Washington Decarbonization Pathways Study

Data, Methods, and Assumptions Manual

VERSION 1

Purpose of this Document

This Data, Methods, and Assumptions (DMA) manual presents the modeling approach used to provide energy and emission benchmarks and projections, as well as a summary of the data and assumptions used in scenario modeling. The DMA makes the modeling elements fully transparent and illustrates the scope of data required for future modeling efforts using the same methodology.

CONTENTS

Glossary

Balancing Authority (BA): an entity responsible for integrating resource plans, maintaining load-interchange-generation balances within a metered boundary (the Balancing Authority Area), and supporting interconnection frequency in real time.

Base Year: the starting year for energy or emissions projections.

Business-As-Usual (BAU): a scenario illustrating energy use and GHG emissions if no additional plans, policies, programs, or projects are implemented.

Business-As-Planned (BAP): a scenario illustrating energy use and GHG emissions if additional plans, policies, programs, and projects which have already been passed or are currently underway continue to be implemented.

Carbon sequestration: The process of storing carbon in a carbon pool.

Commercial Buildings Energy Consumption Survey (CBECS): Developed by the EIA, the CBECS provides information on the estimated 5.9 million commercial buildings in the U.S., including the number of workers, ownership and occupancy, structural characteristics, energy sources and uses, and other energy-related features (2018 data at the time of writing).

Combined heat and power (CHP): the simultaneous production of two or more useful forms of energy, typically electricity and heat, by a single device (also known as co-generation).

Energy Demand and Supply Simulator for the U.S. (EDSSUS): A model and data dictionary developed by SSG and whatIf? Technologies that can be used to simulate energy demand and supply for states, regions, and municipalities within the United States.

Energy Information Administration (EIA): An agency of the U.S. Federal Government that collects, analyzes, and disseminates information on energy and its interaction with the economy and the environment, including production, stocks, demand, imports, exports, and prices.

Environmental Protection Agency (EPA): An agency of the U.S. Federal Government that studies environmental issues, develops and enforces regulations to protect the environment, and provides grants to various entities to promote environmental conservation and human health.

Greenhouse gases (GHG): gases that trap heat in the atmosphere by absorbing and emitting solar radiation, causing a greenhouse effect. The main GHGs are water vapor, carbon dioxide, methane, nitrous oxide, and ozone.

Geographic information system (GIS): a type of a computer program or system that analyzes and displays geographically referenced data.

Heating Degree Day (HDD): a measurement designed to quantify the demand for energy needed to heat a building, consisting of the number of degrees that a given day's average temperature is below 18°C, thus requiring heating.

National Renewable Energy Laboratory (NREL): The National Renewable Energy Laboratory is a federally funded research and development center sponsored by the Department of Energy and operated by the Alliance for Sustainable Energy, specializing in the research and development of renewable energy, energy efficiency, energy systems integration, and sustainable transportation.

Marginal abatement cost curves (MACC): MACCs show the relative economic costs or savings of emission abatement actions, in units of US$/t$CO_2$e over time.

REPLICA: a proprietary provider of modeled and observed building and transportation data. https://replicahq.com/

Residential Energy Consumption Survey (RECS): Developed by the EIA, the RECS provides an estimate of residential energy costs and usage for heating, cooling, appliances, and other end uses, developed using a nationally representative sample of housing units and their energy characteristics combined with data from energy suppliers.

State Energy Data System (SEDS): Developed by the EIA, it provides comprehensive statistics regarding the consumption, production, prices, and expenditures of energy for each state and for the country as a whole.

Intergovernmental Panel on Climate Change (IPCC): a United Nations body that assesses the science related to climate change via regular reports and analyses about the state of scientific, technical and socio-economic knowledge on climate change, its impacts and future risks, and options for reducing the rate at which climate change is taking place.

Scenario: A plausible description of how the future may develop based on a coherent and internally consistent set of assumptions about key driving forces (e.g., rate of technological change, prices) and relationships. Note that scenarios are neither predictions nor forecasts, but are used to provide a view of the implications of developments and actions.

Vehicle Miles Traveled (VMT): distance traveled by vehicles within a defined region over a specified time period.

Washington Department of Commerce (WDOC): A department of the State of Washington that is the lead agency responsible for enhancing and promoting sustainable communities and economic vitality in Washington, through programming and via state boards and commissions.

Washington Department of Ecology (WDOE): A department of the State of Washington with a mission to restore, maintain, and enhance the quality of Washington's air, land, and water resources.

Washington State Department of Transportation (WSDOT): A department of the State of Washington that develops programs related to Washington's systems of transportation, including highways, roads, bridges, railways, and public transit, as well as services related to transportation safety programs, driver and vehicle licensing, and motor carrier regulation.

Washington Utilities and Transportation Commission (UTC): a three-member commission appointed by the governor of Washington and confirmed by the state senate that regulates electric, telecommunications, natural gas, water, and transportation providers.

Western Electricity Coordinating Council (WECC): a non-profit corporation that exists to assure a reliable Bulk Electric System in the geographic area known as the Western Interconnection, which has a footprint extending to 2 Canadian provinces, 14 Western states, and Northern Baja Mexico.

Accounting and Reporting Principles

SSG's greenhouse gas inventory development and scenario modeling approach correlate with IPCC-derived accounting methods for developing fair and true accounts of national and state-level emissions. The GHG inventory includes detailed calculations of emissions of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) in detail, and high-level calculations of perfluorocarbons (PFCs), hydrofluorocarbons (HFCs), sulfur hexafluoride (SF_6), and nitrogen trifluoride (NF_3) for each of the following sectors: transportation, energy, residential, commercial, industry.

The GHG emission and removal estimates contained in Washington's GHG inventory are developed using methodologies consistent with guidelines for National Greenhouse Gas Inventories developed by the Intergovernmental Panel on Climate Change (IPCC) in the Fifth Assessment Report, which incorporates carbon feedback into its Global Warming Potential (GWP) values. For this reason, SSG's GHG inventory results are similar to but not exactly the same as reported in Washington State Greenhouse Gas Emissions Inventory: 1990-2018, published by the Department of Ecology in January 2021.

SSG has developed the following principles for GHG accounting and reporting, based on decades of research and experience working with municipal, state, and national government clients:

Relevance: The reported GHG emissions appropriately reflect emissions occurring as a result of activities and consumption within the state. The inventory is meant to serve the decision-making needs of the State's Agencies, Commissions, and Offices, taking into consideration relevant local, state, and national regulations. Relevance applies when selecting data sources and determining and prioritizing data collection improvements.

Completeness: All emission sources within the inventory boundary are accounted for, and any exclusions of sources (for example electricity generation destined for export) are justified and explained.

Consistency: Emissions calculations are consistent in their approach, boundaries, and methodology.

Transparency: Activity data, emissions sources, emissions factors and accounting methodologies require adequate documentation and disclosure to enable verification.

Accuracy: The calculation of GHG emissions should not systematically overstate or understate actual GHG emissions, and should be accurate enough to give decision makers and the public reasonable assurance regarding the integrity of the reported information. Uncertainties in the quantification process should be reduced to the extent possible and practical.

Scope

Scope of this Manual

This issued version of the Data, Methods, and Assumptions (DMA) Manual is a draft. The DMA is a living document that is updated throughout the course of the project. This draft contains methods and assumptions for model calibration and business-as-usual and business-as-planned scenarios. The final DMA will include methods and assumptions for the decarbonization scenarios. The final DMA will be included as an attachment to the final report.

Project Scope

The purpose of this study is to identify and describe the various potential pathways for investor-owned electric and natural gas utilities to contribute to achieving Washington's overall GHG emission reduction goals.

RCW 70A.45.020 states that Washington shall limit anthropogenic emissions of greenhouse gases (GHGs) as follows:

i. By 2020, reduce GHGs to 1990 levels, or 90.5 million metric tons;
ii. By 2030, reduce GHGs to 50 million metric tons, or 45% below 1990 levels;
iii. By 2040, reduce GHGs to 27 million metric tons, or 70% below 1990 levels;
iv. By 2050, reduce GHGs to 5 million metric tons, or 95% below 1990 levels.

Senate Bill 5092, section 143 (Chapter 334, Laws of 2021), provided funding to the Washington Utilities and Transportation Commission for the study, which must identify and consider:

i. How natural gas utilities can decarbonize;
ii. The impacts of increased electrification on the ability of electric utilities to deliver services to current natural gas customers reliably and affordably;
iii. The ability of electric utilities to procure and deliver electric power to reliably meet that load;
iv. The impact on regional electric system resource adequacy, and the transmission and distribution infrastructure requirements for such a transition;
v. The costs and benefits to residential and commercial customers, including environmental, health, and economic benefits;

vi. Equity considerations and impacts to low-income customers and highly impacted communities; and

vii. Potential regulatory policy changes to facilitate decarbonization of the services that gas companies provide while ensuring customer rates are fair, just, reasonable, and sufficient.

This project is about identifying and describing the various pathways to achieve a certain level of natural gas emissions reduction. This project is not about choosing one pathway.

The Washington Utilities and Transportation Commission will use the Energy Decarbonization Pathways Examination to report to the legislature on feasible and practical pathways for investor-owned electric and natural gas utilities to decarbonize, and the impacts of energy decarbonization on customers and utilities. The State legislature will use the findings of the study to discuss and develop policies related to investor-owned utility decarbonization.

Geographic Boundary

The geographic scope of this project is the state of Washington. SSG completed energy and emissions inventories for the state as a whole, as well as sub-zones that correspond to Washington's 39 counties.

Annual energy demand is simulated at the county level and also by balancing authority (BA) for electricity demand.

Annual electricity generation within the state of Washington is simulated by county and BA. Electricity that is generated outside of Washington but consumed within the state is represented by the state and BA of generation. Emissions resulting from the out-of-state generation of electricity that is consumed in Washington are included in the modeled emissions. Transmission of electricity is modeled as trade among BAs.

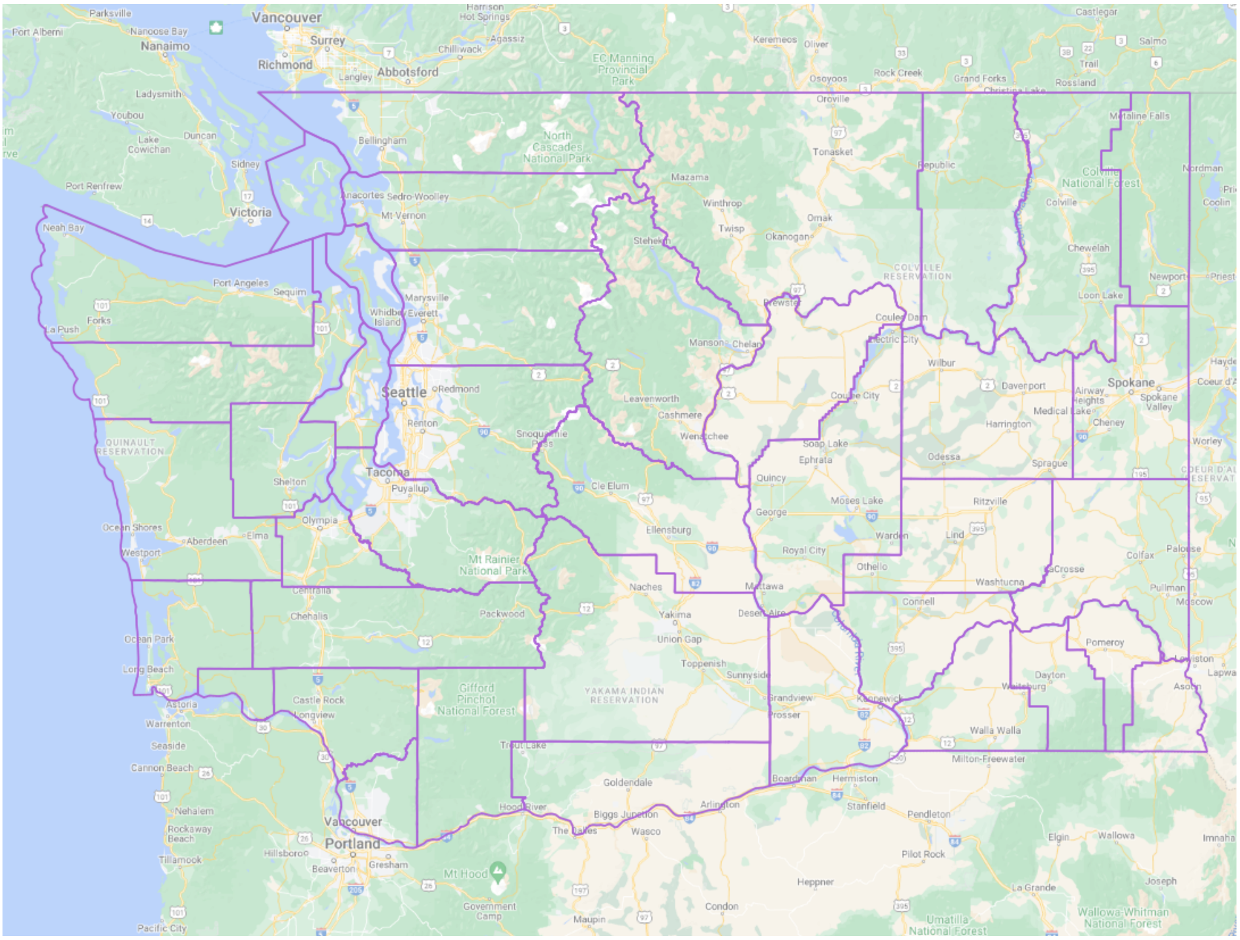
Vancouver
Surrey
Richmond
Abbotsford
Nanaimo
Victoria
Bellingham
Anacortes
Sedro-Woolley
Mt Vernon
Port Angeles
Sequim
Forks
Neah Bay
La Push
Marysville
Everett
Whidbey Island
Seattle
Redmond
Renton
Tacoma
Puyallup
Olympia
Shelton
Aberdeen
Elma
Ocean Shores
Westport
Centralia
Chehalis
Packwood
Ocean Park
Long Beach
Astoria
Longview
Castle Rock
Vancouver
Portland
Gresham
Beaverton
Hillsboro
Mt Hood
Trout Lake
Hood River
The Dalles
Goldendale
Biggs Junction
Wasco
Arlington
Yakima
Union Gap
Toppenish
Sunnyside
Grandview
Prosser
Naches
Ellensburg
Cle Elum
Leavenworth
Cashmere
Wenatchee
Chelan
Manson
Winthrop
Twisp
Omak
Okanogan
Tonasket
Oroville
Osoyoos
Brewster
Coulee Dam
Electric City
Coulee City
Soap Lake
Ephrata
Quincy
George
Moses Lake
Royal City
Mattawa
Othello
Warden
Connell
Kennewick
Boardman
Hermiston
Stanfield
Pendleton
Walla Walla
Milton-Freewater
Dayton
Waitsburg
Pomeroy
Clarkston
Lewiston
Asotin
Pullman
Moscow
Colfax
LaCrosse
Washtucna
Lind
Ritzville
Odessa
Wilbur
Davenport
Harrington
Sprague
Medical Lake
Cheney
Spokane
Spokane Valley
Airway Heights
Newport
Chewelah
Colville
Republic
Metaline Falls
Loon Lake
Grand Forks
Rossland
Trail
Castlegar
Rock Creek
Mazama
Stehekin
Snoqualmie Pass
Mt Rainier National Park
North Cascades National Park
Gifford Pinchot National Forest
Colville National Forest
COLVILLE RESERVATION
YAKAMA INDIAN RESERVATION
QUINAULT RESERVATION
Seaside
Cannon Beach
Tillamook
Pacific City
Heppner
Condon
Pilot Rock
La Grande
Elgin
Wallowa
Joseph

Figure X. Geographic scope and sub-scopes (counties, in purple) of this study.

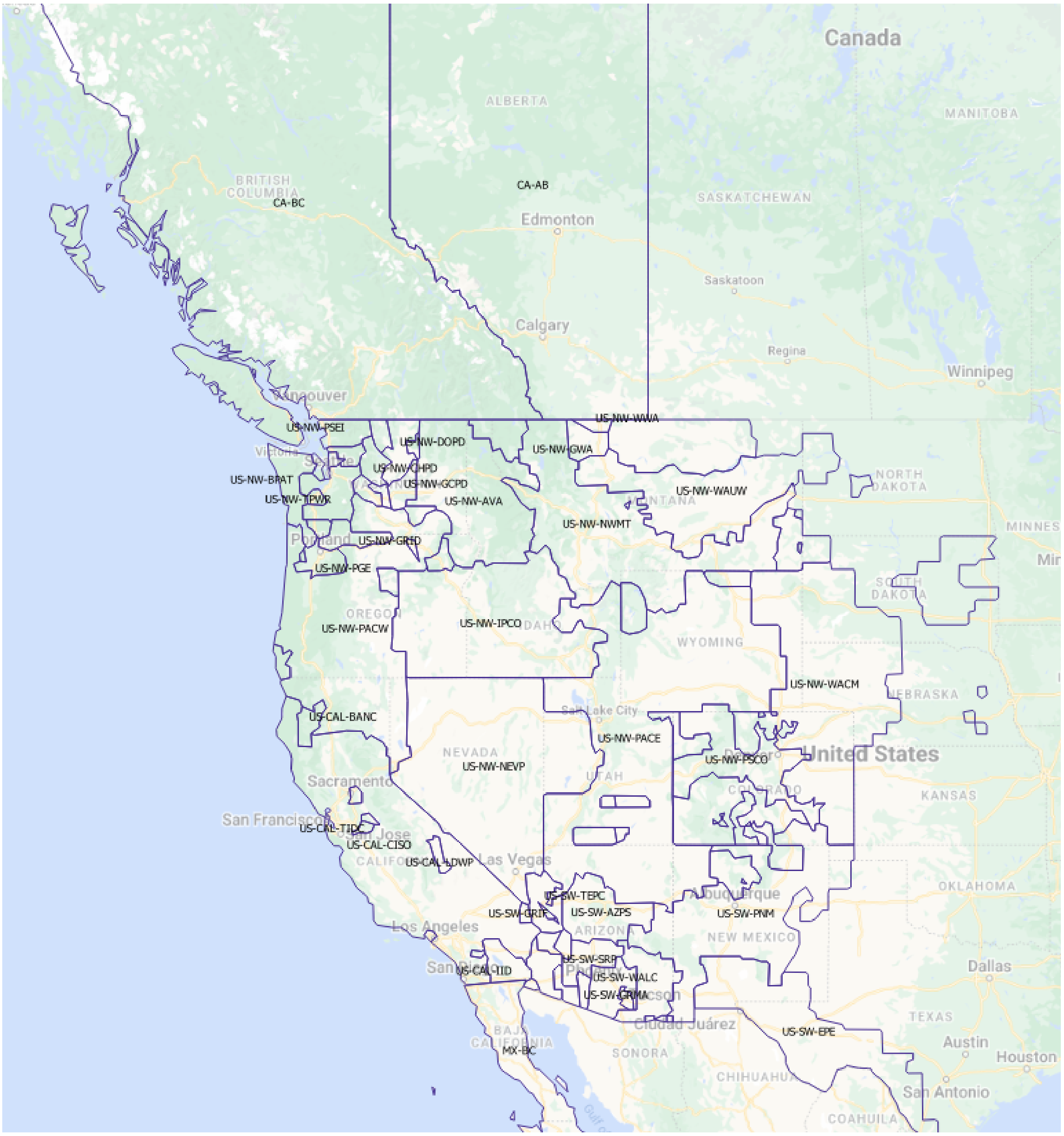

Figure X. Map of the balancing authorities within the Western Electricity Coordinating Council (WECC) used for electricity supply modeling.

Time Frame of Assessment

The modeling time frame includes years 2019-2050. The year 2019 will be used as the base year because it is the year for which the most current and complete data is available for calibration and modeling.

Data from the 2019 American Community Survey (5-year) and the 2020 U.S. Census will also be used. As set by RCW 70A.45.020, the relevant target years are 2030, 2040, and 2050. The goals are for Washington to achieve a 45% reduction below 1990 GHG emissions levels by 2030, a 70% reduction by 2040, and a 95% reduction by 2050. Model calibration for the base year uses as much locally observed data as possible, supplemented by data collected at the federal levels.

The modeling for this project will simulate energy supply and demand in both annual and hourly time steps.

Energy and Emissions Structure

Energy

The total energy consumption for the State is defined as the sum of the following aspects:

$$Energy_{State} = Energy_{transport} + Energy_{buildings} + Energy_{localEnergyProduction}$$

Where:

$Energy_{transport}$ is the movement of goods and people on foot, in vehicles, and using trucks, planes, and trains, etc.

$Energy_{buildings}$ is the use of energy to provide services such as heating and cooling, and other stationary energy use in buildings such as appliances and plugs.

$Energy_{LocalEnergyProduction}$ is energy used within the state of Washington to generate other energy currencies such as steam, electricity, etc.

GHG Emissions

GHG emissions from anthropogenic activities within the state are defined as the sum of all in-scope emissions sources:

$$GHG_{State} = GHG_{transport} + GHG_{buildings} + GHG_{energyGen} + GHG_{fugitive} + GHG_{CarbonCapture} + GHG_{process}$$

Where:

$GHG_{transport}$ are emissions generated by the movement of goods and people (for example, from the use of on-road vehicles (cars, buses, trucks), rail, marine, aviation, and non-road vehicles (construction vehicles, tractors, ATVs, logging trucks).

$GHG_{buildings}$ are emissions generated by energy use (lighting, appliances, heating, cooling, etc.) in buildings (both residential and commercial), including industrial facilities such as refineries.

$GHG_{energyGen}$ are emissions generated by the in-state generation of heat and electricity, the transmission of natural gas through pipelines within the state, and in-state alternative fuel production.

$GHG_{fugitive}$ are emissions caused by leaks from distribution pipelines, regulating equipment, and transfer stations in the state's pipeline network.

$GHG_{CarbonCapture}$ are emissions gathered and stored using carbon capture and storage technologies installed at power generation facilities or elsewhere.

$GHG_{process}$ are emissions generated from industrial processes that emit GHGs (such as cement manufacturing or iron and steel production) or the decomposition of materials in landfills.

Refer to Appendix 1 for a detailed list of included GHG emissions sources by scope.

Models

The modeling for this project integrates the following three component models which are used to analyze different temporal scales and sectors:

- Energy Systems Simulator
- Hourly Electricity Supply and Demand
- Alternative Fuels Production[1]

Each component model is described in the following sections.

Energy Systems Simulator

The Energy Systems Simulator (ESS) is an energy, emissions, and finance accounting tool developed by Sustainability Solutions Group. The model integrates fuels, sectors, and land-use in order to enable bottom-up accounting for energy supply and demand, including:

- renewable resources (hydro, solar, wind, geothermal, renewable natural gas, biofuels, etc.),
- conventional fuels (gasoline, diesel, fossil natural gas, coal, etc.),
- energy-consuming technology stocks (e.g. vehicles, appliances, dwellings, buildings), and
- all intermediate energy flows (e.g. electricity and heat).

Energy and GHG emissions values are derived from a series of connected stock and flow models, evolving based on current and future geographic and technology decisions/assumptions (e.g. electric vehicle (EV) uptake rates). The model accounts for physical flows (e.g. energy use, new vehicles by technology, vehicle miles traveled (VMT)) as determined by stocks (buildings, vehicles, heating equipment, etc.).

The model incorporates and adapts concepts from the system dynamics approach to complex systems analysis. For any given year, the model traces the flows and transformations of energy from sources through energy currencies (e.g. gasoline, electricity, hydrogen) and end uses (e.g. personal vehicle use, space heating) to energy costs and GHG emissions. An energy balance is achieved by accounting for efficiencies, technology conversion, and trading losses at each stage of the journey from source to end use.

[1] A detailed description of the Alternative Fuels Production model will be included in the final DMA.

Table 2. Model characteristics.

Characteristic	Rationale
Integrated	The tool models and accounts for all energy and emissions in relevant sectors and captures relationships between sectors. The demand for energy services is modeled independently of the fuels and technologies that provide the energy services. This decoupling enables exploration of fuel-switching scenarios. Viable scenarios are established when energy demand and supply are balanced.
Scenario-based	Once calibrated with historical data, the model enables the creation of dozens of scenarios to explore different possible futures. Each scenario can consist of either one or a combination of policies, actions, and strategies. Historical calibration ensures that scenario projections are rooted in observed data.
Spatial	The model includes spatial dimensions that can include as many zones (the smallest areas of geographic analysis) as deemed appropriate; in this case, they are Washington counties. The spatial components can be integrated with Geographic Information Systems (GIS) and land-use projections.
Sector-based	The model is designed to report emissions according to categories based on sectors (residential, industry, etc.).
Economic impacts	The model incorporates a high-level financial analysis of costs related to energy (expenditures on energy) and emissions (carbon pricing, social cost of carbon), as well as operating and capital costs for policies, strategies, and actions. This allows for the generation of marginal abatement costs.

ESS Model Structure

The major components of the ESS model and the first level of their modeled relationships (or influences) are represented by the blue arrows in Figure 2. Additional relationships may be modeled by modifying inputs and assumptions—specified either directly by users, or in an automated fashion by code or scripts running "on top of" the base model structure. Integrated modeling generates a total picture of the overall impact of inputs and assumptions, including the emissions or sequestration intensity of other inputs within the model.

The model is also spatially explicit. All buildings, transportation, and land-use data are tracked within the model through a GIS platform, and by varying degrees of spatial resolution. To divide the State into smaller configurations, we use data at the level of Washington's 39 counties. This enables more accurate modeling of energy use for each of the counties, as there are significant differences between, for example, marine climate counties to the West of the Cascades and cold climate counties to the East.

In any given year, various factors shape the picture of energy and emissions flows, including: the population and the energy services it requires; commercial floorspace; energy production and trade; technologies deployed to deliver energy services (service technologies) and to transform energy sources to currencies (harvesting technologies). The model is based on an explicit mathematical relationship between these factors—some contextual and some being part of the energy consuming or producing infrastructure—and the energy flow picture.

Some factors are modeled as stocks—counts of similar things, classified by various properties. For example, population is modeled as a stock of people classified by age and gender. Population change over time is projected by accounting for: the natural aging process, inflows (births, immigration), and outflows (deaths, emigration). The fleet of personal use vehicles—an example of a service technology—is modeled as a stock of vehicles classified by size, engine type and model year, with a similarly classified fuel consumption intensity. As with population, projecting change in the vehicle stock involves aging vehicles and accounting for major inflows (new vehicle sales) and outflows (vehicle discards). This stock-turnover approach is applied to other service technologies (e.g. furnaces, water heaters) and harvesting technologies (e.g. electricity generating capacity).

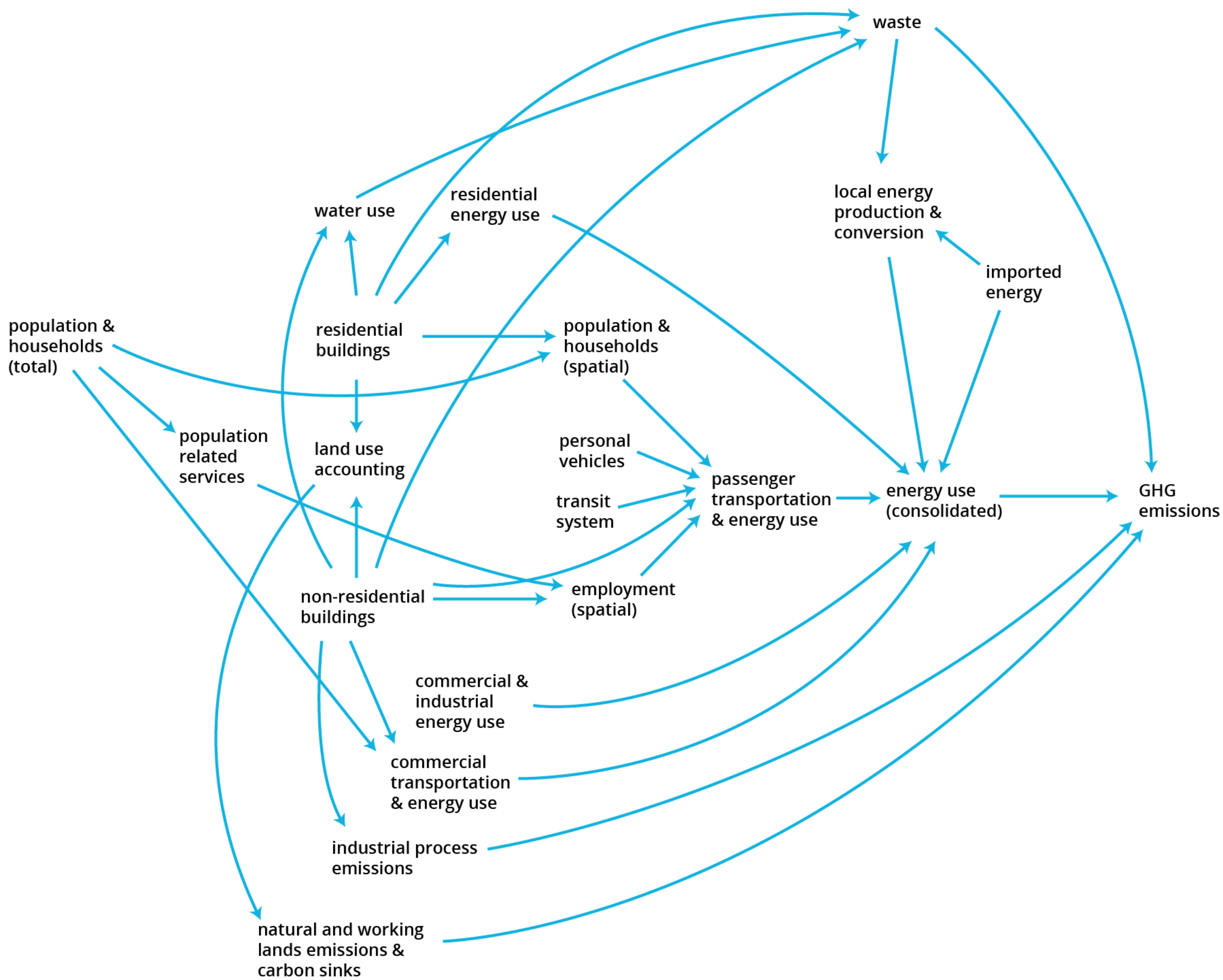

Figure X. Representation of the ESS model structure.

Sub-Models and Local Context Calibration

The overall model operates based on the interactions within and between factors of various sub-models, as described in this section. To develop the business-as-usual, business-as-planned, and decarbonization scenarios, we calibrate the model with local data, building the model from the ground up.

Data Request and Collection

The data we used to calibrate the model was supplied by Washington state agencies, such as the Washington Department of Commerce, Washington State Office of Financial Management, and the Washington State Department of Transportation (WSDOT), supplemented by data from federal and regional sources such as the Northwest Energy Efficiency Alliance (NEEA). The complete list of data and sources is provided in Appendix 5. To supplement any gaps in the observed data, we developed assumptions which are described below. We applied the data and assumptions using the modeling processes described below.

Zone System

The model is spatially explicit: population, employment, residential, and non-residential floorspace are allocated and tracked spatially for each of Washington's 39 counties (see Figure 3). These elements drive stationary energy demand. The passenger transportation sub-model, which contributes to transportation energy demand, also operates within the same zone system.

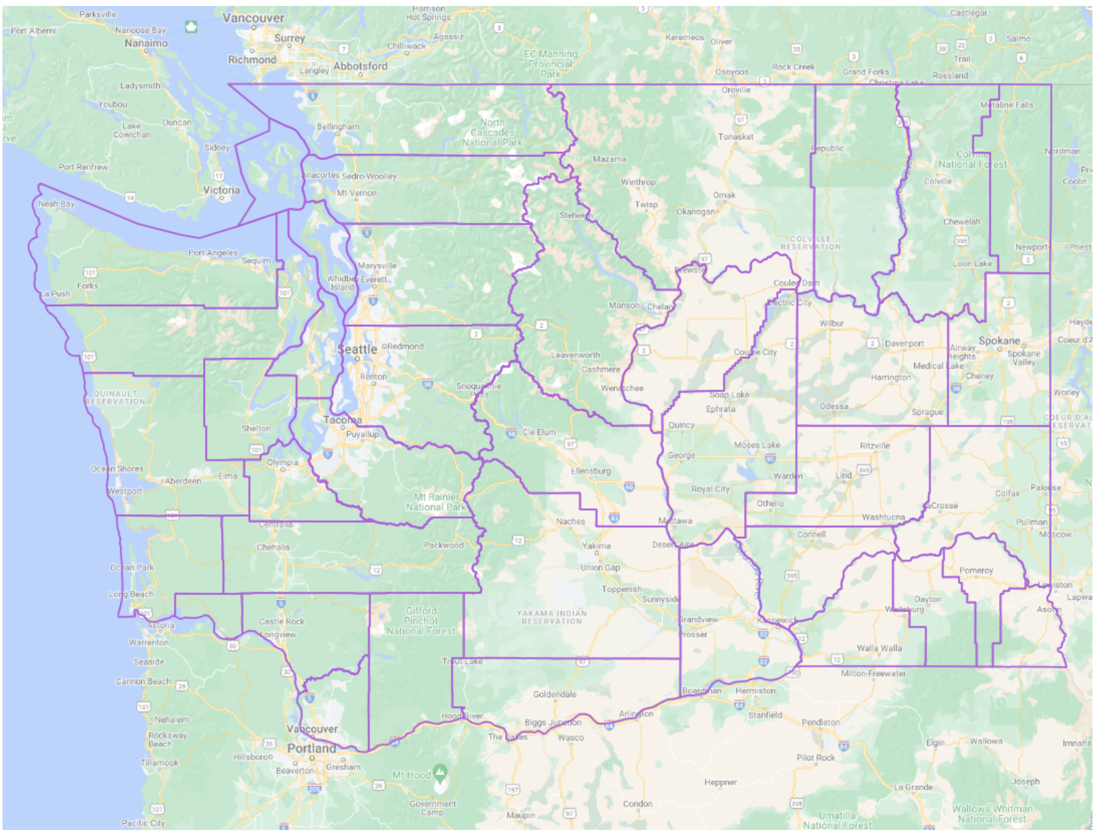

Figure X. Zone system (Washington counties) used in ESS modeling.

Population and Employment

How the Sub-model Works

State-wide population is modeled using the standard population cohort-survival method, disaggregated by single year of age and gender. It accounts for typical components of change: births, deaths, immigration, and emigration. The age-structured population is important for analysis of demographic trends, generational differences and implications for shifting energy use patterns. These numbers are calibrated against base year data and existing projections.

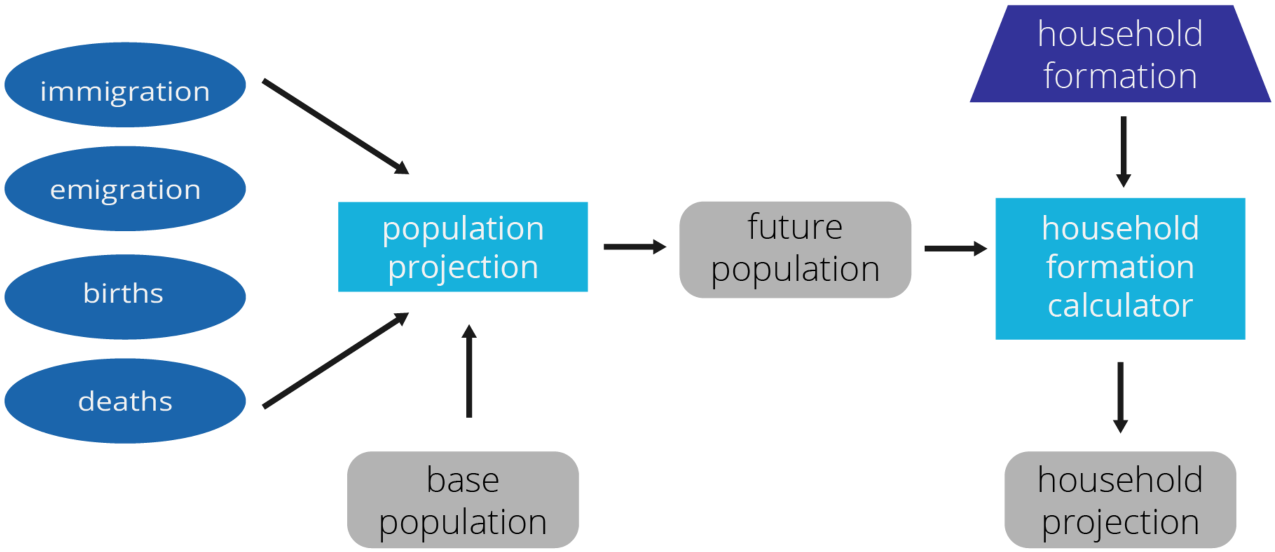

Figure 4. Population and employment submodel design flow. Blue ovals represent flows, light blue rectangles represent model calculations, gray rectangles represent stocks, and violet quadrangles represent model parameters.

Federal Census population and employment data is spatially allocated to the residential (population) and non-residential (employment) buildings. This enables indicators to be derived from the model, such as emissions per household, and drives the business-as-usual (BAU) energy and emissions projections for buildings and transportation.

An additional layer of model logic (not shown explicitly in Figure 4) captures energy-related financial flows and employment impacts. Calculated financial flows include the capital, operating, and maintenance costs of energy-consuming and energy-producing stocks, as well as fuel costs. We also model employment related to the construction of new buildings, retrofit activities and energy infrastructure; assess the financial impact on businesses and households of implementing the strategies, and apply various local economic multipliers (depending on the geographic and economic variability of the calculation and anticipated output) to investments.

How We Calibrate the Sub-model

We distributed the 2019 population to residential buildings in space, using initial assumptions about persons-per-unit (PPU) by dwelling type, and adjusting them so that the total population in the model (which is driven by the number of residential units by type multiplied by PPU by type) matches the total population from census/regional data.

Employment in 2019 is spatially allocated to non-residential buildings, using intensities (e.g. square feet per retail employees). As with population, the model adjusts these initial ratios so that the derived total employment matches total employment from the census and regional data.

Buildings

How the Sub-model Works

Residential buildings are spatially located and classified using a detailed set of 12 building archetypes (see Appendix 2) capturing footprint, height, and type (single-family, duplex, semi-attached, row-housing, apartment high-rise, apartment low-rise, etc.) and year of construction. The archetypes are used to generate a "box" model that helps to estimate the floor area and energy use, and then is used to simulate the impact of energy efficiency measures.

Using assumptions on thermal envelope performance and heating and cooling degree days, the model calculates space-conditioning energy demand independent of space heating or cooling technologies. First, the model multiplies the residential building floorspace area by an estimated thermal conductance (heat flow per unit of surface area per degree day) and the number of degree days (heating and cooling) to derive the energy transferred out of the building during winter months and into the building during summer months. The energy transferred through the building envelope, the solar gain through the building windows, and the heat gains from equipment inside the building constitute the net space-conditioning load required to be provided by the heating and air-conditioning systems (as shown in Figure 5).

This space conditioning demand is satisfied by stocks of energy service technologies, including heating systems, air conditioners, and water heaters. These stocks are modeled with a stock-turnover approach, capturing equipment age, retirements, and additions—exposing opportunities for efficiency gains and fuel-switching, but also constraining the rate of technology adoption.

Residential building archetypes are also characterized by the number of dwelling units they contain, allowing the model to not only capture the energy effects of shared walls, but also the urban form and transportation implications of population density.

Non-residential buildings, commercial and otherwise (see Appendix 2) are located in space and mapped to a set of 40+ archetypes. The floorspace of these archetypes varies by location. Non-residential floorspace generates demand for energy and water, and provides an anchor point for locating employment of various types.

The model calculates the space-conditioning load for non-residential buildings as it does for residential buildings, with two distinctions: the thermal conductance parameter for non-residential buildings is based on floor area instead of surface area, and incorporates data from REPLICA, a proprietary provider of modeled and observed building and transportation data. Using assumptions for thermal envelope performance for each building type, the model calculates total energy demand for all buildings, independent of any space heating or cooling technology and fuel.

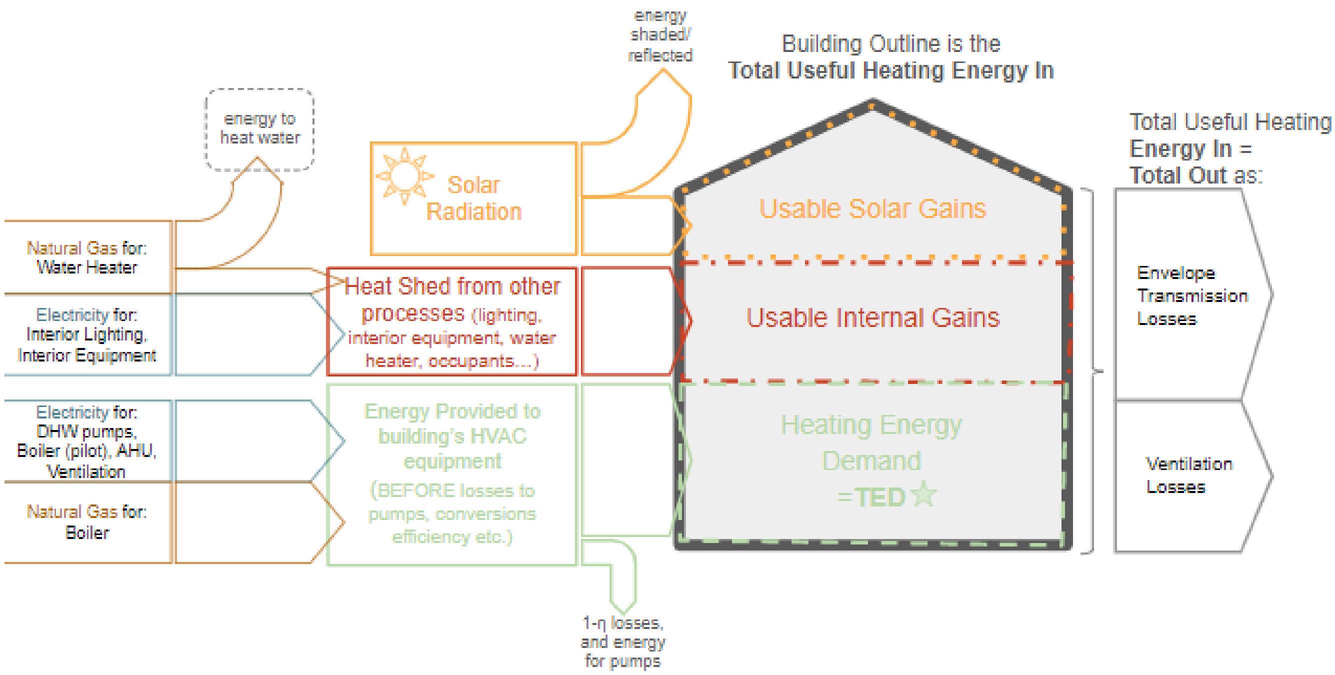

Figure 5: A diagram showing the considerations in the model for energy and emissions related to buildings.

How We Calibrate the Sub-model: Residential Buildings

For each Washington county, building data (including building type, number of stories, number of units, and year built) was sourced from the 2019 U.S. Census for residential buildings, and from REPLICA Places Land Use data for commercial and industrial buildings. Total floorspace area for each building type was calculated referencing building archetypes that are typical in Washington.

The initial estimates for thermal conductance and output energy use intensity by end use and equipment efficiency assumptions are regional averages by dwelling type from a North American energy systems simulator, calibrated for the Pacific Northwest. The assumed distribution of residential heat system types comes from the Northwest Energy Efficiency Alliances' Residential Building Stock Assessment database. The initial thermal conductance and output energy use intensity estimates are adjusted through the calibration process until natural gas use in residential buildings tracks on natural gas deliveries to the residential sector, as reported by Washington state natural gas utilities, and until residential electricity use tracks on Washington state electricity sales to the residential sector, as reported in the EIA Annual Electric Power Industry Report (Form 861).

How We Calibrate the Sub-model: Non-residential Buildings

Starting values for output energy intensities and equipment efficiencies for non-residential end uses are taken from the 2018 Commercial Buildings Energy Consumption Survey (CBECS) complemented by the EPA's Portfolio Manager Technical Reference that provides Energy Use Intensity by Property Type for some additional building types. All parameter estimates are further adjusted during the calibration process. The calibration target for non-residential building energy use is the observed commercial and industrial fuel consumption in the base year, as reported by Washington state natural gas utilities, and in the EIA Annual Electric Power Industry Report (Form 861).

Passenger Transportation

How the Sub-model Works

The model captures personal transportation energy use by modeling household travel. Families make trips for various purposes (work, school, socializing, errands, drop-offs, shopping), and these trips are shared out over the various modes of transportation (walk, bike, auto, transit). The energy use and emissions associated with various types of personal vehicles are calculated by assigning VMT to a stock-turnover personal vehicle model. The induced approach is used to track emissions.

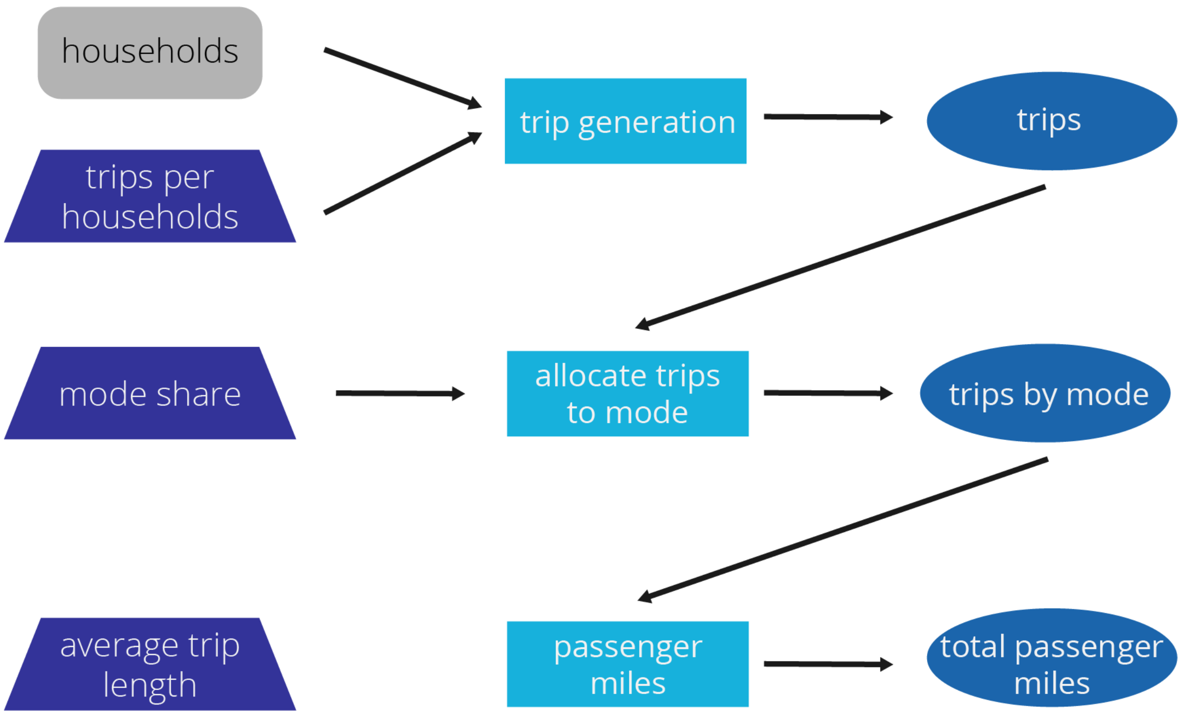

Figure 6. Conceptual diagram of how the model generates trips, trips by mode, and total miles traveled, per a given year. Gray rectangles represent stocks, violet quadrangles represent model parameters, light blue rectangles represent calculations made in the model, and dark blue ovals represent model outputs. All the outputs in this case represent flows.

How We Calibrate the Sub-model

The model is calibrated with data from the Washington State Department of Transportation's Annual mileage and travel information by county, which is collected by agencies throughout the state to support federal reporting requirements via the Highway Performance Monitoring System (HPMS). A stock of personal use vehicles is coupled with the VMT data to calculate energy consumption for personal vehicle use. This category is supplemented by transit fuel use (calculated on the basis of bus VMT), recreational marine fuel use, and off-road fuel use. The remaining commercial vehicle energy use is then calibrated so that total energy use by the transportation sector is aligned with SEDS.

The modeled stock of personal vehicles by size, fuel type, efficiency, and vintage was informed by the regional vehicle registration statistics. The total number of personal-use vehicles is proportional to the projected number of households in the BAU. Transit VMT and fuel consumption were modeled based on bus VMT data provided by ODOT.

Local Electricity Production

How the Sub-model Works

The model simulates in-state production of electricity and combined heat and power (CHP). Production capacity is represented as a stock while generation is modeled as a flow resulting from the use of that capacity. Energy produced from primary sources (e.g. solar, wind) is modeled alongside energy converted from imported fuels (e.g. electricity generation, combined heat and power (CHP)). The model applies a conversion efficiency to calculate fuel use.

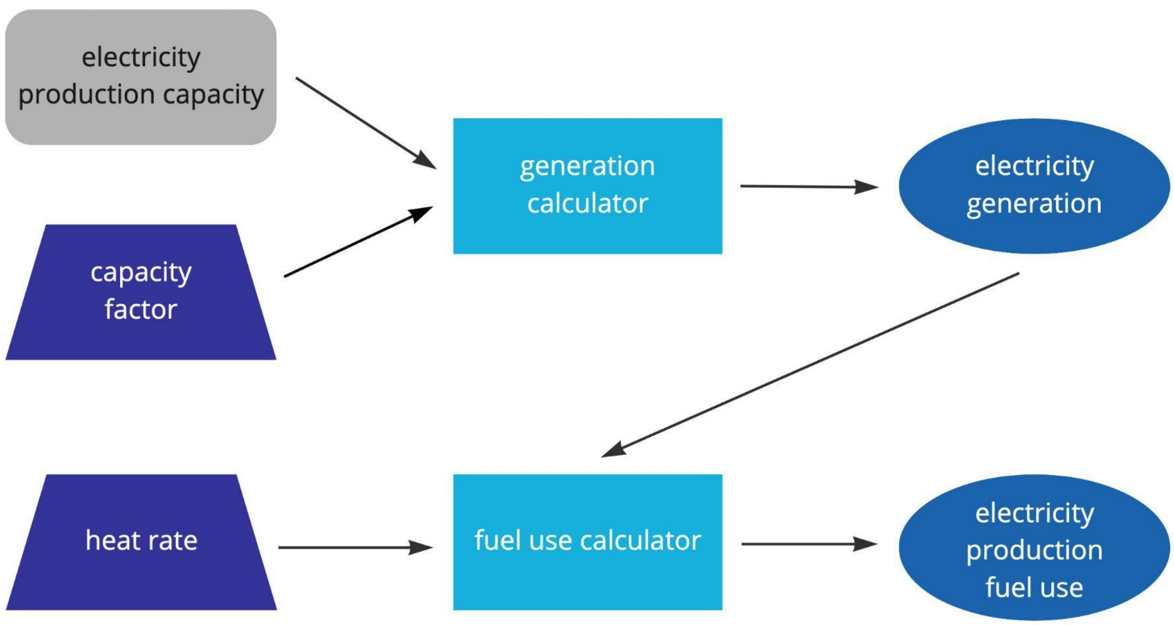

Figure X: Conceptual diagram of how the model derives electricity production generation and fuel use.

In the model, generated electricity either remains within the county of generation, as an approximation of net metering, or is routed to the simulated grid. Electricity demand within each county is first serviced by net metering generation then by grid generation.

How We Calibrate the Sub-model

The allocation of grid generation to demand in each county is based on utility data reported through the Washington Department of Commerce's fuel mix program. Through this program, utilities disclose the generating resources used to provide the electricity sold within Washington state. The data includes the name and characteristics of the generating plant, including plants outside of Washington, as well as the amount of generation claimed by the utility.

Demand by county is calculated based on building electricity use as described in the Buildings section. Service territory data from EIA Form 861 indicates which counties each utility serves. The model uses these two data sources to estimate the amount of electricity each utility provides to each county and in turn the fuel source used to generate the electricity used in each county.

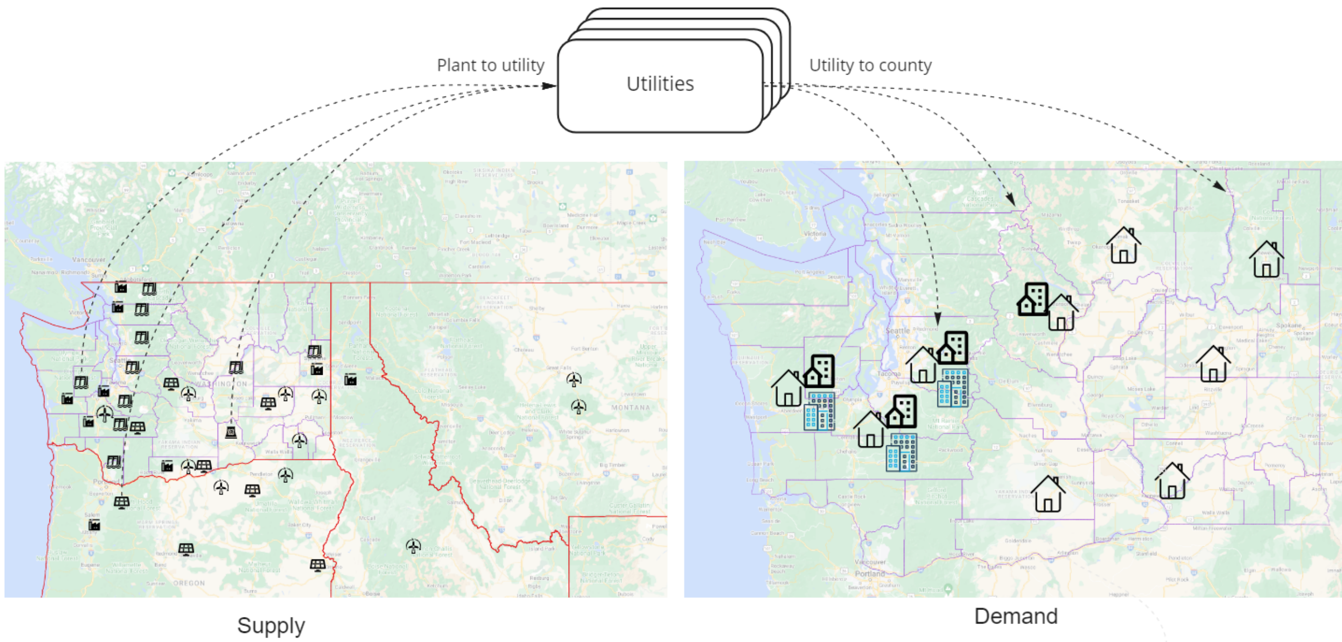

Figure X: Allocation of grid electricity supply to demand by county. The plant to utility mapping is derived from the fuel mix disclosure program data. The utility to county mapping is derived from service territory data from EIA Form 861 and modeled electricity demand by county.

Fugitive Emissions

How the Sub-model Works

Fugitive emissions from natural gas pipelines are modeled as an emissions rate applied to total natural gas sales within Washington state.

How We Calibrate the Sub-model

The fugitive emissions rate is calibrated so that the modeled fugitive emissions match the emissions caused by leaks from distribution pipelines reported by local natural gas distribution companies under Subpart W of the EPA Greenhouse Gas Reporting Program (GHGRP).

Data and Assumptions

Scenario Development

Scenarios are used to evaluate potential futures. A scenario is defined as an internally consistent view of what the future might turn out to be—not a forecast, but one possible future outcome. Scenarios represent plausible options as identified by interested persons. For example, in the building sector, scenarios are generated by identifying future population projections, estimating how many additional households are required, and then applying those additional households according to the existing land-use plans and alternative scenarios. The model then evaluates the impact of new development on transportation behavior, building types, and other variables.

Business-As-Usual Scenario

The Business-As-Usual (BAU) scenario estimates energy use and emissions volumes from the base year (2019) to the target year (2050). Because it assumes the absence of policy measures that would differ substantially from those currently in place, it can be considered a projection of what would happen if nothing changes, except for the anticipated population and economic growth.

Methodology

1. Calibrate model and develop a 2019 base year data for the state using observed data and filling in gaps with assumptions where necessary.
2. Input existing projected quantitative data to 2050 where available, such as:
    - Population, employment, and housing projections by transport zone
    - Build out (buildings) projections by county
    - Transportation modeling from the State
    - Economic growth projections
3. Where quantitative projections are not carried through to 2050, extrapolate what the projected trend would be to 2050.
4. Where specific quantitative projections are not available, develop projections through:
    - Analyzing current, on-the-ground action (reviewing action plans, engagement with staff, etc.), and where possible, quantifying the action.
    - Analyzing existing policy that has potential impact and, where possible, quantifying the potential impact.

Business-As-Planned Scenario

The Business-As-Planned (BAP) scenario estimates energy use and emissions volumes from the base year (2019) to the target year (2050), incorporating assumptions about the likely effects of planned policies and programs.

Methodology

- Create BAU (see steps above)
- Create demand-side BAP
    - Add additional assumptions to the BAU to capture known policies and plans that are or will be implemented in the coming years. Key programs and pieces of legislation reflected in the BAP:
        - The Clean Energy Transformation Act (CETA),[2] which requires Washington's electric utilities to meet 100% of its retail electric load to Washington customers using non-emitting electric generation and electricity from renewable resources by 2045.
        - The Climate Commitment Act (CCA),[3] which creates an emissions cap and invest program that reduces GHG emissions (from approximately 75% of Washington's sources of GHG emissions) to net zero by 2050. Entities covered by the program include industrial facilities, certain fuel suppliers, in-state electricity generators, electricity importers, and natural gas. distributors with annual GHG emissions above 25,000 metric tons of CO_2e.

[2] The CETA requires electric utilities to develop a four-year Clean Energy Implementation Plan (CEIP) for the GHG neutral and clean energy standards, and establish interim targets for meeting the standards. Since this study goes beyond 2026, we cannot accurately anticipate and describe a plan for investor-owned utilities (IOUs) to meet the requirements of CETA. An overall CETA emissions reduction, showing the impact of the CETA target, will be shown as part of the Business-As-Planned (BAP) scenario. Detailed CETA pathways will be modeled as part of the decarbonization scenarios to explore the different ways IOUs could comply with CETA.

[3]Since the CCA is a program based on allowances (compliance instruments) purchased via auction, and does not currently require covered entities to describe how they will reduce emissions in order to come into compliance and meet their purchased (or free) allowances, we cannot accurately anticipate and describe a plan for how these entities will reduce emissions. An overall CCA emissions reduction, showing the impact of the CCA emissions reduction target, is shown as part of the BAP scenario. Detailed CCA pathways will be modeled as part of the decarbonization scenarios to explore the different ways covered entities relevant to this study could comply with the CCA.

        - Move Ahead Washington, a set of transportation budget allocations that will accelerate active transit mode shifts, increase public transit ridership, and electrify some of WA State Ferries.
        - The Advancing Green Transportation Act, which encourages electric vehicle and alternative fuel vehicle adoption by providing tax credits, exemptions and grants for personal, public, and private use vehicles
        - The Clean Buildings for Washington Act and the Clean Buildings Performance Standard, which requires existing commercial buildings over 50,000 square feet to meet energy use performance standards by 2028
        - The 2018 Washington State Energy Code - Commercial, which requires new commercial buildings to use heat pumps for space heating and at least half of water heating needs (with exceptions)
        - Legislation in the cities of Seattle, Shoreline, and Bellingham banning the use of natural gas for space heating in commercial buildings and multifamily buildings over 4 stories tall.
        - Clean Fuel Standard, requires fuel suppliers to gradually reduce the carbon intensity of transportation fuels to 20 percent below 2017 levels by 2038
    - In all cases: Where quantitative projections are not carried through to 2050, historical trends are extrapolated to 2050.

- Where specific quantitative projections are not available, assumptions are identified by:
    - Analyzing current, on-the-ground action (reviewing action plans, engagement with staff, etc.), and where possible, quantifying the action.
    - Analyzing existing policy that has potential impact and, where possible, quantifying the potential impact.

Addressing Uncertainty

There is extensive discussion of the uncertainty in models and modeling results. One reason is that the assumptions underlying a model can be adopted from other locations or large data sets and not reflect local conditions or behaviors. Even if the data does accurately reflect local conditions, it is exceptionally difficult to predict how those conditions and behaviors will respond to broader societal changes, and even what those changes will be.

The SSG modeling approach uses four strategies for managing uncertainty applicable to community energy and emissions modeling:

1. **Sensitivity analysis:** One of the most basic ways of studying complex models is sensitivity analysis, which helps quantify uncertainty in a model's output. To perform this assessment, each of the model's input parameters is drawn from a statistical distribution in order to capture the uncertainty in the parameter's true value (see "A review of urban energy system models: Approaches, challenges and opportunities," Keirstead, Jennings, & Sivakumar, 2012).

   Approach: Selected variables are modified by ±10-20% to illustrate the impact that an error of that magnitude has on the overall total.

2. **Calibration:** One way to challenge untested assumptions is the use of 'back-casting' to ensure that the model can 'forecast the past' accurately. The model can then be calibrated to generate historical outcomes, in order to better replicate observed data.

   Approach: Variables are calibrated in the model by using two independent sources of data. For example, the model calibrates building energy use (derived from building data) against actual electricity data from the electricity distributor.

3. **Scenario analysis:** Scenarios are used to demonstrate that a range of future outcomes is possible given the current conditions and that no one scenario is more likely than another.

   Approach: The model will develop a reference (BAU) scenario.

4. **Transparency:** The provision of detailed sources for all assumptions is critical to enabling policy-makers to understand the uncertainty intrinsic in a model.

   Approach: Modeling assumptions and inputs are presented in this document.

Appendix 1: Detailed Emissions Scope Table

Table 1-1. Detailed emissions scope.

GHG Emissions Sources & GHG Types			
Transportation	**CO_2**	**CH_4**	**N_2O**
On-road transportation, railways, water-borne navigation, aviation, off-road transportation	Motor gasoline, distillate fuel, natural gas, residual fuel, lubricants, aviation gasoline, liquefied petroleum gas (LPG), light rail electricity use, Naphtha		
Residential Buildings	**CO_2**	**CH_4**	**N_2O**
Emissions from fuel combustion and grid-supplied energy consumed by residential buildings	Residential electricity use, natural gas consumption, petroleum consumption, coal consumption		
Commercial Buildings	**CO_2**	**CH_4**	**N_2O**
Emissions from fuel combustion and grid-supplied energy consumed by commercial buildings	Commercial electricity use, natural gas combustion, petroleum combustion, and coal combustion		
Industrial Emissions	**CO_2**	**CH_4**	**N_2O**
Emissions from on-site stationary combustion and industrial processes that emit GHGs (such as cement manufacturing,	Industrial electricity use, natural gas combustion, petroleum combustion, cement manufacture, coal combustion, ammonia production, urea consumption, iron and steel production, soda ash production and consumption, limestone and dolomite use, lime manufacture		

GHG Emissions Sources & GHG Types			
semiconductor manufacturing, or aluminum production)			
Energy and Electricity Production	**CO_2**	**CH_4**	**N_2O**
Emissions from in-state electricity generation and distribution of fuels	Generation of steam, generation of electricity from non-renewables, natural gas pipeline transmission, fugitive emissions from pipelines		

Appendix 2: Building Types

Table 2-1. Building types in the model.

Residential Building Types	Non-residential Building Types	
Single_detached_small	school	surface_infrastructure
Single_detached_medium	hospital	water_pumping_or_treatment_station
Single_detached_large	hotel_motel_inn	industrial_generic
Double_detached_small	recreation	pulp_paper
Double_detached_large	community_centre	cement
Row_house_small	museums_art_gallery	chemicals
Row_house_large	retail	iron_steel_aluminum
Apt_1To3Storey	restaurant	mining
Apt_4To6Storey	commercial	agriculture
Apt_7To12Storey		pipelines
Apt_13AndUpStorey		
inMultiUseBldg		

Appendix 3: Emissions Factors

Table 3-1. Emissions factors used in the model.

Category	Value	Comment
Natural gas	CO_2: 53.06 kg/MMBtu CH_4: 0.001 kg/MMBtu N_2O: 0.0001kg/MMBtu	Sourced from the EPA Center for Corporate Climate Leadership's GHG Emission Factors Hub (Sept 15 2021)
Renewable natural gas	?? depends on the source?	Might be more variable than NG, also we usually take out the Co2
Electricity	Plant-specific emission rates CO_2e: 487 lbs CO_2e per MWh (composite)	eGRID2019 Data File (https://www.epa.gov/egrid/download-data)
Gasoline	CO_2: 69.55 kg/MMBtu CH_4: 4.22 g/MMBTU N_2O: 0.66 g/MMBTU	National inventory report 1990-2019 : Greenhouse Gas Sources and Sinks in Canada. Part 2. Table A6.1–14 This source was used because the units are compatible with SSG's model structure, which uses emission factors per energy unit instead of per mile.
Diesel	Light Duty Vehicles CO_2: 73.84 kg/MMBtu CH_4: 1.88 g/MMBTUmile N_2O: 6.06 g/MMBTU Medium/Heavy Duty Vehicles CO_2: 73.84 kg/MMBtu CH_4: 3.03 g/MMBTU N_2O: 4.16 g/MMBTU	National inventory report 1990-2019 : Greenhouse Gas Sources and Sinks in Canada. Part 2 Table A6.1–14 This source was used because the units are compatible with SSG's model structure, which uses emission factors per energy unit instead of per mile.
Fuel oil	CO_2: 73.9 kg per MMBtu	Environmental Protection Agency. "Emission factors for greenhouse gas inventories." *Stationary*

Category	Value	Comment
	CH_4: 0.003 kg per MMBtu N_2O: 0.0006 kg per MMBtu	*Combustion Emission Factors," US Environmental Protection Agency, available:* [*https://www.epa.gov/sites/production/files/2015-07/documents/emission-factors_2014.pdf*](https://www.epa.gov/sites/production/files/2015-07/documents/emission-factors_2014.pdf) (2014) Table 1 Stationary Combustion Emission Factor, Fuel Oil No. 2
Wood	CO_2: 93.80 kg per MMBtu CH_4: 0.0072 kg per MMBtu N_2O: 0.0036 kg per MMBtu	Environmental Protection Agency. "Emission factors for greenhouse gas inventories." *Stationary Combustion Emission Factors," US Environmental Protection Agency, available:* [*https://www.epa.gov/sites/production/files/2015-07/documents/emission-factors_2014.pdf*](https://www.epa.gov/sites/production/files/2015-07/documents/emission-factors_2014.pdf) (2014) Table 1 Stationary Combustion Emission Factor, Biomass fuels: Wood and Wood Residuals
Propane	CO_2: 62.87 kg per MMBtu CH_4 : 0.003 kg per MMBtu N_2O: 0.0006 kg per MMBtu For mobile combustion: CO_2: 5.7 kg per gallon	Environmental Protection Agency. "Emission factors for greenhouse gas inventories." *Stationary Combustion Emission Factors," US Environmental Protection Agency, available:* [*https://www.epa.gov/sites/production/files/2015-07/documents/emission-factors_2014.pdf*](https://www.epa.gov/sites/production/files/2015-07/documents/emission-factors_2014.pdf) (2014) Table 1 Stationary Combustion Emission Factor, Petroleum Products: Propane Table 2 Mobile Combustion CO_2 Emission Factors: Propane

GHGs	Carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) are included. GWP CO_2 = 1 CH_4 = 34 N_2O = 298	Global warming potential (GWP) assumptions are sourced from the Intergovernmental Panel on Climate Change (IPCC)'s Fifth Assessment Report.

Appendix 4: Data Sources & Uses

Table 4-1. Input assumptions and calibration targets.

Data	Source	Use
Population by county, age, sex	US Census - 2019 ACS	Calibration target
Residential buildings by county, type, and year built	US Census - 2019 ACS	Input assumption
Residential floor space per unit by county and type	Replica land use data	Input assumption
Employment by county and sector	US Census - Longitudinal Employer-Household Dynamics Origin-Destination Employment Statistics (LODES)	Calibration target
Non-residential buildings by type and year built	NEEA CBSA 4	Input assumption
Non-residential floor space by county and type	Replica land use data	Input assumption
Non-residential floor space by type and year built	NEEA CBSA 4	Input assumption
Natural gas deliveries by sector and county	Utility data	Calibration target
Electricity sales by utility and customer sector	EIA Form 861	Calibration target
Gasoline and diesel fuel use	SEDS	Calibration target
End use equipment fuel shares	NEEA CBSA 4 NEEA RBSA II	Input assumption
Industrial emissions from large emitting facilities	EPA GHGRP	Calibration target
Personal use vehicles	WSDOT - vehicle registration data	Calibration target
Transit miles and fuel use	WSDOT - Summary of Public Transportation	Input assumption
Electricity production capacity,	EPA eGRID	Input assumption

Data	Source	Use
generation, and fuel use		
Net metering capacity and generation by utility, sector, and technology	EIA Form 861	Input assumption
Grid electricity allocation to county	WA Department of Commerce Fuel Mix Disclosure	Input assumption
Heating and cooling degree days by county	U.S. Climate Resilience Toolkit Climate Explore (Version 3.1)	Input assumption

Table 4-2. Business-As-Usual assumptions.

Data	Source
Population growth	State of Washington Office of Financial Management - State and County Population Projections (medium scenario)
Employment	State of Washington Office of Financial Management Long-term Economic Forecast Tables (Table 3-2: Washington Non-Agricultural Wage and Salary Employment by Industry (in thousands) 2020-2040)
Transportation	Corporate Average Fuel Economy (CAFE) Fuel Standard for light duty and heavy duty vehicles
Heating & cooling degree days (HDD and CDD)	Climate Explorer (nemac.org)
Energy use	Baseline building equipment types/stocks held from 2019-20250, using data from the Residential Energy Consumption Survey (RECS) for baseline building equipment types and State Energy Data System (SEDS) for building equipment efficiencies
Building growth	Residential buildings are added alongside population growth; building types added based on the building mix of counties where population growth is happening. Non-residential building growth is based on projected growth in employment; building types added (where job growth is happening), based on the current building mix of each county.