The Los Angeles 100% Renewable Energy Study

Chapter 2. Study Approach

FINAL REPORT: LA100—The Los Angeles 100% Renewable Energy Study

March 2021

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Los Angeles Department of Water & Power

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The Los Angeles 100% Renewable Energy Study

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Context

The Los Angeles 100% Renewable Energy Study (LA100) is presented as a collection of 12 chapters and an executive summary, each of which is available as an individual download.

- The **Executive Summary** describes the study and scenarios, explores the high-level findings that span the study, and summarizes key findings from each chapter.
- **Chapter 1: Introduction** introduces the study and acknowledges those who contributed to it.
- **Chapter 2: Study Approach** (this chapter) describes the LA100 study approach, including the modeling framework and scenarios.
- **Chapter 3: Electricity Demand Projections** explores how electricity is consumed by customers now, how that might change through 2045, and potential opportunities to better align electricity demand and supply.
- **Chapter 4: Customer-Adopted Rooftop Solar and Storage** explores the technical and economic potential for rooftop solar in LA, and how much solar and storage might be adopted by customers.
- **Chapter 5: Utility Options for Local Solar and Storage** identifies and ranks locations for utility-scale solar (ground-mount, parking canopy, and floating) and storage, and associated costs for integrating these assets into the distribution system.
- **Chapter 6: Renewable Energy Investments and Operations** explores pathways to 100% renewable electricity, describing the types of generation resources added, their costs, and how the systems maintain sufficient resources to serve customer demand, including resource adequacy and transmission reliability.
- **Chapter 7: Distribution System Analysis** summarizes the growth in distribution-connected energy resources and provides a detailed review of impacts to the distribution grid of growth in customer electricity demand, solar, and storage, as well as required distribution grid upgrades and associated costs.
- **Chapter 8: Greenhouse Gas Emissions** summarizes greenhouse gas emissions from power, buildings, and transportation sectors, along with the potential costs of those emissions.
- **Chapter 9: Air Quality and Public Health** summarizes changes to air quality (fine particulate matter and ozone) and public health (premature mortality, emergency room visits due to asthma, and hospital admissions due to cardiovascular diseases), and the potential economic value of public health benefits.
- **Chapter 10: Environmental Justice** explores implications for environmental justice, including procedural and distributional justice, with an in-depth review of how projections for customer rooftop solar and health benefits vary by census tract.
- **Chapter 11: Economic Impacts and Jobs** reviews economic impacts, including local net economic impacts and gross workforce impacts.
- **Chapter 12: Synthesis** reviews high-level findings, costs, benefits, and lessons learned from integrating this diverse suite of models and conducting a high-fidelity 100% renewable energy study.

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1 Scenarios

This chapter reviews the modeling approach used in the Los Angeles 100% Renewable Energy Study (LA100), including the scenarios, the modeling tools and data that comprise the overall study structure, and the management of data flow among the models.

The study begins with the scenarios, which represent a crucial area of input from the LA100 Advisory Group (see Chapter 1 for additional background on the Advisory Group).

A *scenario* is one possible pathway toward a clean energy future. Each scenario has the same end goal—100% renewable energy—but *how* the goal is achieved varies across the scenarios. The scenarios are not meant to be specific options for the City of LA. Exploring different scenarios helps us understand the potential impacts and tradeoffs among the different choices LA could make in reaching 100% renewable energy. Note that these scenarios do not provide a forecast or recommendation for future action, but rather a range of possibilities that can result from different decisions and investment choices.

The LA100 Advisory Group helped develop and define the scenarios that reflect different interests among the stakeholders, with the goal that the scenarios reflect the broad range of priorities represented in the Advisory Group. In particular, the Advisory Group coalesced around two different sets of priorities that could be evaluated: 1) the speed of the transition—regarding both the renewable energy targets and electrification of end uses; and 2) the eligibility of generation technology options to meet the renewable energy target. Based on consultation with the office of Mayor Garcetti and the Advisory Group, some of the scenarios were modified after the Mayor's Green New Deal 2019 pLAn[1] to better align assumptions about electricity demand projections (i.e., the speed of the electrification transition) with the City's revised targets.

The scenarios are presented below, first in how they vary by the customer; second in how they vary in options for electricity supply.

1.1 Demand (Load)-Related Scenario Distinctions

The scenarios include three demand projections (moderate, high, and stress) that represent different assumptions about the customer's electricity usage—end-use electrification (e.g., vehicles, heating), energy efficiency, and demand response.

- **Moderate**: The Moderate demand projection assumes that customers electrify some end uses that are currently powered by natural gas or gasoline and adopt moderate (above-code) improvements to energy efficiency. For example, 30% of light-duty vehicles are plug-in electric in 2045. The customers have moderate ability to shift demand, largely represented by assumptions about vehicle charging.

- **High**: The High demand projection is designed to match most of the electrification and efficiency goals set forth in the Mayor's Office's Green New Deal 2019 pLAn. For

[1] "L.A.'s Green New Deal: Sustainability pLAn 2019," https://plan.lamayor.org/.

example, 80% light-duty vehicles are plug-in electric in 2045 and almost 100% of building end uses are electric. All customers adopt the highest efficient technologies available when purchasing equipment. The high levels of electrification result in significantly more demand, even with high levels of energy efficiency, compared to Moderate, but this demand is also more flexible in its timing, helping to align customer demand with when renewable energy availability is highest.

- **Stress**: The Stress demand projection reflects aggressive electrification assumptions (same as High) but with lower efficiency and demand response improvements compared to Moderate, which would otherwise help manage the electrification growth. This projection helps us understand the value of energy efficiency and aligning customer demand with available renewable energy supply.

1.2 Supply-Related Scenario Distinctions

The supply-related scenarios—SB100, Early & No Biofuels, Transmission Focus, and Limited New Transmission—represent different assumptions about the target definition, technology eligibility, penetration of customer-adopted rooftop solar, and ability to build new transmission.

- **SB100**: Per its name, the SB100 scenario most closely complies with existing California law Senate Bill 100 and meets all requirements associated with it (60% renewable energy by 2030 and 100% zero carbon energy by 2045). This is the only scenario in which the 100% target is based on retail sales. This means that a small portion of generation—the equivalent of transmission and distribution losses on the grid—can come from non-renewable sources such as natural gas. SB100 is also the only scenario that allows the use of renewable electricity credits (RECs), which are a market-based mechanism to help meet renewable energy targets. This allows natural gas generation to help meet the 100% target if offset by the purchase of RECs.[2] Together these aspects of the scenario allow for *approximately 10%–15% of generation to be derived from fossil fuels*. Existing nuclear generation is allowed, in compliance with the zero-carbon target of the legislation. Biofuels are allowed as a transition fuel. The 100% target is met in 2045.
    - Evaluated under **Moderate**, **High**, and **Stress** demand projections[3]
- **Early & No Biofuels**: This scenario has the earliest compliance (2035 instead of 2045), prohibits fossil and biofuels, and assumes higher levels of customer rooftop solar adoption. Existing nuclear generation is allowed in order to help contribute to the earlier decarbonization target.
    - Evaluated under **Moderate** and **High** demand projections
- **Transmission Focus**: This scenario assumes lower barriers to new transmission, assumes a new multiterminal direct-current (DC) backbone connecting key locations in and

[2] It is assumed that REC usage is constrained by the existing SB350 California RPS compliance categories.
[3] SB100 is the only scenario to evaluate the Stress projection, which was included with one scenario to better understand the impacts of energy efficiency and demand flexibility.

around the city is built, and prohibits fossil fuels and nuclear energy. Biofuels are allowed as a transition fuel. The 100% target is met in 2045.

- Evaluated under **Moderate** and **High** demand projections

- **Limited New Transmission**: This scenario prohibits new transmission capacity that is not already planned, fossil fuels, and nuclear energy, and assumes higher levels of customer rooftop solar adoption. Biofuels are allowed as a transition fuel. The 100% target is met in 2045.
    - Evaluated under **Moderate** and **High** demand projections

The study also includes a reference case based on LADWP's 2017 Integrated Resource Plan (IRP) recommended case in response to a LADWP Board request to increase transparency. The 2017 IRP reflects the latest Board-approved set of projections and has been slightly modified by assuming Moderate demand projections to allow comparison with other Moderate scenarios. As this IRP extends only through 2036, it is included to allow comparisons of near-term cost and reliability with the LA100 Moderate scenarios.

Figure 1 shows the set of scenarios analyzed.

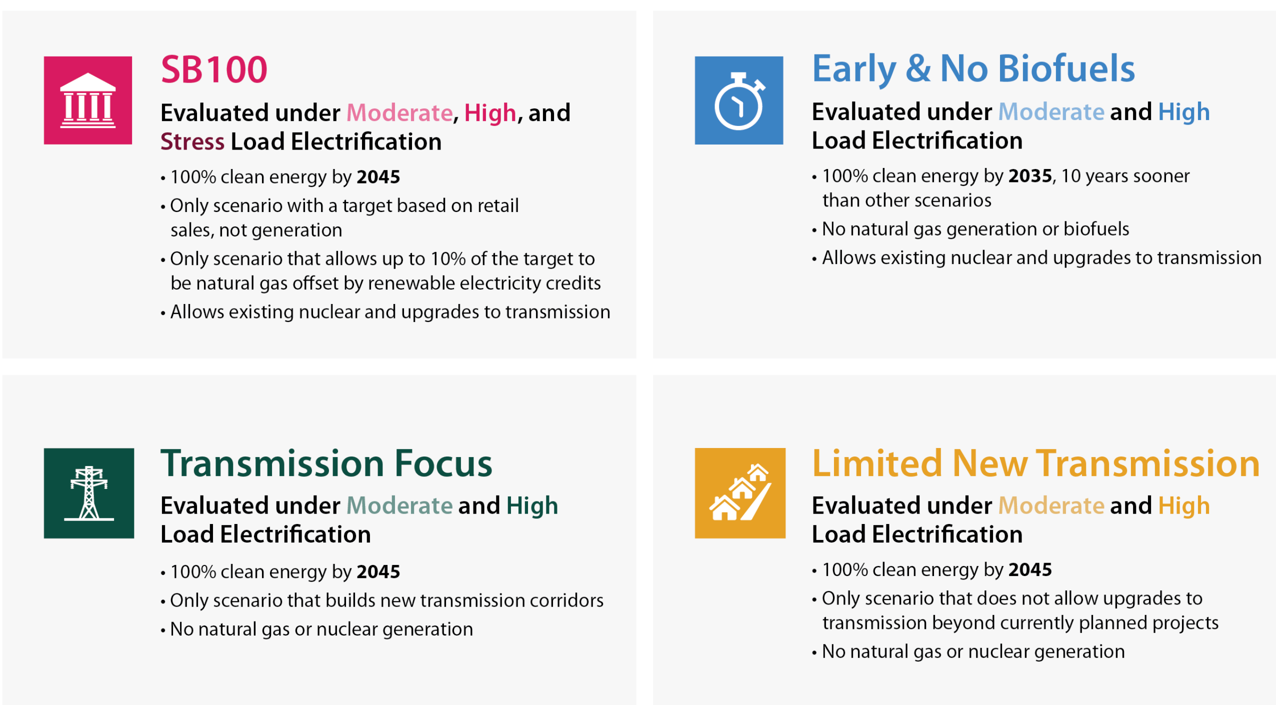

Figure 1. LA100 scenarios

2 Modeling Framework

LA100 is a power system planning study, which is similar to an IRP but with a number of additional components and is longer-term in scope. At its core, LA100 includes a series of modeling and simulation stages to determine the cost-optimal mix of generation, storage, transmission, and distribution resources to ensure reliable operation. This type of long-term assessment forms the basis for future planning studies, such as IRPs, that look ahead 5–15 years to specify the size and types of plants to be built, size and location of new transmission assets, expected outage rates, and other factors.

The objective of the LA100's modeling activities is to identify where, when, how much, and what types of infrastructure and operational changes (generation, transmission, storage, demand response) would achieve reliable electricity at least cost, taking into consideration factors such as renewable energy policies and requirements, technological advancement, fuel prices, and projected demand.[4] This type of modeling is often referred to as capacity expansion modeling, which determines the optimal mix of generation resources by comparing the life cycle cost of different options and their ability to provide various grid services. Capacity expansion models (CEMs) are capable of analyzing both operational and investment (including capital cost) considerations over a long-time horizon and can inform understanding of how the power system might evolve over time.

The capacity expansion modeling is a central element of the LA100 modeling analyses, as it identifies the least-cost investment pathways and associated capacity mix under each scenario and estimates the total system costs associated with each pathway. Because of the large scope of the LA100 study, there is no single CEM in existence that can perform all the analysis required. The use of multiple models to develop and validate utility resource plans is a typical approach. The temporal, geographic, and sectoral scope of this study requires an approach with multiple steps illustrated generally in Figure 2.

The study begins with the two critical steps of data acquisition and defining the scenarios to be evaluated. The workflow then shifts to CEM input modeling (e.g., projections of customer demand and rooftop solar generation, renewable energy resource availability), which serve as exogenous inputs for the CEM. The CEM produces the generation mixes needed to achieve the renewable energy targets as defined in the scenarios, as well as some key performance metrics. However, as discussed in subsequent chapters, the CEM does not have the temporal and spatial resolution to capture all elements of system operational reliability. As such, there are several additional validation modeling steps to ensure the CEM solution produces a reliable power system. If these validation steps find violations, generation and/or transmission is adjusted in the CEM to produce revised results. This is represented by the iterative loop in Figure 2. There is also a set of output modeling steps that generate additional results, including economic and environmental impacts.

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[4] The CEM does not perfectly capture a host of issues that affect investment decisions, including transmission rights, competition with other utilities, construction timelines, and site-specific negotiations. The model serves as a high-level guide to achieve reliable operations, rather than a blueprint for specific investments.

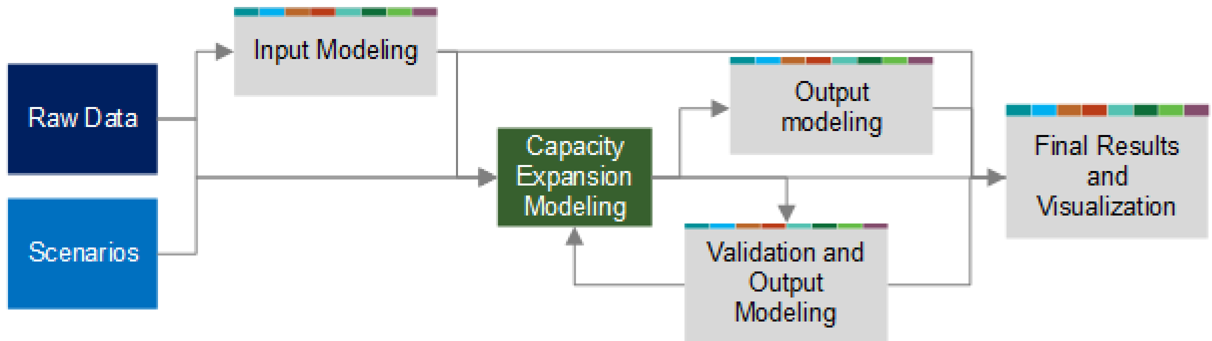

Figure 2. High-level modeling workflow for the LA100 study

3 Detailed Modeling Flow

The general approach illustrated in Figure 2 is broken into the set of 12 discrete steps carried out for each scenario listed below and further described in subsequent chapters.

Input Modeling

1. Estimate load growth, demand profiles, and demand-side technological change (Ch. 3)
2. Determine renewable resource availability and generation profiles (Ch 4. Appendix A)
3. Estimate customer-adopted rooftop solar and storage (Ch. 4)
4. Estimate locations and cost for integrating large ground-mount, distribution-connected solar and storage as a function of capacity (Ch. 5)

Capacity Expansion

5. Develop bulk power, optimal least-cost expansion plan (Ch. 6)

Validation and Output Modeling

6. Simulate grid operation and performance including load balance, operating/replacement reserves, and resource adequacy (Ch. 6)
7. Evaluate transmission system reliability (AC power flow/system stability simulations) (Ch. 6)
8. Validate distribution system operation and estimate cost of required distribution upgrades (Ch. 7)

Output Modeling

9. Quantify greenhouse gas emissions and monetize (Ch. 8)
10. Model air quality changes and public health impacts and monetize (Ch. 9)
11. Evaluate implications for environmental justice (procedural and distributional justice) (Ch. 10)
12. Evaluate local job and economic impacts (Ch. 11)

Note that many of these steps include iterations among the models in order to converge on an optimized solution.

Many of the study components rely on specific types of modeling tools, including both NREL-developed and commercial tools. About a dozen individual tools or models of various types were used in the study (Table 1). Such a large set of tools is required not only because of the range in topics but due to the geographic and temporal scope evaluated in the study—ranging from performance of individual distribution circuits to the entire Western Interconnection at time scales that include subsecond dynamic grid performance and decades-long transmission and generation capacity build decisions.

This is a first-of-kind 100% renewable energy study of a U.S. utility system the size of LADWP that considers all the elements identified in Chapter 1, Figure 4. The study's analysis requirements pushed existing tool sets to new levels of sophistication and drove the development of new data flows among these tools.

Table 1. Modeling Tools Used in the LA100 Study

Chapter	Title	Modeling Tools
Chapter 3	Electricity Demand Projections	ResStock™, https://www.nrel.gov/buildings/resstock.html ComStock™, https://www.nrel.gov/buildings/comstock.html EVI-Pro, https://afdc.energy.gov/evi-pro-lite dsgrid, https://www.nrel.gov/analysis/dsgrid.html
Chapter 4	Customer-Adopted Rooftop Solar and Storage	dGen™, https://www.nrel.gov/analysis/dgen/
Chapter 5	Utility Options for Local Solar and Storage	Distribution grid Integration Solution COst (DISCO). Open-source release coming soon to: https://github.com/NREL/disco
Chapter 6	Renewable Energy Investments and Operations	Resource Planning Model, https://www.nrel.gov/analysis/models-rpm.html PLEXOS, https://energyexemplar.com/solutions/plexos/ PRAS, https://nrel.github.io/PRAS/ PSLF, https://www.geenergyconsulting.com/practice-area/software-products/pslf
Chapter 7	Distribution System Analysis	Distribution Transformation Tool, https://github.com/NREL/ditto Distribution grid Integration Solution COst (DISCO). Open-source release coming soon to: https://github.com/NREL/disco PyDSS, https://github.com/NREL/PyDSS OpenDSS Resource Planning Model, https://www.nrel.gov/analysis/models-rpm.html dGen, https://www.nrel.gov/analysis/dgen/
Chapter 8	Greenhouse Gas Emissions	Methods aligned with prior flagship studies supporting IPCC reports and DOE program *Vision* studies, based on data compiled in the LCA Harmonization project

Chapter	Title	Modeling Tools
Chapter 9	Air Quality and Public Health	Weather Research and Forecasting (WRF) model coupled with Chemistry (WRF-Chem), https://www2.acom.ucar.edu/wrf-chem Environmental Benefits Mapping and Analysis Program - Community Edition (BenMAP-CE), https://www.epa.gov/benmap
Chapter 10	Environmental Justice	No new modeling tools employed, but aligned as closely as possible with CalEnviroScreen, https://oehha.ca.gov/calenviroscreen
Chapter 11	Economic Impacts and Jobs	Computable General Equilibrium JEDI, https://www.nrel.gov/analysis/jedi/models.html IMPLAN, https://implan.com/

4 Data Flow and Overview

The LA100 study produced 50 terabytes of load data, which had to be carefully managed and tracked through the modeling steps. Figure 3 illustrates the detailed data flow that underpins the coordinated modeling, starting with the load modeling in the upper left. Each modeling step uses two sources of data: externally developed input data (labeled "baseline data"), as well as model outputs generated from previous modeling steps. 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.

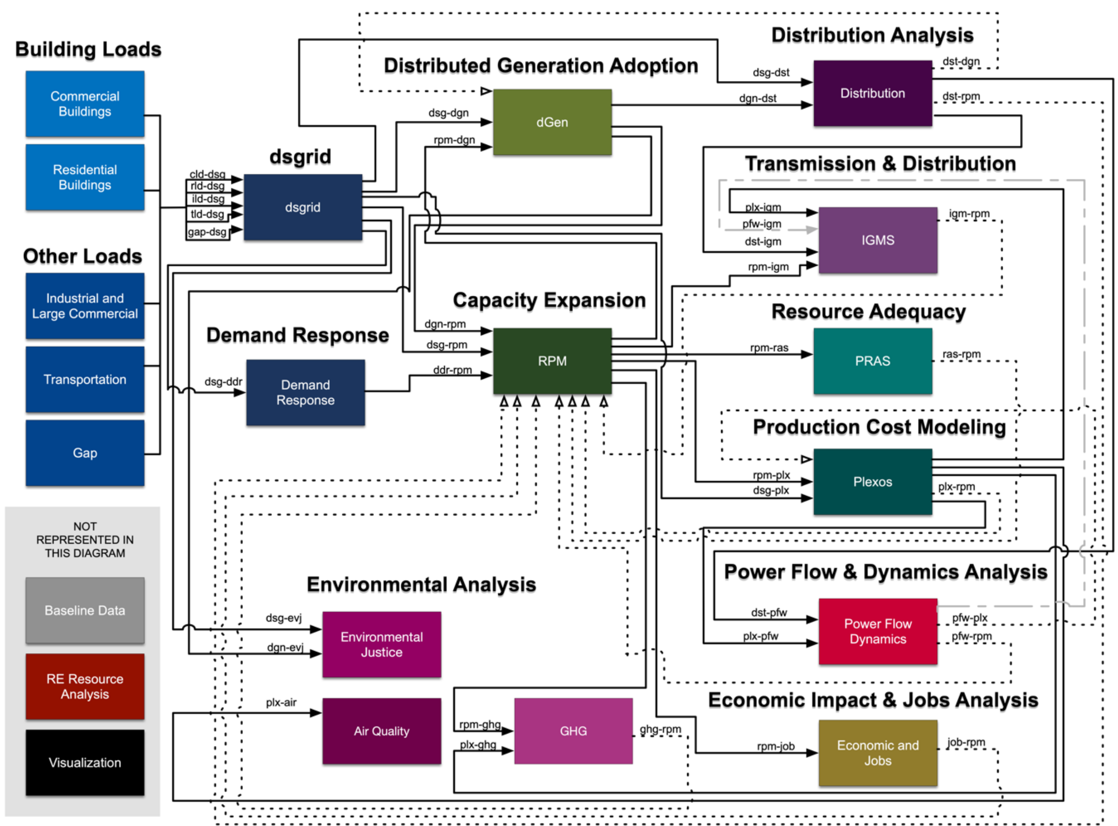

Figure 3. Study data flow, beginning with building and other loads on the left

Solid lines represent data flow; dashed lines represent feedback to inform the modeling.

Each data flow between models was unique. For example, as described more fully in Chapter 3, Figure 4 illustrates the data flow from the load-generating models, through dsgrid, and then out at the required levels of resolution to the downstream LA100 models. The load attributes vary in terms of geographic resolution, timescale, included sectors, and attributes. In similar fashion, other midstream models, such as RPM and PLEXOS, created customized modeling outputs for each downstream model.

A summary of sources for externally developed input data is provided in Table 2.

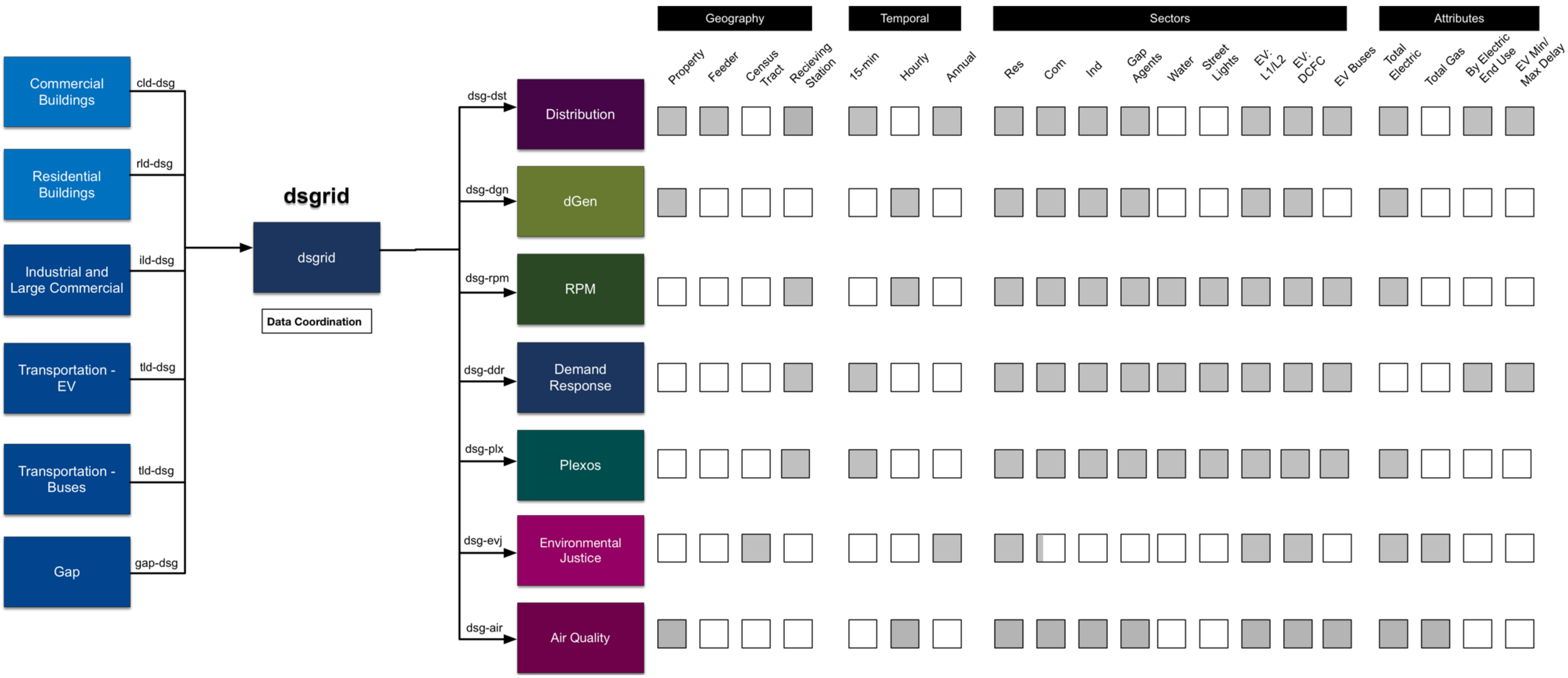

Figure 4. dsgrid flow and model-specific load requirements

Table 2. Summary of LA100 Input Data Appendices

Chapter	Summary of Appendix Data	Related Data Appendices
Chapter 3. Electricity Demand Projections	Provides descriptions of data sources for residential and commercial building characteristics, electric vehicle and transportation loads, industrial, large commercial, and other loads, and demand response. Also includes data acquisition and processing required to set up the LA100-wide agent database.	Appendix A. LA100 Common Data Elements Appendix B. High-Level Overview of Data Sources Appendix C. Residential and Commercial Building Modeling Details Appendix E. Bus Electrification Modeling Details Appendix F. Gap Agent Loads Appendix G. Water System Electricity Demand Appendix H. "Other" Load Modeling Details Appendix I. Agent Generation Appendix J. Agent Load Allocation Appendix K. Agent to Grid Allocation Appendix L. Demand Response Modeling Details
Chapter 4: Customer-Adopted Rooftop Solar and Storage	Describes underlying data sources used for renewable resource performance and technical potential as well as distributed generation modeling	Appendix A. Renewable Resource Performance Appendix B. Model and Data Sources for Distributed Generation Adoption (dGen) Appendix C. Rooftop PV Technical Potential Methods
Chapter 5. Utility Options for Local Solar and Storage	Describes the geospatial data used for the non-rooftop technical potential and economic ranking	Appendix A. Data Sources for Non-Rooftop Technical Potential and Economic Ranking
Chapter 6: Renewable Energy Investments and Operations	Describes the generation and storage technology costs, fuel prices, and data used in RPM, production cost modeling, and power flow and stability	Appendix A. Description of RPM Appendix B. Data Sources for Bulk System Capacity Expansion (RPM) Appendix C. Data Sources for Production Cost Modeling (PCM) Appendix D. Data Sources for Power Flow and Stability
Chapter 7. Distribution System Analysis	Summarizes the geospatial and temporal data sources used for distribution system modeling	Appendix A. Data Sources for Distribution Analysis
Chapter 8. Greenhouse Gas Emissions	Provides an overview of the GHG emission analysis methodology used in the power sector and non-power sectors	Appendix A. Power Sector Methodology and Emissions Factors Appendix B. Non-Power Sector Methodology and Emissions Factors

Chapter	Summary of Appendix Data	Related Data Appendices
Chapter 9. Air Quality and Public Health	Describes the air quality data sources used for model evaluation, emission projections, and scaling factors	Appendix B. Additional Information on Methods and Results for Air Quality Analysis
Chapter 10. Environmental Justice	Provides additional results and background	Appendix A. Additional Analysis of Distributional Justice Aspects of Customer Rooftop Solar
Chapter 11. Economic Impacts and Jobs	Summarizes the data inputs used in economic and job impact analysis	Appendix A. Methodology Detail

5 Advisory Group Feedback

Once per quarter, the NREL team presented progress to the LA100 Advisory Group. After the scenarios were defined in 2018, each subsequent meeting rotated through different topics, in which NREL presented on topics such as methodology, data, assumptions, results, updates to results, and major findings. The goals for this aspect of the meetings were to relay progress, incorporate comments and feedback, and present topics for discussion that would help improve the analysis. The topics presented during each Advisory Group meeting are summarized in Table 3. For each meeting, presentations and meeting summaries are posted to LADWP's website.[5] These meetings were open to the public.

[5] LADWP, "100% Renewable Energy Study," https://www.ladwp.com/ladwp/faces/ladwp/aboutus/a-power/a-p-cleanenergyfuture/a-p-renewableenergystudy.

Table 3. LA100 Advisory Group Meeting Plan

Phase 1 | 2017 LAUNCH AND ORGANIZATION	Phase 2 | 2018 SCENARIOS	Phase 3 | 2019 PRELIMINARY ANALYSIS AND MODELING	Phase 4 | 2020 – 2021 FINAL MODELING AND ANALYSIS
JUNE 23 • Advisory Group Launch • City Council Motion: 100% Renewable Energy Study	**FEBRUARY 15** • Advisory Group Meeting Plan • Preliminary Scenarios and Sensitivities • Field Trip Itinerary • Power Strategic Long-Term Power Resources Plan • Once-Through Cooling Study Update	**JUNE 27** • LA100 Recap and Updates • Buildings Load Modeling • Interpreting Scenario Modeling Outputs • LADWP Financial Office	**MAY 14, 21, 28, JUNE 4** • Electricity Demand Projections and Demand Response • Renewable Options and Trade-offs to Go from 90% to 100% RE • Local Solar and Storage • Hydrogen Eligibility
AUGUST 3 • Advisory Group Charge and Operating Protocols • Introduction to NREL and 100% Renewable Energy Study	**JUNE 7** • Draft 100% Papers: Framing, Data, Methods • Final Scenarios and Sensitivities • Once-Through Cooling Study Update	**SEPTEMBER 19** • LA100 Assumptions & Status • Distribution Grid Analysis • Jobs & Economic Analysis II • Environmental Analysis II	**JULY 9, 16, 23, 30, AUGUST 6** • Pathways to 100% RE • Jobs & Economic Analysis • Environmental Analyses • Distribution Grid Analysis
NOVEMBER 16 • Defining Clean Energy and Renewable Energy • Considerations for Study • Once-Through Cooling Study Overview • Public Outreach Overview	**AUGUST 16** • 100% Data • 100% Methods • Environmental Analysis I • Once-Through Cooling Study Update	**DECEMBER 5** • Results of Initial Run for LA100 Scenarios	**OCTOBER 1, 8, 22, 29** • Community Outreach and Engagement, Website • Technology and Cost Sensitivity Analysis • Greenhouse Gas Emissions • Update to Air Quality Modeling • Reliability
	NOVEMBER 15 • Methods for Calculating Investment & Operating Cost • Jobs & Economic Analysis I		**DECEMBER 10, 17** • Distribution Grid Analysis • Final Update to Bulk Power
			MARCH 3, 4, 11, 18 **APRIL 1** • Air Quality & Health • Environmental Justice • Jobs and Economic Impacts • Synthesis Across the Study • Rate Analysis by LADWP

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