive events
- Use high resolution transmission network representations and AC power flow to focus on electrical stability of system rather than adequacy of resources
- PCM/RA output can help identify important scenarios for NRM
  - Iterations between NRM and PCM can be performed until all violations are resolved
  - Reliability violations are fixed with transmission upgrades or operational changes
  - Since NRM level of detail is not modeled in other tools, feedback is challenging
- Tools generally model the same phenomena; the main consideration for ISSP is ease of linking with other tools and existing databases
  - Important scenarios come from PCM, but the process for selecting and repairing scenarios is open question. See example work in appendix.

Selected Network Reliability Modeling Tools

Tool*	Owner	Notable Users	Frequency Stability	Voltage Stability	Contingency Assessment	Transient Stability Assessment
PSS/E	Siemens	Eastern Interconnect, ERCOT. Used widely around the globe including EU, Middle-East, South East Asia and India	✓	✓	✓	✓
PSLF	General Electric	WECC	✓	✓	✓	✓
Powerworld	PowerWorld Corp	Within US both by some utilities/ISOs in WECC, EI and ERCOT	✓	✓	✓	✓
DSATools	Powertech labs	Within US both by some utilities/ISOs in WECC, EI and ERCOT	✓	✓	✓	✓
DigSilent Powerfactory	DigSilent	Mostly EU and Latin Americas	✓	✓	✓	✓
TARA	Power GEM	Only for specialized steady state assessment and steady state contingency studies				
POM	V&R Energy	Only for specialized steady state assessment and steady state contingency studies				

** Source: Tool column names linked to the respective websites*

3

Review of Select Prominent Studies

Summary of Studies Reviewed

Power System Objective(s) Considered

Study	Resource Expansion	Operations Simulation & RA/Reliability	Power Flow & Network Stability	Economy-wide
1. NREL—The Los Angeles 100% Renewable Energy Study (LA100)	Generation, Transmission, End-use	Generation, Transmission, Distribution	Transmission, Distribution	Other Sectors & System Issues
2. Princeton—Net-Zero America Study	Generation, Transmission, End-use	Generation, Transmission		Other Sectors & System Issues
3. LBNL—Illustrative Strategies for the United States to Achieve 50% Emissions Reduction by 2030	Generation, Transmission	Generation, Transmission		Other Sectors & System Issues
4. Telos Energy—Puerto Rico Distributed Energy Resource Integration Study	Generation, Transmission	Generation, Transmission, Distribution	Transmission, Distribution	
5. Vibrant Clean Energy—A Plan for Economy-Wide Decarbonization for the United States	Generation, Transmission	Generation, Transmission, Distribution		Other Sectors & System Issues
6. The Brattle Group—The Road to 100% Renewable Electricity by 2030 in Rhode Island Study	Generation			Other Sectors & System Issues
7. MISO—Renewable Integration Impact Assessment (RIIA)	Generation, Transmission	Transmission	Transmission	

Generation · Transmission · Distribution · End-use · Other Sectors & System Issues

References

Abhyankar, Nikit, et al. “Illustrative strategies for the United States to achieve 50% emissions reduction by 2030.” Lawrence Berkeley National Laboratory (2021).

Clack, Christopher TM, et al. “A Plan for Economy-Wide Decarbonization of the United States.” Vibrant Clean Energy (2021).

Cochran, Jaquelin, et al. “The Los Angeles 100% Renewable Energy Study (LA100): Executive Summary.” National Renewable Energy Laboratory (NREL) (2021).

“Puerto Rico Distributed Energy Resource Integration Study.” Telos Energy (2020).

Larson, Eric, et al. “Net-Zero America: Potential Pathways, Infrastructure, and Impacts, Final report.” Princeton University (2021).

“MISO’s Renewable Integration Impact Assessment (RIIA).” MISO (2021).

Murphy, Dean, et al. “The Road to 100% Renewable Electricity by 2030 in Rhode Island.” The Brattle Group, Rhode Island Office of Energy Resources (2020).

Landscape of Prominent Studies Applying Integrated Energy System Planning Approaches: Overview

- Integrated energy system modeling is applied in a wide range of research projects, from renewable and/or distributed energy resource integration studies to state and national electric sector decarbonization studies.
- There is a split between studies motivated by policy goals (e.g., reaching policy-driven net-zero carbon goals) and studies motivated by the engineering aspects of a transitioning system. The latter more often include more detailed granularity in modeling.
- Studies leverage both in-house models and commercial tools, depending on the institution performing the study.

Landscape of Prominent Studies Applying Integrated Energy System Planning Approaches: Coverage of Topics

- The coverage of generation, transmission, DER, distribution systems varies by study, with most integrated modeling approaches utilizing capacity expansion and production cost modeling for generation and transmission.
- Temporal and/or spatial granularity used varies by study, with some emphasizing the efforts to improve these modeling choices.
- Many studies reviewed explore relatively simple bulk system reliability issues (e.g., resource adequacy), but only few consider detailed power flow and transmission system stability.
- None of the studied reviewed cover resource planning across generation, transmission, and distribution systems, ***and*** explicitly considers mitigation measures for potential grid reliability deficiencies.

Landscape of Prominent Studies Applying Integrated Energy System Planning Approaches: Coverage of Topics (continued)

- Many studies reviewed here extend impacts analysis beyond the power sector (e.g., GDP impacts, jobs, public health), although the engineering focus is on the power system.
- Studies do not explicitly model other systems such as the gas and communications systems.

Landscape of Prominent Studies Applying Integrated Energy System Planning Approaches: Implementation

- Most integrated energy modeling frameworks employ "soft links" between different modeling tools (i.e., outputs from one model are used as inputs in the next model), with some incorporating an endogenous feedback between tools to inform prior decisions. Few studies use modeling tools with limited co-optimization capabilities.
- Many studies use several modeling tools that require further integration.
- Data acquisition approaches vary widely, with some studies relying on publicly available data, others proprietary data, and still others developing their own input data via coordinated modeling.

Landscape of Prominent Studies Applying Integrated Energy System Planning Approaches: Application

- Reviewed studies focused on answering the policy or engineering question, and not on providing information about *how* to conduct integrated energy system modeling.
- Documentation of how each component of the modeling framework is linked is inconsistent among studies, with some offering illustrative diagrams or high-level information only, and others providing full documentation with mathematical formulations.
- Few studies discussed how the planning processes used may be integrated into actual utility practices.

1. NREL—LA100 Study: Overview

- Objective
  - To inform Los Angeles, LADWP, and other stakeholders of possible pathways to achieve 100% renewable energy, and the economic, environmental, public health, and environmental justice (EJ) implications of these pathways.
- Approach
  - Used a combination of linked models to estimate demand, evaluate technology availability, design scenarios, develop least-cost expansion plan for the bulk power system, conduct model validation via grid operation simulation and reliability analysis, and implement environmental and EJ modeling.
  - Several scenarios are developed for electricity demand projections, electrification, biofuel, and transmission infrastructure.
- Selected Findings
  - Least-cost "no regrets" options for LAWDP include new wind, solar, batteries, and transmission—and coupled with smart-grid operational practices that make more efficient use of these investments.
  - Pathways to 100% required significant distributed customer adopted and utility driven solar and storage on the distribution system.

Source: https://maps.nrel.gov/la100/la100-study/report

1. NREL—LA100 Study: Modeling Highlights

- Input Modeling
  - Electricity demand projections; customer rooftop solar and storage adoption; and utility options for solar and storage.
- Validation and Output Modeling (RPM, PLEXOS, PRAS, PSLF, Distribution Transformation Tool, DISCO, PyDSS, OpenDSS, dGen)
  - The study used additional models to validate capacity expansion model outputs due to the capacity expansion planning model's inability to consider high resolution temporal and spatial elements of system operational reliability.
  - Grid operations and performance simulation; transmission system reliability analysis; and distribution operations validation
  - Detailed analysis of most of LADWP's distribution feeder systems given multiple scenarios to reach 100% renewable energy to serve their customers.
- Additional Output Modeling
  - Quantify and monetize GHG emissions; air quality changes and public health impacts; impacts on environmental justice; economic impacts and local job changes.

Source: https://maps.nrel.gov/la100/la100-study/report

1. NREL—LA100 Study: Modeling Highlights (continued)

- Each modeling step used both baseline data (externally developed input data from LADWP) and model outputs produced from previous modeling steps.
- "Soft links" among different components of the modeling framework, as well as links that provided endogenous feedback were developed.
- A comprehensive data management protocol was developed for this study to ensure data were correctly transferred between modeling steps and to enable coordinated analysis across the entire LADWP system.
- Distribution modeling is linked to multiple other model tools used.

Source: https://maps.nrel.gov/la100/la100-study/report

2. Princeton—Net-Zero America Study: Overview

- Objectives
  - To investigate energy system requirements, costs, and impacts of the U.S. meeting an economy-wide net-zero CO_2 goal by 2050.
  - To provides a "granular picture" of actionable public and corporate policies to support decarbonization.
- Approach
  - Coordinated modeling for end-use, supply-side resource requirements, and downscaling analysis.
  - Uses EIA projections for energy demands.
  - Evaluates five different pathways to net-zero.
  - Uses a macro-regional perspective (14 regions across US).
- Selected Findings
  - Uncontrolled coal eliminated by 2030; significant use of carbon capture.
  - Electrification drives rapid declines in petroleum-based liquid fuels and gas.
  - Increased capital expenditures are necessary.

Source: https://netzeroamerica.princeton.edu

2. Princeton—Net-Zero America Study: Modeling Highlights

- EnergyPATHWAYS (EP) calculates final energy by type to meet projected energy service demands; used to develop economy-wide energy demand scenarios.
- RIO (energy supply-side optimization tool) uses outputs from EP and optimizes a 30-year NPV of system costs to determine fuel mix and technology deployment to meet demand under the carbon constraint; returns supply-side decisions to EP for additional costs and emissions accounting.
- Downscaling analysis uses EP and RIO results to develop more granular state or sub-state-level geographic resolution.
  - For visualization, RIO's coarser-resolution model results are downscaled. "Candidate project areas" are selected to meet the regional level of solar and wind generation in RIO.
  - For wind and solar, high resolution (4 km x 4 km) evaluation of siting is conducted.

3. LBNL—2030 Report: Overview

- Objectives
  - To explores strategies for the United States to reach 50% carbon reduction by 2030, including the power, transportation, buildings and industry sectors.
  - To assesses pathways to keep customer costs low or nearly the same.
- Approach
  - Uses a series of models to evaluate economy-wide emission reduction strategies, including detailed pathways in the power sector using a regional electricity capacity expansion planning model combined with a production cost model to test system operational feasibility.
  - Explores two central cases, with three primary sets of future renewable energy and battery storage cost assumptions.
- Selected Findings
  - “Scaling up renewables to achieve 90% clean energy by 2035 is feasible.”
  - Reaching 80% carbon-free electricity by 2030, retiring all coal generation by 2030, and selling only electric new cars by 2030 and trucks by 2035 drive most scenario emissions reductions.
  - Cost savings for average household with EVs of $1000/year (based on wholesale electricity price comparisons).

Source: https://eta.lbl.gov/publications/illustrative-strategies-united-states

3. LBNL—2030 Report: Modeling Highlights

- Power sector strategies are modeled using NREL's Regional Energy Deployment System (ReEDS) capacity-expansion model.
- Operational feasibility is tested using the PLEXOS production-cost model.
- Economy-wide assessment using Energy Policy Simulator (EPS).
- Bottom-up approach to assess fleet vehicle level impacts of vehicle sales.
- Job losses and gains estimates based on IMPLAN; GHG and air pollutant emissions from ReEDS.

4. Telos Energy—Puerto Rico DER Integration Study

- Objectives
  - To provide an economic and technical analysis of Puerto Rico achieving 50% renewable energy by 2035 and 100% by 2050, prioritizing rooftop solar and storage DERs.
  - To understand the operational, transmission, and distribution opportunities, and challenges associated with DER integration.
  - To present a possible schedule for fossil fuel generation phase out.
- Approach
  - Leverages a combination of power system optimization and simulation modeling software for modeling grid operations, reliability, and distribution requirements.
  - Uses detailed distribution modeling.
  - Four scenarios for future power systems with DER: (1) Base scenario; (2) 25% DER; (3) 50% DER; (4) 75% DER.
- Selected Findings
  - Puerto Rico can shift its power system to one that is based on local, renewable, and resilient distributed energy.
  - Results show grid operations changing markedly as the system reaches higher DER penetration.

Source: https://cambiopr.org/wp-content/uploads/2021/03/Puerto-Rico-Distributed-Energy-Resource-Integration-Study-Telos-Energy.pdf

4. Telos Energy—Puerto Rico DER Integration Study: Modeling Highlights

- Scenario-based capacity expansion *assuming* increasing levels of DER, including residential PV, commercial PV, behind-the-meter battery energy storage, and corresponding fossil generator retirements.
- Hourly production cost modeling using PLEXOS.
- Transmission stability analysis using Siemens' PSS/E power follow model.
- Distribution analysis using EPRI's OpenDSS distribution tool with validation using DNVGL's Synergi model to identify circuit hosting capacity and necessary distribution system upgrades
  - DER was distributed proportionately to load across 288 38kV buses;
  - Thevenin Equivalent source for grid representation at the distribution level was calculated for each load bus in PSSE.

5. Vibrant Clean Energy—A Plan for Economy-Wide Decarbonization for the United States: Overview

- Objective
  - To identify pathways the U.S. can take to meet 50% carbon reductions by 2030 and 100% net-zero carbon emissions by 2050, aligned with the Biden Administration energy plan goals. This study focuses the role of DER in decarbonization, less on bulk resources.
- Approach
  - Uses WIS:dom-P, an integrated capacity expansion and production cost model for co-optimizing utility-scale generation, storage, transmission, and DERs.
  - Considers two main scenarios:
    1. Decarbonization of the U.S. economy with predominantly utility-scale generation. Large-scale transmission is allowed to expand, but the model does not co-optimize the distribution system with the utility-scale generation.
    2. Decarbonization of the U.S. economy with utility-scale and distribution system co-optimization. Large-scale transmission is allowed to expand and co-optimizes the distribution system with utility-scale generation. DERs are allowed to grow subject to supply chain constraints.
- Selected Findings
  - Co-optimizing the distribution system and allowing DERs to be deployed can save the U.S. $109 billion in total resource costs by 2030.
  - By 2050, the co-optimized utility-scale and distribution system scenario saves over $515 billion in total resource costs over the utility-scale only scenario.

Source: https://www.vibrantcleanenergy.com/wp-content/uploads/2021/10/US-Econ-Decarb_CCSA.pdf

5. Vibrant Clean Energy Decarbonization Study: Modeling Highlights

- WIS:dom-P has developed methods to capture utility-scale power systems planning and operations and the distribution system under a single modeling framework.
  - It makes several simplifications in order to retain its linear programming formulation and coverage of technologies and end-uses (reviewed in more detail in the complementary ISSP technical literature reviews).
- WIS:dom-P resolves the transmission topology of the modeled grid down to each 69-kV substation resolution.
- The study models the contiguous United States, and electrical flows with Canada and Mexico.
- Uses the NREL ATB 2021 “moderate” cost projections for installed capital and operation and maintenance (O&M) costs.

6. The Brattle Group—The Road to 100% Renewable Electricity by 2030 in Rhode Island: Overview

- Objectives
  - To provide a high-level economic analysis for Rhode Island to meet 100% of its electricity demand with renewables by 2030.
  - To recommend specific policies that can support the 2030 goal.
- Approach
  - The study integrates analysis of load, existing renewables, resource acquisitions and the ISO-NE market into a rate-payer cost model.
  - Provides economic impacts analysis of technology bookend and portfolios as well GHG emissions impacts.
- Selected Findings
  - Rhode Island's goal of 100% renewable electricity by 2030 is achievable, but will not be without costs to the ratepayer.
  - "In the near term, renewable electricity will cost more than fossil-fired generation, and utility bills will be higher regardless of the composition of the ultimate portfolio of renewable resources." Overall net costs depend on how the resource portfolio changes over time.
  - Utility-scale on-shore, off-shore, and solar resources are most cost-effective based on the scenarios modeled.

Source: http://www.energy.ri.gov/documents/renewable/The Road to 100 Percent Renewable Electricity - Brattle 04Feb2021.pdf

6. The Brattle Group—Rhode Island 100% Renewables Study: Modeling Highlights

- The study integrates an analysis of load and existing renewables, resource acquisitions, and resources in the ISO-NE market into a central rate-payer cost model.
- A renewable supply gap analysis performs a comparison of demand forecasted through 2030 and existing renewable generation.
- The Brattle Group (TBG)'s in-house GridSIM capacity expansion planning model optimizes the remaining set of resources for the future New England regional power system as it decarbonizes.
- A central ratepayer above-market cost impact analysis evaluates the cost of achieving 100% renewable electricity for the set of portfolios selected by GridSIM.
- An economic impact analysis is performed through post-processing of the results. Impacts on GDP and in-state employment are modeled using:
  - JEDI (the Jobs and Economic Development Impact), and
  - IMPLAN (Impact Analysis for Planning) models.

7. MISO—Renewable Integration Impact Assessment: Overview

- Objective
  - To understand the impacts of renewable energy growth in the MISO region by examining integration issues and potential mitigation solutions.
- Approach
  - The study framework used a combination of commercial production cost and grid power flow and reliability modeling tools to investigate system conditions.
  - Considered several scenarios to represent different levels of renewable energy penetration, adding wind and solar resources in 10% increments up to 50%.
- Selected Findings
  - Renewable penetration beyond 50% can be achieved in MISO, but penetrations beyond 30% increases integration complexity significantly and will require transmission expansion and "transformational change in planning, markets, and operations."
  - The study proposes system-wide actions to be implemented to achieve various levels of renewable penetration, including technology, operating, market and planning practices.
  - "Diversity of technologies and geography improves the ability of renewables to serve load."

Source: https://www.misoenergy.org/planning/policy-studies/Renewable-integration-impact-assessment/#nt=%2Friiatype%3AReport&t=10&p=0&s=Updated&sd=desc

7. MISO—RIAA: Modeling Highlights

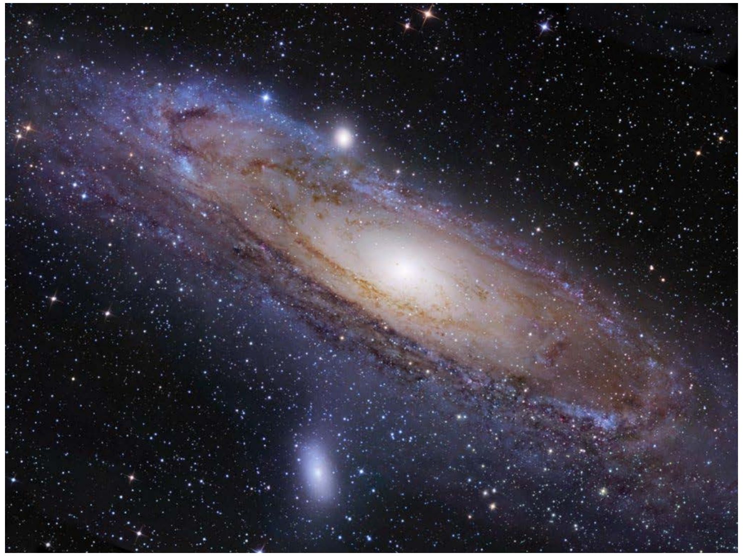
- Analysis focused on three key areas:
  1. Resource adequacy to ensure that there are sufficient resources to reliably serve demand. PLEXOS is used to determining ELCCs at each milestone, and retirements.
  2. Energy adequacy to ensure the system can provide energy in all operating hours continuously throughout the year; explored via PLEXOS production cost hourly dispatch modeling.
  3. Grid operations reliability to ensure that the system can withstand unanticipated component losses or disturbances. PSSE, TARA, TSAT, and VSAT used to preform power flow and dynamics modeling to assessing reliability of the system at selected stressed hours.

4

Research Needs and Opportunities for Future Integrated Planning Practices

Research Need #1: Integrated Energy Systems Planning Needs a Holistic Modeling Approach

- None of the studies reviewed address low-carbon resource planning across generation, transmission, and distribution systems, ***and*** explicitly consider potential impacts on system reliability from increasing renewables and DER levels.
- Efforts to improve methods for integrated energy systems planning focus on either incorporating more operational reliability analysis into capacity-expansion planning or expanding the set of resources considered for long-range planning (e.g., transmission, distributed energy resources), but not both.



EPRI's ISSP Initiative delivers a holistic approach for integrated energy systems planning across G, T, D, and end-use systems by linking analytical capabilities from capacity expansion planning, production cost modeling, resource adequacy assessment, power flow and transmission reliability assessment, and distribution system analysis.

Research Need #2: Processes for Integrated Energy Systems Planning Need to be More Transparent and Transferrable

- Most studies focus on policy, economic, or engineering questions, not on instructing future integrated modeling studies.
- Study reports emphasize modeling results and technology insights, not the modeling approaches or their validation.
- There is a general lack of availability of detailed documentation about how to link different processes and modeling tools for a coordinated analysis. For example, how do assumptions from one tool map to another? What processes can be used to link two tools with different spatial or temporal resolution?
- Transferability of integration approaches differs among studies; few studies describe configurable tools.

EPRI's ISSP Initiative provides detailed documentation on the modeling framework developed, challenges, lessons learned, and insights for implementation so that utility planning staff and other stakeholders can apply the concepts in their own situations.

Research Need #3: New Approaches for Integrated Planning Need to Align with Company-Level Business Practices

- Most existing studies do not consider stakeholders' planning processes and how they may be integrated within actual electric company business practices. For new integrated planning methods to be valuable to the industry at large, companies need guidance on how approaches align with their own established practices.
- Electric companies are seeking guidance on how integrated planning aligns with the role they play within the industry. The wide range of electric companies that participate in the electric sector—from vertically-integrated to G&T-only to wires-only to IPPs, and whether they participate in an organized market—necessitates better understanding about how to adapt integrated planning approaches to different entities.

EPRI's ISSP Initiative aims to provide guidance about how new "holistic" approaches for integrated energy systems planning can be used by utilities, companies, and other organizations within the electric power industry based on their perspectives and established planning practices.

ISSP Goals

Study	Resource Expansion	Operations Simulation & RA/Reliability	Power Flow & Network Stability	Economy-wide
1. NREL—Los Angeles 100% Renewable Energy Study (LA100)	Generation, Transmission, End-use	Generation, Transmission, Distribution	Transmission, Distribution	Other Sectors & System Issues
2. Princeton—Net-Zero America Study	Generation, Transmission, End-use	Generation, Transmission		Other Sectors & System Issues
3. LBNL—Illustrative Strategies for the United States to Achieve 50% Emissions Reduction by 2030	Generation, Transmission	Generation, Transmission		Other Sectors & System Issues
4. Telos Energy—Puerto Rico Distributed Energy Resource Integration Study	Generation, Transmission	Generation, Transmission, Distribution	Transmission, Distribution	
5. Vibrant Clean Energy—A Plan for Economy-Wide Decarbonization for the United States	Generation, Transmission	Generation, Transmission, Distribution		Other Sectors & System Issues
6. The Brattle Group—The Road to 100% Renewable Electricity by 2030 in Rhode Island Study	Generation			Other Sectors & System Issues
7. MISO—Renewable Integration Impact Assessment (RIIA)	Generation, Transmission	Distribution	Transmission, Distribution	
8. EPRI—Integrated Strategic System Planning Initiative	Generation, Transmission, Distribution, End-use	Generation, Transmission, Distribution	Transmission, Distribution	End-use

Generation **Transmission** **Distribution** **End-use** **Other Sectors & System Issues**

EPRI.com

EPRI.com is our online resource to support your business needs

Set bookmark and shortcut to our website: www.EPRI.com

Resources Include:

- Program Overviews and Research Project Progress
- Results to fit your needs:
  - Reports
  - Guidelines
  - Databases
  - Software
  - Training Modules
  - Tools
  - Videos
- Events, Webcasts, and Collaboration Spaces
- Email Subscriptions, Announcements, and News
- Supplemental Project Opportunities
- A Personal Dashboard where you can subscribe to email notifications, favorite EPRI content, and register for events.

Log-In today to get started!

For questions or website assistance, please contact EPRI Customer Assistance Center (CAC) at askepri@epri.com or 800-313-3774, option 4.

Together…Shaping the Future of Energy®

.

About EPRI

Founded in 1972, EPRI is the world's preeminent independent, non-profit energy research and development organization, with offices around the world. EPRI's trusted experts collaborate with more than 450 companies in 45 countries, driving innovation to ensure the public has clean, safe, reliable, affordable, and equitable access to electricity across the globe. Together, we are shaping the future of energy.

3002028537

EPRI
3420 Hillview Avenue, Palo Alto, California 94304-1338 USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com