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Documentation for application of City-based Optimization Model for Energy Technologies (COMET) to New York City to support metropolitan-scale air, climate, and energy planning

Office of Research and Development
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Documentation for application of City-based Optimization Model for Energy Technologies (COMET) to New York City to support metropolitan-scale air, climate, and energy planning

By

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DATA AVAILABILITY

All the Appendices and the COMET v15.0.9 and COMET v16.0.1 model files can be downloaded at DOI: 10.23719/1532264

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Abstract

The City-based Optimization Model for Energy Technologies (COMET-NYC) is an energy system modeling tool developed by the U.S. Environmental Protection Agency's Office of Research and Development to support long-term, metropolitan-scale air, climate, and energy planning for New York City. Built on the internationally recognized TIMES modeling framework, COMET-NYC identifies the least-cost mix of technologies and fuels required to meet projected energy demands from 2010 to 2055 across NYC's buildings, transportation, and electricity sectors.

COMET-NYC uses a scenario-based optimization approach to simulate the deployment of energy technologies under various assumptions, policies, and constraints. It incorporates local data sources to estimate and calibrate energy consumption and emissions at the borough level. It tracks both greenhouse gases (GHGs) and criteria air pollutants, supporting city-level climate and air quality policy evaluation.

The model includes detailed modules for the residential, commercial, industrial, and transportation sectors, accounting for current and future technology costs, fuel types, and efficiency parameters. It uses linear programming to minimize system-wide costs while meeting energy service demands and emissions targets. COMET-NYC supports both retrospective analysis (e.g., calibration to 2010, 2015, and 2020) and future scenario exploration, such as electrification strategies.

Two versions of the model are documented here: v15.0.9, which underpinned emissions reduction planning during the 2023–2024 NYC budgeting cycle, and v16.0.1, which includes updated buildings data and improved calibration.

COMET-NYC is a critical decision-support tool that enables policymakers to evaluate the costs, benefits, and tradeoffs of various technology mixes and policy strategies across NYC's complex urban energy system.

In addition to NYC specific COMET, US EPA developed an open-source version of the model called "Generative COMET[1]" that can be applied to medium- to large-scale cities in the U.S.

[1] DOI: 10.23719/1532263

1 Introduction

Local, state and regional authorities are facing challenges caused by a changing climate, urbanization, limited natural resources, and aging infrastructure. As of 2021, more than 130 million people in the U.S. are estimated to live in areas that exceed one or more National Ambient Air Quality Standards (NAAQS) (EPA, 2024). Challenges may also come from the increasing energy demands associated with population and economic growth. Increasing temperatures introduce challenges as well, including greater space cooling requirements in buildings, decreased efficiency of thermo-electric cooling at power plants, limits on the discharge of cooling water into rivers & lakes, and the air quality impacts associated with increased photochemical reaction rates.

Many are interested in pursuing environmental goals while stimulating economic growth. Governments have begun to set emissions reduction targets to protect human health and the environment. At the federal level, there are various standards and regulations, and at the regional level, states have agreed to work together to reduce emissions through programs such as the Regional Greenhouse Gas Initiative (RGGI), an electric sector cap-and-trade program, Section 177 light-duty Zero-Emission Vehicle (ZEV) sales targets, and the multi-state medium- and heavy-duty ZEV Initiative. Furthermore, at the state level, 23 states and the District of Columbia (DC) have adopted GHG emission reduction targets, while 30 states and DC have adopted either Renewable Portfolio Standards or Clean Energy Standards in the electric sector (NCSL, 2021).

The energy system and its resulting emissions will be impacted by difficult-to-predict factors such as technology development and adoption, climate, the availability of water and energy resources, and current and future energy and environmental policy. Another complicating factor is that the time frames typically associated with air quality management can be very different. Air quality management can often involve time horizons of a decade or less, while energy and infrastructure decisions and build out may stretch to longer time horizons. In this complex landscape, planners need tools and information that will allow them to understand the synergies and tradeoffs among air and energy objectives and to develop robust and cost-effective management strategies. Given a limited number of resources, planners can benefit from systematically evaluating multiple potential strategies for achieving economic and environmental goals related to energy transition issues. Specifically, state and local decision makers need to understand the environmental and health implications of energy supply and use in their regions, as well as the extent to which energy resources and technologies may contribute to achieving current and future environmental goals.

U.S. Environmental Protection Agency's Office of Research and Development (EPA/ORD) has been developing and applying various energy system tools to evaluate the long-term economic and environmental benefits of technology and infrastructure deployment strategies, to understand the environmental and health implications of energy supply and use in their regions, and to analyze which energy resources and technologies may contribute to achieving current and future environmental goals.

COMET – City-based Optimization Model for Energy Technologies, developed by EPA/ORD, is an application of TIMES energy-environment-economic optimization framework. In its New York

City application (COMET-NYC), the model identifies the least-cost mix of technologies and fuels needed to meet projected energy demands from 2010 to 2055. It accounts for market trends, federal policies, and state actions, and evaluates their impacts on GHG emissions and air pollution. COMET optimizes technology investments and fuel use across end-use sectors such as buildings and transportation, considering constraints like emissions limits and electrification standards. The model includes supply curves for primary energy carriers (e.g., oil, natural gas, coal, hydrogen, and renewables), and deployment of energy conversion technologies (e.g., power plants, combined heat and power) based on capital costs, efficiency, and other performance parameters.

COMET-NYC offers a detailed representation of the city's energy system, including electric generating units (EGUs) dispatching power via the New York Independent System Operator. It models energy flows from resource extraction/import to end-use across the five boroughs and New York State. Using linear programming, it minimizes the system's net present cost while satisfying energy demands and user-defined constraints. Outputs include technology pathways, total system costs, emissions (GHG and CAP), and energy prices. The model also supports scenario analysis to evaluate the effects of new technologies or policies. Designed for city-level application, COMET helps assess technology portfolios to meet urban energy, climate, and environmental goals.

This report provides an overview of the COMET, data sources, and calibration against actual energy consumption data and discusses a reference case providing a future year energy outlook. We provide assumptions for the versions 15.0.9 and 16.0.1.

2 Background on TIMES

TIMES is an economic model generator for local, national, multi-regional, or global energy systems, which provides a technology-rich basis for representing energy dynamics over a multi-period time horizon. TIMES is maintained through the Energy Technology and Systems Analysis Program (ETSAP) of the International Energy Agency (IEA). ETSAP currently has as contracting parties 21 countries and one private sector sponsor. TIMES can assist in the design of least-cost pathways for sustainable energy systems and is ideally suited for the preparation of Low-Emissions Development Strategies (LEDS) and Intended Nationally Determined Contributions (INDC) and Nationally Determined Contributions (NDC) roadmaps. It is usually applied to the analysis of the entire energy sector but may also be applied to study single sectors such as the electricity and district heat sector.

2.1 Description

TIMES consists of generic variables and equations constructed from the specification of sets and parameter values depicting an energy system for each distinct region in a model. To construct a TIMES model, a preprocessor first translates all data defined by the modeler into special internal data structures representing the coefficients of the TIMES matrix applied to each variable for each equation in which the variable may appear. This step is called Matrix Generation. Once the model is solved (optimized) a Report Writer assembles the results of the run for analysis by the modeler. The matrix generation, report writer, and control files are written in GAMS (the General Algebraic Modelling System). GAMS is a powerful high-level language specifically designed to facilitate the process of building large-scale optimization models. GAMS accomplishes this by relying heavily on the concepts of sets, compound indexed parameters, dynamic looping and conditional controls, variables and equations. Thus, there is a very strong synergy between the philosophy of GAMS and the overall concept of the Reference Energy System (RES) specification embodied in TIMES, making GAMS very well suited to the TIMES paradigm. Furthermore, by nature of its underlying design philosophy, the GAMS code is very similar to the mathematical description of the equations. Thus, the approach taken to implement a TIMES model is to “convert” the input data by means of a (rather complex) preprocessor while taking care of the necessary exceptions to properly construct the matrix coefficients for the Linear Programming (LP) model. In addition, the GAMS platform integrates seamlessly with a wide range of commercially available optimizers such as CPLEX and/or XPRESS. To build, run, and analyze a TIMES model, several software tools have been developed in the past or are currently under development, so that the modeler does not need to provide the input information needed to build a TIMES model directly in GAMS. These tools are the model interfaces VEDA2.0. EPA/ORD currently holds licenses to utilize **VEDA2.0** to build TIMES models. The TIMES model generator has extensive documentation and demo models to build instances of TIMES models (Loulou et al 2016, Loulou et al 2016, Goldstein et al 2016, & Goldstein et al 2016).

In TIMES, a complete scenario consists of four types of inputs: energy service demand curves, primary resource supply curves, a policy setting, and the descriptions of a complete set of technologies. The basis of a TIMES model is a network diagram called a Reference Energy System (RES), which depicts an energy system from resource supply to end-use demand (*Figure*

1) The RES constructs an energy system up from a list of technology types, energy carriers, and user demands. The four technology types represented are resource, process, conversion, and demand technologies as defined in detail below:

1) Resource technologies represent the extraction cost and availability of resources such as coal, oil, and natural gas.

2) Conversion technologies represent the conversion of fuel inputs into electricity.

3) Process technologies represent other means of converting resources into end-use fuels including refineries and coal-to-liquid processes.

4) Demand technologies represent the technologies that meet specific user demands, such as vehicles, air conditioners, and water heaters.

These technologies feed into a final stage consisting of end-use demands for useful energy services. End-use demands include items such as residential lighting, commercial air conditioning, and automobile passenger miles traveled. Estimates of end-use energy service demands (e.g., vehicle miles traveled; residential lighting, steam heat requirements in the paper industry; etc.) are provided by the user for each region to drive the reference scenario. In addition, the user provides estimates of the existing stocks of energy related equipment in all sectors, and the characteristics of available future technologies, as well as present and future sources of primary energy supply and their potentials.

Using these as inputs, the TIMES model aims to supply energy services at minimum global cost (more accurately at minimum loss of total surplus) by simultaneously making decisions on equipment investment and operation; primary energy supply; and energy trade for each region. For example, if there is an increase in residential lighting energy service relative to the reference scenario (perhaps due to a decline in the cost of residential lighting, or due to a different assumption on GDP growth), either existing generation equipment must be used more intensively or new – possibly more efficient – equipment must be installed. The choice by the model of the generation equipment (type and fuel) is based on the analysis of the characteristics of alternative generation technologies, on the economics of the energy supply, and on environmental criteria.

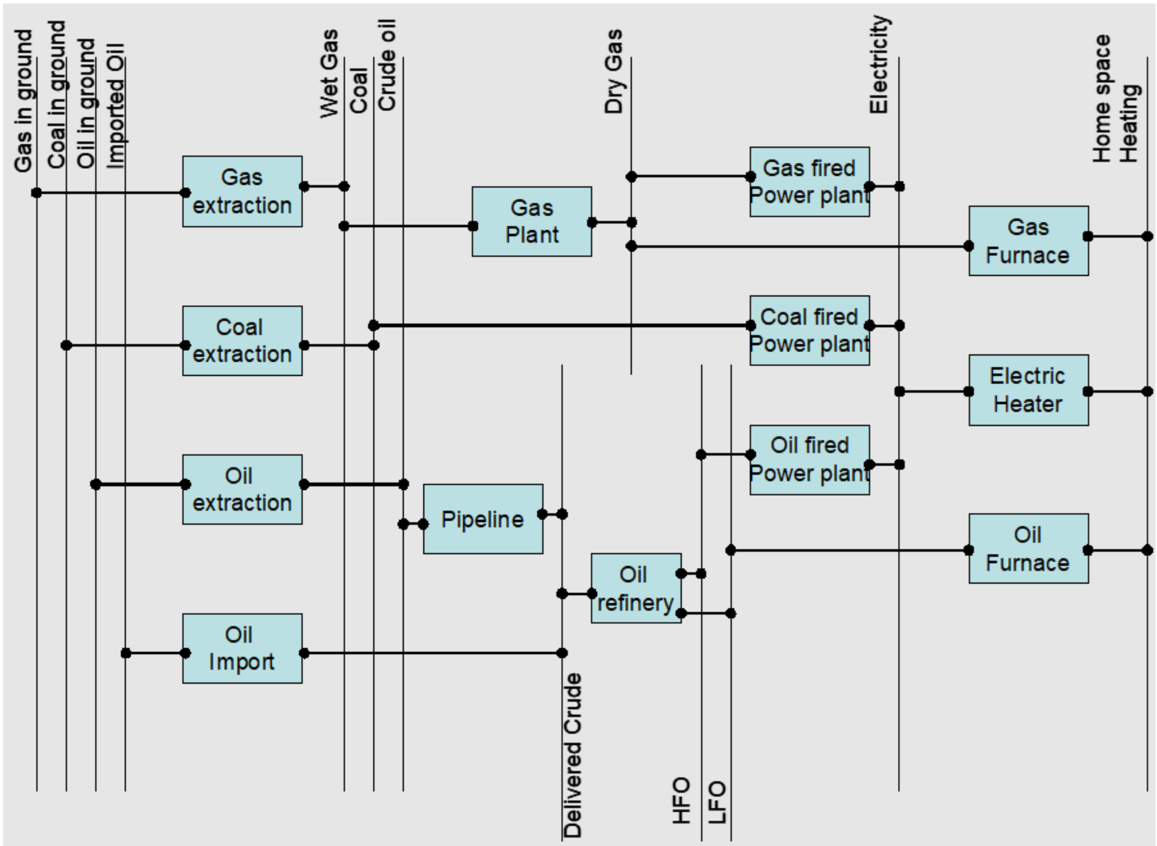

Figure 1 Illustrative Reference Energy System

TIMES is thus a vertically integrated model of the entire extended energy system. The scope of the model extends beyond purely energy-oriented issues, to the representation of environmental emissions, and perhaps materials, related to the energy system. In addition, the model is suited to the analysis of energy-environmental policies, which may be represented with accuracy thanks to the explicitness of the representation of technologies and fuels in all sectors. In TIMES, the quantities and prices of the various commodities are in equilibrium, i.e., their prices and quantities in each "time period" are such that the suppliers produce exactly the quantities demanded by the consumers. This equilibrium has the property that the total economic surplus is maximized. It is useful to distinguish between a model's structure and a particular instance of its implementation. A model's structure exemplifies its fundamental approach for representing a problem—it does not change from one implementation to the next. Therefore, all TIMES models exploit an identical underlying structure.

Thus, the structure of a TIMES model is ultimately defined by variables and equations created from the union of the underlying TIMES equations and the data input provided by the user. This information collectively defines each TIMES regional model database, and therefore the resulting mathematical representation of the RES for each region.

2.2 Data Requirements

The user input sets contain the fundamental information regarding the structure and the characteristics of the underlying energy system model. The user input sets can be grouped according to the type of information related to them:

- One dimensional sets defining the components of the energy system: regions, commodities, processes;
- Sets defining the Reference Energy System (RES) within each region;
- Sets defining the inter-connections (trade) between regions;
- Sets defining the time structure of the model: periods, time slices, time slice hierarchy;
- Sets defining various properties of processes or commodities.

The following is a list of the classifications of data needed to build instances of TIMES models, and the most common data parameters for each classification. For the purposes of brevity, TIMES documentation files include all the necessary information regarding input data needs to build a basic TIMES model. Following are parameters needed to build a typical energy system model using TIMES.

- Energy Service Demands
  - Demand projections for buildings and transportation sectors
  - Season/time-of-day pattern of the demand
- Energy Carrier Profiles
  - Input energy
  - Output energy
- Costs
  - Resource supply
  - Investment in new capacity
- Fixed and variable operations and maintenance (O&M)
  - Fuel delivery
  - "Hurdle" rates
- Technology Profiles
  - Resource supply steps and cumulative resource limits
  - Existing installed capacity and limits on new investment
  - Fuels in and out
  - Efficiency and Availability
- Environmental Indicators
  - Unit emissions per resource
  - Emission constraints/taxes per pollutant
  - Unit emissions per resource
  - Emission constraints/taxes by pollutant
- System and other parameters
  - Electric reserve margin

- Season/time-of-day fractions describing the electrical load
- System-wide discount rate

Furthermore, the TIMES models include time periods for modeling horizon. TIMES is 'demand driven' in that feasible solutions are obtained only if all the specified end-use demands for energy services are satisfied for every time-period. *Table 1* summarizes the parameters needed to build a typical energy system model using TIMES.

TIMES also distinguishes between two types of units for characterizing energy system technologies, activity, and capacity. Activity represents the use of a technology. Most technology activity is measured in petajoules (PJ). Capacity represents the size (installed capacity) of the technology stock and is measured according to the ability to provide for some amount of activity per unit time. Accordingly, capacities for most technologies are measured in petajoules per year (PJ/yr). Electricity generation technology capacities are measured in gigawatts (GW), and transportation technology activities are measured in billions of miles per year.

Table 1 Variable Types in the Model and Corresponding Data Requirements

Variable Type	Input Requirements
End-Use Energy Service Demands	Projections for energy service demands for: **TRANSPORTATION**: Light-duty vehicle demand (bn-vmt-yr), bus transportation demand (bn-vmt-yr), heavy-duty short-haul truck transportation demand (bn-vmt-yr), passenger rail transportation demand (pn-passs-miles), medium-duty truck transportation demand (bn-vmt-yr), **RESIDENTIAL BUILDINGS:** space cooling (PJ/yr), space heating (PJ/yr), water heating (PJ/yr), lighting (billion lumens/yr), other electricity demand (PJ/yr), other natural gas demand (PJ/yr), **COMMERCIAL BUILDINGS**: space cooling (PJ/yr), space heating (PJ/yr), water heating (PJ/yr), lighting (billion lumens/yr), other electricity demand (PJ/yr), other natural gas demand (PJ/yr), *All demands include load shape for electric demand profiles.*
Energy Carriers *Any kind of entity that is a form of energy that is produced or consumed in the energy system (e.g., coal, refined oil, natural gas, gasoline, electricity)*	- Transmission efficiency - Transmission capacity - Investment cost - Operation and maintenance cost - Electricity Transmission and distribution cost - Reserve margin for electricity
Resource Technologies *Technologies that characterize raw fuels exported or imported into the energy system*	- Resource supply cost for each supply step - Cumulative Resource limits for an energy carrier for each period - Cumulative Resource limits for an energy carrier over the entire modeling horizon - cost and capacity limits of Resource transportation - cost of extraction and production of Resource

Variable Type	Input Requirements
Process, Conversion, and Demand Technologies *Any kind of technology that can change the location, form, and/or structure of the energy carriers*	- New capacity investment cost - Fixed operation and maintenance cost - Variable operation and maintenance cost as a function of activity - Fuel delivery charges - Technical efficiency as a ratio between input and output - Technology investment availability year - Availability factor - Capacity utilization factors - Base year installed capacity - Upper bound on new capacity investment (if exists) - Upper bound on incremental new investment (growth rate) - Upper bound on total capacity installed over the modeling horizon - "Hurdle" rate for a technology
Emissions	- Emissions factor per unit of fuel consumed - Emissions factor for per unit of activity - Emissions factor for per unit of installed capacity - Upper bound for emission for each period - Emission constraints over the entire modeling horizon - Emission constraints for any given sector

Scenario Framework

A scenario approach is appropriate to the assessment of long-term technological development in the energy system. Extended research, policy, and assessment horizons make business-as-usual extrapolations, conventionally used in shorter-term energy futures analyses, inappropriate. The technology innovation process is inherently uncertain and unpredictable. Over a period of decades, we simply cannot know which technologies will achieve fundamental breakthroughs and which will not. Changes in economic structures, consumer preferences, resource supplies, and other variables similarly lead to inherent unpredictability. With these factors in consideration, COMET-NYC was constructed under the energy system optimization modeling principles presented in DeCarolis et al. (2017). These principles include considerations such as minimizing model bias, setting clear spatio-temporal boundaries and goals, maximizing model and data transparency and quality assurance.

The scenario approach to assessing technology futures requires that the menu of technology options being built into the models be appropriately connected to a set of driving forces to produce informative and internally consistent scenarios. Driving forces are the key elements that influence how the future turns out. Any scenario approach must identify the key driving forces that are expected to have an impact on the issues under consideration. Scenarios are then built from combinations of values or realizations of these driving forces. Major driving forces for the energy system technology futures include:

- Economic growth
- Population growth
- Changes in the structure of the economy, work, and recreation
- Land use and transportation policy
- Air pollution and environmental policy
- Oil and natural gas supply

- Consumer attitudes
- Rates and patterns of technological change

Future Technologies and Scenarios

For the technologies of interest in our scenario assessment, we collected estimates of technology costs, performance, and availability. Because many of these technologies are still under development, these data will be estimates of future cost, performance, and availability. There is therefore considerable uncertainty about these parameters. Indeed, it is this uncertainty that is the motivation for and source of our scenario assessment.

We are looking for a range of values that covers plausible future outcomes. Therefore, for each parameter it is best to gather data from several different sources and to provide some evaluation of the reliability of each source and the assumptions supporting each estimate. Having this well-documented range of values will allow us to construct scenarios that explore the range of possible futures. The researcher will determine, based on an analysis of available data, what data parameters will be used initially to input the technology into the database.

3 COMET-NYC Structure

COMET-NYC uses New York City's annual greenhouse gas inventory (GHGI) reports to estimate energy consumption in residential, commercial, and industrial buildings and transportation. The modeling time-period runs from 2010 until 2055 with 5-year time intervals for reporting. The 2010 (City of New York, 2011), 2015 NYC GHGI reports (City of New York, 2017) and 2020 NYC GHGI reports are used to calibrate the model's results for 2010, 2015 and 2020.

New York City–specific data sources are used for most inputs within COMET-NYC. Vehicle miles travelled (VMT) projections from New York Metropolitan Transport Council (NYMTC) are used for transportation demand (2023). Population projections from NYMTC, combined with statistics of residential and commercial real estate from PLUTO, are used to find the projected demand for energy in residential and commercial buildings. Projections from NYSERDA are used to adjust these energy demand forecasts to account for increased cooling load and decreased heating load due to rising temperatures. The New York Independent System Operator (NYISO) Gold Book is used to find projected electricity demand in the rest of New York State and to find the locations of current electric generators in New York State (2023). National projections from the EIA's Annual Energy Outlook (AEO) are used to find the projected cost and efficiency of new energy technologies, as well as cost curves for generating energy from fossil or renewable sources (EIA, 2016). The model was also calibrated to match historical New York City GHG emissions from the GHG Inventory (City of New York, 2023).

Furthermore, the COMET-NYC includes data specific to NYC such as New York City Department of Environmental Protection (NYCDEP), the New York State Energy Research & Development Authority (NYSERDA), and a variety of other sources. Where local data is unavailable, the COMET-NYC relies on a database created for U.S. energy system. For instance, the U.S. Environmental Protection Agency (EPA) has been maintaining a model representing the U.S. national energy system through nine census divisions (known as the EPAUS9rT model) for use within the TIMES energy-economy-environment modeling framework (Lenox et al., 2013). Data for the EPAUS9rT are derived primarily from the U.S. Energy Information Administration (EIA)'s National Energy Modeling System (NEMS) model, and the results are calibrated every two years to the corresponding Annual Energy Outlook (AEO) published by EIA.

The COMET-NYC consists of six regions including Brooklyn, Bronx, Manhattan, Staten Island, Queens and New York State (to cover EGUs in the state). Each of the six-regions is structured in a different RES diagram. Those diagrams are interconnected through technology links (i.e. fuel trades). The naming conventions for each fuel type remain same from one region to another. The naming identification of regions are presented in *Figure 2*. For instance, in the model, R1 represents the all the EGUs in New York State except the ones in the New York City. This region is the source of electricity and transfers electricity to other regions via trade technologies.

In addition to the six regions, there is an outer region for model fuel supply (R0-"dummy"). This is the supply region of the model that characterizes the fossil fuel sources located outside of the (or trade) option, a transportation cost, capacity limits, and capacity extension cost (investment cost) are defined.

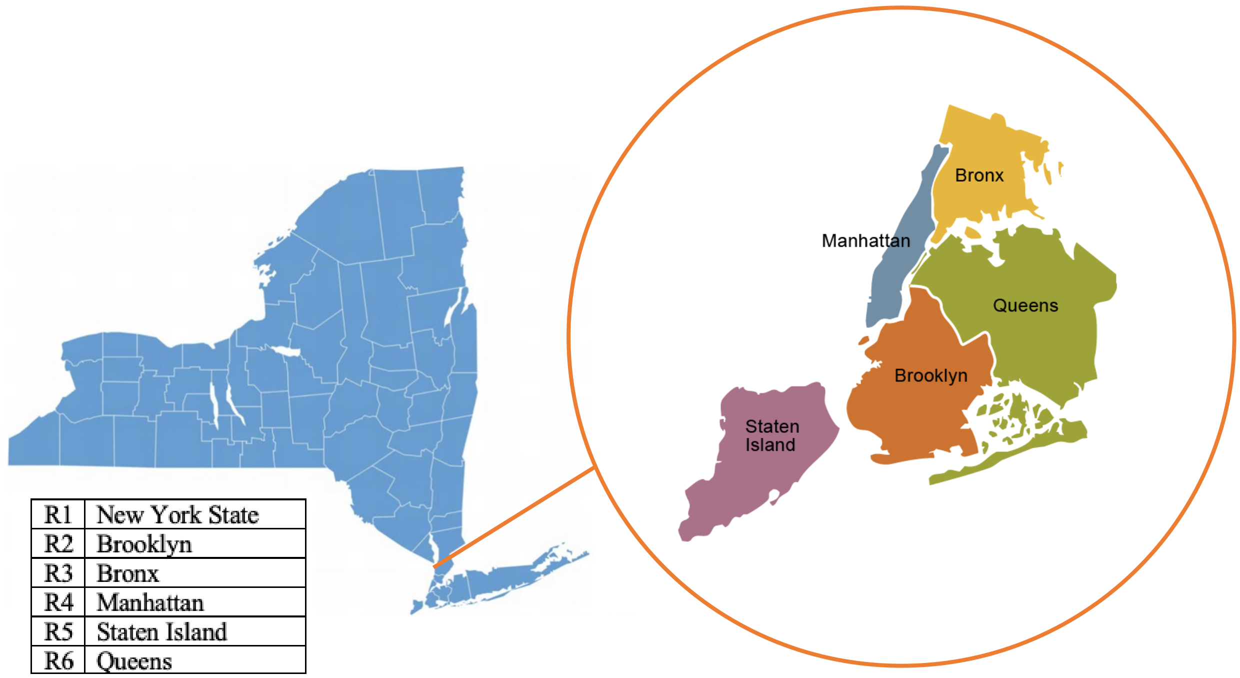

Figure 2 COMET-NYC regional coverage – New York State and Boroughs of New York City

3.1 Units

The cost data is given in 2005 million U.S. dollars. Energy carriers are given in terms of PJ. Most end-use demands are given in terms of PJ with the following exceptions:

- Commercial and Residential Lighting Demand: billion lumens per year (bn-lum-yr),
- Light-duty Transportation: billion vehicle miles traveled (bn-vmt),
- Medium- and Heavy-duty Transportation: billion vehicle miles traveled (bn-vmt),
- Passenger rail: billion passenger miles (bn-pass-miles).

3.2 System-wide Model Assumptions

- There are numerous assumptions that are used to compute the annual investment cost such as annual discount rate, also referred to as “hurdle rate.” It is applied as 3% and 4% to the system-wide economy (that covers all 6 regions). This discount rate can be adjusted for a specific technology if this technology requires a different rate.
- The year is divided into 12 different time slices over the planning horizon as seen in *Table 2*. The fraction of the year is specified in the database. These time slices were derived from the EIA’s National Energy Model System (NEMS) to appropriately represent the seasons and intraday time slices (Goudarzi, 2007; Appendix A).
- Grid transmission losses are characterized as “transmission efficiency.” This value is selected as 95% based on EIA state profile.
- The reserve margin/capacity for electricity is 20%.

Table 2 Time-Slice Fractions Used to Characterize Load- Duration Curves

Description	Time Fraction
Intermediate Day – AM	8.36%
Intermediate Night – PM	9.95%
Intermediate Night	13.93%
Intermediate Peak	1.19%
Summer Day – AM	9.75%
Summer Day – PM	10.54%
Summer Night	11.14%
Summer Peak	1.99%
Winter Day – AM	6.91%
Winter Day – PM	9.87%
Winter Night	15.19%
Winter Peak	1.18%

SOURCE: Goudarzi (2007); Appendix B

3.3 Pollutant Coverage

The COMET-NYC includes emission factors for: carbon dioxide (CO_2), nitrogen oxides (NO_x), particulate matter < 10 µm (PM_{10}), particulate matter < 2.5 µm ($PM_{2.5}$), sulfur dioxide (SO_2), volatile organic compounds (VOC), methane (CH_4), carbon monoxide (CO), Organic Carbon (OC), and Black Carbon (BC) for each region and sector across the whole energy system related to fuel consumption. System-level carbon dioxide is reported in million tons (Mt) per year, where all other emissions within sectors are reported in thousand tons (kton) per year.

3.4 Version control

This documentation provides details on the V15.0.9 of the COMET-NYC model. This version was modified and updated to aid NYC Office of Management and Budget with their city budgeting process during time frame 2023 through 2024. The COMET-NYC is used to generate various emission reduction scenarios for the city in line with their climate goals.

Since more updates are conducted to the model, V16.0.1 includes some updates to the buildings module. In the following sections, we will describe each update separately.

4 Buildings Module

The building end-use energy demands are split into residential, commercial, and industrial (facility level) buildings. A majority of the industrial sector is lumped in with the commercial for V15.0.9. In V16.0.1, manufacturing and concentration will be broken out into in the industrial sector. The level of end-use demand in each of the three sub-sectors is estimated using a bottom-up approach based on the U.S. EIA's AEO (Specifically, the U.S. EIA's Commercial Building Energy Consumption Survey (CBECS) and the U.S. EIA's Residential Energy Consumption Survey (RECS)), the NYC Primary Land Use Tax Lot Output (PLUTO), official NYC energy and emissions and other related official data.

4.1 Calibration to base years

COMET-NYC characterizes existing building stock through its end-use energy service demand and includes suite of future technologies and retrofits to meet these demands. This sector is built using the data collected under the NYC Benchmarking Law (LL84) along with Primary Land Use Tax Lot Output (PLUTO) files. PLUTO dataset contains data on all buildings in NYC - where each building has a unique Borough-Block-Lot (BBL) number. LL84 provides annual measurements of energy and water consumption for some building types. The data set is included in the public data repository associated with this report (Appendix B). In addition, city's GHG inventory data provide various fuel consumption levels per each building type. All data is matched (by BBL as well as reporting year) to allocate existing building stock to the associated energy use for each building. We utilized the PLUTO data to build baseline calibration framework. The GHG inventory data has fuel consumption by type for each building type categorized as Residential (1-4 units and multifamily), Commercial and Institutional (commercial, institutional, and streetlights) and Manufacturing and construction (industrial). Each individual fuel consumption (e.g., natural gas consumption) per building type (e.g., residential buildings) is needed to calibrate end-use energy service demands. We obtained data set from NYC Department of Health and Mental Hygiene that characterizes fuel allocations per space heating, water heating, space cooling, lighting, conveyance, process loads, and miscellaneous for calendar year 2014 for each building type. This data did not provide borough-specific values. A close look at PLUTO 2010 shows us total building area by building type in each borough (*Figure 3*). Thus, we used this information to allocate energy consumption values per building type per end-use service demand into five boroughs. This data set is included in the public data repository associated with this report (Appendix C).

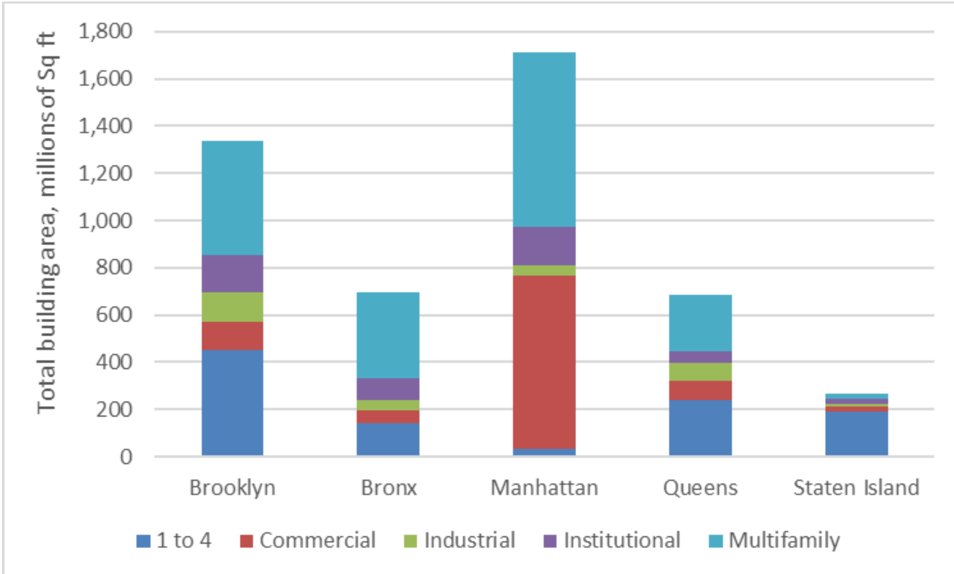

Figure 3 Total building area in sq.ft by building type and region. Data sourced from PLUTO 2010. "1-4" refers to 1-4 unit family and multi-family households.

Next is to characterize existing technology stock per end-use service demand. This activity includes finding, for instance, capacity and efficiency of boilers, furnaces, and heat pumps for space heating per each borough. This type of detailed technology data does not exist specific to NYC, therefore we rely on EIA's Commercial and Residential Energy Consumption Surveys (CBECS and RECS) and EIA's AEO to gather information specific to the NYC census division. Technology capacity, costs, and efficiency data for Middle Atlantic Census Division from CBECS and RECS is gathered for our calculations. Future technology representations are gathered from EIA[2].

[2] https://www.eia.gov/analysis/studies/buildings/equipcosts/pdf/appendix-a.pdf also provided in Appendix D.

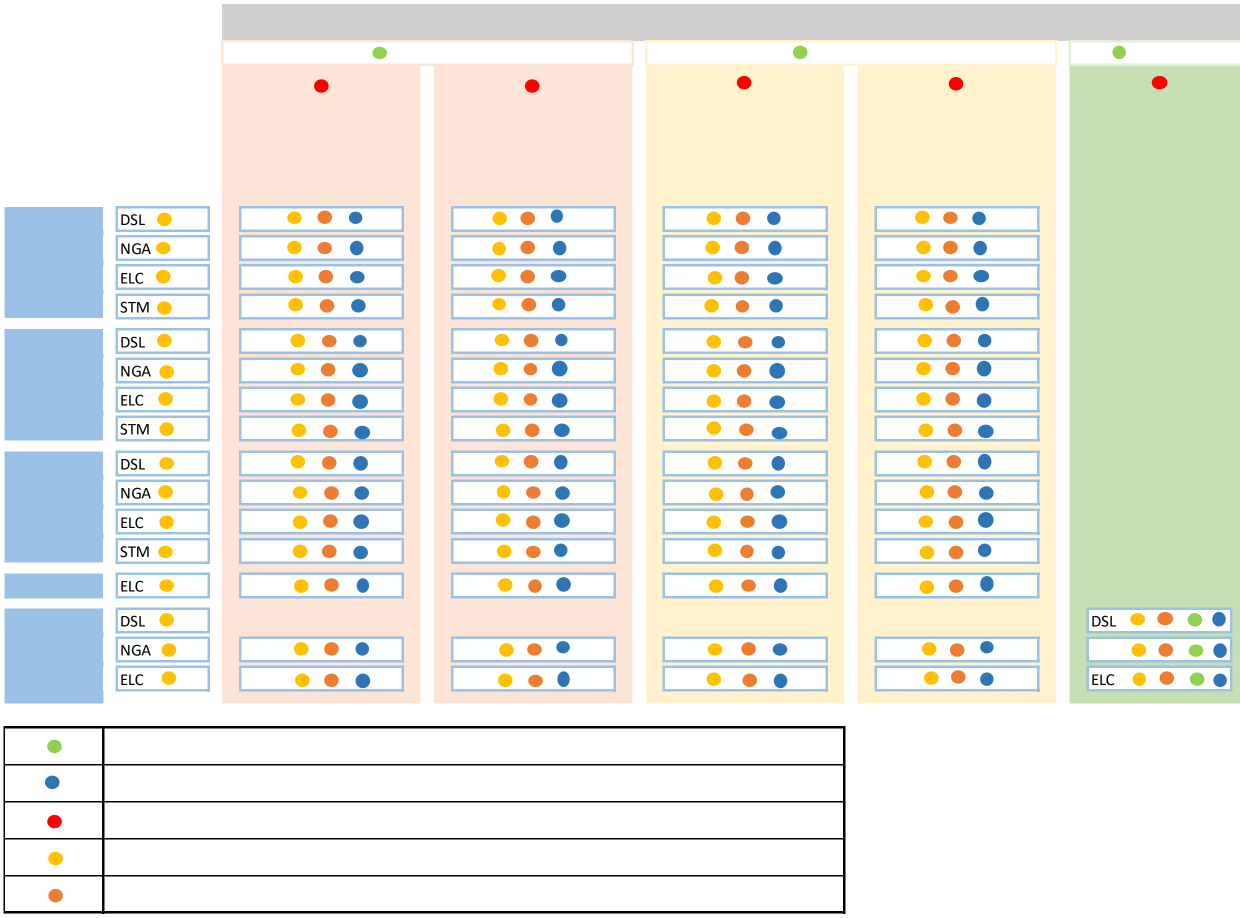

Figure 4 Data Sources for Buildings Sector

4.2 Residential Sector

4.2.1 Residential Sector Demand Projections

Residential sector energy service demand includes 1-4-unit family and multifamily households. Total energy demand for the residential sector is classified under four main sections (space heating, space cooling, water heating, lighting) and two aggregated fuel consumptions (other-electricity and other-natural gas). The nomenclature and related units are given in *Table 3*.

Table 3 Residential End-use Service Demands

Demand	Units	Description
RSC	PJ/yr	Space Cooling
RSH	PJ/yr	Space Heating
RWH	PJ/yr	Water Heating
RLT	billion lumens/yr	Lighting
ROE	PJ/yr	Other - Electricity
ROG	PJ/yr	Other - Natural Gas

The end-use service demand projections for buildings need to be determined as this is one of the key model inputs. The projections depend on various drivers such as population projections (*Table 4*), economic growth, number of people per household (*Table 5*), type of housing, building envelope efficiency and additional need for cooling and heating (due to changes in Heating Degree Day (HDD) and Cooling Degree Day (CDD) (*Table 5*)). Population average square feet of space per household are the key drivers of the demand growth. We gathered borough specific population projections from the city (see *Table 4)* (NYMTC, 2020). The raw data from NYMTC is included in Appendix E. In addition, we gather HDD and CDD projections specific to NYC (see *Table 5*) (NYSERDA, 2024).

Table 4 New York City Population Projections

Region	2010	2015	2020	2025	2030	2035	2040	2045	2050
Brooklyn	2,552,911	2,593,655	2,647,112	2,760,391	2,820,822	2,860,506	2,894,388	2,928,160	2,956,932
Bronx	1,385,108	1,423,160	1,454,816	1,515,667	1,548,245	1,573,786	1,595,881	1,616,845	1,633,550
Manhattan	1,585,873	1,636,537	1,668,548	1,698,050	1,735,482	1,754,534	1,768,412	1,781,885	1,791,292
Staten Island	468,730	477,525	484,897	491,202	495,047	498769	502,327	505,464	507,920
Queens	2,250,002	2,294,943	2,349,324	2,418,636	2,463,405	2,483716	2,500,457	2,517,076	2,528,763

SOURCE: NYMTC 2020

Table 5 Average number of persons per household in 2005[3]

Region	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050	2055
Brooklyn	2.6	2.6	2.7	2.7	2.7	2.7	2.6	2.6	2.6	2.6	2.6
Bronx	2.6	2.6	2.7	2.7	2.7	2.7	2.6	2.6	2.6	2.6	2.6
Manhattan	2.0	2.0	2.1	2.1	2.1	2.0	2.0	2.0	2.0	2.0	2.0
Queens	2.9	2.9	3.0	3.0	3.0	2.9	2.9	2.9	2.9	2.9	2.9
Staten Island	2.9	2.9	2.9	3.0	2.9	2.9	2.8	2.8	2.8	2.8	2.8
NYC	2.6	2.6	2.7	2.7	2.7	2.6	2.6	2.6	2.6	2.6	2.6

Table 6 Heating and Cooling Degree Days

Region	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
COOLING DEGREE DAYS, CDD											
NYC	1112	1142	1503	1544	1635	1636	1637	1653	1801	1815	1938
HEATING DEGREE DAYS, HDD											
NYC	4376	4376	4376	4376	3930	3933	3958	3938	3759	3741	3576

SOURCE: NYSERDA 2024

[3] https://www.nyc.gov/assets/planning/download/pdf/data-maps/census/census2010/t_sf1_p5_nyc.pdf
The city level growth rate is applied to borough level 2005 baseline value. The data is for 2010, therefore we assumed that this value was the same for prior years. Values came from NYC Planning Department.

The total city-wide energy consumption per end-use service demand reported in 2015 is used as benchmark for projections. Below we walk through how to determine Residential Space Heating Demand for 2045 in Brooklyn ($RSH_{2045,\ BK}$):

$RSH_{2045,\ BK}$ = HousingHeatingCoefficient * AverageHouseSquareFootage $_{BK}$ * NumberOfHouseholds $_{2045,BK}$ * HDD_Projection $_{2045,\ NYC}$ / Conversion Factor

Housing Heating Coefficient = AdjustedHeatingServiceDemand$_{2045,\ BK}$ * Conversion Factor / (AverageHouseSquareFootage$_{2045}$ * NumberOfHouseholds$_{2045,\ BK}$ * HDD_Projection$_{2045,NYC}$)

AdjustedHeatingServiceDemand$_{2045,\ BK}$ = AdjustedHeatingServiceDemand$_{2005}$ * (1-RetrofitEnvelopGain$_{2045}$) * (1-NewBuildEnvelopeGain$_{2045}$) * (HDD$_{2045}$/HDD$_{2005}$) * (NumberOfHouseholds$_{2045}$/NumberOfHouseholds$_{2005}$) * (AverageHouseSquareFootage$_{2045}$/AverageHouseSquareFootage$_{2005}$) * (SpaceHeatingCoefficient$_{BK}$)

SpaceHeatingCoefficient$_{BK}$ = BuildingAdjustment/PopulationEffect/1.1

BuildingAdjustment = FuelConsumption$_{2010,\ BK}$/FuelConsumption$_{2010,\ NYC}$

PopulationEffect = NumberOfHouseholds$_{2010,\ BK}$/NumberOfHouseholds$_{2010,\ NYC}$

NumberOfHouseholds$_{2045,BK}$ = PopulationProjection$_{2045,\ BK}$/AverageNumberOfPersonsPerHousehold$_{2045,\ BK}$

AdjustedHeatingServiceDemand$_{2005}$ = $RSH_{2005,NYC}$ * NumberOfHouseholds$_{2005,\ BK}$/ NumberOfHouseholds$_{2005,\ NYC}$ * SpaceHeatingCoefficient$_{BK}$

$RSH_{2005,NYC}$ = $RSH_{2010,NYC}$ * AEOSpaceHeatingFinalEnergy$_{2005}$ / AEOSpaceHeatingFinalEnergy$_{2010}$

$RSH_{2010,NYC} = RSH_{ELC,2010,NYC} + RSH_{NGA,2010,NYC} + RSH_{DSL,2010,NYC} + RSH_{STM,2010,NYC}$

$RSH_{2015,NYC} = RSH_{2010,NYC}$

$RSH_{2020,NYC}$ = $RSH_{2015,NYC}$ * AEOSpaceHeatingFinalEnergy$_{2020}$ / AEOSpaceHeatingFinalEnergy$_{2015}$

$RSH_{2025,NYC}$ = $RSH_{2020,NYC}$ * AEOSpaceHeatingFinalEnergy$_{2025}$ / AEOSpaceHeatingFinalEnergy$_{2020}$

…

$RSH_{2050,NYC}$ = $RSH_{2045,NYC}$ * AEOSpaceHeatingFinalEnergy$_{2050}$ / AEOSpaceHeatingFinalEnergy$_{2045}$

FuelConsumption$_{2010,\ BK}$ = FuelConsumption$_{ELC,2010,BK}$ + FuelConsumption$_{NGA,2010,BK}$ + FuelConsumption$_{DSL,2010,BK}$ + FuelConsumption$_{STM,2010,BK}$

FuelConsumption$_{ELC,2010,BK}$ = FuelConsumption$_{ELC,2010,BK,\ 1\text{-}4}$ + FuelConsumption$_{ELC,2010,BK,\ Multifamily}$

FuelConsumption$_{ELC,2010,BK,\ 1\text{-}4}$ = (PLUTOBuildingArea$_{BK,\ 1\text{-}4}$ / PLUTOBuildingArea$_{NYC,\ 1\text{-}4}$) * (FuelConsumption$_{ELC,\ 2014,\ 1\text{-}4}$ / FuelConsumption$_{ELC,\ 2014,\ NYC}$) * FuelConsumption$_{ELC,\ 2010,\ NYC}$ * (FuelConsumption$_{SH,ELC,2014,1\text{-}4}$ / FuelConsumption$_{ELC,2014,1\text{-}4}$)

Similarly, the end-use service demands are calculated for all types per borough, and summarized in *Table 6*.

Table 7 Residential Sector Demand Projections (COMET_NYC V15.0.9)

Borough	2015	2020	2025	2030	2035	2040	2045	2050
Residential Cooling Demand (PJ)								
Bronx	4.47	4.91	5.14	5.28	5.42	5.96	6.04	6.48
Brooklyn	8.15	8.94	9.36	9.61	9.86	10.80	10.94	11.73
Manhattan	6.66	7.29	7.46	7.65	7.83	8.54	8.62	9.20
Queens	6.50	7.15	7.39	7.56	7.71	8.41	8.48	9.04
Staten Island	1.39	1.51	1.54	1.56	1.59	1.73	1.74	1.86
Residential Heating Demand (PJ)								
Bronx	23.25	21.66	22.67	23.40	23.70	22.80	22.85	21.93
Brooklyn	39.29	36.54	38.28	39.53	39.94	38.34	38.36	36.81
Manhattan	42.72	39.70	40.58	41.92	42.22	40.37	40.23	38.43
Queens	19.80	18.47	19.10	19.66	19.75	18.86	18.78	17.93
Staten Island	7.27	6.73	6.85	6.97	7.00	6.69	6.65	6.35
Residential Lighting Demand (Billion Lumens/Year)								
Bronx	1.64	1.59	1.67	1.73	1.77	1.79	1.82	1.84
Brooklyn	2.81	2.72	2.87	2.96	3.02	3.06	3.10	3.13
Manhattan	2.69	2.60	2.68	2.77	2.82	2.84	2.86	2.88
Queens	1.42	1.38	1.43	1.48	1.50	1.51	1.52	1.53
Staten Island	0.54	0.52	0.53	0.54	0.55	0.56	0.56	0.56
Residential Miscellaneous Electric Demand (PJ)								
Bronx	4.87	4.74	4.69	4.51	4.45	4.38	4.32	4.25
Brooklyn	9.56	9.29	9.21	8.86	8.71	8.57	8.43	8.30
Manhattan	6.79	6.59	6.37	6.13	6.01	5.89	5.78	5.66
Queens	4.91	4.79	4.68	4.49	4.39	4.30	4.21	4.12
Staten Island	2.45	2.37	2.28	2.16	2.11	2.07	2.02	1.98
Residential Miscellaneous Gas Demand (PJ)								
Bronx	0.49	0.69	0.69	0.69	0.67	0.66	0.65	0.65
Brooklyn	0.91	0.90	0.90	0.89	0.87	0.85	0.85	0.85
Manhattan	1.41	1.40	1.36	1.34	1.31	1.27	1.27	1.27
Queens	0.18	0.18	0.18	0.17	0.17	0.16	0.16	0.16
Staten Island	0.09	0.09	0.09	0.09	0.09	0.08	0.08	0.08
Residential Water Heating Demand (PJ)								
Bronx	7.67	7.94	8.29	8.43	8.36	8.26	8.12	7.98
Brooklyn	12.48	12.90	13.48	13.71	13.58	13.38	13.14	12.90
Manhattan	13.28	13.72	13.99	14.23	14.05	13.79	13.48	13.18
Queens	6.25	6.49	6.69	6.78	6.68	6.55	6.40	6.25
Staten Island	2.07	2.13	2.16	2.17	2.13	2.09	2.04	1.99

SOURCE: U.S. EPA, with EIA's Commercial and Residential Energy Consumption Surveys

In COMET-NYC V15.0.9, PLUTO 2010 values are used as basis for the calibration, along with 2010 inventories. In COMET-NYC V16.1, we pulled historic data from the main PLUTO database, and able to calibrate the model using PLUTO 2010, 2015 and 2020 data with corresponding inventory data. Since the floorspace allocation differed from one year to another the historic demand values are shifted slightly.

Next to populate the future technology portfolio that can meet the end-use service demands. The technology and fuel combinations are given in *Table 7*. Future technology cost and efficiency values for residential space heating, space cooling, water heating and lighting are taken from EIA's Updated Buildings Sector Appliance and Equipment Costs and Efficiencies (2023). All parameters related to residential sector technologies are provided exogenously into the model.

Table 8 Residential Technology and Fuel Combinations

End-use Demand	Technology Type	Fuel
Space Heating	Radiant – Boiler System	Electric, Natural Gas, Distillate
	Furnace	Natural Gas, Distillate, Kerosene
Space Cooling	Room AC	Electric
	Central AC	Electric
Space Heating and Cooling (Simultaneous)	Air-Source Heat Pump	Electric
	Ground-Source Heat Pump	Electric
Water Heating		Electric, Natural Gas, Distillate, Solar
Lighting	Incandescent	Electric
	CFL	Electric
	LED	Electric
	Halogen	Electric
	Linear Fluorescent	Electric
	Reflector	Electric

4.2.2 Residential Emissions Accounting

COMET-NYC tracks fuel combustion related emissions as well as some process and leakage emissions occurring along the energy system. For instance, CO_2 emissions are tracked through quantity of fuel combusted and verified for 2010, 2015 and 2020 using New York City's Greenhouse Gas Inventory. Methane emissions are tracked throughout the system, with the main contribution coming from oil and gas operations, which are beyond the geographical scope of this analysis. Criteria air emission factors are derived from U.S. EPA's National

Emissions Inventory (NEI) platform and AP-42 datasets (EPA November 2024, and EPA 2015). These emission factors are tied to fuel and technology combinations.

4.2.3 Residential Sector Constraints

COMET-NYC utilizes constraints to mimic more realistic outputs in accordance with the existing city policy implications. For instance, to model the city's plan to phase out petroleum-based space heating options, an upper bound on diesel consumption is set for the 2015-2055 period (*Table 8*). However, we also include a lower bound on electricity consumption on the space heating to assure that the share of electricity-based space heating will not drop unrealistically over the modeling period. Additionally, district heat was constrained to Manhattan (R4) to mimic real world conditions. In addition to fuel share constraints, technology splits are included to mimic AEO 2016 Residential Unit Consumption of Energy with respect to the equipment classes.

Table 9 Residential Fuel Use and Technology Mix Constraints

End-use Service Demand	Fuel/Tech	At Least	At Most	Year
Residential Space Heating	Diesel	17.4%	20.2%	2015
	Diesel	12.3%	12.3%	2055
	Diesel	0%		2055
	Electric	0.9%	1.8%	2015
	Electric		2.2%	2020
	Electric	3.0%	100.00%	2055
	Natural Gas	73.4%		2015
	Natural Gas	73.4%		2020
	Natural Gas	0%		2055
	Furnace	46.6%		2015
	Furnace	34.0%		2055
	Furnace- Diesel		15.0%	2015
	Furnace- Diesel		9.2%	2055
	Furnace- Electric		4.40%	2015
	Furnace- Electric		6.60%	2055
	Heat Pump	0.60%		2015
	Heat Pump	0.50%		2055
	Radiant	42.7%		2015
	Radiant	31.2%		2055
Residential Water Heating	Diesel	13.4%	29.9%	2015
	Diesel	4.1%	18.3%	2020
	Natural Gas	81.60%		2015
	Natural Gas	59.60%		2020
	NG - Instantaneous	2.00%		2015
	NG - Instantaneous	2.00%		2055

End-use Service Demand	Fuel/Tech	At Least	At Most	Year
	Solar		10.00%	2050
	Electric	2.8%	3.5%	2015
	Electric	2.0%	100.00%	2055
Residential Space Cooling	Central Heat Pump	2.3%		2015
	Central Heat Pump	1.7%		2055
	Central AC	38.1%		2015
	Central AC	27.8%		2055
	Central AC	59.4%		2015
	Central AC	43.0%		2055

4.3 Commercial Sector

Commercial sector energy service demand covers Commercial, Institutional and Industrial buildings. Total energy demand for the commercial sector is classified under four main sections (space heating, space cooling, water heating, lighting) and two aggregated fuel consumptions (other-electricity and other-natural gas).

4.3.1 Commercial Energy Demand Services

The commercial sector in COMET-NYC V15.0.9 is an aggregation of Commercial, Institutional and Industrial Buildings. Industrial building emissions are defined in the industrial sector files, however institutional and industrial buildings demands are lumped in and included in the demand calculations for the commercial sector. These data inputs are sourced from the 2015 NYC GHG inventory under manufacturing and construction.

In the COMET-NYC V16.1, the industrial building demand is separated from the Commercial and Institutional Buildings. The industrial building demand which is listed under Manufacturing and Construction in the inventories are represented in the IND workbook.

The methodology and technology structure are similar the residential sector. Hence some sections of the commercial sector section are curtailed. The commercial sector module includes details of commercial sector energy demands and their corresponding end-used technologies. The nomenclature and corresponding units for those end use energy demands are listed in *Table 10*.

The main driver for commercial demand would be projection of total floor space. Conventional methods rely on gathering the best estimate of the current floor space dedicated to the different types of businesses and the current employees working at these businesses. This approach leads to estimation of the average floor space needed per employee for different types of commercial businesses. The Northwest Power and Conservation Council implemented a methodology where they made estimates using employee trends (2021). In future work, it is possible to implement a similar methodology to then look at the future number of employees in the region and derive the estimated need for commercial floor space from the projected employment trends. However, in our data search we could not allocate any future projections for employment trends per business type. Therefore, in interim, we calculated total commercial floor area per capita using 2020 population data per borough and reported aggregate floor area from PLUTO (*Table 9*).

Table 10 2020 Floor Area (Commercial + Institutional + Industrial)

Borough	2020 (sqft)
BK	402,983,294
BX	193,021,586
MN	789,411,121
SI	61,710,960
QN	333,675,891

Table 11 Commercial Demand

Demand	Units	Description
CSH	PJ/yr	Space Heating
CSC	PJ/yr	Space Cooling
CWH	PJ/yr	Water Heating
CLT	billion lumens/yr	Lighting
CME	PJ/yr	Misc - ELC
CMN	PJ/yr	Misc - NG

Final energy consumption in 2010 and 2015 are calibrated against reported actual final energy consumption data provided by NYC Department of Health and Mental Hygiene. Demands are then calculated similar to what is outlined for residential sector and presented in *Table 11*.

Table 12 Commercial Sector Demand Projections

Borough	2015	2020	2025	2030	2035	2040	2045	2050
Commercial Cooling Demand (PJ)								
Brooklyn	26.29	26.88	28.45	29.05	29.05	29.10	31.35	31.21
Bronx	12.43	12.86	13.63	13.90	13.90	13.95	15.06	15.02
Manhattan	50.76	52.71	55.73	55.54	55.55	55.47	59.52	59.03
Staten Island	21.62	22.19	23.55	23.75	23.67	23.57	25.27	25.03
Queens	4.04	4.14	4.36	4.32	4.26	4.24	4.55	4.50
Commercial Heating Demand (PJ)								
Brooklyn	24.70	22.17	22.64	22.78	22.47	21.21	20.86	19.65
Bronx	11.81	10.61	10.83	10.89	10.77	10.19	10.03	9.46
Manhattan	47.33	42.43	42.29	42.56	41.86	39.35	38.54	36.16
Staten Island	3.75	3.35	3.32	3.29	3.23	3.03	2.97	2.78
Queens	20.06	18.06	18.21	18.26	17.91	16.82	16.46	15.43

Borough	2015	2020	2025	2030	2035	2040	2045	2050
Commercial Lighting Demand (Billion Lumens/Year)								
Brooklyn	14.71	15.67	17.01	17.78	18.69	19.58	19.81	20.00
Bronx	7.04	7.51	8.14	8.51	8.96	9.41	9.53	9.63
Manhattan	28.85	30.69	32.52	34.00	35.62	37.18	37.46	37.66
Staten Island	2.26	2.40	2.53	2.61	2.72	2.84	2.86	2.87
Queens	12.15	12.97	13.91	14.49	15.14	15.78	15.89	15.96
Commercial Miscellaneous Electric Demand (PJ)								
Brooklyn	14.58	16.25	18.31	20.11	22.06	24.20	26.56	29.16
Bronx	6.97	7.78	8.76	9.62	10.58	11.63	12.78	14.04
Manhattan	28.59	31.83	35.01	38.46	42.05	45.96	50.23	54.89
Staten Island	2.24	2.49	2.72	2.95	3.22	3.51	3.83	4.19
Queens	12.03	13.45	14.97	16.39	17.87	19.51	21.30	23.26
Commercial Miscellaneous Gas Demand (PJ)								
Brooklyn	1.20	1.27	1.39	1.55	1.82	2.18	2.18	2.19
Bronx	0.58	0.61	0.67	0.74	0.87	1.05	1.05	1.05
Manhattan	2.36	2.49	2.66	2.97	3.48	4.13	4.13	4.12
Staten Island	0.19	0.19	0.21	0.23	0.27	0.32	0.31	0.31
Queens	0.99	1.05	1.14	1.27	1.48	1.75	1.75	1.75
Commercial Water Heating Demand (PJ)								
Brooklyn	4.04	4.12	4.30	4.39	4.46	4.51	4.56	4.61
Bronx	1.93	1.98	2.06	2.10	2.14	2.17	2.20	2.22
Manhattan	7.92	8.08	8.22	8.40	8.49	8.56	8.63	8.67
Staten Island	0.62	0.63	0.64	0.64	0.65	0.65	0.66	0.66
Queens	3.34	3.41	3.52	3.58	3.61	3.63	3.66	3.68

SOURCE: U.S. EPA , with EIA's Commercial and Residential Energy Consumption Surveys

4.3.2 Commercial Technology Structure

Several demand technology and fuel combinations are included in the model (*Table 12*). Each of these technology and fuel combinations have distinct technology attributes such as investment cost, O&M cost, starting year, and fuel efficiency. We utilized AEO's Commercial Technology Equipment Type Description File (EIA, 2023) and Commercial Building Energy Consumption Surveys (CBECS) to determine values for various end-use sectors such as space heating, cooling etc. Specifically, CBECS is utilized to allocate technology shares among end-use service demands (2018).

Table 13 Commercial Technology and Fuel Combinations

End-Use Demand	Technology Type	Fuel
Space Heating	Boiler	Electric, Natural Gas, Diesel
	Furnace	Natural Gas, Diesel
Space Cooling	Centrifugal Chiller	Electric, Natural Gas
	Reciprocating Chiller	Electric
	Scroll Chiller	Electric
	Screw Chiller	Electric
	Rooftop AC	Electric, Natural Gas
	Window/Wall AC	Electric
	Central AC	Electric
Space Heating and Cooling (Simultaneous)	Air-Source Heat Pump	Electric
	Ground-Source Heat Pump	Electric
Water Heating		Electric, Natural Gas, Diesel, Solar
Lighting	Incandescent	Electric
	CFL	Electric
	LED	Electric
	Halogen	Electric
	Linear Fluorescent	Electric
	Metal Halide	Electric

4.3.3 Commercial Emissions Accounting

Emission accounting follow same procedure as residential sector.

4.3.4 Commercial Sector Constraints

Similarly to in the residential sector, COMET-NYC uses constraints to achieve realistic adoption of certain commercial technologies.

Table 14 Commercial Fuel Use and Technology Mix Constraints

	Fuel/Tech	At Least	At Most	Year
Commercial Space Heating	Electric	9.20%		2015
	Electric		10.80%	2020
	Electric	6.70%	21.60%	2055
	Natural Gas	49.10%		2015
	Natural Gas	49.10%		2020
	Natural Gas	0%		2055
	Diesel		8.10%	2015
	Diesel		16.2%	2055
	Boiler	31.00%		2015
	Boiler	0%		2055

	Furnace	47.80%		2015
	Furnace	0%		2055
Commercial Space Cooling	Electric	77.90%		2015
	Electric	56.90%		2055
	Natural Gas	17.10%		2015
	Natural Gas	12.50%		2055
	Rooftop	49.30%		2015
	Rooftop	36.00%		2055
	Central	14.50%		2015
	Central	10.60%		2055
	Window/Wall	10.80%		2015
	Window/Wall	7.90%		2055
	Ground-Source Heat Pump	3.20%		2015
	Ground-Source Heat Pump	2.30%		2055
	Air-Source Heat Pump	5.20%		2015
	Air-Source Heat Pump	3.80%		2055
Commercial Water Heating	Electric	0.60%	3.50%	2015
	Electric	0.40%	100%	2055
	Natural Gas	76.30%	83.90%	2015
	Natural Gas	0%	61.30%	2055
	Diesel		20.80%	2015
	Diesel		15.20%	2055
	Solar		1.00%	2055

SOURCE: U.S. EPA, with LL84 Dataset and EIA's Commercial and Residential Energy Consumption Surveys

5 Transportation Sector

The transportation sector covers the vehicle technologies that are used to meet the passenger and freight demand. Technologies are classified under two main technology sets namely light-duty vehicles (LDV) and heavy-duty vehicles (HDV) – which includes medium duty vehicles.

LDV technologies include gasoline, diesel, compressed natural gas (CNG), hydrogen (H_2), and electric powered cars including plug-in, electric vehicle (EV), and hybrid, which meet passenger demand measured in billion vehicle miles traveled per year (bn-vmt-yr). HDV technologies include heavy-duty short haul trucks, buses, and electric passenger rail to account for NYC's extensive public transit system.

5.1 Light-Duty Vehicles

Light-Duty Vehicle (LDV) demand account for personal vehicle miles travelled (VMT) for passenger demand. Transportation Light-duty (TL) demand is represented not only by various demand technologies (including different fuel type and efficiency levels) but also fuel distribution networks for gasoline, diesel, electricity, etc. Mini-compact, compact, full size, minivan, pick-up truck, small SUV, and large SUV are the main vehicle class sizes.

5.1.1 Light-Duty Vehicle Energy Demand Services

Light-duty vehicle demand for base year is calculated with respect to the total fuel consumption provided in NYC greenhouse gas emission inventory report using base year average vehicle efficiency, aggregate vehicle miles travelled. The historic NYC VMT values are based on NYMTC outputs. These values cover trips originating in the city and ends in the city, plus trips ending in the city and plus originating in the city. The vehicles passing through the city is not included. Therefore, long-haul freight and interstate passenger transport are not included. VMT projections are gathered from NYMTC's Transportation Conformity Determination's regional transportation forecast (2023) (Appendix 2A; Summer Values). Demand trajectories are adjusted for each borough according to population forecasts. 2010 LDV fleet distribution for the NYC is set as a constraint.

Table 15 NYC's Historic Vehicle Miles Traveled and Future Projections for COMET

Year	COMET Inputs	VMT Data	Sources for the VMT
2010	19,657,033,169	19,657,033,169	NYC GHG Inventory - passenger cars
2015	19,662,888,322	19,662,888,322	NYC GHG Inventory - passenger cars
2016		20,244,327,807	NYC GHG Inventory - passenger cars
2017		20,439,338,696	NYC GHG Inventory - passenger cars
2018		21,080,754,312	NYC GHG Inventory - passenger cars
2019		21,523,925,338	NYC GHG Inventory - passenger cars
2020	20,141,922,090	16,593,133,288	NYC GHG Inventory - passenger cars
2021		20,188,205,867	NYC GHG Inventory - passenger cars
2022		21,323,591,647	NYC GHG Inventory - passenger cars
2023			
2024			
2025	21,581,580,205	21,581,580,205	NYMTC-CONFORMITY Appendix 2A (Summer)
2026		21,634,210,285	NYMTC-CONFORMITY Appendix 2A (Summer)
2030	22,083,405,748		Linear extrapolation between 2025 and 2035
2035	22,585,231,290	22,585,231,290	NYMTC-CONFORMITY Appendix 2A (Summer)
2040	23,015,341,268		Linear extrapolation between 2035 and 2045
2045	23,445,451,245	23,445,451,245	NYMTC-CONFORMITY Appendix 2A (Summer)
2050	23,367,934,005	23,367,934,005	NYMTC-CONFORMITY Appendix 2A (Summer)

Table 16 Light-Duty Vehicle Demand Projections per Borough

Region	(billion VMT)								
	2010	2015	2020	2025	2030	2035	2040	2045	2050
Brooklyn	4.35	4.53	4.71	7.98	8.18	8.37	8.55	8.72	8.48
Bronx	3.01	3.09	3.23	3.14	3.20	3.27	3.32	3.36	3.45
Manhattan	3.11	3.08	3.14	3.56	3.63	3.70	3.76	3.82	3.87
Staten Island	2.03	2.08	2.14	2.18	2.24	2.29	2.33	2.37	2.41
Queens	7.16	6.88	6.92	4.71	4.84	4.96	5.07	5.17	5.16
TOTAL	**19.66**	**19.66**	**20.14**	**21.58**	**22.08**	**22.59**	**23.02**	**23.45**	**23.37**

SOURCE: U.S. EPA, with NYMTC

5.1.2 Technology Structure

The light-duty demand (TL) is met by eleven different engine types for seven car classes (*Table 16*).

Table 17 Light-Duty Vehicle Fuel and Technology Combination

		Mini-Compact	Compact	Full-Size	Minivan	Pickup	Small SUV	Large SUV
Gasoline	Conventional	X	X	X	X	X	X	X
	Hybrid		X	X	X	X	X	X
	Plug-in hybrid (20 miles per charge)		X	X	X	X	X	X
	Plug-in hybrid (40 miles per charge)		X	X	X	X	X	X
Diesel	Conventional		X	X	X	X	X	X
	Hybrid		X	X	X		X	X
CNG	Conventional		X	X	X	X		
	Flex fuel		X	X	X	X		
H2	Fuel cell		X	X	X	X	X	X
Electric	100-mile range	X	X	X	X	X	X	X
	200-mile range	X	X	X	X	X	X	X

5.1.3 Light-Duty Vehicle Emissions Accounting

COMET-NYC assigns CO_2 emission factors to each transportation fuel based on carbon content of the fuel. The emissions are then calculated by means of the total consumption of the fuel within the transportation technologies. For criteria air pollutants, emission factors are defined on the technology itself to represent transportation related air regulations. Transportation sector criteria pollutant emission factors for each vehicle type and fuel are gathered from the U.S. EPA's Motor Vehicle Emission Simulator (MOVES2014b). MOVES creates emission factors for on-road motor vehicles and gathers estimate of emissions from cars and trucks under a wide range of user-defined conditions e.g., vehicle types, time periods, geographical areas, pollutants, and vehicle operating characteristics. Emissions factors were obtained by postprocessing MOVES simulations outputs with custom MySQL scripts. The ratio between emissions and activity (distance traveled) were used to create activity-weighed emissions factors. COMET-NYC includes county-level emissions factors simulated via MOVES using vehicle in-place data per county obtained from NYSDEC. More information on how the improved emissions factors were calculated using MOVES can be found in Appendix A.

5.1.4 Light-Duty Vehicle Constraints

The LDV sector includes seven car classes including Mini-compact, Compact, Full-size, Minivan, Pick-up, Small and Large SUV. Car shares are based on regional car and truck sales (sales data by class) for the Middle Atlantic region presented in AEO.

5.2 Heavy-Duty Vehicles

Table 18 presents demand naming conventions for the heavy-duty vehicles (HDV) sector. The HDV sector includes buses (TB), short haul heavy-duty trucks (THS), medium size, passenger rail transport (TRP) and subway in the COMET-NYC database. The reported fuel consumption inventory values from NYC cover trips originating in the city and ends in the city, plus trips ending in the city and plus originating in the city. The vehicles passing through the city is not included; therefore, long-haul freight is not included.

5.2.1 Energy Demand Services

Input data that are concerning heavy-duty technologies are collected from NYC 2010 fuel consumption data and various fleet constraints based on Transportation Data Book and AEO (2014).

"TH" end use energy demands are calculated with the assumption that calibration year existing technology combinations in EPAUS9rT are also valid for NYC. NYC energy consumption value for transportation sector is combined with the average efficiency of existing fleet to calculate the TH demand, then the demand is extended according to the AEO demand projections.

All heavy-duty vehicles transportation demands are exogenous to the model. The demands are projected using population and economic activity data. The inventory years are calibrated in the model.

Table 18 Heavy-Duty Vehicle Demand Projection

Borough	2015	2020	2025	2030	2035	2040	2045	2050
Bus Transportation *(bn-vmt)*								
Bronx	0.06	0.06	0.06	0.07	0.07	0.07	0.08	0.08
Brooklyn	0.11	0.11	0.12	0.12	0.13	0.13	0.14	0.14
Manhattan	0.07	0.07	0.07	0.07	0.08	0.08	0.08	0.09
Queens	0.09	0.1	0.1	0.1	0.11	0.11	0.12	0.12
Staten Island	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03
Medium-Duty Trucks *(bn-vmt)*								
Bronx	0.09	0.09	0.09	0.09	0.09	0.09	0.1	0.1
Brooklyn	0.16	0.16	0.16	0.16	0.17	0.17	0.17	0.18
Manhattan	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Queens	0.14	0.14	0.14	0.14	0.14	0.14	0.15	0.15
Staten Island	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Passenger Rail *(bn-pass-miles)*								
Bronx	1.66	1.73	1.85	1.96	2.07	2.21	2.34	2.48
Brooklyn	3	3.17	3.37	3.56	3.73	3.97	4.18	4.43
Manhattan	1.87	1.96	2.07	2.17	2.25	2.37	2.49	2.62

Borough	2015	2020	2025	2030	2035	2040	2045	2050
Queens	2.66	2.79	2.94	3.07	3.19	3.38	3.59	3.79
Staten Island	0.53	0.58	0.61	0.64	0.67	0.7	0.76	0.81
Short-Haul Heavy-Duty *(bn-vmt)*								
Bronx	0.11	0.12	0.12	0.13	0.14	0.15	0.16	0.16
Brooklyn	0.2	0.21	0.22	0.23	0.25	0.26	0.28	0.29
Manhattan	0.13	0.13	0.14	0.14	0.15	0.16	0.17	0.17
Queens	0.18	0.19	0.2	0.2	0.21	0.22	0.24	0.25
Staten Island	0.04	0.04	0.04	0.04	0.04	0.05	0.05	0.05
TRN.SHIP *(bn-t-m)*								
Brooklyn	1.87	1.76	1.65	1.57	1.56	1.58	1.58	1.58

SOURCE: U.S. EPA, with NYMTC and AEO

Table 19 Heavy-Duty Transportation Demands

Name	Description	Units	Unit Description
TB	Bus	bn-vmt	billion vehicle miles traveled
TMS	Medium Duty Trucks	bn-vmt	billion vehicle miles traveled
THS	Short Haul Heavy Duty Trucks	bn-vmt	billion vehicle miles traveled
TRP	Passenger Rail (includes Subway)	bn-pass-miles	billion passenger miles

5.2.2 Technology Structure

Table 19 represents the available engine and fuel type pairs in the COMET-NYC and distinguishes them with respect to the efficiency improvements and different vintage years with available fuel options. User-defined constraints are set for the calibration year to mimic the real fuel investment data.

Table 20 Heavy-Duty Vehicle Demand Types, Fuel, and Technology Combinations

End-Use Demand	Fuel	Efficiency Improvements
Bus Demand	Diesel	Improved Eff, Adv. Tech, Adv. Hybrid, Conventional
	Electric	Improved Eff, Conventional
	CNG	Improved Eff, Adv. Tech, Adv. Hybrid, Conventional
	Hydrogen fuel cell	Hybrid, Conventional
Medium- and Heavy-Duty Vehicles - Short-Haul Demand	Diesel	Improved Eff, Adv. Tech, Adv. Hybrid, Conventional
	CNG	Improved Eff, Adv. Tech, Adv. Hybrid, Conventional
Rail Passenger Demand - Commuter	Diesel	
	Electric	

End-Use Demand	Fuel	Efficiency Improvements
Rail Passenger Demand - Passenger Rail Subways & Streetcars	Electric	

5.2.3 Heavy Duty Vehicle Constraints

In HDV sector, the model has several constraints. CNG-powered buses are given a fixed amount of investment for 2010 to represent existing stock of CNG bus fleet. Additionally, medium-duty CNG and heavy-duty gasoline and CNG vehicles were given a fixed amount of investment cost by defining an upper bound. The model has both commuter rail and subway to meet TRP demand. To keep the balance to mimic the actual sector conditions the percent of total demand that can be met by commuter rail is protected by lower bounds that belong to the actual NYC transportation data for 2010 (City of New York, 2012). Diesel and electric buses are protected by a lower bound in this same way.

6 Electric Sector

The COMET calculates annual emissions from electric generating facilities providing electricity to New York City. NYC (NYISO Zone J) generates electricity, while the rest of the demand is met through electricity from facilities in New York (NY) state and New Jersey (NJ) state.

The ELC workbook contains technology characterization for all electric generating units (EGU) located in New York and New Jersey. In addition, imports from Canada and neighboring states are represented. The EGUs in New York City are dual fuel generators using natural gas or oil. The ELC sector also includes CHP capacity, and CHP for district heating. The CHP details are taken from the U.S. Department of Energy (DOE) CHP database and U.S. EIA's Historical State database for New York (2023). The transmissions and distribution network capacity for electric trade linkages are included.

All generators in NY and NJ are grouped into 3 different regions based upon their location as listed below.

- In City (NYISO zone J which corresponds to New York City)
- Zone ABCDEF + GHI (NYISO zones A through F; NYISO zones G, H and I)
- PSEG (Portion of PJM in New Jersey) and Imports from Canada

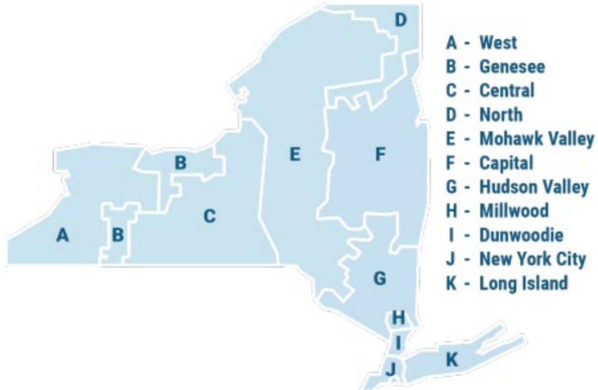

Figure 5 NYISO Load Zone Map | Source: NYISO 2023

Total generation for each of the three different regions are then calculated based upon generation reported from input data sources (EIA 923, EIA 860, EPA CEMS and NYISO Gold Book) and membership of generating facilities to each region. Model determines the electricity demand for the New York City's boroughs through detailed technology representation in buildings and transportation. The electricity demand for the rest of the state is taken exogenously from NYISO GoldBook high demand scenario. Based on the total electric demand, model acts as a capacity expansion model, and calculates future model years EGU capacity based on capital, O&M and fuel costs. In addition, we incorporate constraints to mimic city's access to upstate renewable sources in zones G,H, and I.

It is assumed that a portion of generation from each of those regions listed above goes to serve NYC's load. All the electricity generated in the city is used in the city. Total emissions from each generating facility in NY and NJ are calculated based upon total generation, fuel emission coefficient and heat rate. COMET is not a dispatch model; therefore, we created rules on how generation is allocated to the city. This information came from the NYC sources based on prior electric dispatch studies. These assumptions are then used to calculate the emission intensity of electricity. Following list includes main assumptions:

1. 100% of generation in Zone J is used to serve Zone J's load. For example, if NYC's load is 50,000 GWh and Zone J's annual generation is 25,000 GWh, Zone J's regional distribution factor is 50%.
2. Model includes imports from Canada and PJM grid specifically from PSEG. The total aggregate electricity generation from PSEG plants are represented as import flows, and we calculated an emission intensity for that flow based on the generator heat rate and fuel consumption data.
3. The remainder of NYC's load (i.e. after subtracting zone J generation and PSEG imports) is served by generation in ABDCEF and GHI. The model optimizes on the least cost pathway for the capacity expansion. For calculating NYC specific electricity intensity, we assume a 50/50 split between zones A-F and zones GHI.

We added an installed reserve margin of 20% based on information from NYSIO (2023).

7 Reference Case

The Reference Case is defined as a business-as-usual case that contains all implemented federal and state policies relevant to energy and environment starting in 2010. The methodology and data sources described in the previous sections are utilized to generate a baseline reference case for New York City such that the energy consumption values reported in the NYC GHG Inventory is matching sector-by-sector energy consumption for 2015. The COMET-NYC model outputs can be broken down by sector, technology, region, and several other ways. *Figure 6* depicts the overall trends in fuel consumption for each sector and fuel type for the reference case scenario. The following sections will further break down these trends.

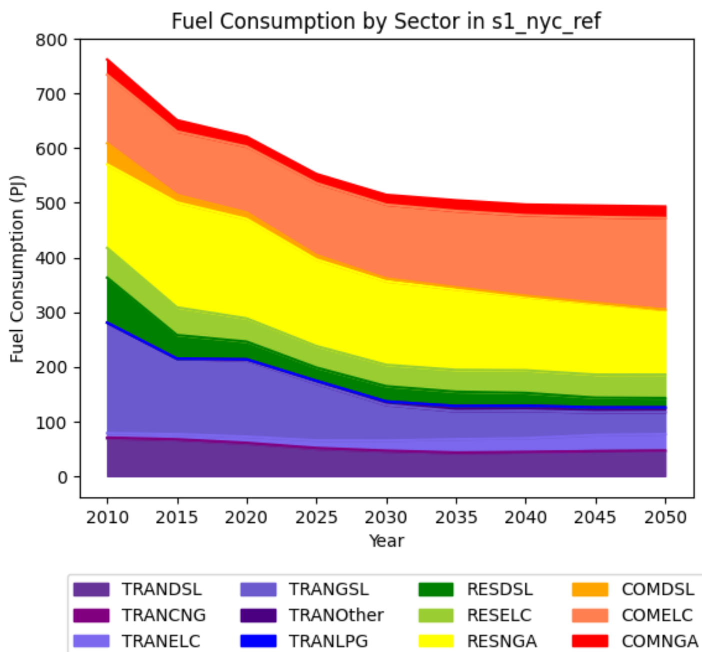

Figure 6 The stacked area chart shows the fuel consumption that belong to transportation, commercial, residential, and industry sectors in New York City from 2010 through 2050. Each color represents the type of fuel consumed by different sectors. The electricity values are presented in source energy consumption. Sectors: Transportation (TRAN), Residential (RES), Industrial (IND), and Commercial (COM). Fuel Types: Diesel (DSL), Compressed Natural Gas (CNG), Electricity (ELC), Gasoline (GSL), and Liquefied Petroleum Gas (LPG).

7.1 Electricity Sector

Figure 7 reflects the expected transformation of New York City's fuel consumption from 2010 to 2050 for the Reference Case scenario (i.e. s1_nyc_ref). It is clear to see the baseline reference data inputs, mentioned above, for years 2010 and 2015 in *Figure 7*. These same baseline reference years are used across all scenarios. In the reference case, *Figure 7*, renewable energy integration is expected to grow over time and with continued reliance coming largely from natural gas. This indicates that without local, state, and federal action the electricity sector would not likely see significant change in its energy mix. Thus, growth in renewable sources, such as wind and solar, are projected to increase significantly, in line with the state's renewable energy targets when state and local actions are implemented. This trend is further seen in *Figure 8* which depicits the projected CO_2 emissions from the electiricty sector in the reference case scenario. The refrence case shows these emissions staying relatively steady and not dipping below 20 MT of CO_2.

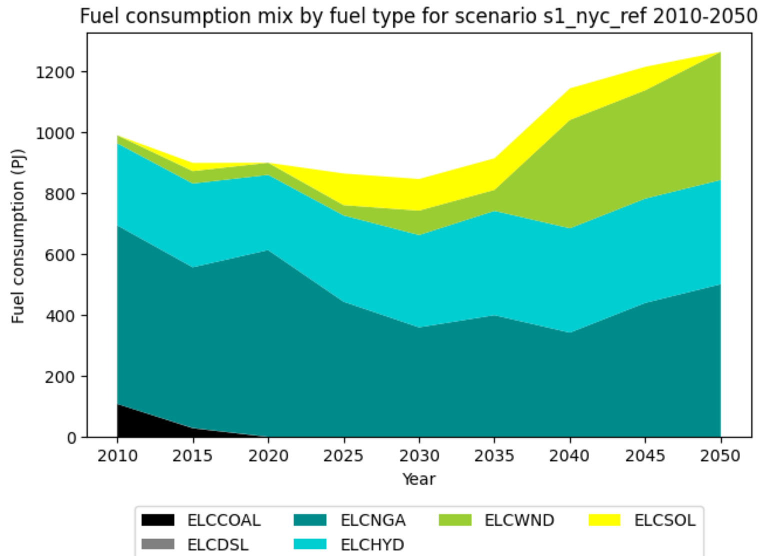

Figure 7 Electricity sector fuel generation by fuel type for the reference scenario from 2010-2050

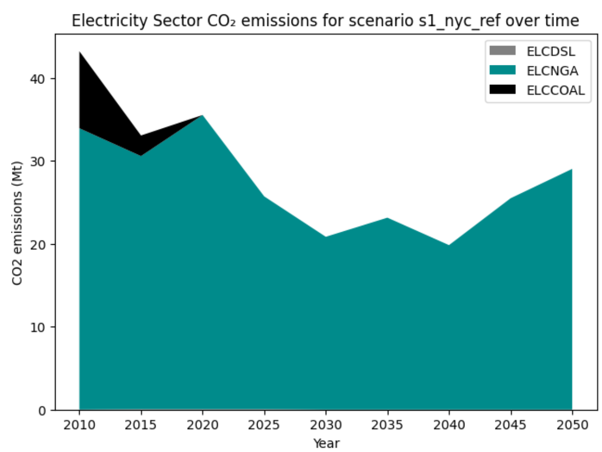

Figure 8 Electricity Sector Carbon dioxide Emissions by Fuel Type for the reference case scenario COMET-NYC also allows users to break down changes in scenarios by region. In this case, the regions were grouped by in the city (NYC) and outside of the city (NY State) (Figure 8). In scenarios where more energy reduction policies or clean energy indicatives are enacted, NYC fuel consumption shifts from natural gas to wind energy. In NY State, the energy mix has a larger breadth as there are more reliable energy production technology that may be implemented outside of the city.

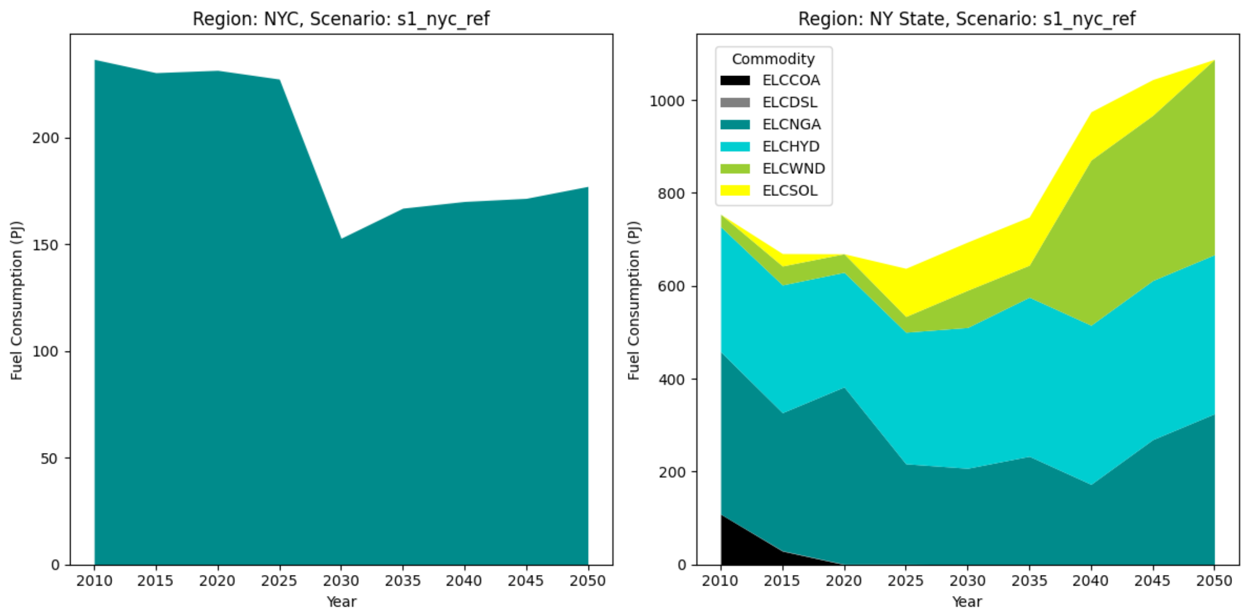

Figure 9 Fuel consumption by fuel type and region from years 2010-2050 for the reference case scenario

In addition to emission and energy consumption projections, COMET-NYC also provides financial information such as investment cost. *Figure 10* breaks down the reference case scenario investment cost by fuel type and region. The investment cost for the projected shifts in the electricity sector largely occur in the state, as this is where most electricity generation takes place. Additionally, the reference case scenario optimization projects see large increases in investment for renewable sources, such as wind and solar, and in natural gas over time. Financial figures get further broken down in the *Cost Implications* section.

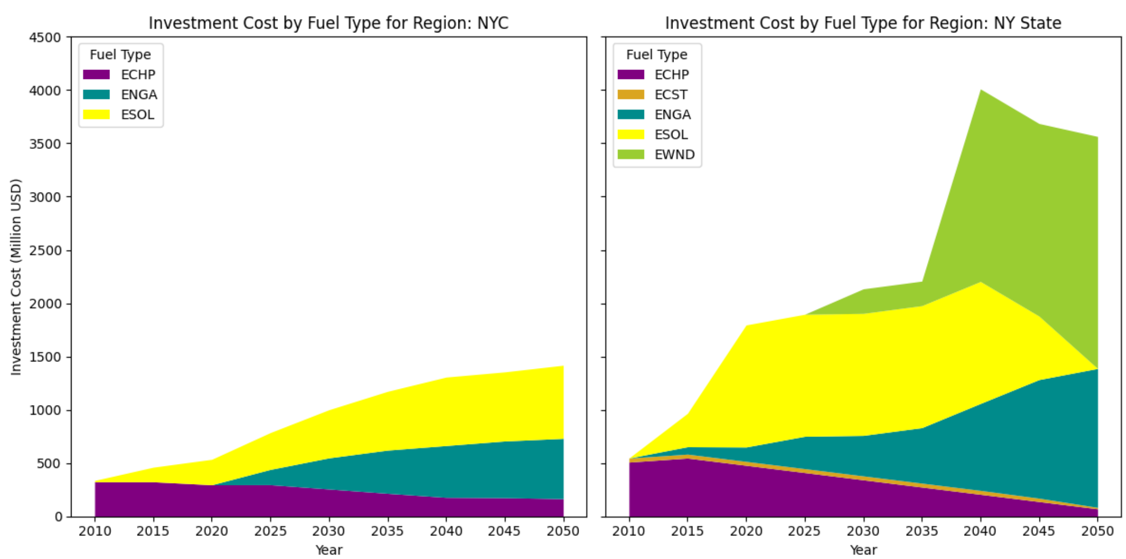

Figure 10 Investment cost for the electric sector by fuel type and Region for the reference scenario from 2010-2050

7.2 Building Sector

COMET-NYC allows users to look at building sector results in several ways. Users may pull data on end-use service demands by appliance/technology, by the specific building sector, by fuel type, etc. *Figure 11* displays an overall decrease in energy consumption for the building sector from 2010 to 2050 for the reference case scenario. The overall energy consumption in the building sector is projected to moderately decrease over time, however substantial decreases in natural gas consumption in the sector is unlikely without federal, state, or local action. Similar trends are seen amongst the different regions, seeing the greatest changes in consumption and fuel type mix in R4, Manhattan (*Figure 12*).

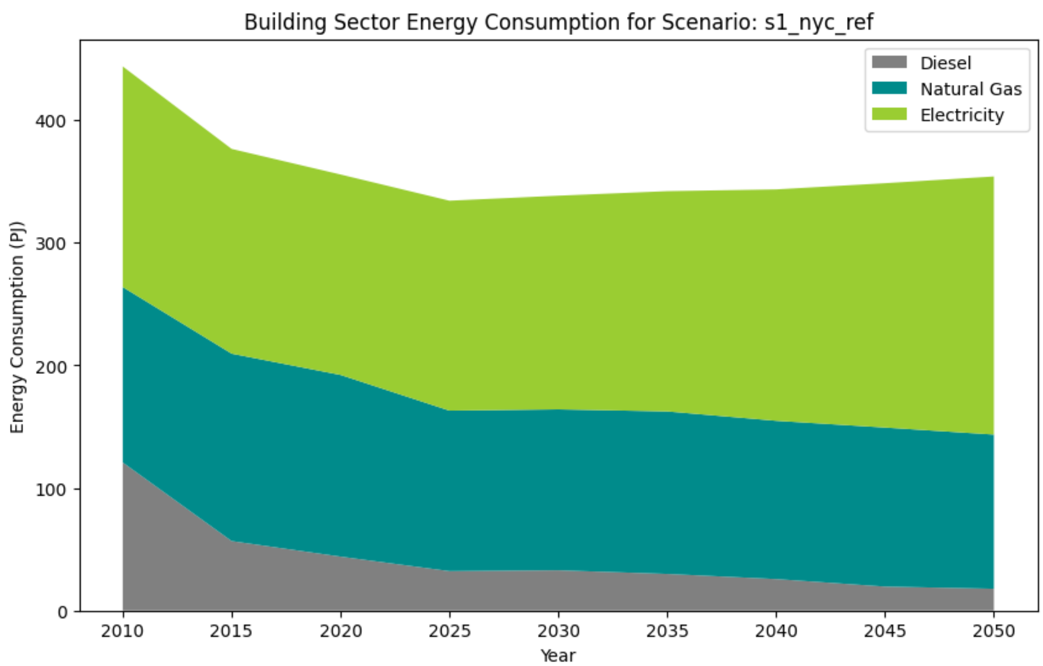

Figure 11 Building sector energy consumption by fuel type from years 2010-2050 for the reference case scenario

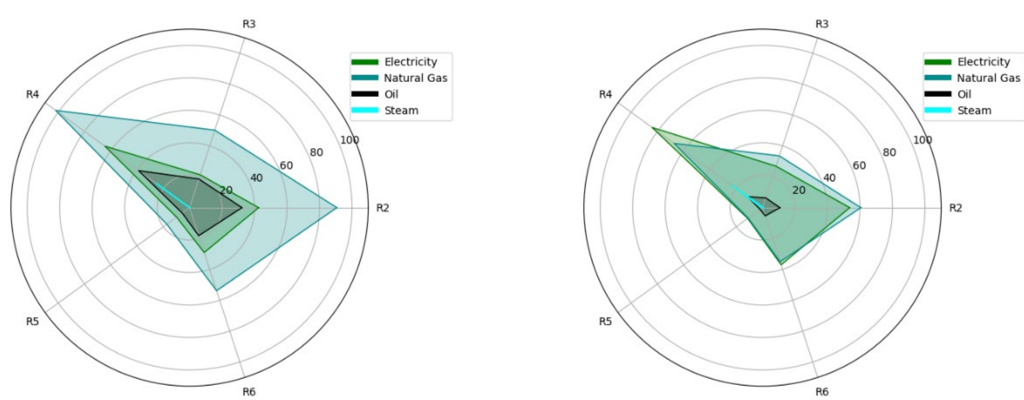

Figure 12 Building sector radar chart depicting building sector energy consumption by fuel type and region for the reference case scenario. Left Panel: year 2015. Right Panel: year 2050

There has been a shift in number of HDDs and CDDs over the years. With the impact of increasing global temperatures, the number days for cooling needs is projected to increase and the number of days for heating needs is steady. These yields following trends in buildings. The space heating demand for residential (*Figure 17*) and commercial buildings (*Figure 23*) is projected to decrease 8 and 22 percent in 2050 compared to 2015, respectively. Contrary to this, the space cooling demand for residential and commercial buildings is projected to increase 41 and 14 percent in 2050 compared to 2015, respectively. These shifts in demands yield a decrease in total energy demand, resulting in need for less fuel in the buildings sector. On top of this, the technology turnover rate, efficiency improvements in technologies, switching to electric appliances yields further decrease in fuel and electricity consumption for buildings sector. As a result, we observe reductions in CO_2 emissions in the reference scenario.

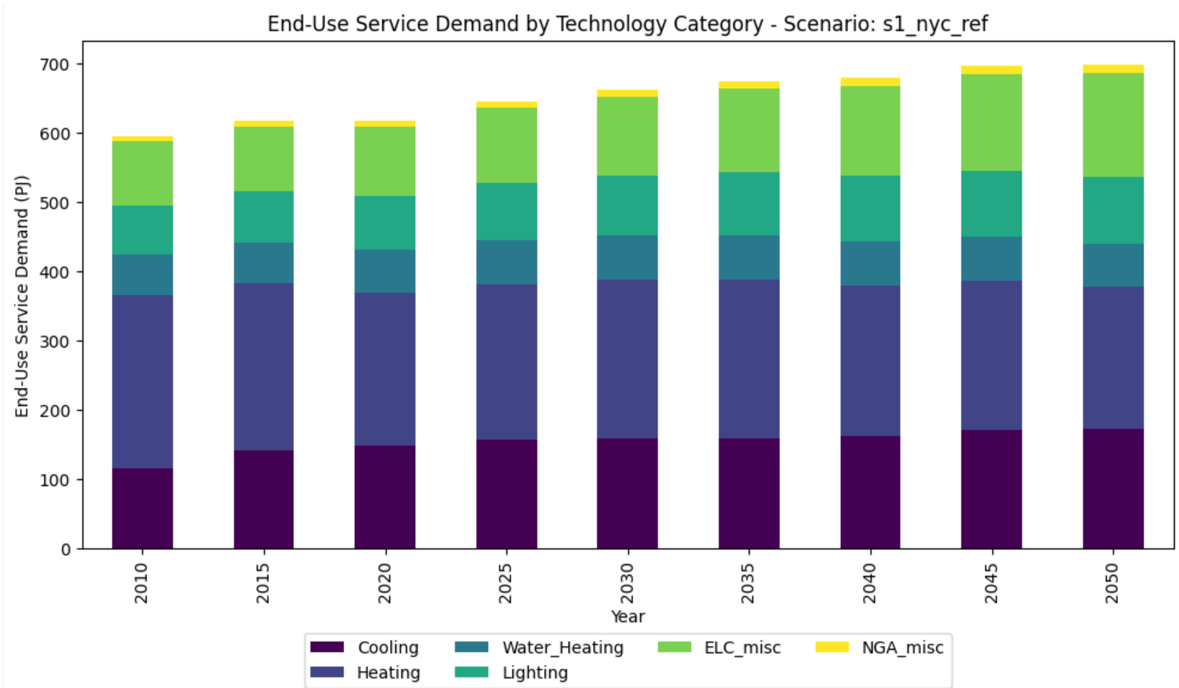

Figure 13 End-use service demand by technology type for all sectors from years 2010-2055 for the reference case scenario

7.2.1 Residential

Residential sector technology is broken down into the following categories: lighting (RLT), space cooling (RSC), space heating (RSH), water heating (RWH), electricity miscellaneous (ROE), and natural gas miscellaneous (ROG). Most of the annual end-use demand from the residential sector technologies is coming from space heating (*Figure 14*). *Figures 15-18* demonstrate the projected changes over time for technology types creating the end-use demand. For technology categories lighting, water heating, and space cooling these categories experience the greatest amount of electrification by 2050. Alternatively, likely due to its size, technology performance, and cost in NYC, space heating is still projected to use natural gas and diesel technologies by 2050 to meet end-use demand.

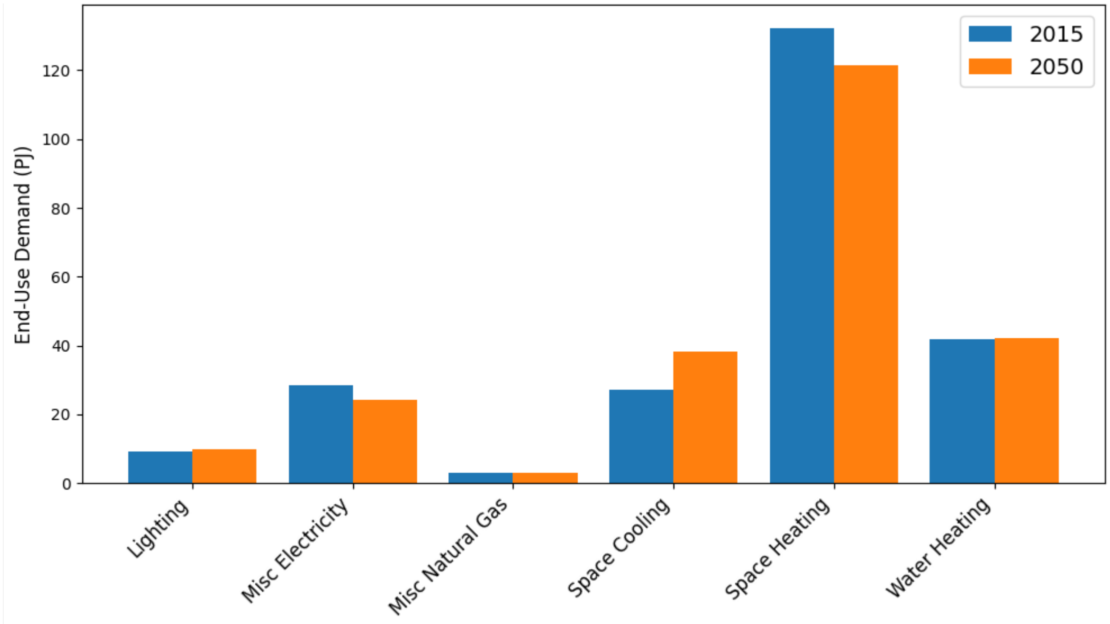

Figure 14 End-use demand for the residential sector in years 2015 and 2050 from the reference case scenario

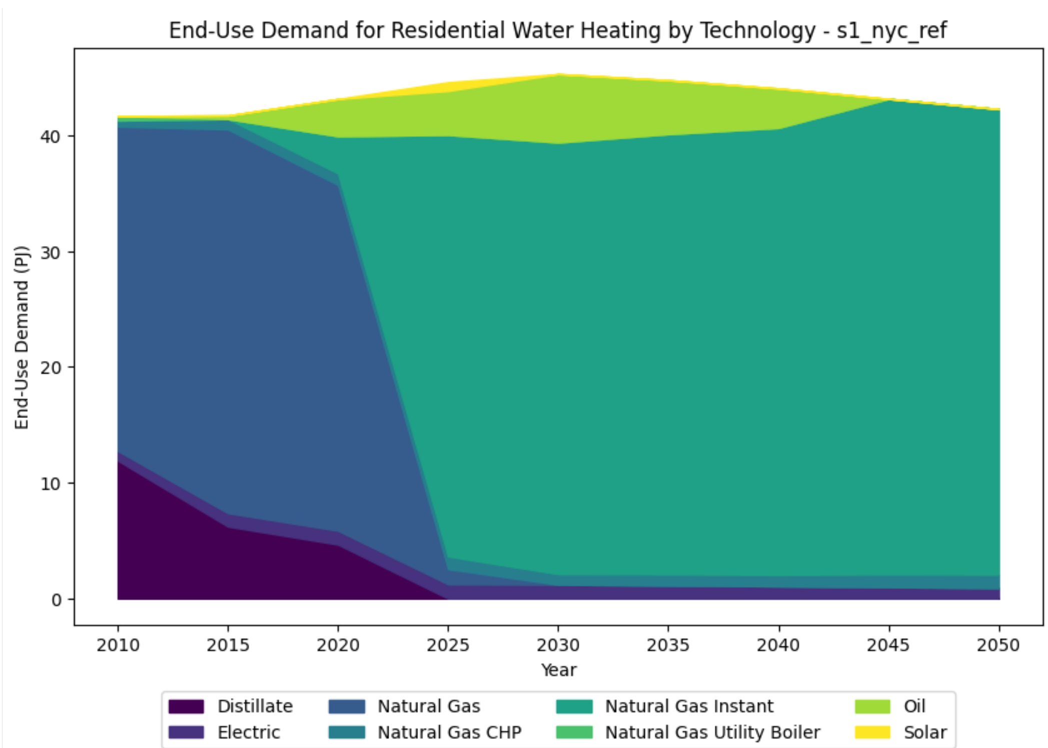

Figure 15 Breakdown of end-use demand by water heating technology in the residential sector for years 2010-2050 for the reference case scenario. All fuel types for this category are electricity

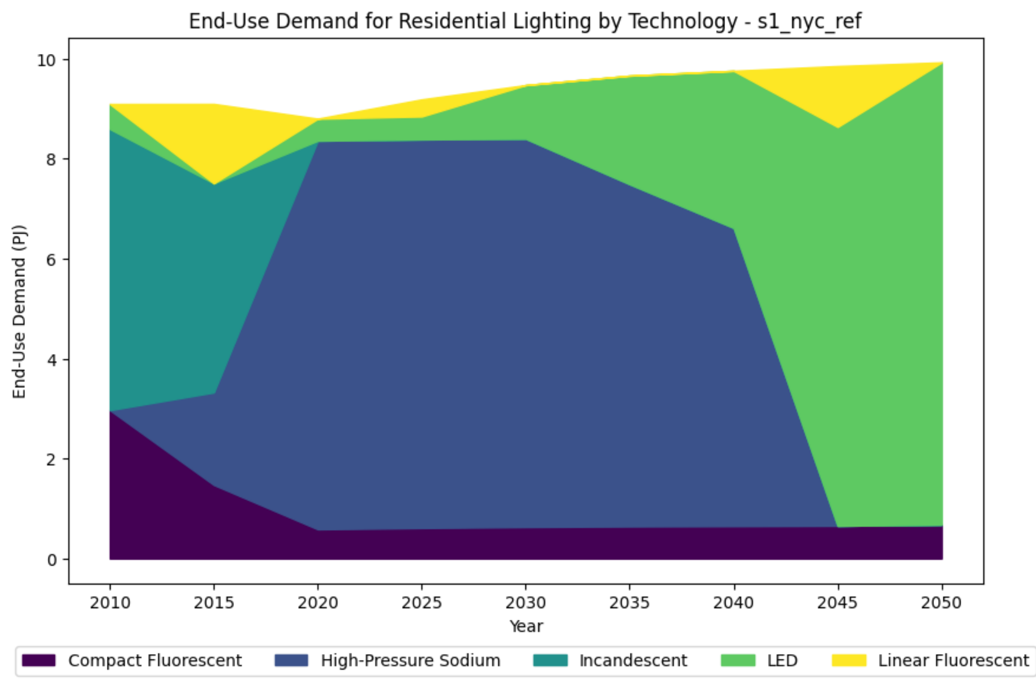

Figure 16 Breakdown of end-use demand by lighting technology in the residential sector for years 2010-2050 for the reference case scenario

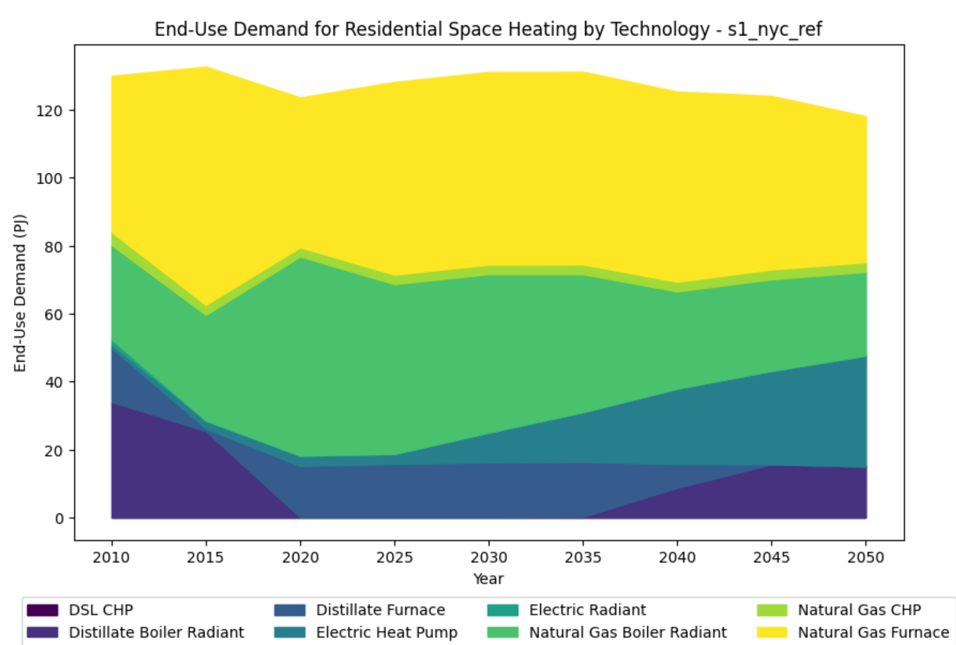

Figure 17 Breakdown of end-use demand by space heating technology in the residential sector for years 2010-2050 for the reference case scenario

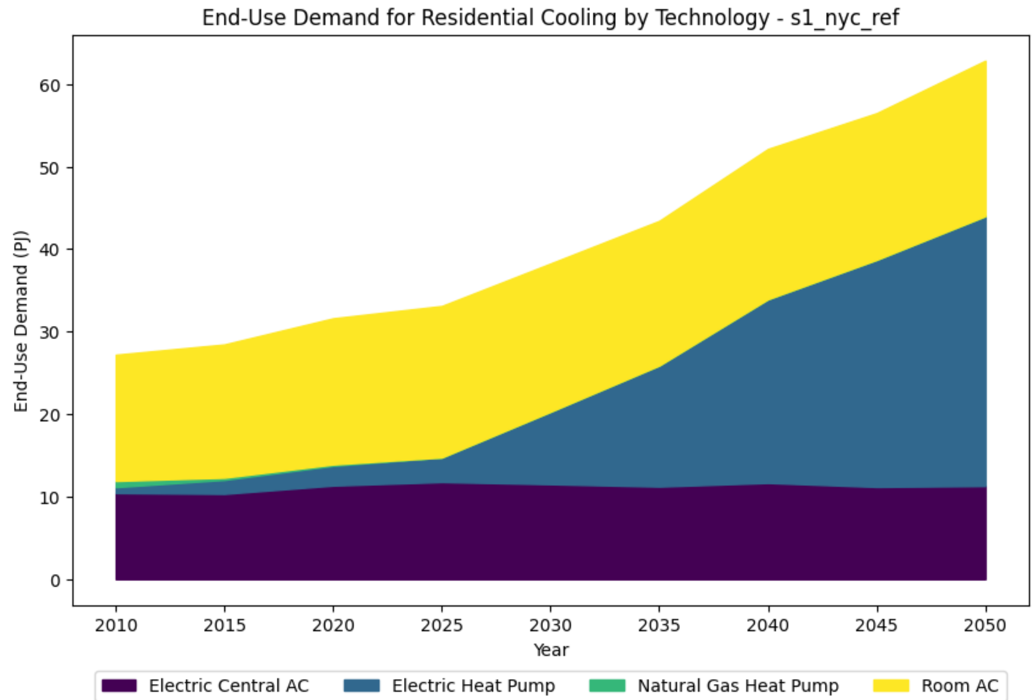

Figure 18 Breakdown of end-use demand by space cooling technology in the residential sector for years 2010-2050 for the reference case scenario

7.2.2 Commercial

Residential sector technology is broken down into the following categories: lighting (CLT), space cooling (CSC), space heating (CSH), water heating (CWH), electricity miscellaneous (CME), and natural gas miscellaneous (CMN). In the base case scenario, the projected end-use demand for every technology category increases over time except for space heating (Figure 19). Similarly to the residential sector, electrification is most prevalent in the space cooling and water heating technology categories in COMET-NYC optimization projections (*Figure 20-23*). Space heating maintains the largest share of natural gas as a fuel type amongst the technology categories.

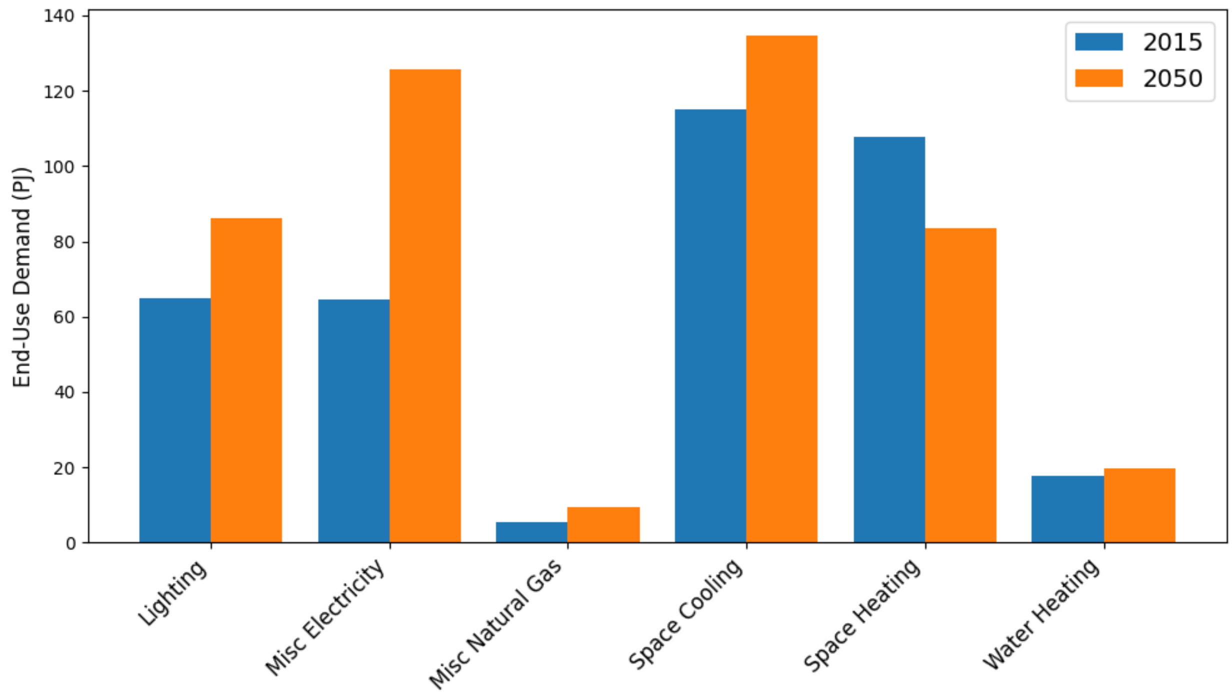

Figure 19 End-use demand for the commercial sector in years 2015 and 2050 from the reference case scenario

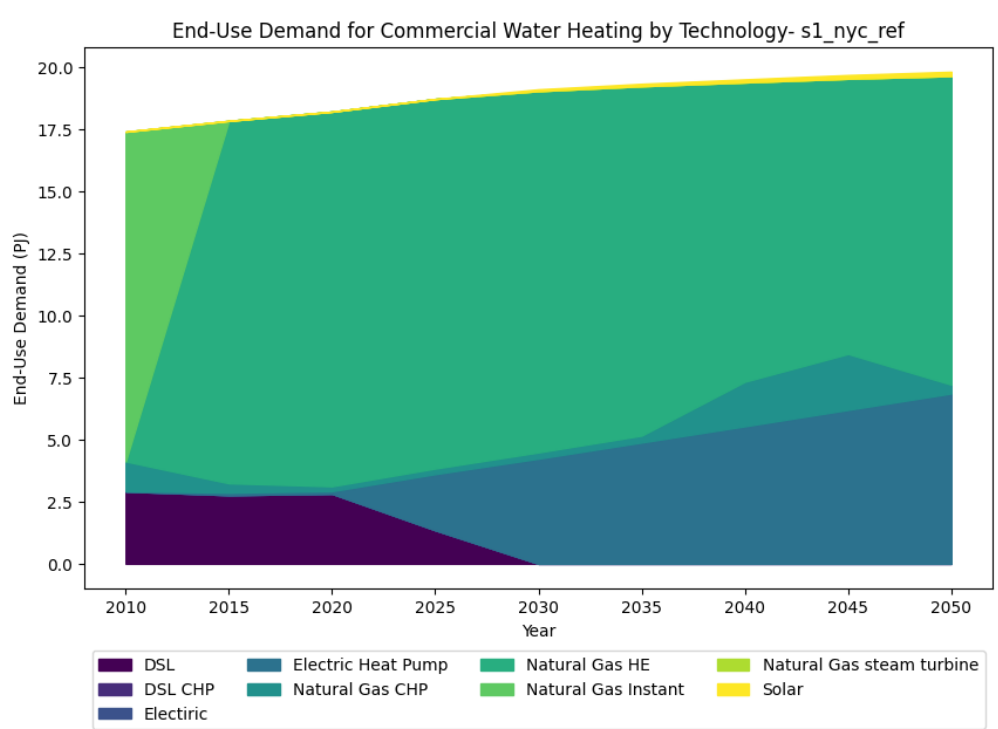

Figure 20 Breakdown of end-use demand by water heating technology in the commercial sector for years 2010-2050 for the reference case scenario

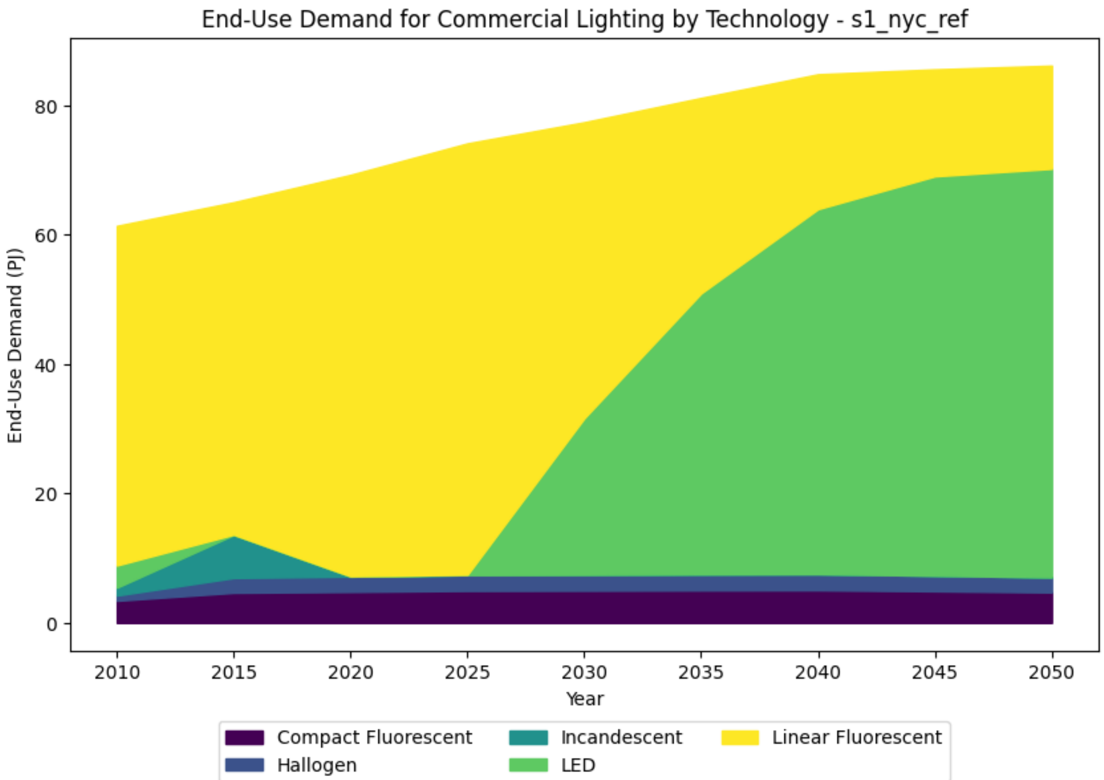

Figure 21 Breakdown of end-use demand by lighting technology in the commercial sector for years 2010-2050 for the reference case scenario

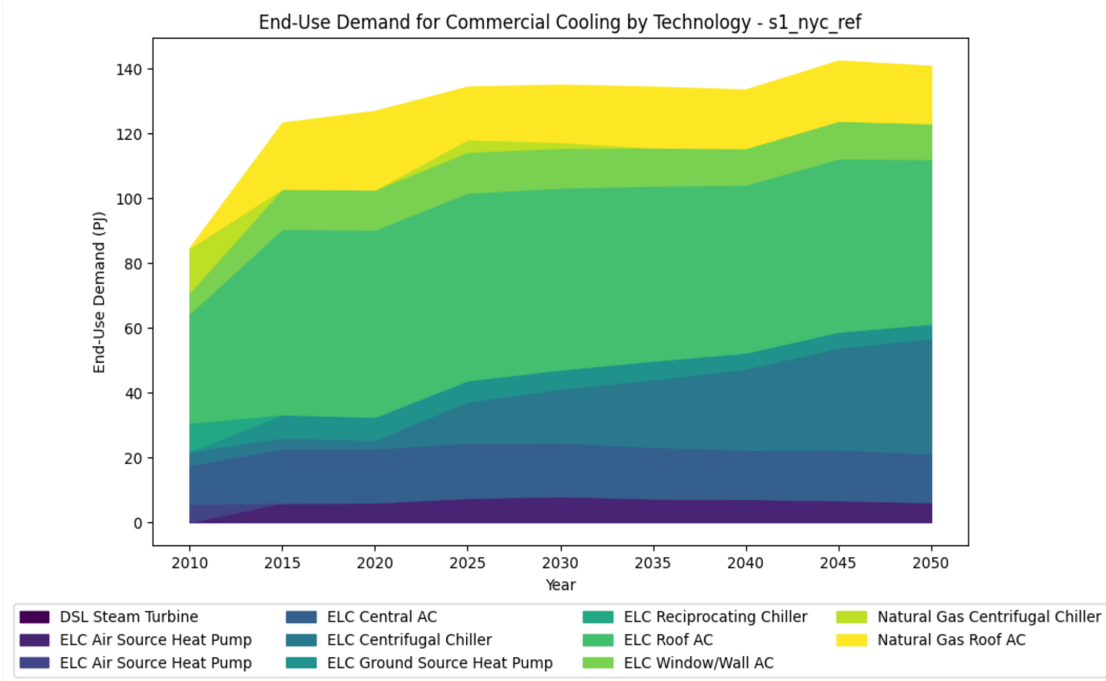

Figure 22 Breakdown of end-use demand by space cooling technology in the commercial sector for years 2010-2050 for the reference case scenario

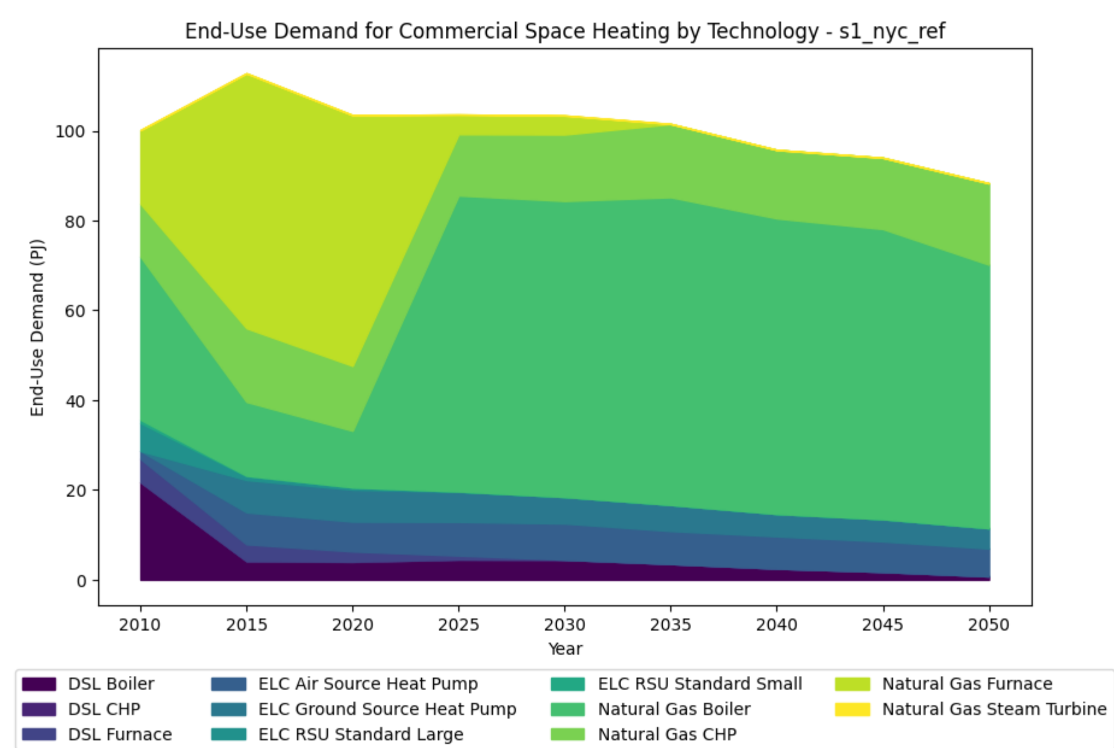

Figure 23 Breakdown of end-use demand by space heating technology in the commercial sector for years 2010-2050 for the reference case scenario

7.3 Transportation

In 2015, gasoline was the main fuel meeting the light-duty demand, whereas diesel is mainly consumed by buses and heavy-duty short-haul vehicles (*Figure 24-26*). Although an increase in CO_2 emissions is expected with population growth, urbanization and economic development, the implementation of national light-duty fuel efficiency standards and vehicle turnover to more efficient technologies lead to reduced fuel consumption and therefore reductions in city-wide emissions, and transportation CO_2 emissions (*Figure 27*). In addition, penetration of electric vehicles contributes to reduction in CO_2 emissions. In the heavy-duty sector, the diesel consumption is still prominent and grows steadily, however compared the light-duty sector, their contribution is to overall CO_2 emissions is low.

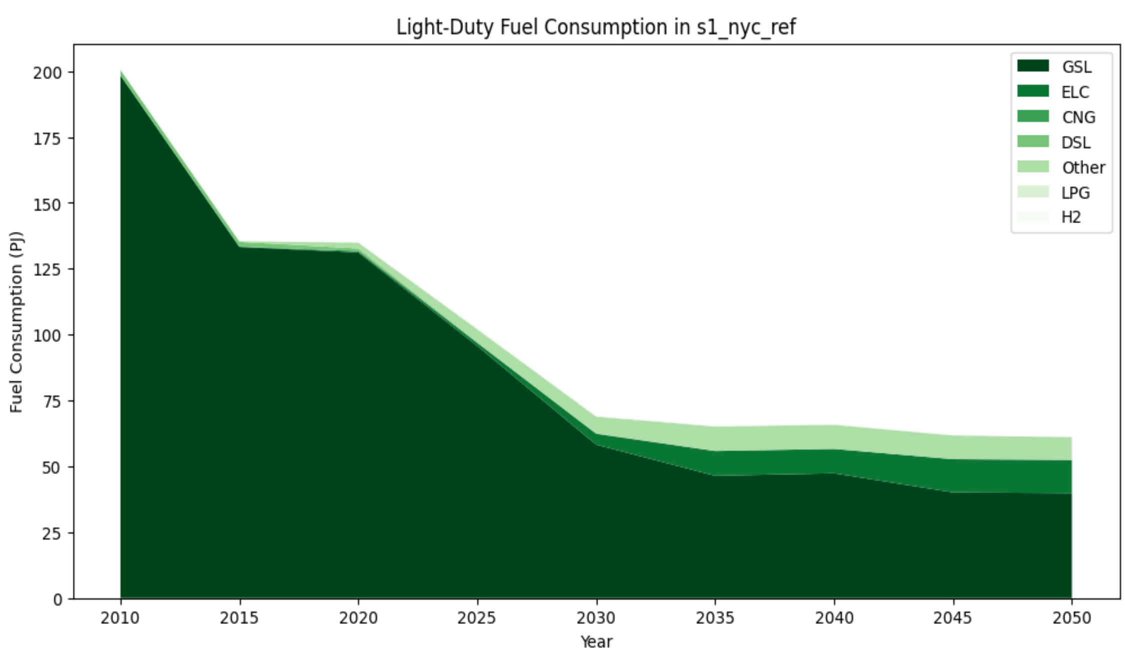

Figure 24 Light-Duty vehicle fuel consumption by fuel type from years 2010-2050 for the reference case scenario

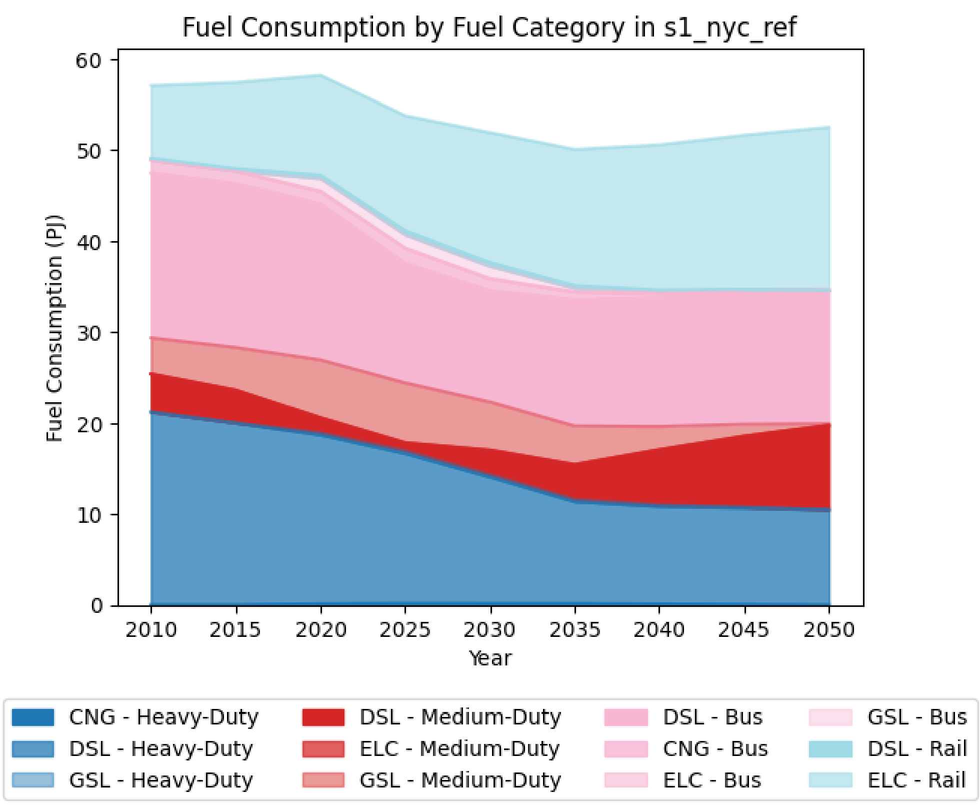

Figure 25 Fuel Consumption for non-light-duty vehicles 2010-2050 for the reference case scenario

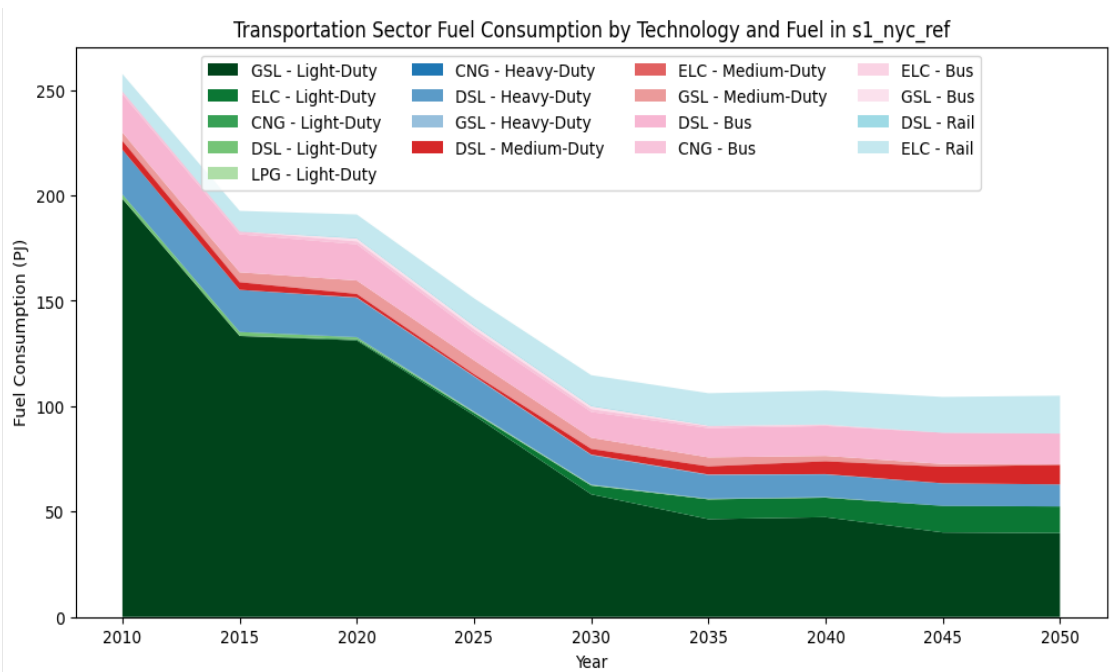

Figure 26 Reference case fuel consumption by fuel type and vehicle type for the transportation sector 2010-2050

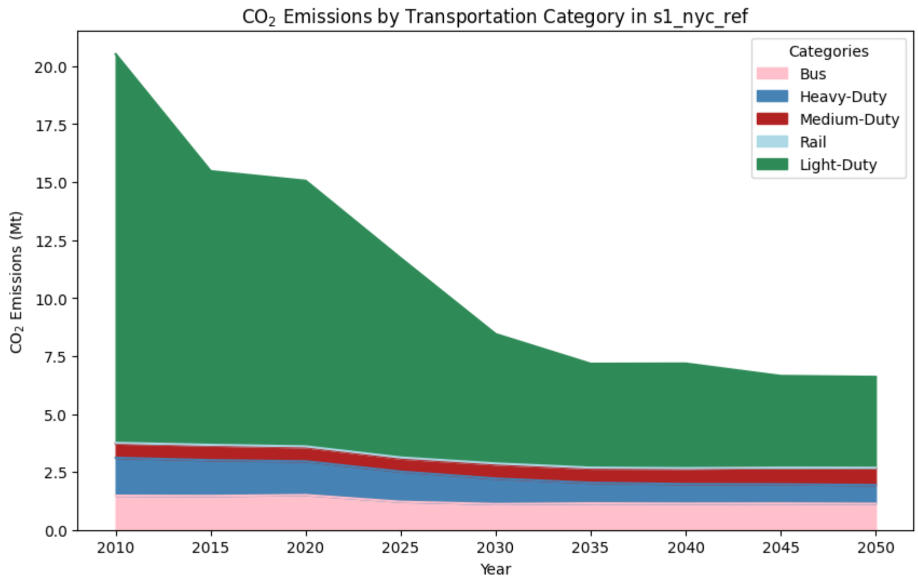

Figure 27 Reference Case CO2 emissions for the transportation sector by vehicle type 2010-2050

7.3.1 Fuel Consumption for the Transportation Sector by Region

Transportation sector light-duty vehicles fuel consumption is projected to decrease and shift towards electrification from 2010 to 2050. Specifically, fuel consumption is projected to shift from R6, Queens, to R2, Brooklyn, for light-duty vehicles in the reference case (*Figure 28*). On the other hand, heavy-duty, medium-duty, and buses are not seeing the same geographical shifts in fuel consumption and electrification (*Figures 29-31*). Rail is projected to increase in all regions and to see a shift to full electrification (*Figure 32*).

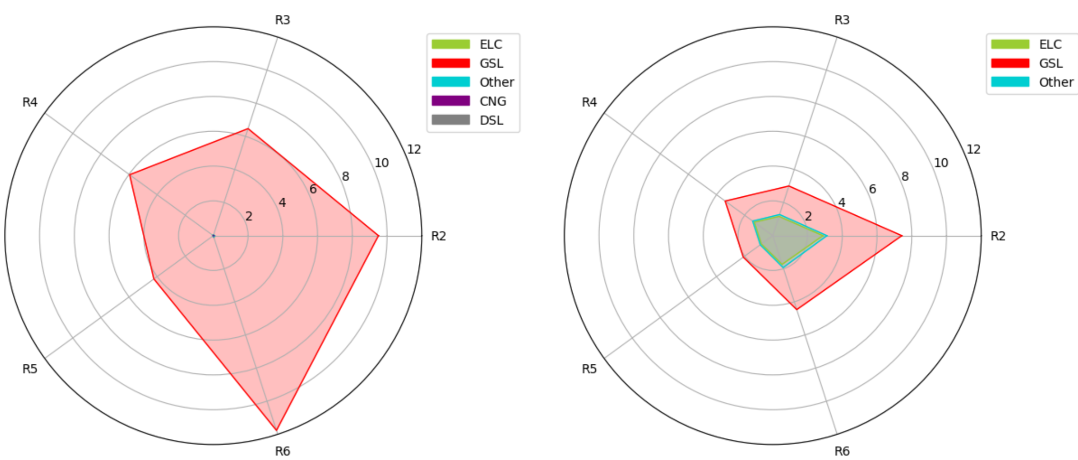

Figure 28 Left Panel: Light-Duty Fuel Consumption (PJ) by region for Reference Case 2015, Right Panel: Light-Duty Fuel Consumption (PJ) by region for Reference Case 2050

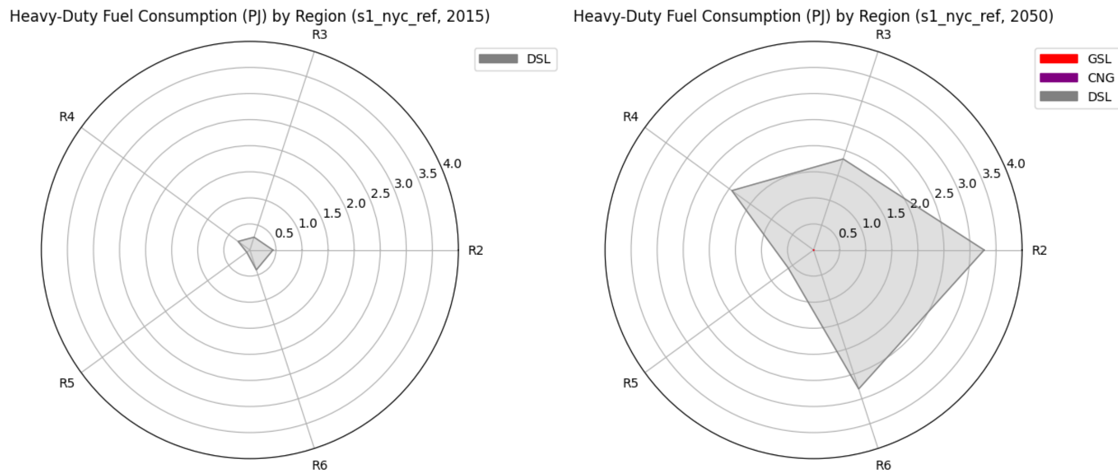

Figure 29 Left Panel: Heavy-Duty Fuel Consumption by region for Reference Case 2015, Right Panel: Heavy -Duty Fuel Consumption by region for Reference Case 2050

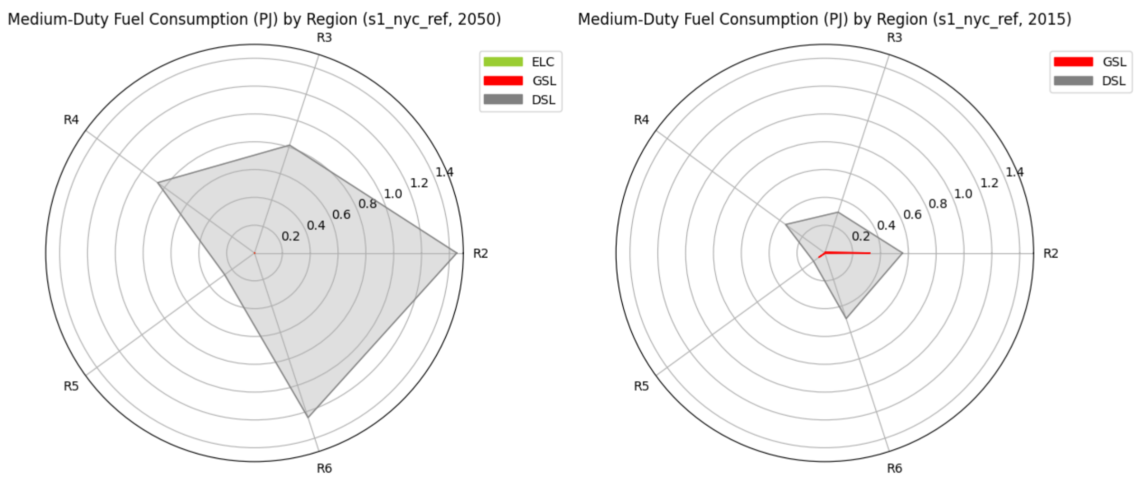

Figure 30 Left Panel: Medium-Duty Fuel Consumption by region for Reference Case 2015, Right Panel: Medium-Duty Fuel Consumption by region for Reference Case 2050

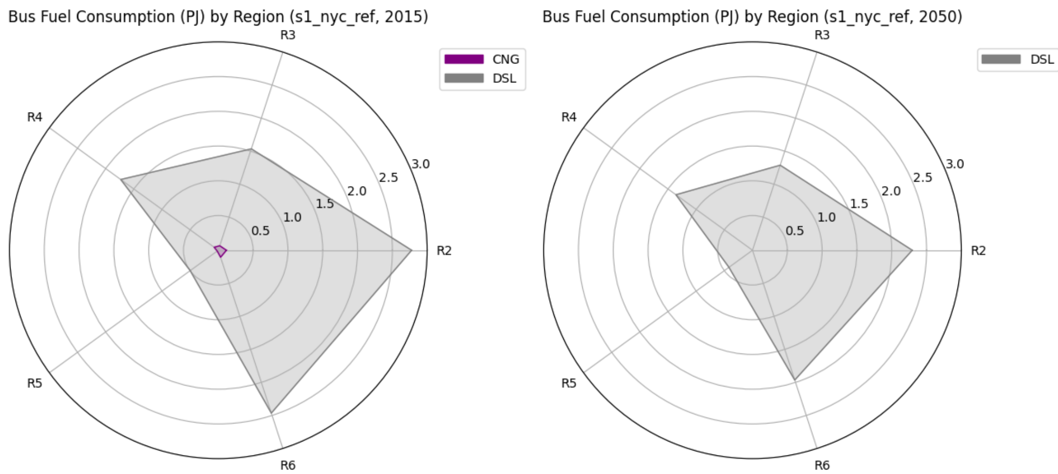

Figure 31 Left Panel: Bus Fuel Consumption by region for Reference Case 2015, Right Panel: Bus Fuel Consumption by region for Reference Case 2050

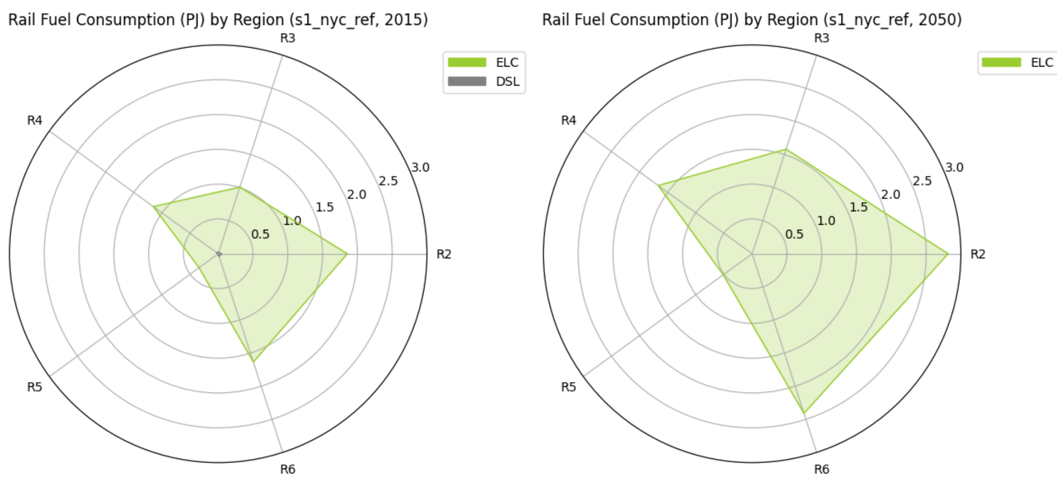

Figure 32 Left Panel: Rail Fuel Consumption by region for Reference Case 2015, Right Panel: Rail Fuel Consumption by region for Reference Case 2050

7.4 System Wide Emissions

In the reference case, all air pollution emissions are projected to reduce over time (*Figures 33-42*). For the reference case scenario, the greatest relative reductions are seen for NOx and SO2.

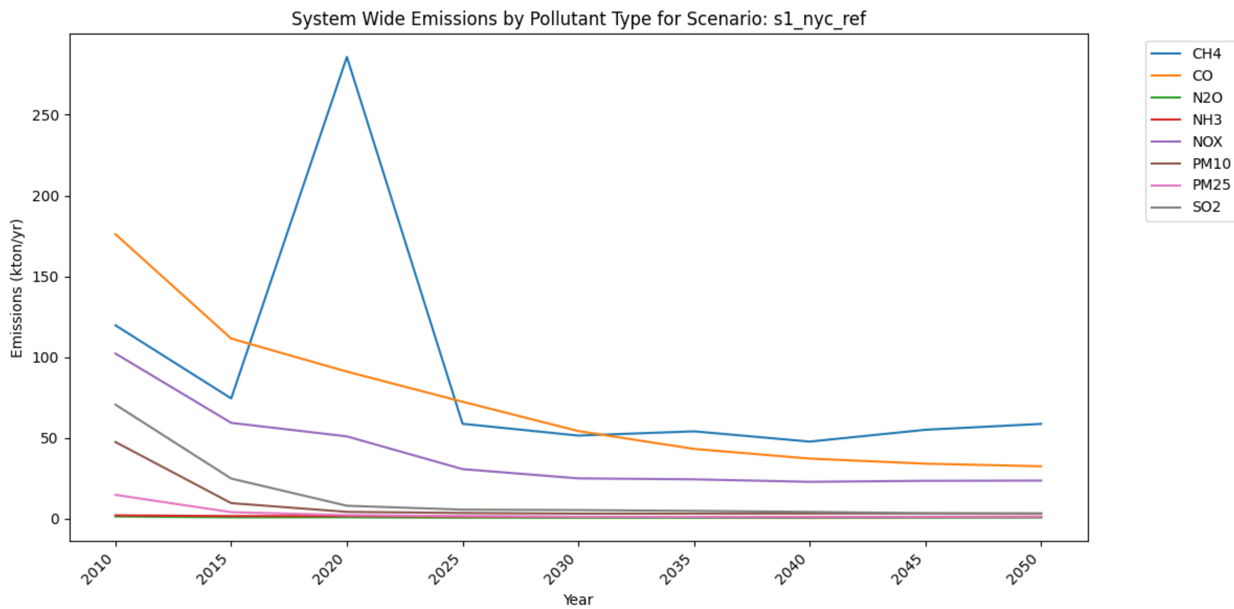

Figure 33 System wide air pollution emissions by pollutant type for years 2010-2050 for the reference case scenario

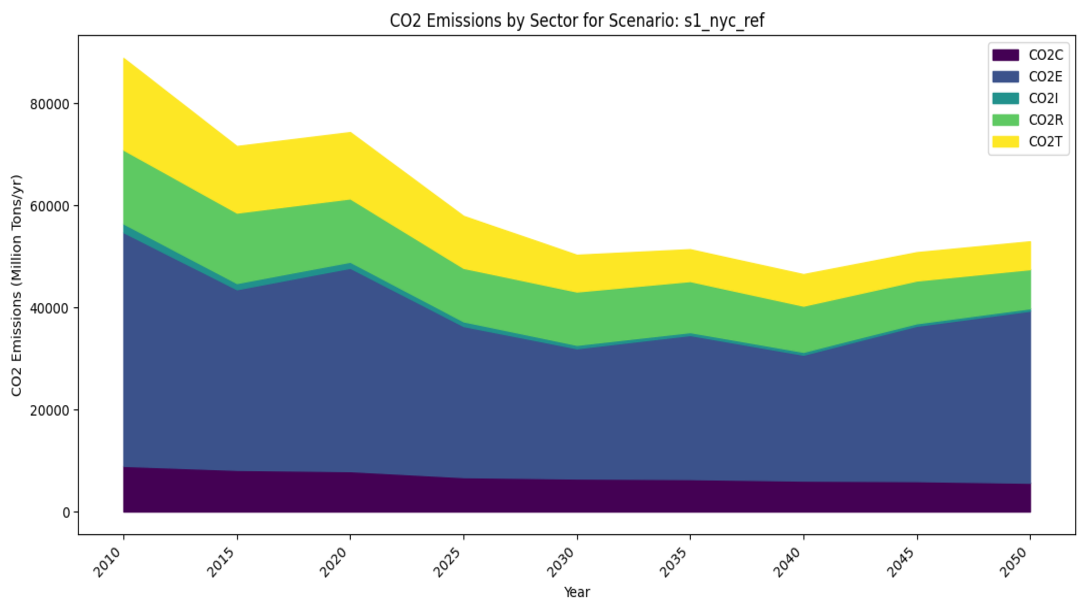

Figure 34 System wide CO2 emissions by sector for the reference case scenario. Sectors: CO2C (commercial), CO2E (Electricity), CO2I (Industrial), CO2R (Residential), and CO2T (Transportation).

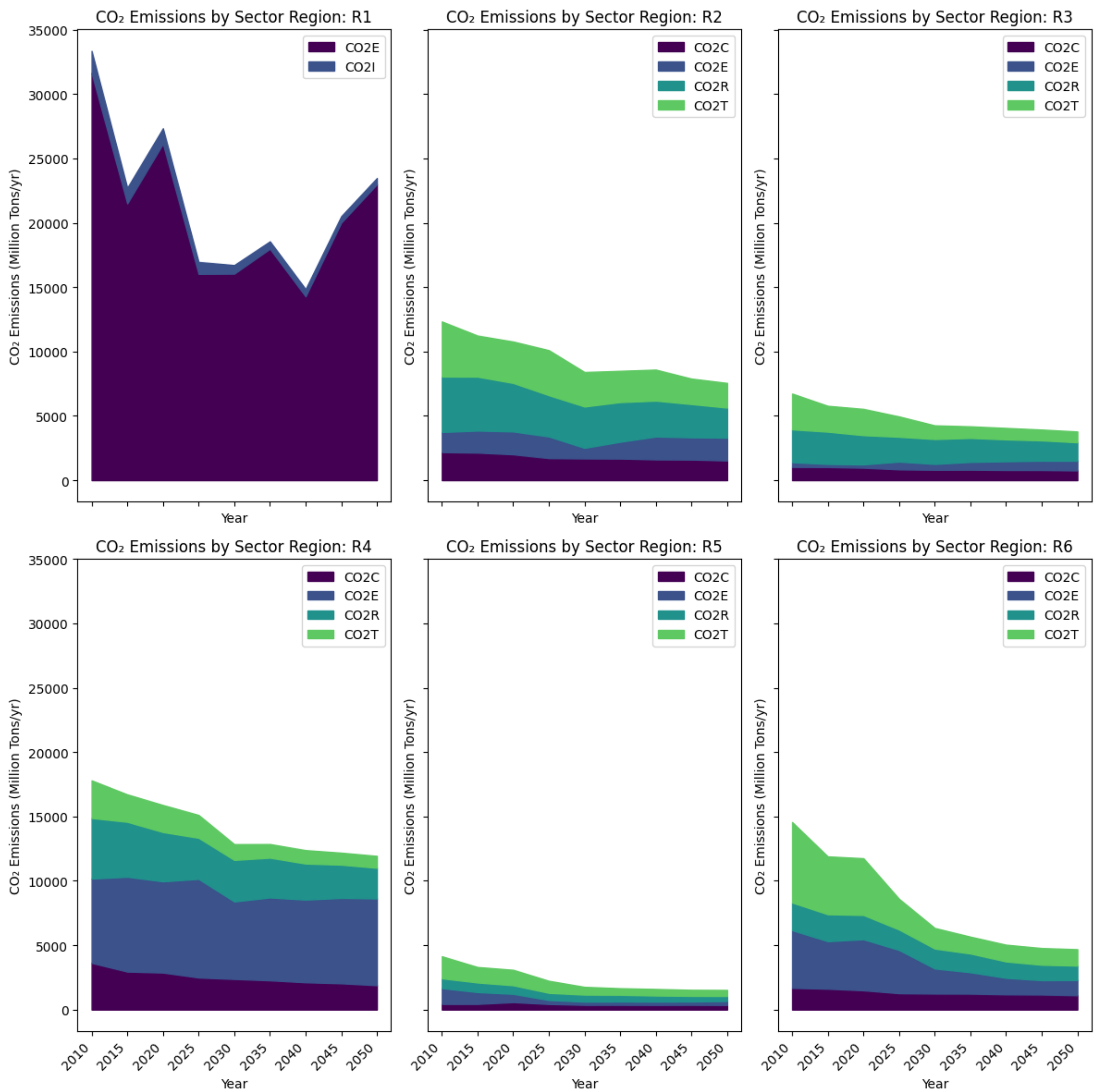

Figure 35 System wide CO2 emissions by sector and region for the reference case scenario. Sectors: CO2C (commercial), CO2E (Electricity), CO2I (Industrial), CO2R (Residential), and CO2T (Transportation).

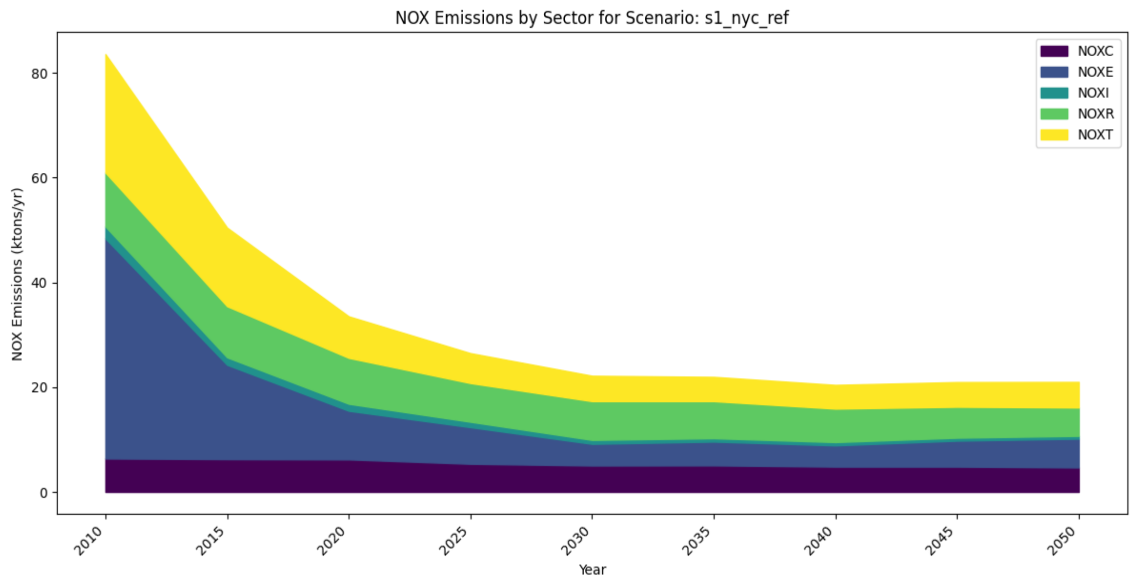

Figure 36 System wide NOX emissions by sector for the reference case scenario. Sectors: NOXC (commercial), NOXE (Electricity), NOXI (Industrial), NOXR (Residential), and NOXT (Transportation).

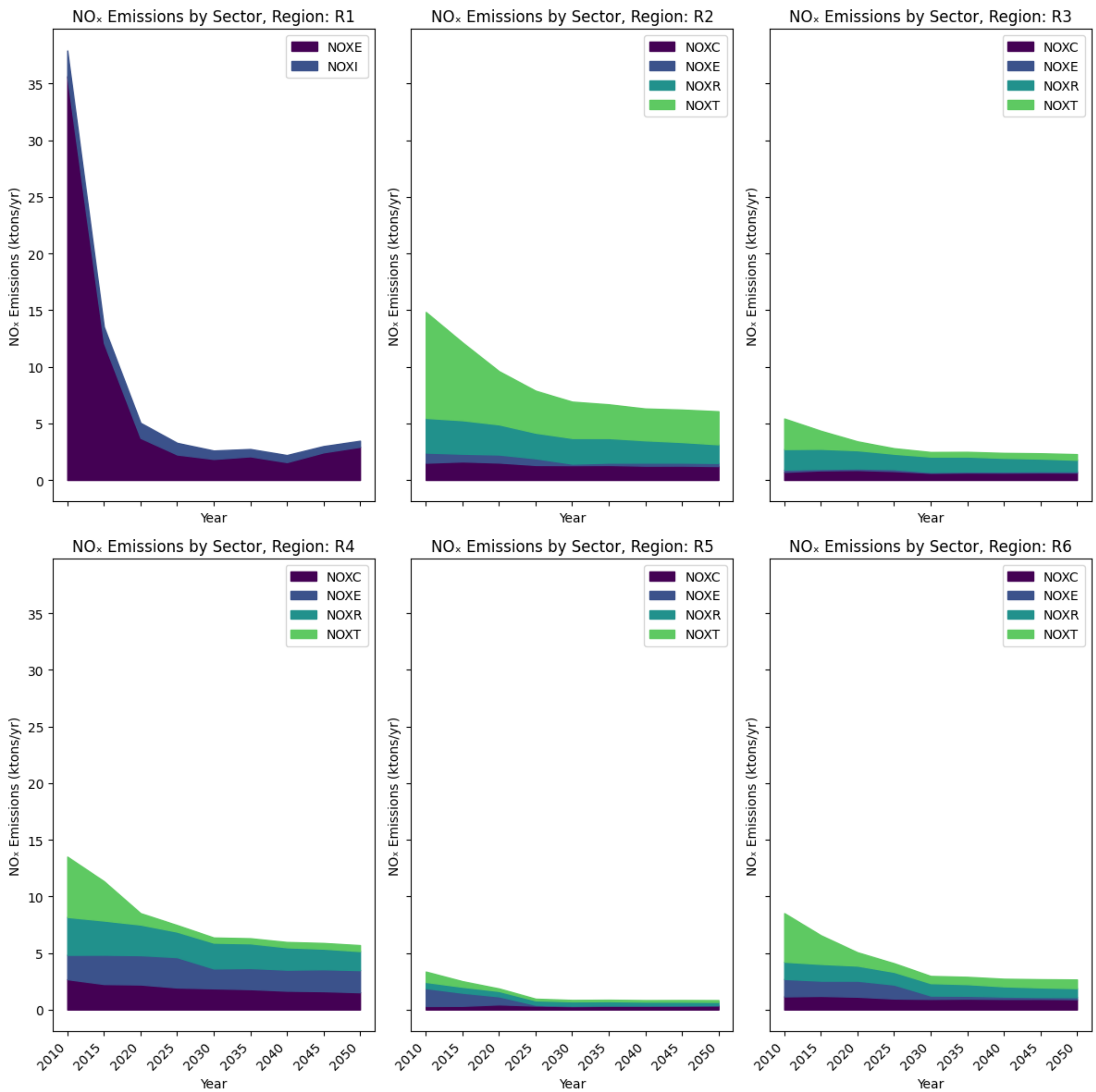

Figure 37 System wide NOX emissions by sector and region for the reference case scenario. Sectors: NOXC (commercial), NOXE (Electricity), NOXI (Industrial), NOXR (Residential), and NOXT (Transportation).

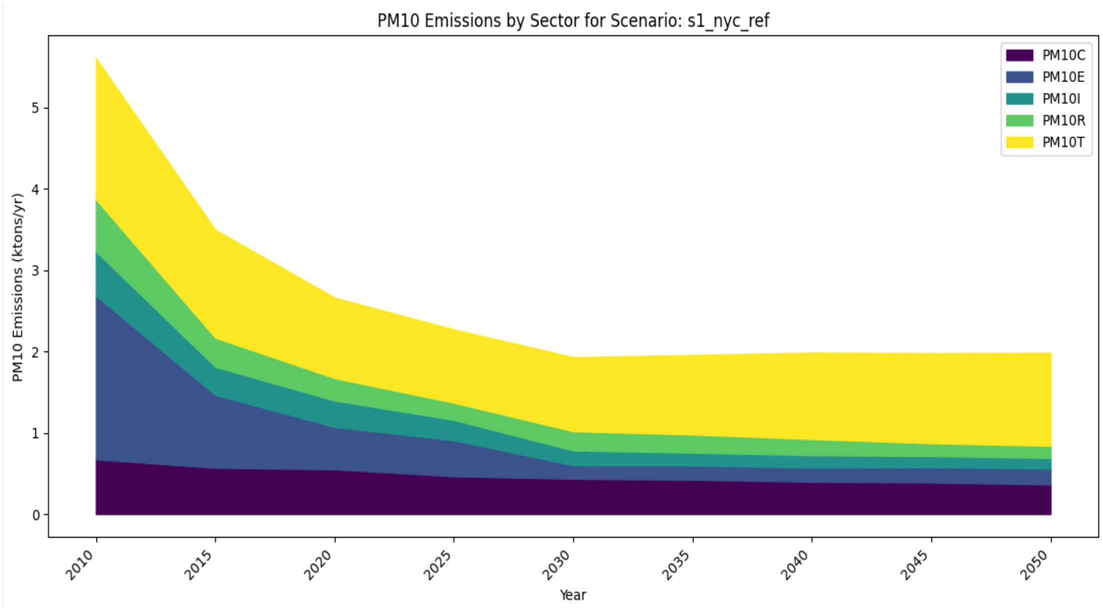

Figure 38 System wide PM_{10} emissions by sector for the reference case scenario. Sectors: PM10C (commercial), PM10E (Electricity), PM10I (Industrial), PM10R (Residential), and PM10T (Transportation).

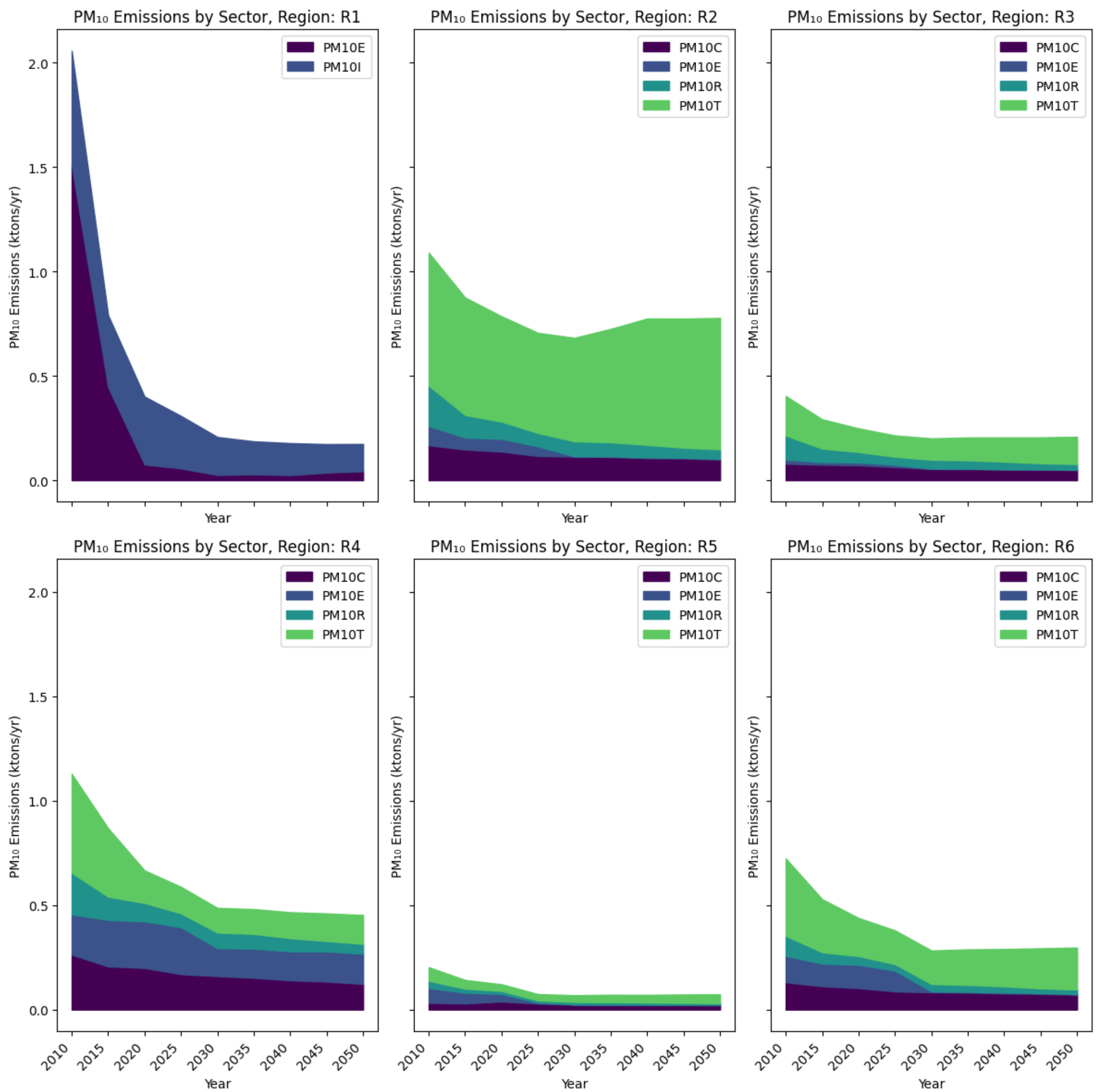

Figure 39 System wide PM_{10} emissions by sector and region for the reference case scenario. Sectors: PM10C (commercial), PM10E (Electricity), PM10I (Industrial), PM10R (Residential), and PM10T (Transportation).

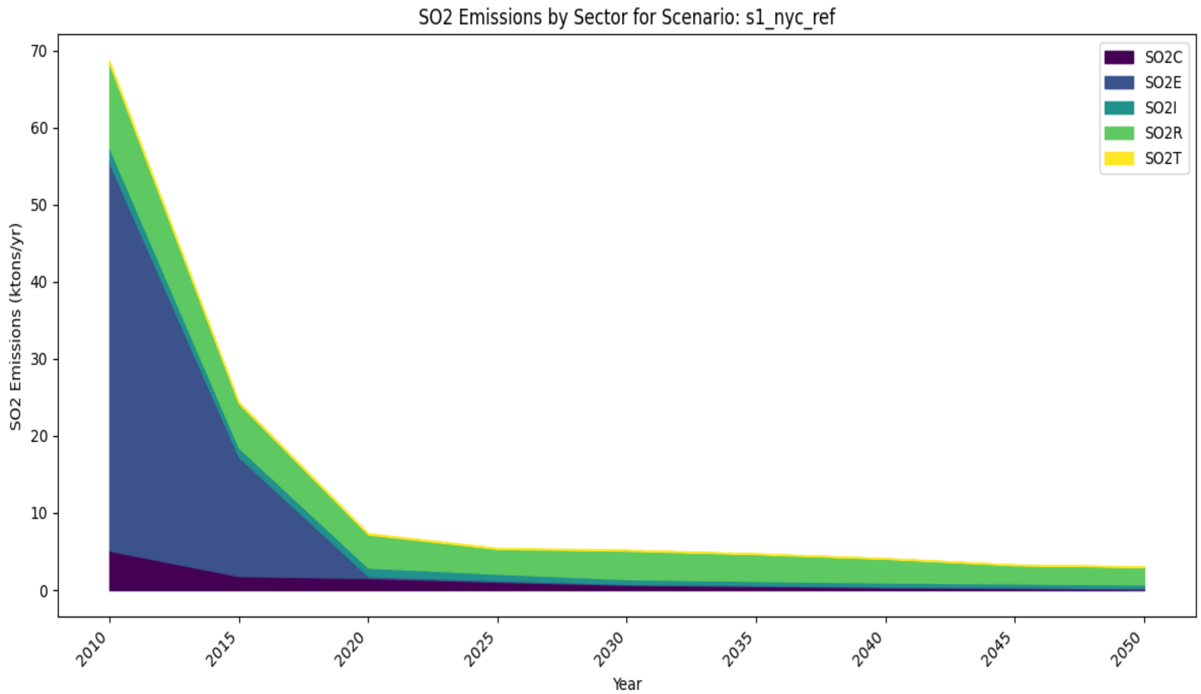

Figure 40 System wide SO2 emissions by sector for the reference case scenario. Sectors: SO2C (commercial), SO2E (Electricity), SO2I (Industrial), SO2R (Residential), and SO2T (Transportation).

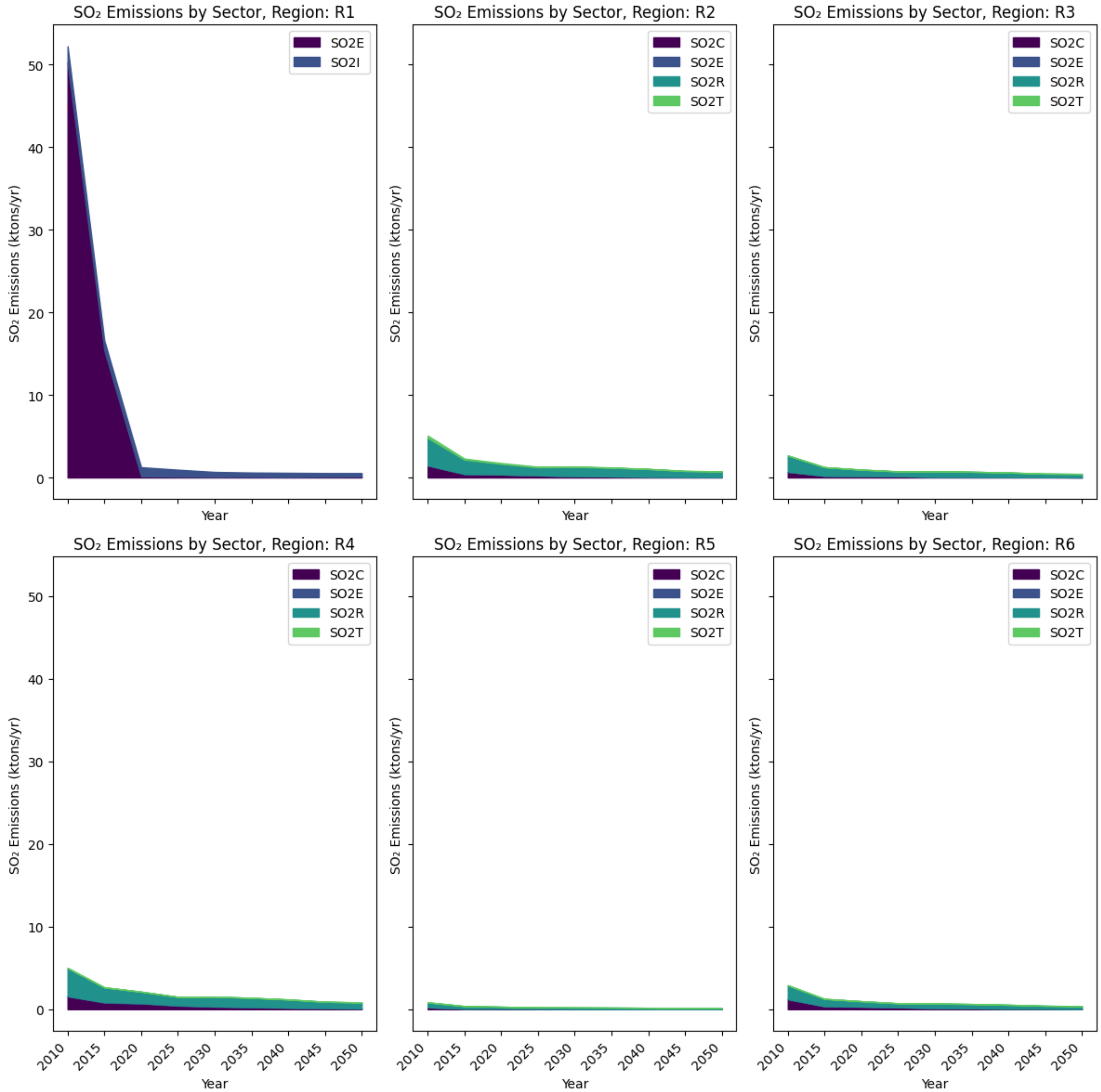

Figure 41 System wide SO2 emissions by sector and region for the reference case scenario. Sectors: SO2C (commercial), SO2E (Electricity), SO2I (Industrial), SO2R (Residential), and SO2T (Transportation).

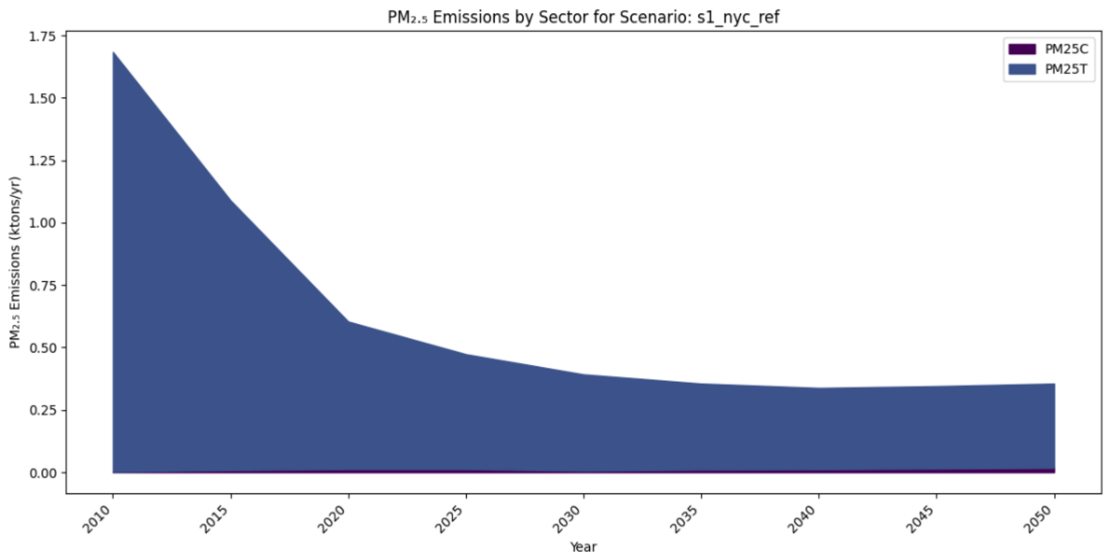

Figure 42 System wide PM2.5 emissions by sector for the reference case scenario. Sectors: PM25C (commercial) and PM25T (Transportation).

8 Final Remarks

The COMET is developed to perform scenario analysis at the city and regional level. The COMET-NYC is calibrated to current technology stock and fuel consumption values for New York City. The model can be used to make long-term projections for energy consumption. The COMET-NYC uses several official data sources to provide useful model outcomes. The data is planned to be updated on a regular basis in accordance with the release of the document updates including borough-based population forecasts, AEO forecasts, local GHG emission reports, EIA state level electricity generation reports, etc.

COMET-NYC finds the cheapest technology and fuel combination portfolio that meets demands in transportation and buildings. COMET-NYC calculates levelized cost of investing and operating a technology to meet end-use demand using engineering economics principles. COMET-NYC makes decisions using capital costs endogenously generated fuel price, electricity price, and salvaging costs for older technologies. The objective function then incorporates annualized costs using a global discount rate to calculate the net present value of all life-cycle costs of investments. The costs which are incurred in all regions (i.e., resource supply region, New York City boroughs, and rest of New York State), are included in the objective function. Hence, the total system cost contains all energy sector related costs such as investment, operating and maintenance costs of the technologies within New York City's whole energy system (including electricity generation units in the city, transportation, and building sectors) and New York State's power sector. In addition, cost of fuel delivery, extraction, refinery, and import from outer regions are covered in the total system cost.

The COMET-NYC model serves as an example for other cities and communities who are interested in leveraging the benefits of performing energy planning as population growth and rising temperatures place increasing pressure on aging infrastructure. This type of modeling framework could aid policy making process through generating technically robust and high-fidelity technology evaluations, therefore leading to more efficient policy design mitigate of emissions while properly identifying costs.

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Appendix A

Time slice documentation

Appendix B

PLUTO 2010 data

Appendix C

Original 2014 building end-use demand splits for NYC

Appendix D

EIA 2023 building technology data

APPENDIX E

2015 NYMTC SEDS population and employment forecasts

APPENDIX F

Documentation of Transportation Sector Emission Factors Updates

United States
Environmental Protection
Agency

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