

SLOPE Scenario Planner 2023 Data Sources & Methodology

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1 Introduction

The U.S. Department of Energy’s State and Local Planning for Energy (SLOPE) Platform, published by the National Renewable Energy Laboratory (NREL), aims to empower data-driven state and local energy planning. This documentation explains SLOPE’s web-based map interface called the [SLOPE Scenario Planner](#), which delivers energy system scenario data down to a county-level spatial resolution. The SLOPE Scenario Planner offers users the chance to compare how various energy strategies would influence energy consumption, associated carbon dioxide (CO₂) emissions, air pollutant (SO₂ and NO_x) emissions, and energy system costs out to 2050 at the county, state, and quasi-national (conterminous United States) levels. This document outlines the data that can be accessed via the SLOPE Scenario Planner, the sources of the data, and the methodologies used to create them.

1.1 Overview of Data and Analysis Sources

The SLOPE Scenario Planner illustrates the implications of various energy strategies out to 2050. Each scenario is defined by discrete assumptions related to the future of U.S. energy demand and electricity supply (Table 1), which are interrelated. Results for each scenario are summarized through four key energy system metrics—consumption, CO₂ emissions, SO₂ and NO_x emissions, and system costs—which can be presented at varying levels of spatial resolution ranging from county-level to quasi-national scale.

To define the energy scenario of interest, users select discrete variables within two high-level Scenario Selection categories in the SLOPE Scenario Planner’s Control Panel: Electricity Supply Scenario and Electricity Demand Scenario. The Electricity Supply Scenario selection is defined by a CO₂ emissions reduction trajectory for the U.S. electricity supply mix. Selections under the Electricity Demand Scenario category—including Level of Electrification and Level of Building Energy Efficiency—further define the evolution of energy demand into the future. The Level of Electrification varies the extent to which energy consumers choose to switch from nonelectric to electric end-use technologies in the buildings and transportation sectors. The Level of Energy Efficiency varies the extent of customer adoption of commercial and research-grade energy conservation measures in residential and commercial buildings, resulting in energy savings compared to current typical efficiency levels.

The underlying data associated with all scenario settings were derived from previously published analyses, which primarily focused on state-level and national-scale results; therefore, additional models and data sources were applied to generate the county-level information that is available in the SLOPE Scenario Planner (Table 1). Most models listed in the first two columns of Table 1 were developed and are maintained by NREL, and each one represents the state of the art in techno-economic analysis in its field of inquiry. Each model makes use of the best available information and has undergone intensive validation.

Table 1. Summary of Data Sources for All SLOPE Scenario Planner Inputs

Original Analysis Source (Models)	Additional Analysis	Relevant Scenario Selections
<i>Electricity Supply</i>		
2022 Standard Scenarios (ReEDS and dGen)	SLOPE: Implementing all energy demand scenario settings to enable generation mix and emissions factors for each combination of settings	Electricity Supply Scenario, Level of Electrification, Level of Building Energy Efficiency
<i>Transportation Energy Demand</i>		
Electrification Futures Study (EnergyPATHWAYS)	Transportation Energy & Mobility Pathway Options (TEMPO) ¹ : produce county-level data from the original state-level analysis results	Level of Electrification
<i>Industrial Energy Demand</i>		
2019 Annual Energy Outlook (NEMS)	Cities-LEAP: produce county-level data from the original subnational analysis results	--
<i>Buildings Energy Demand</i>		
Electrification Futures Study (EnergyPATHWAYS)	ComStock ² and ResStock ³ : produce county-level data from the original state-level analysis results	Level of Electrification
Scout Core Measures Scenario Analysis 2019 (Scout)	EIA Form-860 ⁴ : produce county-level data from the original analysis results reported by NEMS Electricity Market Module region	Level of Building Energy Efficiency

¹ Muratori, Jadun, Bush, Hoehne, Yip, et al. 2021.

² “ComStock Analysis Tool.” 2021. www.nrel.gov/buildings/comstock.html.

³ “ResStock Analysis Tool.” 2021; Wilson et al. 2017. www.nrel.gov/buildings/resstock.html.

⁴ “Form EIA-860 detailed data with previous form data (EIA-860A/860B).” 2020. <https://www.eia.gov/electricity/data/eia860/>

Based on the scenario settings selected by the user, the SLOPE Scenario Planner presents projections for four primary energy system metrics (Table 2): consumption, CO₂ emissions, air pollutant (SO₂ and NO_x) emissions, and system costs. Energy consumption, energy CO₂ emissions, and energy NO_x emissions are presented for each economic sector at a county, state, or quasi-national scale, with further delineation between the electric and nonelectric portions of each. Energy SO₂ emissions are presented at a county, state, or quasi-national scale, but without delineation by sector or energy carrier type (electric and non-electric). Energy system costs—including additional investment requirements as well as savings—are reported relative to the business-as-usual projection at a state or quasi-national scale; they are reported separately for the electric and energy demand sectors, and they are further delineated by various categories of capital and operating expenditures.

Table 2. Summary of Information Presented on the SLOPE Scenario Planner

Scenario Planner Energy Metric	Sectoral Breakdown	Categories	Spatial Resolution	Timeframe^a
Energy Consumption	Residential, Commercial, Industrial, Transportation (on-road vehicles)	Electric, Non-Electric	County, State, National	Projected through 2050
Energy CO₂ Emissions	Residential, Commercial, Industrial, Transportation (on-road vehicles)	Electric, Non-Electric	County, State, National	Projected through 2050
NO_x Emissions	Residential, Commercial, Industrial, Transportation (on-road vehicles)	Electric, Non-Electric	County, State, National	Projected through 2050
SO₂ Emissions	Aggregation of Residential, Commercial, Industrial, and Transportation (on-road vehicles)	Aggregation (Electric and Non-Electric)	County, State, National	Projected through 2050
Energy System Costs	Electricity Supply, Energy Demand (including buildings, industry, and on-road vehicle transportation)	Energy Capital, Energy Delivery Infrastructure, Operations and Maintenance	State, National	Projected through 2050

^a Information presented for 2020–2022 is based on model results; such results have been calibrated against historical data, but they will not match exactly with reported energy data.

1.1.1 Major Differences between the 2021 and 2023 SLOPE Scenario Planner Data

This document describes the analysis sources, data, and methodologies that were employed in the 2023 update to the SLOPE Scenario Planner. This update replaces data that were published in the original 2021 launch of the SLOPE Scenario Planner. The most prominent change between SLOPE Scenario Planner versions (2021 and 2023) is the addition of the Inflation Reduction Act. Together with the Infrastructure Investment and Jobs Act of 2021, this policy represents the largest commitment of U.S. federal government investments in the energy system, and it is expected to drive modernization and decarbonization of the system. Recent analysis found that these policies could drive substantial increases in clean electricity shares, with corresponding reductions in energy sector CO₂ emissions and net *decreases* in total and average annual bulk power system costs (Steinberg et al. 2023).

These policies include incentives that influence both energy supply and demand; in turn, the “Reference” settings in the 2023 SLOPE Scenario Planner data include greater electrification and lower power sector emissions intensities than in the 2021 SLOPE Scenario Planner data. As a result, the impacts of different user settings may be more muted than in the previous version of the platform. The number of settings under “Level of Electrification” has also been reduced, due to the fact that analysis to date indicates a new “business as usual” trajectory that includes accelerated and expanded electrification, based on provisions in the Inflation Reduction Act.

Another change between SLOPE Scenario Planner versions is the removal of user settings that were determined to be less utilized. The 2021 SLOPE Scenario Planner included settings that would allow users to explore the impacts of reduced transmission availability, or increased levels of demand flexibility. These settings primarily influenced the System Cost Energy System Metric, because they did not directly influence the overall amount of energy being demanded. They also had a minor impact on CO₂ emissions, because they shifted the economic competitiveness of variable renewable energy technologies relative to other generation options. Both settings were removed in the 2023 update to the SLOPE Scenario Planner.

Finally, the Electricity Supply Scenario definitions were modified in the 2023 SLOPE Scenario Planner update. Users can still select from two different power sector decarbonization trajectories; however, the depth and timing of the emissions reduction requirements have been updated, consistent with the most recently published version of NREL’s Standard Scenarios (Gagnon et al. 2023) at the time of the SLOPE Scenario Planner update.

Finally, the 2023 SLOPE Scenario Planner update introduces a new Energy System Metric, which presents air pollutant emissions results for SO₂ and NO_x. This update represents an important step for state and local planners who are interested in the air quality implications of electrification, energy efficiency, and power sector decarbonization. The methodology used to generate the data for this new planning metric is detailed below, but in general, it closely follows the methodology previously employed for CO₂ emissions in the 2021 SLOPE Scenario Planner data (but with unique emissions factors).

1.2 Interpreting Scenario Results

The SLOPE Scenario Planner includes two resources to assist users with the interpretation of scenario results. First, for any valid combination of scenario selections, a paragraph describing

the chosen scenario is provided in a pane located below the SLOPE Scenario Planner window. The paragraph describes the types of strategies represented in the scenario and qualitative descriptions of how aggressively each strategy is pursued.

The second resource for assisting with the interpretation of scenario results is a set of five “planning metrics,” which provide quantitative information about the assumptions and results for a given set of scenario selections. The purpose of these planning metrics is to provide users with additional intuition about the scenario they are viewing in quantifiable, readily understandable terms that are related to energy goal setting and planning. The planning metrics are defined by the scenario selections, so they remain visible and unchanged regardless of which energy system metric is being visualized. The planning metrics are reported at the state and national levels; so, when a user views county-level data, the planning metrics displayed refer to the state the county is in. By clicking and dragging a slider, the metrics can be reported for any year between 2020 and 2050. Those metrics, along with the sources of data used to calculate them, are described in [Appendix F](#).

Two of the five planning metrics are intended to provide users with intuition regarding the aggressiveness of the assumed extent of electrification (as defined by the Level of Electrification scenario selection). The first energy planning metric summarizes the fraction of residential and commercial space heating services that is supplied by electricity (inclusive of both air-source heat pumps and resistive heating). A second energy planning metric tracks the share of electric vehicles (including battery electric and plug-in hybrid electric vehicles) within the light-duty vehicle stock.⁵

The remaining three planning metrics are defined by the combination of Energy Demand and Electricity Supply Scenario selections. One summarizes the portfolio of electricity generation resources in terms of the share of electricity generation that is provided by renewable energy resources⁶; another presents the percentage reduction in energy CO₂ emissions relative to 2005 levels⁷; and another reports the net change in system cost relative to a business-as-usual projection, to provide an estimate for the level of additional investment that is required to achieve that scenario.

Finally, despite the technical rigor and extensive validation that underlie all the data presented in the SLOPE Scenario Planner, it is important to note the inherent uncertainty in the results shown. This uncertainty stems from a combination of simplifying assumptions made by each model and the fact that our knowledge of the future is always imperfect. All results should be interpreted with this uncertainty in mind.

⁵ The data sources for these metrics are service demand and end-use technology stock data from the Electrification Futures Study.

⁶ Imports of electricity from Canada are assumed to consist of hydroelectric power, and as such they are included in this metric. This metric is calculated as the fraction of total end-use load plus losses that is supplied with renewable energy generation.

⁷ Energy-related CO₂ emissions reductions are calculated from 2005 U.S. Energy Information Administration (EIA) state-level baseline values (“Energy-Related Carbon Dioxide Emissions by State, 2005–2016” 2019). Note that since the percentage CO₂ emissions reduction specified in the electricity supply scenario is enforced in ReEDS as a national constraint, individual states may be above or below the target in the year it is enforced.

The remainder of this documentation describes the analysis sources, data, and methodologies that were employed to populate the SLOPE Scenario Planner. The document is organized around the four energy system metrics that are available for user selection in the Control Panel.

2 Energy Consumption Data

The energy consumption data visualized in the SLOPE Scenario Planner are defined by the Level of Electrification and Level of Building Energy Efficiency scenario selections. Each of these selections will alter sector-level energy consumption relative to the “Reference” scenario (defined by setting all control panel options to “Reference”), which serve as a baseline of comparison to the other scenarios. Energy demand in the “Reference” scenario⁸ includes a representation of the Inflation Reduction Act, which simultaneously drives increased adoption of electric heat pumps to serve space heating needs in buildings and growth in electric vehicle adoption, especially for light-duty vehicles. Energy efficiency also increases modestly over time, based on recent trends in customer adoption of energy conservation measures. Altogether, the assumed evolution of energy demand sectors drives electricity’s share of final energy to grow by approximately 50% over the next three decades in the “Reference” scenario.

Two Energy Demand Scenario settings allow the SLOPE Scenario Planner user to explore alternative trajectories for energy demand. First users can explore a **High Electrification** scenario, which represents transformational change in electricity’s share of final energy consumption, such as that which could result from a combination of technology advancements, policy drivers, and consumer enthusiasm for electric technologies. Electricity’s share of final energy nearly doubles over the next three decades due to the adoption of electric technologies in all major end uses. Data for the High Electrification scenario are derived from NREL’s Electrification Futures Study (EFS) (“Electrification Futures Study: A Technical Evaluation of the Impacts of an Electrified U.S. Energy System” 2021). Detailed documentation for the development of the High Electrification level presented on the SLOPE Scenario Planner can be found in the EFS publication series (NREL 2021).

Each Level of Electrification defines the hourly demand for electricity and annual direct fuel use within the residential buildings, commercial buildings, transportation, and industrial sectors. Aggregate results are presented on the SLOPE Scenario Planner, but they are rooted in detailed information from the EnergyPATHWAYS model that tracks final energy demand by technology, sector, state, and year out to 2050 (Haley 2019).

Users can also explore a **High Building Energy Efficiency** scenario, which represents the availability and adoption of more energy efficient equipment and building envelope technologies in U.S. residential and commercial buildings from 2022 to 2050. The represented energy conservation measures include both currently available technologies up to best available efficiencies, as well as higher efficiency technologies currently in development but expected to be commercialized between the present year and 2030. Technologies and building envelope

⁸ Note that the 2023 update to the SLOPE Scenario Planner involved a significant change to the “Reference” scenario assumptions. Customer incentives available under the Inflation Reduction Act are assumed to accelerate and expand electrification, resulting in energy consumption patterns in the 2023 “Reference” scenario that are comparable to the Medium Electrification scenario setting in the 2021 release.

components are assumed to be replaced at end of life; this scenario does not consider significant accelerated replacements (or early retirements), efficiency policy mandates, or incentives that reduce the total installed price of more efficient building technologies.

The Level of Energy Efficiency specifies site electricity and fossil fuel savings by building sector and end use for each of the 25 Electricity Market Module (EMM) regions in the National Energy Modeling System (NEMS).⁹ These site energy savings are calculated using Scout, which quantifies savings relative to the NEMS “reference case” from the 2021 Annual Energy Outlook (Nalley and LaRose 2021) (GitHub 2023) (Scout 2023) (U.S. Department of Energy 2023).

Data for the High Building Energy Efficiency scenario are derived from the Scout Core Measures Scenario Analysis 2019 (Langevin et al. 2021). A detailed description of the High Building Energy Efficiency scenario can be found in Langevin et al. (2019), where it is referred to as “scenario 3.” Updated versions of the energy conservation measures included in the scenario, as well as documentation of changes since the initial scenario release, can be found on Zenodo (Langevin et al 2021).

This section summarizes the additional processing steps that were required to disaggregate the state-level energy consumption data from the EFS and EMM region-level energy savings data from Scout to a county resolution and prepare the data for use in the SLOPE Scenario Planner. Wherever we introduce a proxy dataset in the following subsections, our disaggregation methodology was to simply allocate the state-level energy consumption in the category under discussion to the counties within each state, using the county-level values in the proxy dataset as weights. In each case, the county-level values in the proxy dataset were divided by the state sum, and the resulting fraction was multiplied by the state-level energy consumption to produce a county-level estimate. Some proxies offer projections out to 2050, while others only offer historical data. In the latter case, we assume no change in the intra-state distribution of energy consumption for the given end-use technology through 2050.

2.1 Residential and Commercial Energy Consumption

2.1.1 Level of Electrification

Building off the state-level EFS results for residential and commercial energy consumption in all 50 states, we disaggregated the results of each relevant EnergyPATHWAYS scenario to the county-level using building stock data from NREL’s ResStock™ and ComStock™ models as a proxy. We used the ResStock and ComStock source input files to establish county-level data distribution factors, which we applied to the state-level final energy demand outputs for each EFS electrification level. The input files utilize Census Public Use Microdata Area (PUMA) geometries related to county geometries.

For the residential sector, the EFS input file values were separated into heating and nonheating demand sector categories. The PUMA-level heating file was used to generate state and county level summaries by fuel type, yielding county-level distribution factors by fuel type. The

⁹ The EIA Electricity Market Module regions align with North American Electric Reliability Corporation subregions and Independent System Operator territories: https://www.eia.gov/outlooks/aeo/pdf/nerc_map.pdf.

residential allocation factors for nonheat demand sectors were derived by weighting building-type distribution at the PUMA level and aggregating to state and county summaries.

A similar process was conducted for the commercial sector; however, the ComStock input file was already at the county level and, therefore, required less aggregation.¹⁰ County-level distributions for commercial energy demand were derived by aggregating the building area by fuel type to the state and county levels for electricity, pipeline gas, and district services. Solar and diesel fuel allocations are derived from aggregations of total building area, irrespective of fuel type, at the county and state level.

2.1.2 Level of Building Energy Efficiency

Scout reports annual energy savings as a fractional reduction in annual energy consumption from the NEMS “reference case,” broken out by sector and final energy (i.e., electricity vs. direct fuel consumption) for each of the 25 EMM regions. These regional fractional energy savings were applied to the county-level consumption associated with the “Reference” scenario by mapping counties to EMM region.¹¹ Finally, county-level fractional energy savings were multiplied by consumption from the “Reference” scenario for each year, sector (residential and commercial energy consumption), and final energy category (electricity and direct fuel consumption). Since Scout is based on NEMS simulations, energy consumption (or savings) data for the High Energy Efficiency scenario were only available for the conterminous United States. Therefore, the viewing of Alaska and Hawaii is disabled when the “High Building Energy Efficiency” setting is selected in the Scenario Planner Control Panel.

2.2 Industrial Energy Consumption

County-level industrial energy consumption data in the SLOPE Scenario Planner are replicated from the SLOPE Data Viewer.¹² As a result, the SLOPE Scenario Planner includes only one projection for industrial energy consumption, which means the data are independent of Energy Demand Scenario selections associated with electrification and energy efficiency. In other words, we do not assume any meaningful electrification of the industrial sector—because many energy-intensive activities are difficult to electrify—and we do not represent other strategies for increasing energy efficiency or reducing direct emissions from within the industrial sector.

Due to a lack of county-level data, we currently only consider industrial sector demand for natural gas and electricity; all other fuel types are excluded from the industrial energy consumption values presented on the SLOPE Scenario Planner. Figure 1. compares historical energy demand from the U.S. industrial sector for all fuel types (“Monthly Energy Review - November 2021” 2021) against what is presented for industrial energy consumption in the SLOPE Scenario Planner. The resulting gap indicates that roughly half of the industrial sector’s

¹⁰ Some alterations to the ComStock input files were necessary to correct for three outdated county FIPS values—two were renumbered, and the third was merged into another county FIPS record.

¹¹ The mapping from EMM region to county involved an interim step of matching counties with their ReEDS balancing areas (see Section 3.1). For the ReEDS balancing areas that overlap multiple EMM regions, we weighted the influence of each EMM region overlapping a given balancing area by the distribution of electricity generation capacity within the balancing area (from the EIA-860 database, as a proxy for energy consumption).

¹² A detailed methodology for the SLOPE projections of industrial sector demand for electricity and natural gas at a county level are available on the SLOPE Data Viewer: <https://app.box.com/s/t0t3j6zztzan94a4tu1so8pse4btkn1>.

total energy consumption is not captured in the SLOPE Scenario Planner, primarily due to the lack of county-level data for petroleum demand (“Monthly Energy Review - November 2021” 2021) in our projection of industrial energy consumption.

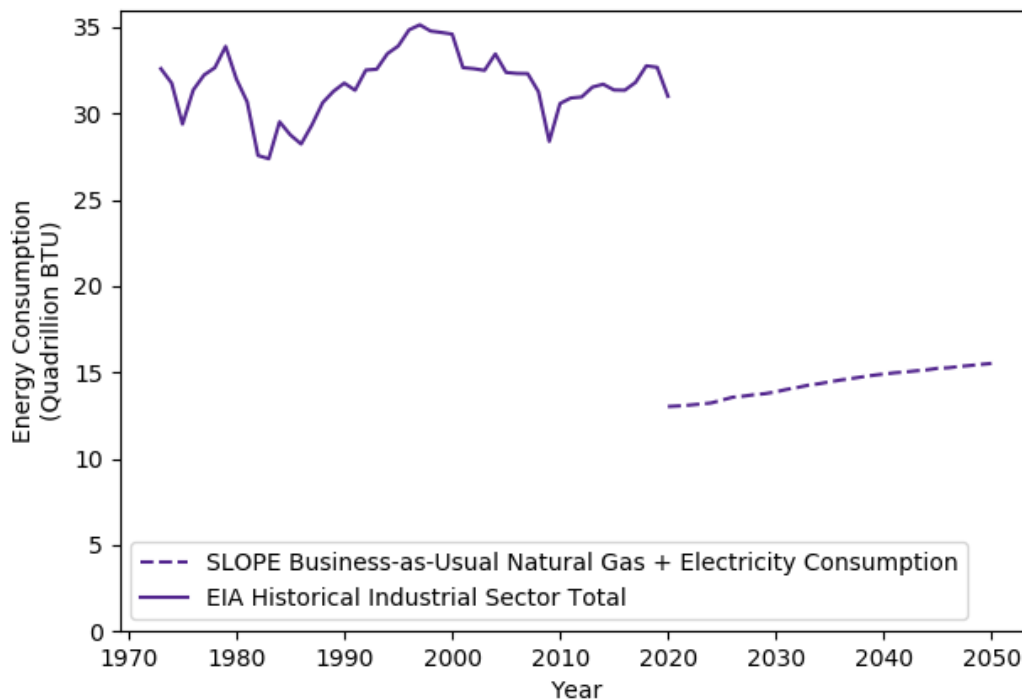


Figure 1. Comparison of historical total U.S. industrial sector energy consumption against the SLOPE Scenario Planner’s business-as-usual projection for industrial sector demand for natural gas and electricity

2.3 Transportation Energy Consumption

The end-use technologies that make up the transportation sector’s energy consumption are diverse in terms of their spatial distribution, and vehicles are mobile and exhibit distinct patterns of movement by type. Therefore, several different proxies were used to disaggregate the EFS state-level transportation energy consumption data to the county level.¹³

For all light-duty vehicles and motorcycles, county-level results from the TEMPO™ model were used as a proxy for the state-to-county level disaggregation. The TEMPO model was previously employed for the SLOPE Data Viewer to project county-level sales, stock, and vehicle miles traveled (VMT) for personally owned light-duty vehicles (by type) through 2050, consistent with the EFS High Level of Electrification.¹⁴ We leveraged the previously developed county-level VMT data to develop a mapping from each light-duty vehicle and motorcycle subsector (from the EFS) to corresponding vehicle types in the TEMPO dataset (see [Appendix C](#), Table C-2.).

¹³ The mapping of each transportation subsector (as referred to in the detailed dataset available for download by the “SUBSECTOR” column) to the proxy used for disaggregation is listed in [Appendix C](#), Table C-1. .

¹⁴ A detailed methodology behind the creation of the TEMPO projections is available on the SLOPE Data Viewer page: <https://gds-files.nrel.gov/slope/SLOPE%20TEMPO%20Transportation%20Methodology.docx>.

To spatially disaggregate the energy consumed by medium- and heavy-duty trucks and buses, we used a county-level dataset of total 2016 diesel fuel consumption created through previous SLOPE efforts as a proxy for the distribution of such vehicles. [Appendix D](#) details the methodology behind the creation of that dataset.

The SLOPE Scenario Planner data excludes energy consumption from all non-road transportation subsectors—including aviation, shipping, boating, and travel and shipping via rail—because we have not yet identified acceptable county-level proxy datasets. Altogether, these non-road transportation subsectors accounted for roughly 10% of energy consumption within the transportation sector in 2020, and the EFS estimates that they could account as much as 25% of the sector’s energy consumption by 2050 (Figure 2). Finally, while the EFS scenarios assume steady increases in the efficiency of the U.S. transportation fleet, the SLOPE Scenario Planner does not consider energy efficiency of vehicles in isolation. In other words, transportation energy consumption is unaffected by the Level of Building Energy Efficiency setting in the SLOPE Scenario Planner Control Panel.

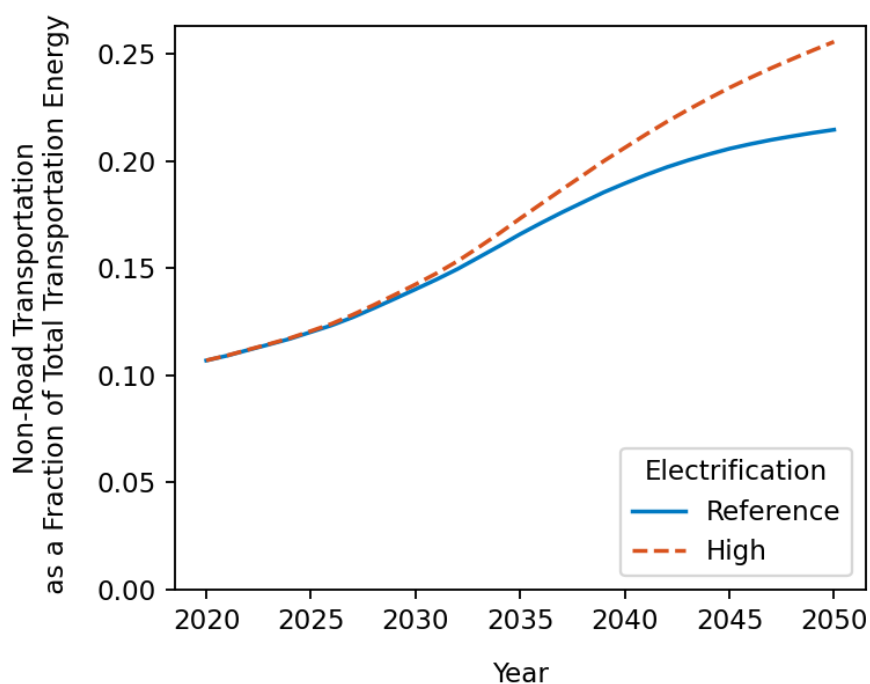


Figure 2. The share of projected energy consumption from all non-road transportation subsectors, which are not included in the data reported in the SLOPE Scenario Planner (EFS 2021).

3 Energy Sector CO₂, SO₂, and NO_x Emissions

To translate the SLOPE Scenario Planner’s energy consumption data (Section 2) into projections for energy CO₂, SO₂, and NO_x emissions levels, we applied annual emissions factors for electric and nonelectric energy sources. Unique emissions factors were developed for each emissions type (CO₂, SO₂, NO_x) and each Electricity Supply Scenario (Section 3.1); these factors were then combined with annual electricity demand to generate estimates for electricity-related CO₂, SO₂, and NO_x emissions for each energy demand sector (Section 3.2). To estimate emissions

associated with direct fuel use in buildings, transportation, and industry, we applied emissions factors for each fuel type (Section 3.3).

3.1 Electricity Supply Scenarios from the ReEDS Model

The Electricity Supply Scenarios available on the SLOPE Scenario Planner were developed using NREL’s Regional Energy Deployment System (ReEDS™)¹⁵ and the Distributed Generation (dGen™)¹⁶ models. ReEDS is NREL’s flagship power system planning model, which projects future bulk power system infrastructure investment decisions using data representing today’s electric power system and various assumptions about future technology costs and improvements, policies, electricity consumption patterns, and operational constraints. To represent the evolution of distribution-sited systems, results from the dGen model for future customer adoption of distributed solar and energy storage are included as inputs to each ReEDS scenario.

Because of the complexity of the bulk electricity system, ReEDS aggregates the transmission network into regions termed “balancing areas” (Figure 3), within which no transmission limitations are represented. These balancing areas constitute the native spatial resolution for serving load and investing in generation and storage assets within ReEDS. Transmission of power can occur on interfaces across regions, and investments can be made within the model to expand the capacity of these interfaces. The ReEDS balancing areas respect state boundaries, such that native ReEDS results can readily be aggregated to the state level. However, the spatial extent of the ReEDS model does not include Alaska or Hawaii, so electric sector results (including emissions factors and power system costs) are not included for these states on the SLOPE Scenario Planner.

¹⁵ Ho et al. 2021.

¹⁶ Prasanna et al. 2021; Sigrin et al. 2021.

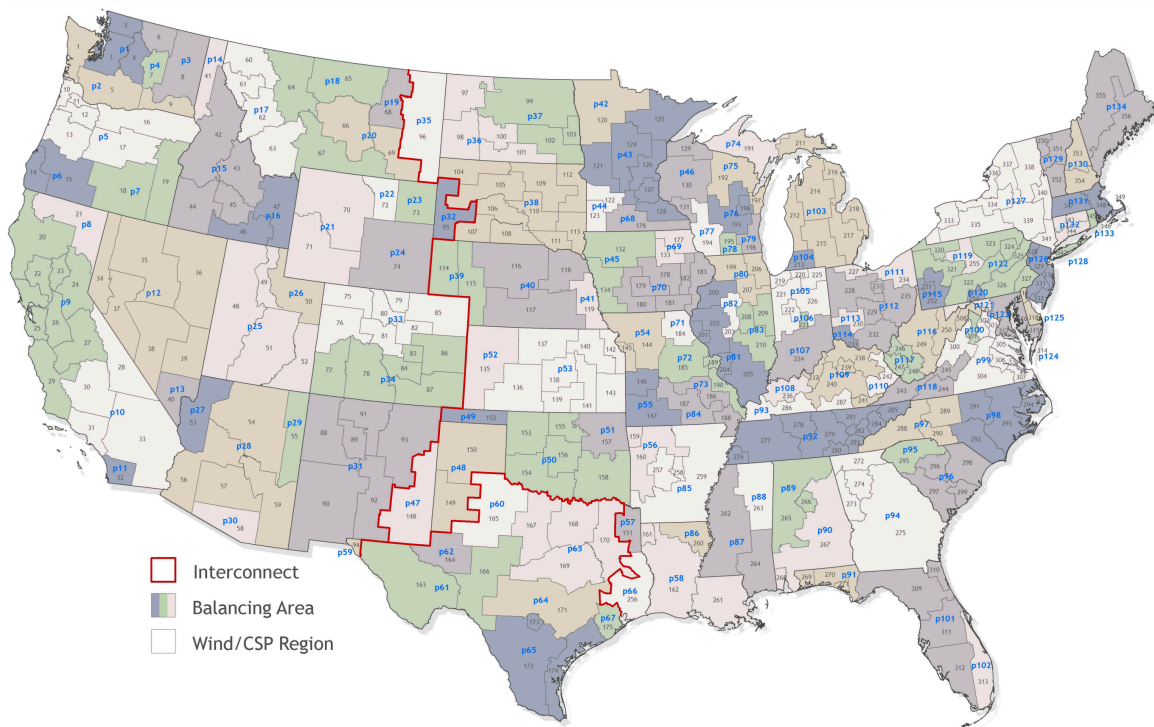


Figure 3. Map of ReEDS balancing areas

In developing the Electricity Supply Scenarios for the SLOPE Scenario Planner, we populated the ReEDS model with electricity demand profiles based on the highly detailed bottom-up projections of future changes in electricity demand patterns for each Level of Electrification (Section 2). To create an electricity demand profile representing the “High Energy Efficiency” Energy Demand Scenario, we applied fractional load derates to the “Reference” electrification demand profile for each year and balancing area within ReEDS. These derates were calculated by mapping annual fractional electricity reductions (reported by Scout) from NEMS EMM regions to balancing areas, with weighting to account for each sector’s share of total electric load using the bottom-up energy consumption projections described in Section 2. This methodology assumes that the annually-averaged reductions in electricity consumption reported by Scout are spread evenly across all hours of the year. In addition, our implementation reduces *annual* electricity demand based on the spatial resolution and scenario outcomes from Scout, and it does not capture the potential effects of energy efficiency on the *shape* of electricity demand. Such effects could be captured in future updates if hourly load profiles associated with the widespread adoption of energy conservation measures are available.

These electricity demand assumptions were then combined with the Electricity Supply Scenario definitions from the 2022 Standard Scenarios analysis (Gagnon et al. . The “Reference” Electricity Supply Scenario setting is inclusive of key provisions of the Inflation Reduction Act related to electricity production technologies. Most notably, this includes the investment and production tax credits for zero-carbon emitting electricity generation and storage, as well as tax credits for CO₂ capture and storage and existing nuclear plants (Steinberg et al. 2023). We further leveraged two scenario definitions from the 2022 Standard Scenarios, which represent carbon policies (or caps) that force a linear reduction in U.S. bulk power system CO₂ emissions

to: (a) 95% below 2005 levels by 2050 or (b) net-zero by 2035. These carbon policy assumptions were layered with all available Energy Demand Scenario settings presented on the SLOPE Scenario Planner.¹⁷ Therefore, when SLOPE Scenario Planner users select a given Electricity Supply Scenario setting, the corresponding emissions projections reflect ReEDS scenario results based on the combination of all user selections.¹⁸

3.2 Emissions from Electric Energy Consumption

Emissions that result from electricity consumption are defined by the portfolio of generation resources being used to supply power to the grid; therefore, we calculated emissions factors from the ReEDS results, based on the dispatch decisions for each year and Electricity Supply Scenario.¹⁹ We included only direct emissions of CO₂, SO₂, and NO_x to the atmosphere in the calculation of emissions factors; other life cycle emissions associated with building or maintaining power system infrastructure were not considered.

To calculate emissions associated with electricity consumption for each sector, we summed state-level CO₂, SO₂, or NO_x emissions reported by ReEDS for each year and allocated them proportionally according to the electricity consumed by each sector and county. Although the native spatial resolution in ReEDS (the balancing area) could allow us to calculate emissions at a finer spatial resolution, we sum to the state level to approximate inter-balancing area transmission of electricity. This methodology was adopted to represent the pervasive trading of electricity supply, but it does not reflect the ability (and common practice) of transmitting electricity across state boundaries.

By multiplying annual electricity consumption by annually averaged emissions factors, we assumed that the consumption by each end use is spread out evenly across all hours of the year—that is, we did not consider hourly variation in both the emissions from electricity generation and energy consumption by each end use technology within each sector.

3.3 Emissions from Nonelectric Energy Consumption

To calculate annual CO₂, SO₂, and NO_x emissions from direct fuel use in buildings, transportation, and industry, the annual consumption of each fuel type was multiplied by an emissions factor related to the average mass emitted per MMBTU of fuel consumed. Those emissions factors, their sources, and any other assumptions made can be found in [Appendix E](#) and the footnotes below Table E-1. Most values are from the Environmental Protection Agency's (EPA's) Emissions Factor Hub, EPA's 2020 National Emissions Inventory, and the EIA's published list of emissions coefficients (US EPA 2015; "Carbon Dioxide Emissions Coefficients" n.d.). By implementing representative emissions factors by fuel type, our results do

¹⁷ The use of balancing area generation mix results would yield electric sector emissions factors of zero in balancing areas that import 100% of their annual energy within ReEDS.

¹⁸ 0 lists all the ReEDS scenarios included in the SLOPE Scenario Planner by Electricity Supply Scenario and Level of Electrification. The ReEDS scenario names are used as unique identifiers in the detailed data that are available for download.

¹⁹ Each electricity generation technology in ReEDS is associated with an emissions rate for CO₂ and several other pollutants. See Section 3.2 and Table 9 in the 2020 ReEDS model documentation for the rates of individual generation technologies and plant vintages (Ho et al. 2021).

not explicitly capture the combustion efficiencies of the equipment options that are detailed in the EnergyPATHWAYS results from the EFS or the Scout Core Measures Scenario Analysis.

Finally, note that all sectoral and fuel-type exclusions described in Section 2 propagate through to the energy-related emissions results as well. Therefore, industrial emissions only include emissions associated with natural gas and electricity consumption, and transportation emissions only reflect on-road transportation services. These exclusions explain why the national-scale results for energy emissions on the SLOPE Scenario Planner are lower than annual data tracked by the EIA.

4 Energy System Costs

State-level energy system costs are reported on the SLOPE Scenario Planner as the change from a business-as-usual projection (i.e., “Reference Case” in [Appendix A](#)); investment levels that exceed those in the business-as-usual projection will appear as incremental costs (positive values), whereas reduced investment levels will appear as system cost *savings* (negative values). If a SLOPE Scenario Planner user selects the Reference level for all scenario selections, no costs will be displayed because the change from a business-as-usual projection will be zero for all cost categories. For a valid set of scenario selections, a net system cost level will also be presented, which reflects the sum of all cost categories in a given year.

We adopted the approach of presenting relative energy system costs (rather than absolute changes) because the EFS data that underlie the Level of Electrification track only *incremental* costs associated with equipment capital in demand sectors (i.e., the change in capital cost for an air-source heat pump compared to a natural gas furnace). To provide some context for the system cost results presented in the SLOPE Scenario Planner, calculations from the EFS estimate that the net present value of economy-wide expenditures related to energy supply and consumption under a business-as-usual projection are on the order of \$28 trillion (through 2050) (Murphy et al. 2021); however, it is important to note that this is likely an underestimate.

All energy system incremental costs and savings represent annual cash flows discounted to 2019 at a 3% discount rate (in keeping with the EFS) and adjusted for inflation to be reported in 2020 dollars (Murphy et al. 2021). Our cost methodology largely follows that of Murphy et al. (2021); Appendix C, Section C.1 of that publication details the methodology used for the SLOPE Scenario Planner, provides more context, and explains limitations of the scope of the costs reporting.

4.1 System Costs Associated with Electricity Supply

Electricity system costs (displayed in shades of blue in the SLOPE Scenario Planner) are based on ReEDS and dGen results, for which annualized system costs are aggregated to the state level. These costs represent capital expenditures associated with infrastructure investments as the debt service that would be incurred on those investments each year, assuming a 20-year financial lifetime for all bulk power system investments.

The electricity supply system costs for High Electrification will always be higher than those associated with a business-as-usual projection, and a carbon policy for the power system is similarly expected to increase investment requirements on the bulk power system; therefore, both

of these scenario settings will result in incremental costs (i.e., positive values) on the SLOPE Scenario Planner. On the other hand, electricity supply system costs for an increasing Level of Building Energy Efficiency will be *lower* than those associated with a business-as-usual projection, due to the reduced demand for electricity and, in turn, new investments in new electricity supply resources.

The following categories are delineated for the electricity supply system costs:

- **Electricity Supply: Generation and Storage** – reflects capital costs associated with new generation and storage investments, which are dominated by utility-scale projects and account for savings associated with the federal investment tax credit (for select technologies).
- **Electricity Supply: Fuel and Operations and Maintenance (O&M)** – reflects annual expenses associated with operating the bulk electricity system, as dispatched within ReEDS, including fuel consumption costs associated with electricity generation; non-fuel O&M costs associated with electricity generation and storage; and the federal production tax credit (for select technologies).
- **Electricity Supply: Transmission and Distribution (T&D [Wires])** – reflects electricity distribution, administration, intra-regional transmission, and long-distance transmission costs consistent with each unique combination of user settings, following the methodology presented in Brown et al. (2022).

As with our calculation of energy sector emissions, no cost adjustments were made to account for interstate energy trading.

4.2 Demand-Side Costs and Savings

4.2.1 Level of Electrification

Reported system costs for the energy demand sectors (displayed in shades of orange in the SLOPE Scenario Planner) are based mainly on the same EnergyPATHWAYS modeling that created the energy consumption projections for the various Levels of Electrification presented. Details of the methodology for producing these estimates for demand sector system costs can be found in Murphy et al. 2021.

Although EnergyPATHWAYS results were reported at the state level, the costs and savings associated with them were reported for the conterminous United States. To approximate state-level costs and savings, we first calculated state-level electrification (i.e., the increase in annual load versus the Reference Electrification level) as a fraction of the total electrification across the conterminous United States in each year.²⁰ We then multiplied the aggregate, quasi-national

²⁰ To do this, we subtracted the annual state-level electricity load in the Reference Electrification level from the annual state-level electricity load in the Medium and High Electrification levels (as seen in ReEDS).

costs and savings from EnergyPATHWAYS by each state’s fraction of electrification to apportion and report demand-side energy system costs and savings at the state level.

The following categories are delineated for the demand sector system costs:

- **Demand: Equipment Capital:** represents the incremental capital costs for electric end-use equipment compared to their direct fuel use counterparts.
- **Demand: Fuel Consumption and O&M:** represents direct fuel consumption costs in all demand sectors and O&M costs for end-use equipment.
- **Demand: Fuel Infrastructure:** reflects infrastructure and delivery costs outside the electric sector, and it is dominated by natural gas transmission and distribution pipelines.

The system costs for the energy demand sectors are largely independent of the chosen Electricity Supply Scenario, as they primarily depend on capital and operational expenditures within the buildings, transportation, and industrial sectors. However, the “Demand: Fuel Consumption and O&M” category does vary slightly depending on the selected Electricity Supply Scenario, because natural gas prices from ReEDS (which has an endogenous representation of the price elasticity of demand) are used to scale the cost of natural gas burned for nonelectric final energy demand. Moreover, final energy demand estimates are specific to the energy demand sectors of buildings, transportation, and industry. Approximately 10 quads of annual energy consumption (at a national scale) from refining; oil, coal, and natural gas extraction; and combined heat and power are excluded from our final energy consumption results.

4.2.2 Level of Building Energy Efficiency

Based on the Scout scenario results, the efficiency measures deployed in U.S. residential and commercial building energy efficiency measures (from 2022 to 2050) influence two demand sector cost categories: *incremental equipment costs* associated with purchasing efficient technologies and *reduced consumer energy costs* due to energy savings. The total incremental equipment cost investment of \$313 billion (from 2022 to 2050) leads to site energy savings in 2050 of 5.33 quads (1553 TWh) and consumer energy cost savings of \$96 billion. Considering savings from all years across the full time horizon, site energy savings are 104 quads and consumer energy cost savings are \$1.9 trillion.

Scout calculates incremental equipment cost as the difference between the cost of the efficient equipment adopted and the comparable baseline technology. For example, if a heat pump water heater that costs \$2,500 is adopted in place of an electric resistance water heater that costs \$1,000, the incremental equipment cost is \$1,500. The adoption of higher performance equipment yields energy use reductions. These energy savings lead to lower energy costs from lower utility bills, where the consumer energy cost savings are calculated as the difference in utility bills with the more efficient equipment adopted and if the baseline equipment were instead adopted.

To characterize these equipment costs for presentation in the Scenario Planner, we disaggregated *national* incremental equipment stock costs produced by Scout (for each year and building sector) based on state-level projections of energy efficiency potential from the Electric Power

Research Institute (EPRI 2017). The study published estimates of potential reductions in electricity consumption for every five years from 2020 to 2035 given incentives ranging from \$0–\$20/MWh. We used savings projected for the \$20/MWh incentive as our proxy for disaggregating equipment costs since it most closely reflects the conditions modeled by Scout for the “higher energy efficiency” scenario. Linearly interpolating between years and extrapolating no change in energy efficiency potential from 2035 onward, we disaggregated equipment costs to the state level by multiplying the national value (from Scout) by the fraction of national energy efficiency potential (from EPRI) for each sector and year.

Consumer energy costs (savings) are treated differently depending on the final energy consumption category. Energy savings due to reductions in electricity consumption are expressed in the “Electricity Supply” categories since lower electric load results in reduced electric system costs within ReEDS. Scout also provides energy savings data for non-electric energy consumption by EMM region, but the categorization of energy conservation measures did not map cleanly to the technology cost categories from the EFS. Therefore, we disaggregated the Scout non-electric consumer energy cost savings to states according to each state’s share of total commercial and residential building non-electric energy consumption within each EMM region. This assumption that savings are evenly distributed across fuels and demand technologies for EMM regions does not reflect the effects of climate zones within an EMM region, which would likely influence the localized savings potential associated with heating and cooling demands.

5 Data Access

In addition to downloading the data as displayed in the SLOPE Scenario Planner, more detailed datasets that include energy consumption and CO₂ emissions by subsector and technology (e.g., electric space heaters, light-duty internal combustion engine vehicles) are available for download from SLOPE, along with supporting metadata (e.g., a county name-to-FIPS code mapping). For user reference, this document includes the names of ReEDS scenarios and end-use electrification scenarios as they appear in this more detailed dataset (see [Appendix A](#) and [Appendix B](#)).

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Appendix A. ReEDS Scenarios

Table A-1. ReEDS Scenarios and the Three Settings That Map to Each Scenario Within the SLOPE Scenario Planner

Scenario Set	Electricity Supply Scenario	End-Use Electrification	Building Energy Efficiency	ReEDS Scenario Name
REFERENCE	Reference Case	Reference	Reference	memt
SUPPLY-SIDE VARIATIONS (ONLY)	95% grid decarbonization by 2050	Reference	Reference	memt_95by2050
	100% grid decarbonization by 2035	Reference	Reference	memt_100by2035
ELECTRIFICATION VARIATIONS	Reference	High	Reference	hemt
	95% grid decarbonization by 2050	High	Reference	hemt_95by2050
	100% grid decarbonization by 2035	High	Reference	hemt_100by2035
ENERGY EFFICIENCY VARIATIONS	Reference	Reference	High	efficiency
	95% grid decarbonization by 2050	Reference	High	efficiency_95by2050
	100% grid decarbonization by 2035	Reference	High	efficiency_100by2035

Appendix B. Electrification Scenario Name Mapping

Table B-1. Mapping of Electrification Scenario Names as Seen by Scenario Planner Users to the Detailed Datasets Available for Download

Term Used in Scenario Planner	Term Used in Downloadable Datasets
Reference	MEDIUM ELECTRIFICATION - MODERATE TECHNOLOGY ADVANCEMENT
High	HIGH ELECTRIFICATION - MODERATE TECHNOLOGY ADVANCEMENT

Appendix C. Transportation Disaggregation Proxies

Table C-1. Mapping of Transportation Subsectors to the Proxies Used for Disaggregating Energy Consumption From the State to County Level

Subsector	Proxy Dataset
MEDIUM DUTY TRUCKS	Diesel fuel consumption
HEAVY DUTY TRUCKS	Diesel fuel consumption
LIGHT DUTY AUTOS	TEMPO Vehicle Miles Traveled
LIGHT DUTY TRUCKS	TEMPO Vehicle Miles Traveled
TRANSIT BUSES	Diesel fuel consumption
SCHOOL AND INTERCITY BUSES	Diesel fuel consumption
PASSENGER RAIL	Excluded ²¹
FREIGHT RAIL	Excluded
AVIATION	Excluded
DOMESTIC SHIPPING	Excluded
MOTORCYCLES	TEMPO Vehicle Miles Traveled
INTERNATIONAL SHIPPING	Excluded
RECREATIONAL BOATS	Excluded

²¹ The subsectors with the value “Excluded” in this column are off-road transportation subsectors that were excluded from the data reported in the SLOPE Scenario Planner because no adequate proxy dataset could be identified for disaggregating these values to the county level.

Table C-2. Mapping of End-Use Transportation Technologies to Vehicle Categories Within the TEMPO VMT Dataset for Use in Spatial Disaggregation

All demand technologies shown here are subsets of the subcategories denoted as using the “TEMPO Vehicle Miles Traveled” dataset for disaggregation.

Demand Technology	TEMPO Vehicle Category
REFERENCE GASOLINE LIGHT-DUTY AUTO	ICEV_Gasoline ²²
ELECTRIC LIGHT-DUTY AUTO - 200 MILE RANGE	BEV ²³
PHEV - 50 MILE RANGE – LIGHT-DUTY AUTO	PHEV ²⁴
PHEV - 25 MILE RANGE – LIGHT-DUTY AUTO	PHEV
CNG LIGHT-DUTY AUTO	BEV
PROPANE ICE LIGHT-DUTY AUTO	BEV
HYDROGEN FUEL-CELL LIGHT-DUTY AUTO	BEV
DIESEL - ELECTRIC HYBRID LIGHT-DUTY AUTO	HEV_Gasoline ²⁵
GASOLINE-ELECTRIC HYBRID LIGHT-DUTY AUTO	HEV_Gasoline
REFERENCE TDI LIGHT-DUTY AUTO	ICEV_Gasoline
ELECTRIC LIGHT-DUTY AUTO - 100 MILE RANGE	BEV
ELECTRIC LIGHT-DUTY AUTO - 300 MILE RANGE	BEV
REFERENCE GASOLINE LIGHT-DUTY TRUCK	ICEV_Gasoline
ELECTRIC LIGHT-DUTY TRUCK - 200 MILE RANGE	BEV
PHEV - GASOLINE - 50 MILE RANGE – LIGHT-DUTY TRUCK	PHEV
PHEV - GASOLINE - 25 MILE RANGE – LIGHT-DUTY TRUCK	PHEV
CNG LIGHT-DUTY TRUCK	BEV
PROPANE ICE LIGHT-DUTY TRUCK	BEV
HYDROGEN FUEL-CELL LIGHT-DUTY TRUCK	BEV
ELECTRIC - DIESEL HYBRID LIGHT-DUTY TRUCK	HEV_Gasoline
ELECTRIC - GASOLINE HYBRID LIGHT-DUTY TRUCK	HEV_Gasoline
REFERENCE TDI LIGHT-DUTY TRUCK	ICEV_Gasoline
ELECTRIC LIGHT-DUTY TRUCK - 100 MILE RANGE	BEV
ELECTRIC LIGHT-DUTY TRUCK - 300 MILE RANGE	BEV
N/A ²⁶	ICEV_Gasoline

²² Internal combustion engine vehicle.

²³ Battery electric vehicle.

²⁴ Plug-in hybrid electric vehicle.

²⁵ Gasoline-powered hybrid electric vehicle.

²⁶ This represents the MOTORCYCLES subsector, which does not have any demand technology specified.

Appendix D. On-Road Fuel Consumption Methodology

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Overview

The data for aggregate 2016 vehicle fuel consumption for cities and towns²⁷ were derived through an analytical process performed by NREL. This process estimated fuel consumption by integrating publicly and commercially available datasets at various spatial resolutions describing traffic intensity, vehicle fuel economy, and regional fuel consumption totals. Table D-1 below outlines the source and characteristics of datasets used by NREL. The analysis methods are described in more detail in the Methods section below.

²⁷ Data are available at <https://data.openei.org/submissions/149>.

Table D-1. Data Sources Used for Estimation of Fuel Consumption

Dataset	Measures	Source	Vintage	Publicly Available
Highway Performance Monitoring System (HPMS) Public Release Shapefiles	VMT Rural/Urban Road Class (seven types) State	FHWA Highway Performance Monitoring System	2016	Yes
Highway Statistics Series VM-2: Vehicle-miles of travel, by functional system	Total Vehicle Miles Traveled Rural/Urban Road Class (seven types)	FHWA Highway Statistics Series	2016	Yes
Highway Statistics Series VM-4: Distribution of Annual Vehicle Distance Traveled	Percent of VMT Rural/Urban Generalized Road Class (three types) Vehicle Type (six types)	FHWA Highway Statistics Series	2016	Yes
Vehicle Inventory and Use Survey Microdata	Vehicle type (two types) Fuel economy (mpg)	U.S. Census Bureau	2002	Yes
Highway Statistics Series VM-1: Vehicle miles of travel and related data, by highway category and vehicle type	Vehicle type (six types) Fuel economy (mpg)	FHWA Highway Statistics Series	2016	Yes
Polk Counts of Light Duty Vehicle Registrations	Vehicle type (six types) Fuel economy (mpg) Fleet type (personal, dealer, etc.)	RL Polk & Company	2016	No
EPA Fuel Economy Estimates	Combined Highway and City Miles Per Gallon	U.S. Environmental Protection Agency	2019	Yes
USDOT 2009 National Household Travel Survey	Average Trip Distance (mi) Urban/Rural	USDOT Bureau of Transportation Statistics	2009	Yes

Highway Statistics Series MF-21: Motor Fuel Use	Vehicle Fuel Consumption (gallons) Fuel type (gas/diesel)	FHWA Highway Statistics Series	2016	Yes
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Methods

The fundamental dataset supporting the SLED estimates of vehicle fuel is the Federal Highway Administration (FHWA) Highway Performance Monitoring System (HPMS) Shapefiles. These data provide a highly spatially resolved estimate of traffic intensity across the United States. Specifically, they include estimates of the total annual VMT mapped to individual, geolocated road segments. NREL combined these data with average vehicle fuel economies (miles per gallon, or mpg) for representative vehicles along each road segment to estimate the fuel consumption associated with the reported traffic, following Equation 1.

Equation 1:

$$\text{Fuel Consumption} = \text{VMT} * 1/\text{MPG}$$

To determine representative fuel economy for each road segment in the HPMS dataset, NREL integrated several ancillary datasets on traffic intensity and fuel economy. First, NREL used the FHWA Highway Statistics Series VM-2 and VM-4 datasets, respectively, to backfill missing VMT data for minor road classes and disaggregate VMT along road segments by vehicle type (e.g., passenger cars, light trucks, etc.). Next, NREL integrated a series of sources describing vehicle fuel economies and fuel types for different classes of vehicles, including Polk Light Duty Vehicles for passenger cars and light trucks, U.S. Census Bureau Vehicle Inventory and Use Survey (VIUS) for single-unit and combination trucks, and FHWA Highway Statistics Series VM-1 for buses. From the latter two datasets, NREL derived regional (state and national, respectively) estimates of average fuel economy and proportions of vehicles by fuel type (diesel and gasoline), which NREL then applied to all roads by region.

Using this combination of ancillary data, NREL produced a refined version of the HPMS road segments that included estimates of both VMT and average fuel economy, segmented by vehicle type and fuel type. NREL applied Equation 1 to these refined data to estimate the fuel consumption by vehicle and fuel type along each road segment, and then used linear rescaling to calibrate the estimates to sum exactly to the reported total state vehicle fuel consumption totals for diesel and gasoline (FHWA Highway Statistics Series MF-21). Finally, for the purposes of reporting in SLED, NREL summed total fuel consumption by fuel type to the aggregate level of cities and towns and counties.

This analysis drew heavily on the methodology developed by Gately et al. (2015) and shares several core datasets, assumptions, and methods; however, the work performed by NREL diverges in a few key areas. First, for reasons outlined in their work, Gately et al. (2015) calculated their results natively at the county level. As a result, subcounty (e.g., city or town) level results require additional methods and assumptions for spatial disaggregation. In contrast, because NREL's results are resolved down to individual road segments, they can be easily summarized at a variety of spatial resolutions. Secondly, whereas Gately et al. (2015) used

national average fuel economies for all road segments, NREL's method used regionally and locally resolved estimates of fuel economies to capture greater spatial variation in the composition of vehicles. Finally, to calibrate fuel estimates along road segments to reported state totals, Gately et al. (2015) applied a sophisticated optimization routine that allowed for small adjustments in various measures. For this same goal, NREL simply linearly rescaled road segment fuel consumption totals to precisely match the state totals.

Appendix E. Emissions Factors for Nonelectric Energy Consumption

Table E-1. Emissions Factors and Data Sources Used to Calculate CO₂ Emissions From Primary Energy Consumption

FINAL_ENERGY	Sector	Emission Factor (kgCO ₂ /MMBTU)	Source
DIESEL FUEL		73.15	EIA Emissions Factors
PIPELINE GAS		53.06	EPA GHG Emissions Factor Hub
LPG FUEL		61.71	EPA GHG Emissions Factor Hub
BIOMASS - WOOD		93.8	EPA GHG Emissions Factor Hub
KEROSENE FUEL		75.2	EPA GHG Emissions Factor Hub
GASOLINE FUEL		71.26	EIA Emissions Factors
COMPRESSED PIPELINE GAS		53.06	EPA GHG Emissions Factor Hub
LIQUEFIED PIPELINE GAS		62.28	EIA Emissions Factors
COAL	commercial	95.35	EIA Emissions Factors: "Coal: Residential/Commercial"
COAL	residential	95.35	EIA Emissions Factors: "Coal: Residential/Commercial"
STEAM		66.33	EPA GHG Emissions Factor Hub

Table E-22. Emissions Factors and Data Sources Used to Calculate SO₂ Emissions From Primary Energy Consumption

FINAL_ENERGY	Sector	Emission Factor (lbSO ₂ /MBTU ²⁸)	Source
DIESEL FUEL	residential	289-578	NREL ReOPT ²⁹ User Manual
DIESEL FUEL	commercial	289-867	NREL ReOPT User Manual
DIESEL FUEL	transportation	0.736-3.06	Shi (2017), Murphy (2021)
PIPELINE GAS	industrial	0.579	NREL ReOPT User Manual
PIPELINE GAS	residential	0.579-1.737	NREL ReOPT User Manual
PIPELINE GAS	commercial	0.579-2.316	NREL ReOPT User Manual
LPG FUEL	residential	0	NREL ReOPT User Manual
LPG FUEL	transportation	0.468-0.592	Shi (2017), Murphy (2021)
BIOMASS - WOOD	residential	23.12	EPA AP-42, Residential Wood Stoves (conventional wood stove)
KEROSENE FUEL	residential	3.04	EPA AP-42, Fuel Oil Combustion (residential furnace, assuming 0.3% sulfur content of fuel)
GASOLINE FUEL	transportation	1.015-1.580	Shi (2017), Murphy (2021)
COMPRESSED PIPELINE GAS	transportation	0.468-0.892	Shi (2017), Murphy (2021)
LIQUEFIED PIPELINE GAS	transportation	0.468-0.592	Shi (2017), Murphy (2021)
COAL	residential	596.15	EPA AP-42, Bituminous And Subbituminous Coal Combustion (hand-fed units)
STEAM	commercial	25	EPA National Emissions Inventory (NEI)

²⁸ Note the different units: emissions factors in this table are presented as pounds (lb) of SO₂ per thousand British thermal units (MBtu).

²⁹ NREL Renewable Integration and Optimization web tool: <https://reopt.nrel.gov/tool/reopt-user-manual.pdf>

Table E-33. Emissions Factors and Data Sources Used to Calculate NO_x Emissions From Primary Energy Consumption

FINAL_ENERGY	Sector	Emission Factor (lbNO_x/MMBTU)	Source
DIESEL FUEL	commercial	0.56-1.68	NREL ReOPT User Manual
DIESEL FUEL	residential	0.56-1.12	NREL ReOPT User Manual
DIESEL FUEL	transportation	0.077-0.647	Shi (2017), Murphy (2021)
PIPELINE GAS	commercial	0.0914-0.3656	NREL ReOPT User Manual
PIPELINE GAS	industrial	0.0914	NREL ReOPT User Manual
PIPELINE GAS	residential	0.0914-0.2742	NREL ReOPT User Manual
LPG FUEL	residential	0.153	NREL ReOPT User Manual
LPG FUEL	transportation	0.0867-0.1863	Shi (2017), Murphy (2021)
BIOMASS - WOOD	residential	0.1618	EPA AP-42, Residential Wood Stoves (conventional wood stove)
KEROSENE FUEL	residential	0.1286	EPA AP-42, Fuel Oil Combustion (residential furnace)
GASOLINE FUEL	transportation	0.046-0.207	Shi (2017), Murphy (2021)
COMPRESSED PIPELINE GAS	transportation	0.0867-0.1863	Shi (2017), Murphy (2021)
LIQUEFIED PIPELINE GAS	light-duty	0.0867-0.1863	Shi (2017), Murphy (2021)
COAL	residential	0.35	EPA AP-42, Bituminous And Subbituminous Coal Combustion (hand-fed units)
STEAM	commercial	0.251	EPA NEI

Appendix F. Description of SLOPE Scenario Planner Planning Metrics

Table F-1. Description of All Planning Metrics, Their Calculation, and Where They Can Be Found in the Files Available for Download From the SLOPE Website

Topic	Buildings	Transportation	Grid Mix	Energy CO ₂ Emissions	System Cost
Metric	Residential and commercial heating demand electrified	EV stock	Renewable energy penetration	Supply and demand emissions	Net system cost impact
Units	%	%	% of total generation supplied by renewable energy sources	% reduction from 2005 levels	% difference in total cost across state from reference scenario
Text to User	Share of Space Heating Services Supplied by Electricity (%)	Battery- and Plug-In-Electric Share of Light-Duty Vehicles (%)	Share of Electricity Provided by Renewable Energy (%)	Reduction in Energy-Related CO ₂ Emissions from 2005 (%)	Statewide Net Change in System Cost from Reference Scenario (Billions 2020 \$)
Source	EnergyPATHWAYS	EnergyPATHWAYS	ReEDS results	CO ₂ emissions as described in Section 3	System costs as described in Section 4
Scenario Column Refers To	Electrification	Electrification	ReEDS Scenario	ReEDS Scenario	ReEDS Scenario
File	intuition_metrics_demandside.zip	intuition_metrics_demandside.zip	intuition_metrics_supplyside.zip	intuition_metrics_supplyside.zip	intuition_metrics_supplyside.zip

