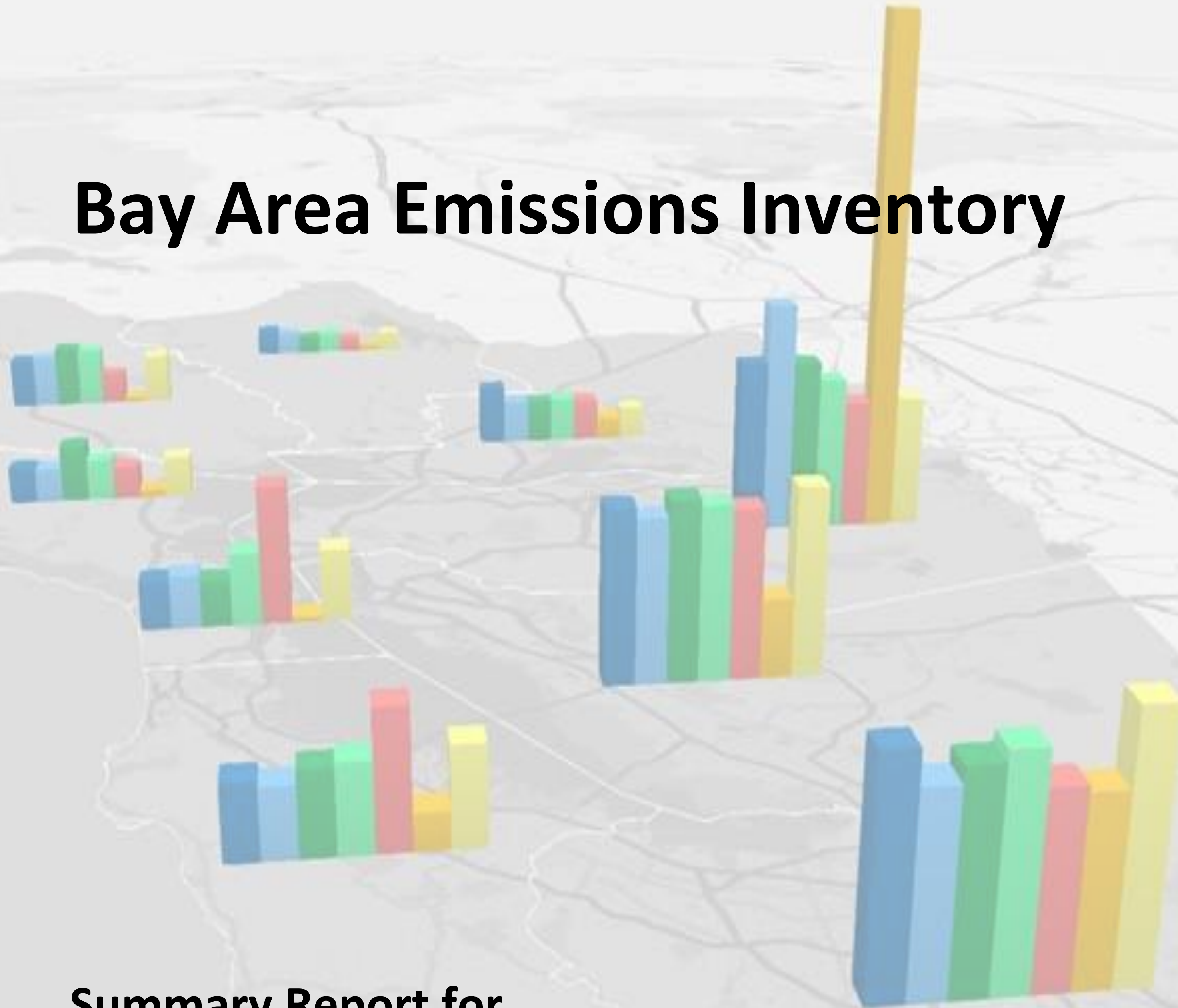
Bay Area Emissions Inventory



Summary Report for Criteria Air Pollutants

February 2024

Bay Area Air Quality Management District
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BAY AREA EMISSIONS INVENTORY

SUMMARY REPORT FOR CRITERIA AIR POLLUTANTS

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Glossary

Abbreviation	Definition
BAAQMD	Bay Area Air Quality Management District (also known as the Air District)
BY	Base Year
CAP	Criteria Air Pollutant
CARB	California Air Resources Board
CEPAM	California Emission Projection Analysis Model
CH_4	Methane
CO	Carbon Monoxide
EI	Emissions Inventory
EMFAC	EMission FACtors Model
EPA	U.S. Environmental Protection Agency
GDP	Gross Domestic Product
GHG	Greenhouse Gas
NAAQS	National Ambient Air Quality Standards
NH_3	Ammonia
NO	Nitric Oxide
NO_2	Nitrogen Dioxide
NO_x	Nitrogen Oxides
O_3	Ozone
Pb	Lead
PM_{10}	Particulate Matter (inhalable particles with diameter ≤ 10 micrometers)
$PM_{2.5}$	Particulate Matter (fine inhalable particles with diameter ≤ 2.5 micrometers)
ROG	Reactive Organic Gases
SFBA	San Francisco Bay Area
SIP	State Implementation Plan
SO_2	Sulfur Dioxide
TAC	Toxic Air Contaminant
TOG	Total Organic Gases
VMT	Vehicle Miles Traveled

1. INTRODUCTION

The Bay Area Air Quality Management District (BAAQMD *or* Air District) is the regional government agency responsible for the regulation of air pollution from stationary sources within the San Francisco Bay Area (SFBA). The Air District's jurisdiction includes Alameda, Contra Costa, Marin, Napa, San Francisco, San Mateo, Santa Clara, southwestern Solano, and southern Sonoma counties. To support the development of new regulations and improvements to existing regulations, as well as to comply with statutory reporting requirements, the agency maintains inventories of emissions for criteria air pollutants (CAPs), greenhouse gases (GHGs), and toxic air contaminants (TACs).

An emissions inventory (EI) is a periodic accounting of emission amounts, sorted by pollutant, location, and characteristic group. An EI typically accounts for emissions over time, including past and projected future years. A representative recent year or base year (BY) is chosen as the basis to estimate emissions for future years. Further discussion of the base year and projections, as applicable to this report, is included in *Chapter 3* on *Inventory Methodology Overview*. The Air District uses emission inventories for many purposes, such as providing inputs for regional air quality modeling to estimate pollutant concentrations and exposures; highlighting sources to target in future rules or enhanced regulations; and providing direction for air quality planning and policy formulation to attain clean air goals.

This report presents an overview of the regional EI of criteria air pollutants and/or their precursors in the SFBA from years 1990 to 2040. The target audience for this report consists of public officials, technical staff, and general public with some familiarity and prior knowledge of EIs and their accounting. The pollutants included in this EI are particulate matter with diameters 10 micrometers and smaller (PM_{10}) and 2.5 micrometers and smaller ($PM_{2.5}$), total organic gases (TOG), reactive organic gases (ROG), nitrogen oxides (NO_x), carbon monoxide (CO), and sulfur dioxide (SO_2). A detailed explanation of CAPs is covered in *Chapter 2*. GHG inventories have been developed separately from criteria pollutants (*BAAQMD, 2015*); estimates of emissions for TACs, including lead (Pb) and ammonia (NH_3), are also covered under a separate reporting process (*BAAQMD, 2020*).

For this emissions inventory, a base year of 2015 is typically used as a reference point for estimating emissions for historical (backcasting) and future (forecasting) years. Wherever possible, the best available data, including actual emissions, are used. However, it is important to note that projections made using the base year may not reflect actual emissions (see *Chapter 3.4*). Emissions data are summarized over an annual timescale and presented as annual totals (tons/year) or daily averages (tons/day). The rest of this report is organized into three chapters. *Chapter 2* provides an overview of the emission inventory, including emissions distributed by county and by source sector. *Chapter 2* also includes plots for sub-sector level categorization of emissions and presents emission time series for multiple pollutants along with trends in socioeconomic indicators from 1990 to 2040. *Chapter 3* describes the methodology used to estimate and classify emissions in this report and in a companion methodology document; it also explains how backcast and forecast assumptions are made for emissions estimation. *Chapter 4* discusses the limitations of this emissions inventory and potential improvements for subsequent updates.

Any questions and clarifications about this report or the emissions inventory data should be forwarded to the Air District's emissions inventory team at the following email address: aim@baaqmd.gov.

2. EMISSIONS INVENTORY OVERVIEW

This chapter provides an overview of the regional emissions inventory. The pollutants covered in this inventory include PM (with sub-groups of PM_{10} and $PM_{2.5}$), TOG (including ROG), NO_x, CO, and SO_2 (see *Chapter 2.1*). The county-level apportionment of pollutant-specific emissions is presented in *Chapter 2.2*. Emissions are presented across five major anthropogenic sectors in *Chapter 2.3*, and then in more depth at the pollutant-specific sub-sector level in *Chapter 2.4*. Finally, the evolution of pollutant-specific emissions with time is shown in *Chapter 2.5* for each sector and compared to regional socio-economic indicator trends.

2.1. Criteria Pollutants

To assess and regulate air quality of a region, the US Environmental Protection Agency (EPA) has set national ambient air quality standards for six criteria air pollutants or CAPs (*EPA, 2015*). These pollutants include particulate matter (PM), carbon monoxide (CO), nitrogen dioxide (NO_2), sulfur dioxides (SO_2), ozone (O_3), and lead (Pb).

Ground-level O_3 is a secondary CAP, which is formed when nitrogen oxides (NO_x) react with a class of pollutants called reactive organic gases (ROG) in the presence of sunlight. Since O_3 is not directly emitted to the atmosphere, emissions of ROG, which is a precursor to O_3 formation, are included in the inventory. Also included in the inventory are total organic gases (TOG; see below). Lead was historically and primarily exhausted from motor vehicles using leaded gasoline and found in commercial and residential paints before it was substantially controlled through regulations. Since its removal from gasoline, lead is now primarily produced from industrial processes (e.g., metal processing) and off-road sources (e.g., small aircraft). Monitoring data in the SFBA indicates that the level of lead is generally below state and federal-mandated health standards. Lead emissions are not included in this report; however, the Air District continues to report lead emissions from permitted stationary sources to the California Air Resources Board (CARB) as part of annual toxics emissions reporting (*BAAQMD, 2020*).

The pollutants included in the inventory are summarized below.

Particulate Matter (PM): PM can be directly emitted from sources or formed secondarily when gaseous emissions react in the atmosphere. PM is composed of a mixture of small airborne particles suspended in liquid droplets (aerosols) floating in the air. For regulatory purposes, particles are defined by their diameters – PM_{10} with diameter of 10 micrometers or less and $PM_{2.5}$ with diameter of 2.5 micrometers or less. $PM_{2.5}$ thus comprises a portion of PM_{10}. Both PM_{10} and $PM_{2.5}$ particles are small enough to penetrate lungs; $PM_{2.5}$ is typically characterized as more potent because they are more likely to travel into the deeper parts of the lung, or even the bloodstream. PM deposited on the lung surface can induce tissue damage, lung inflammation, and other respiratory ailments. $PM_{2.5}$ exposure remains the leading public health risk and contributor to premature death from air pollution in the Bay Area.

PM_{10} and $PM_{2.5}$ are components of filterable particles (or PM_{FIL}), which include any PM that may be physically captured on a filter during sampling. In contrast, condensable PM (PM_{CON}) are ultra-fine particles emitted from a high-temperature source in the gas phase and condensed to sub-micron particles after cooling (*WVDEP, 2013*). PM_{CON} is smaller than 2.5 microns in diameter and is not typically captured by standard filter-based source tests. For applicable sources, the condensable fraction of direct

$PM_{2.5}$ can be anywhere from 10 to 50% of total $PM_{2.5}$ emissions depending on control measures, temperature, and other source-specific conditions. Emissions contributions from condensable PM data are included in the inventory only for some industrial facilities (e.g., refineries and cement manufacturing), but the Air District plans to quantify condensable PM emissions for additional sources (e.g., combustion and wood product sources) in future inventory updates (see *Chapter 4.2*).

Total Organic Gases (TOG): Total Organics Gases or TOG represent a vast group of hydrocarbon compounds, including methane (CH_4), carbonic acid, and many halogenated and oxygenated hydrocarbons. For emissions inventory purposes, TOG includes reactive organic gases (ROG) and other less reactive compounds such as CH_4 and ethane. In the regional inventory, TOG is represented as the sum of ROG and CH_4. The Air District considers reducing TOG emissions, both indoors and outdoors, an important health and environmental goal.

Reactive Organic Gases (ROG): Reactive Organic Gases or ROG are those volatile organic compounds (VOCs) that are considered a concern as both indoor and outdoor air pollutants. Indoors, ROG can pose a potential health risk to occupants due to their toxicity. Outdoors, the primary concern of ROG is their contribution to the formation of photochemical smog and secondary PM. Most ROG are photochemically reactive and can interact with NO_x, thereby playing a critical role in determining the rate of ozone production.

The following air pollutants are mostly emitted from combustion processes involving fossil fuels:

Nitrogen Oxides (NO_x): NO_x is a group of highly reactive gases, with NO and NO_2 as the principal constituents. NO_x is normally produced when fuel is burned at high temperatures. NO_x typically reacts with other volatile organic compounds in the atmosphere to produce ozone on hot summer days.

Carbon Monoxide (CO): CO is a gas produced from incomplete combustion of fuels such as those burned in cars, engines, stoves, fireplaces, and furnaces. CO also indirectly contributes to the buildup of GHGs by reacting with and using up hydroxyl (OH) radicals that would otherwise destroy tropospheric CH_4 and ozone, thus increasing their concentrations in the lower atmosphere.

Sulfur Dioxide (SO_2): Sulfur oxides are compounds that consist of sulfur and oxygen molecules with sulfur dioxide (SO_2) being the predominant form found in the lower atmosphere. SO_2 is a gas that reacts with other compounds to form sulfuric acid, sulfurous acid, and sulfate particles harmful to humans.

2.2. Emissions by County

The regional total and county daily average emissions for base year 2015 are summarized in *Table 1 and Figure 2* below.

Table 1: Distribution of pollutant emissions by county in the San Francisco Bay Area for base year 2015.

	Daily Average Emissions (tons/day)									
County	**Alameda**	**Contra Costa**	**Marin**	**Napa**	**San Francisco**	**San Mateo**	**Santa Clara**	**Solano**	**Sonoma**	**SFBA (tons/ day)**
PM_{10}	17.8	19.6	4.3	3.5	5.2	7.2	20	7.2	6.3	**91**
$PM_{2.5}$	7.0	10.9	1.7	1.3	2.4	2.7	7.1	2.2	2.8	**38**
TOG	139.0	146.5	50.9	17.2	37.2	59.9	139.7	38.5	59.2	**688**
ROG	52.7	51.3	14.3	8.1	22.7	24.8	57.8	16.2	22.1	**270**
NO_x	46.7	39.3	10.6	5.4	39.8	35.1	44.7	14.1	11.4	**247**
CO	176.6	137.9	44.6	24.4	70.6	85.8	206	36.2	58.9	**841**
SO_2	1.9	12.4	0.2	0.2	0.1	0.8	3.7	0.6	0.1	**20**

In the SFBA, daily average PM_{10} emissions are approximately 91 tons. About 42% of those emissions are of $PM_{2.5}$ or fine particles. $PM_{2.5}$ pollution is one of the leading causes of respiratory and cardiovascular ailments in the SFBA. Additionally, daily average TOG emissions from anthropogenic sources located in the SFBA are 688 tons; approximately 40% of those TOG emissions are reactive organics emissions, which are photochemically reactive compounds that contribute to the formation of ground-level ozone. The remaining TOG component is methane (CH_4), an important GHG pollutant; CH_4 emissions are mainly generated from landfills, wastewater systems, animal waste, and various oil and natural gas systems.

The summary of emissions by county shown in *Table 1* can also be visualized (in terms of relative percentage) using a stacked-bar illustration in *Figure 1*. The color-scheme assigned to the nine counties in *Table 1* and *Figure 1* is applied consistently across this report. Based on the data presented in *Figure 1*, it can be inferred that the relative distribution of $PM_{2.5}$ and PM_{10} emissions in SFBA generally corresponds with the distribution of the human population across counties. In areas with a larger population and higher numbers of emission sources and activities, emissions tend to be higher. For some pollutants, certain counties account for a larger proportion of the SFBA total emissions inventory. For example, San Francisco County has approximately 12% of Bay Area's resident population but accounts for 16% of regional NO_x emissions. San Francisco city's prominence as the region's main business and commerce hub leads to a large inflow/outflow of mobile sources (e.g., on-road vehicles) that contribute to an increased share of NO_x emissions. Industry-driven SO_2 emissions are concentrated in the Contra Costa (CC) county as most of SFBA's refineries, which are major SO_2 emitters, are located in this county. The fuel-refining-related industry in Contra Costa County is also a major contributor to regional PM_{10} and $PM_{2.5}$ emissions. This base year inventory includes emissions only from portions of Sonoma and Solano counties that fall under the jurisdiction of the Air District.

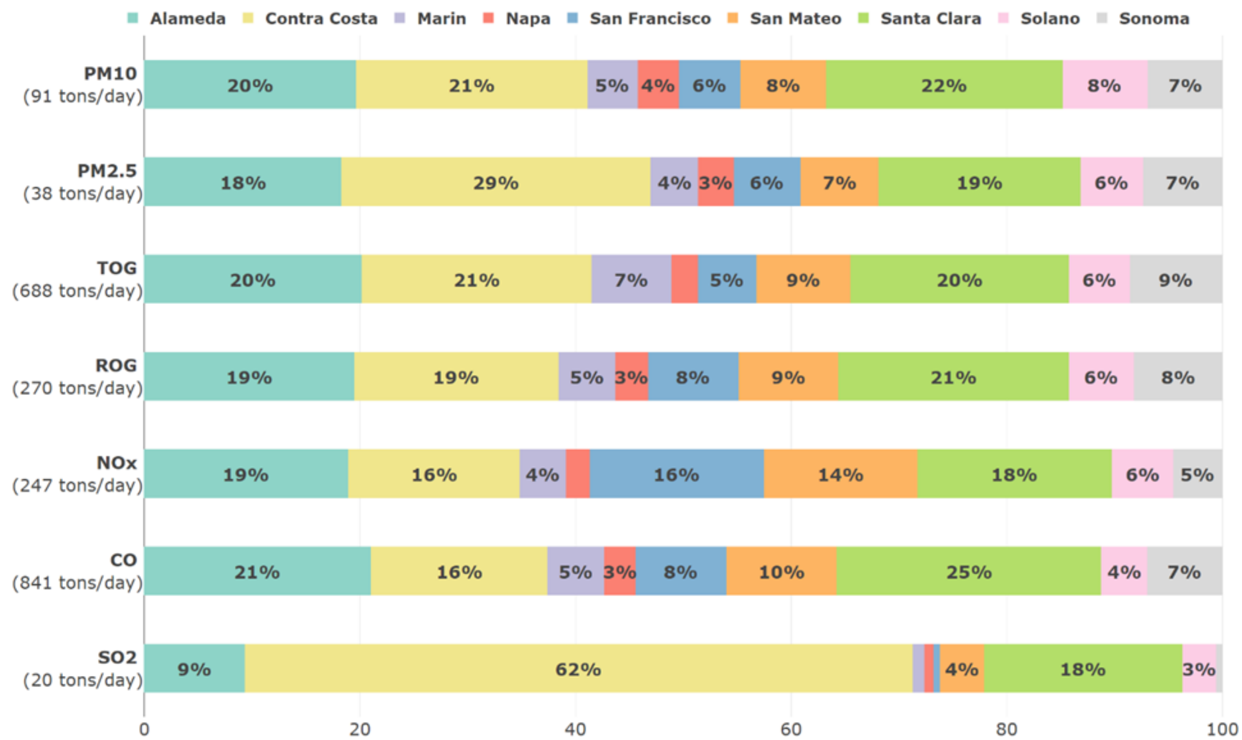


Figure 1: Percent distribution of pollutant emissions by county in the San Francisco Bay Area for base year 2015.

2.3. Emissions by Source Sector

Emissions are presented in this section at the sector level for the base year 2015. Please refer to the *Introduction* section for the definition of base year and its applicability.

Table 2 presents daily average emissions by pollutant (in tons/day) across five major anthropogenic source sectors: Stationary Combustion sources, Stationary Non-Combustion sources, Mobile On-Road sources, Mobile Off-Road sources, and Miscellaneous sources. A sector-based classification color scheme is presented in both *Table 2* and *Figure 2* and is consistently used throughout this report. The source sector apportionment of emissions (relative percentage) can also be visualized in a horizontal stacked-bar illustration as shown in *Figure 2*.

The emissions summary presented in *Table 2* and *Figure 2* shows that the Stationary Combustion sector (orange), which includes fuel combustion categories from residential (e.g., wood burning) and industrial (e.g., generators, boilers, power plants etc.) sub-sectors (see *Table 3* in *Chapter 2.4*), is a primary source of fine particulate emissions, accounting for 37% of SFBA's total $PM_{2.5}$ emissions. For PM_{10} emissions, 55% of the SFBA's total is attributed to sub-sectors of road dust and construction activities in the Miscellaneous (purple) sector (*Table 3*).

Table 2: Distribution of pollutant emissions by source sector in the San Francisco Bay Area for base year 2015.

	Daily Average Emissions (tons/day)					
Sector	**Stationary Non-combustion**	**Stationary Combustion**	**Mobile On-road**	**Mobile Off-road**	**Miscellaneous**	**Total (tons/day)**
PM_{10}	12.3	14.2	10.2	4.4	50.0	**91**
$PM_{2.5}$	7.6	13.9	5.1	3.8	7.6	**38**
TOG	341.9	33.0	53.0	44.7	215.3	**688**
ROG	81.3	7.6	47.5	39.4	94.8	**270**
NO_x	2.0	38.0	99.5	107.0	0.2	**247**
CO	1.7	99.2	386.9	346.5	6.7	**841**
SO_2	8.4	9.7	0.7	1.1	<0.1	**20**

As seen in *Figure 2* below, emissions apportionment by sector for each pollutant can vary significantly. For example, the Mobile On-Road sector accounts for nearly half of total CO emissions but contributes only a small amount (4%) of the total SO_2 emissions due to the use of low-sulfur fuel. Therefore, to ensure a balanced presentation, it is necessary to provide pollutant-specific sub-sectors breakdowns.

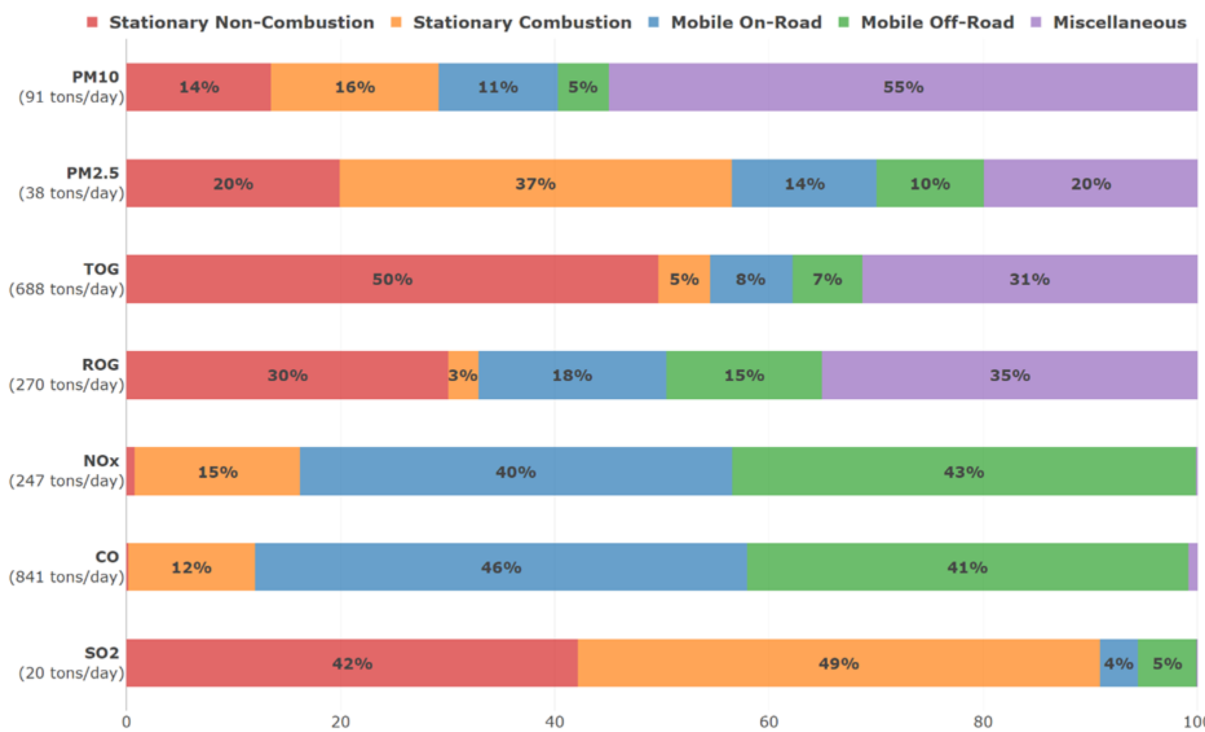


Figure 2: Percent distribution of pollutant emissions by source sector in the San Francisco Bay Area for base year 2015.

2.4. Emissions by Sub-Sector

This section presents the relative distribution of emissions across pollutant-specific sub-sectors for the base year 2015. *Table 3* presents a list of major contributing sub-sectors for each source sector. The classification scheme with five general source sectors is set across all pollutants covered in the base year inventory; sub-sectors are pollutant-dependent (see *Figure 7a in Chapter 3.3*) because the emissions contribution from various sub-sectors may change across different pollutants. For example, road dust and animal waste are both sub-sectors under the Miscellaneous sector; however, road dust is a sub-sector with major PM emissions contribution (for paved and non-paved roads) and animal waste is a sub-sector with major contribution for TOG and ROG emissions.

Table 3: Classification of emissions inventory sectors with major contributing sub-sectors.

	Source Sectors					
	Stationary Combustion	**Stationary Non-combustion**	**Mobile On-road**	**Mobile Off-road**	**Miscellaneous**	**Natural Sources**
Source Sub-Sectors	• Residential Wood Burning • Residential Natural Gas Combustion • Refinery External Combustion • Industrial and Commercial Natural Gas Combustion • Cogeneration and Power Plants • Landfill Fuel Combustion • Other: Coke / coal combustion	• Petroleum Refining • Commercial Cooking • Organic Compounds Evaporation • Waste Management • Industrial and Chemical Manufacturing • Fuel Distribution • Concrete/ Cement/ Asphalt Processing • Other: Winery Fermentation	• Passenger Cars • Light-Duty Trucks • Medium-Duty Trucks • Heavy-Duty Trucks • Other Vehicles	• Lawn and Garden Equipment • Ships • Aircrafts • Off-road Equipment • Locomotives • Other: Agricultural Equipment, Recreational Vehicles	• Road Dust • Other Dust • Consumer Products • Animal Waste • Planned Fires • Agriculture Operations • Natural Gas Leakage • Other: Ozone Depleting Substance Substitutes, Pesticides	• Biogenic Sources • Wildfires

For completeness, Table 3 also presents a Natural Sources (NATS) sector, which includes biogenic sources and wildfires, consistent with the sector classification scheme of the CARB and EPA emissions inventories. Emissions in the NATS sector occur from widely dispersed regional-scale sources with a large dependency on an ever-changing set meteorological conditions and/with an unpredictable frequency of occurrence (e.g., wildfires).

For biogenic sources, the Air District has used the CARB's 2016 State Implementation Plan database to obtain relevant emissions estimates (CEPAM, 2018). Emissions from biogenic sources can be significant for organic gases; for example, approximately 22% of the SFBA total TOG emissions in the year 2022 are associated with natural, rural, and urban vegetation. The current base year inventory for biogenic emissions derived from CARB's data is limited and does not reflect year-by-year variations. To improve the methodology for emissions estimation of biogenic sources, the Air District plans to incorporate data generated from the EPA's Biogenic Emission Inventory System (BEIS) model to effectively project seasonal and inter-annual changes in an updated biogenic emissions inventory.

For wildfire sources, the Air District has not developed specific estimates; instead, CARB's statewide wildfire emissions estimates are obtained and used for inventory purposes (CEPAM, 2018). In recent years, wildfires have become an increasingly significant source of PM and NO_x emissions in the SFBA. However, wildfire emissions can vary substantially by location and time, and are difficult to measure, regulate, and mitigate due to the unpredictable nature and complexity (e.g., duration, geographic coverage, and fuel type). For example, CARB estimated 44,000 tons of PM_{10} emissions from wildfires in the Bay Area in 2017 (30% higher than the total of PM_{10} emissions from all other sources), as compared to 942 tons in year 2015. In Table 3, wildfire emissions are classified as Natural Sources, consistent with the emissions sector classification schemes from CARB and EPA. However, the Air District recognizes that, increasingly, wildfires are now an anthropogenic source, with a strong connection to human-induced climate change.

Considering the limited estimation methodology and significant uncertainty, in this report, biogenic and wildfire emissions are briefly discussed here. The potential magnitude and year-to-year variations in these emissions may lead to skewed data patterns and representations when presented together with emissions data for other source sectors. Therefore, detailed emissions estimates for biogenic and wildfire sources are not included in the county/regional totals presented in tables or figures in this report. The Air District will continue the improvement of emissions estimation for biogenic and wildfire sources in future inventory updates.

For each pollutant, the following "sunburst" charts (*Figures 3a through 3g*) illustrate sub-sectors within the parent sectors that contribute to the emissions in the base year inventory. In each sunburst chart, the inner ring shows the common set of five sectors, while the outer ring splits those sector contributions further into pollutant-dependent sub-sectors. Each chart is accompanied by a summary of highlights and key observations specific to that pollutant. In addition, *Tables 4a through 4g* in the *Appendix* in *Chapter 6* provide summary tables showing the sub-sector level distribution of emissions for each pollutant.

A key takeaway from the sunburst charts is that the contribution to total emissions from sub-sectors is highly dependent on the pollutant of concern. For example, the Waste Management sub-sector within the Stationary Non-Combustion sector (red) and the Animal Waste sub-sector within the Miscellaneous sector (see *Figure 3c*) have a large contribution to SFBA's TOG emissions (50% and 31%, respectively) and ROG emissions (30% and 35%, respectively). NO_x and CO are primarily emitted from the exhaust of On-Road (i.e., motor vehicles) and Off-Road (e.g., construction equipment) Mobile sources (blue and green bars), which account for 83% and 87% of total NO_x and CO emissions, respectively. A majority of the SO_2 emissions occur from petroleum refining operations and cement plants associated with the Stationary Combustion and Non-Combustion sectors (see *Figure 3g*).

In Figures 3a and 3b, within the Mobile On-Road sector, PM emissions for each vehicle-type source subsector include engine exhaust emissions and brake wear and tire wear emissions. Following CARB and EPA emissions reporting conventions, road dust from on-road mobile sources is reported under the Miscellaneous sector. For many applications, however, classifying road dust as part of the Mobile On-Road sector may be necessary, and some inventory reports not intended for state or federal emissions comparisons will include PM from road dust with traditional mobile source emissions.

2.4.1 PM_{10} emissions by sub-sector

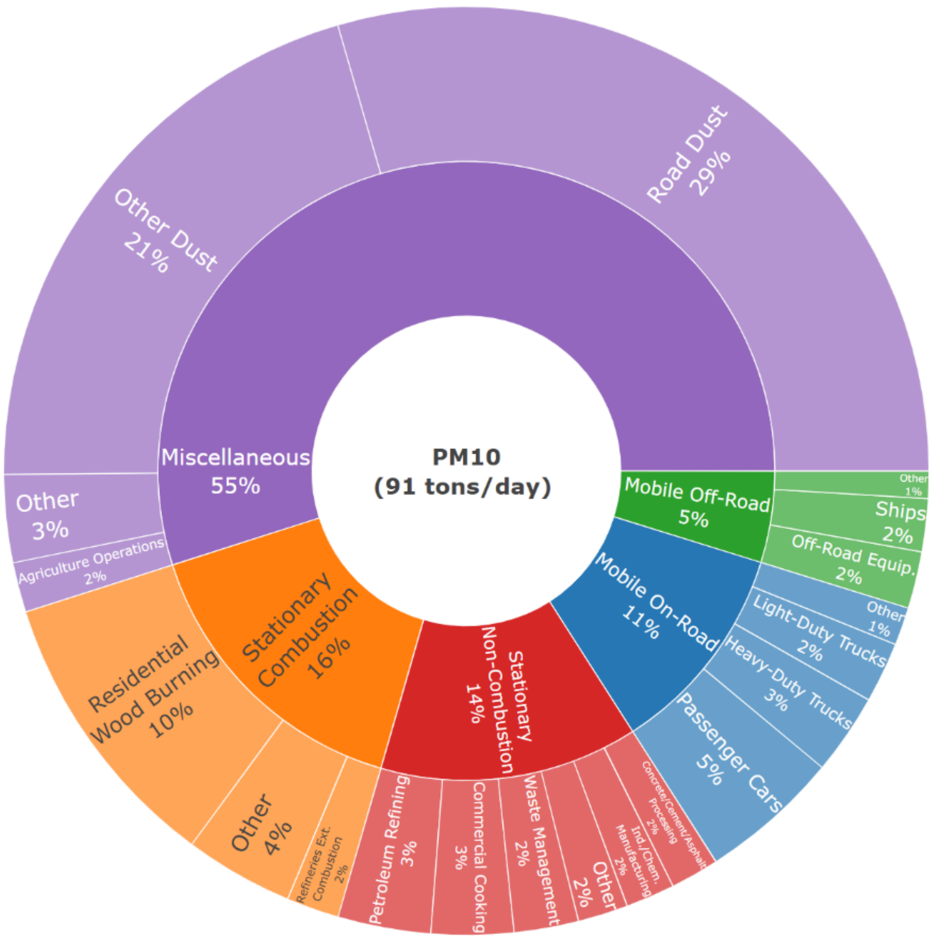


Figure 3a: Distribution of PM_{10} emissions by source sector and sub-sector.

- The Miscellaneous sector is the largest contributor, with dust from paved and unpaved roads (29%) and dust from other sources such as construction activities (21%) as major emitting categories.
- Mobile sources (On-Road and Off-Road) are important contributors (16%).
- Residential wood burning (10%) is an important source under the Stationary Combustion sector.

2.4.2 $PM_{2.5}$ emissions by sub-sector

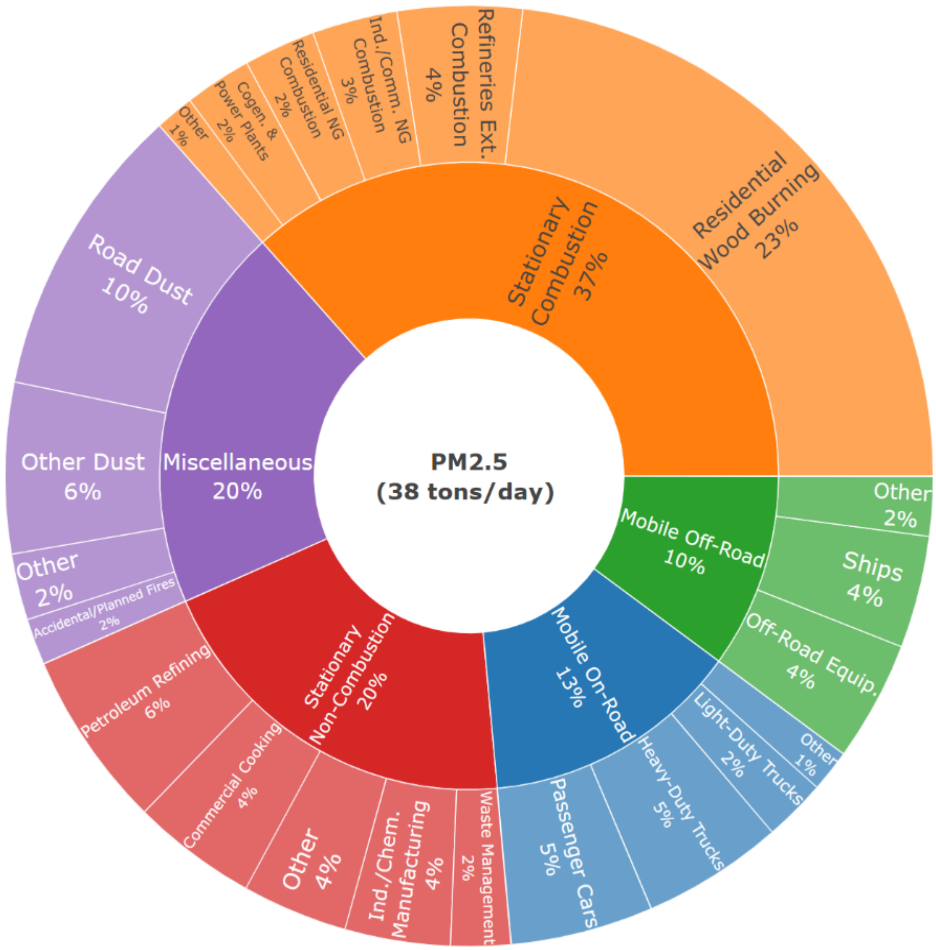


Figure 3b: Distribution of $PM_{2.5}$ emissions by source sector and sub-sector.

- Residential wood burning (23%) is the single largest source category of $PM_{2.5}$.
- Dust from roadways and other sources in the Miscellaneous sector contributes 16% of total $PM_{2.5}$ emissions.
- On-Road and Off-Road Mobile sources account for approximately a quarter of total $PM_{2.5}$ emissions.
- Emissions from the Stationary Non-Combustion sector (20%) are evenly distributed among several sub-sectors.

2.4.3 TOG emissions by sub-sector

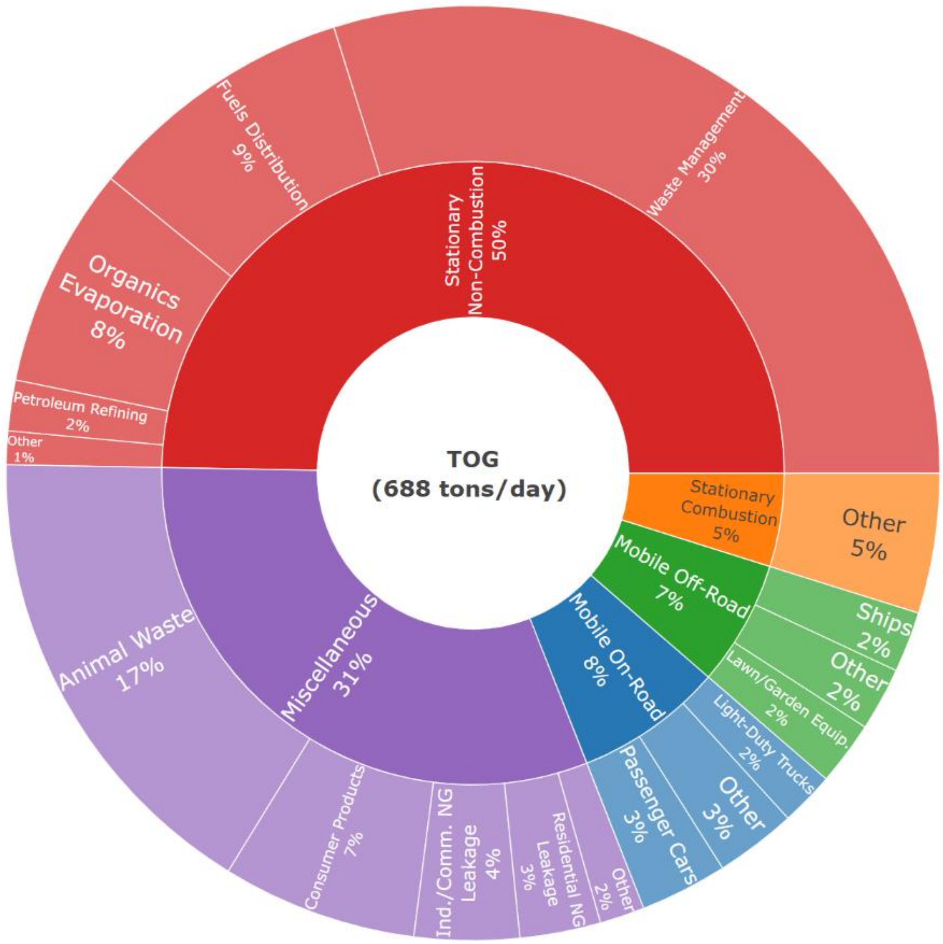


Figure 3c: Distribution of TOG emissions by source sector and sub-sector.

- The Stationary Non-Combustion sector accounts for approximately half of TOG emissions, with waste management (30%) as the single largest sub-sector (primarily due to the inclusion of CH_4 emissions).
- The Miscellaneous sector accounts for about 1/3rd of TOG emissions, with animal waste (17%) as a major source category.
- On-Road, Off-Road, and Stationary Combustion sectors each contribute <10% of TOG emissions.

2.4.4 ROG emissions by sub-sector

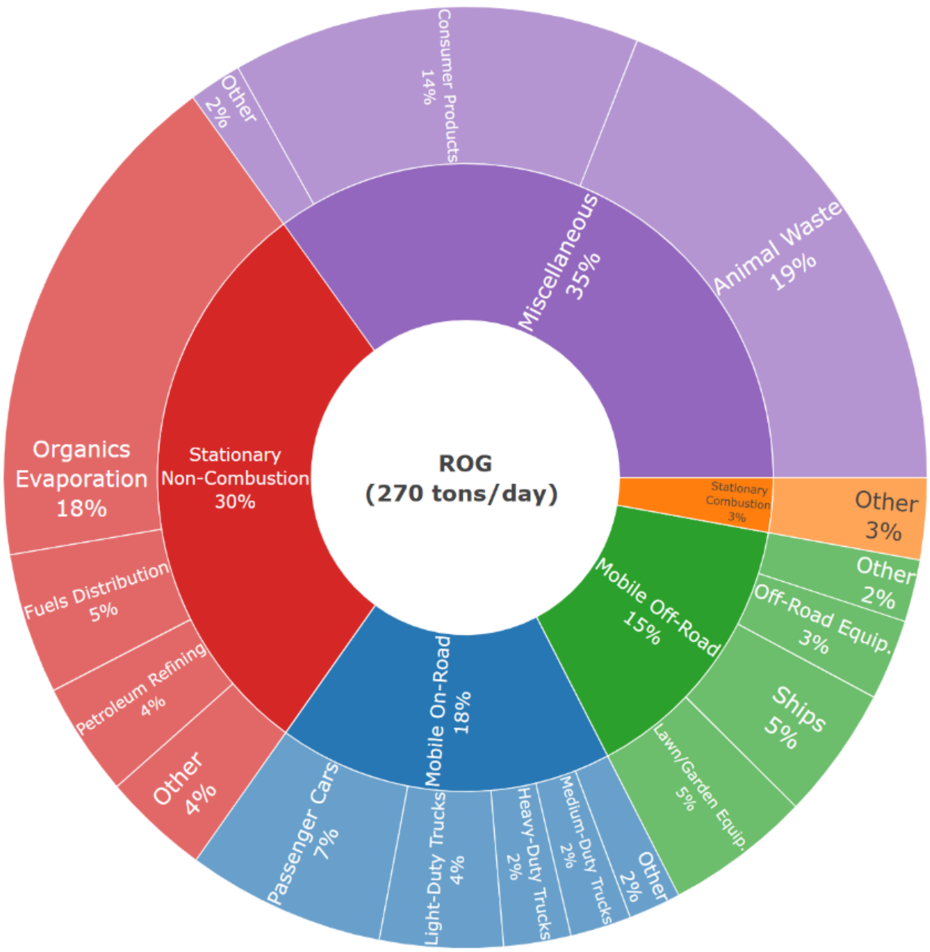


Figure 3d: Distribution of ROG emissions by source sector and sub-sector.

- Animal waste (19%) and consumer products (14%) are major ROG sources within the Miscellaneous sector.
- Organics evaporation from using solvents and coatings contributes about 18% of total ROG emissions.
- On-Road and Off-Road Mobile sources, combined, contribute 1/3rd of total ROG emissions.

2.4.5 NO_x emissions by sub-sector

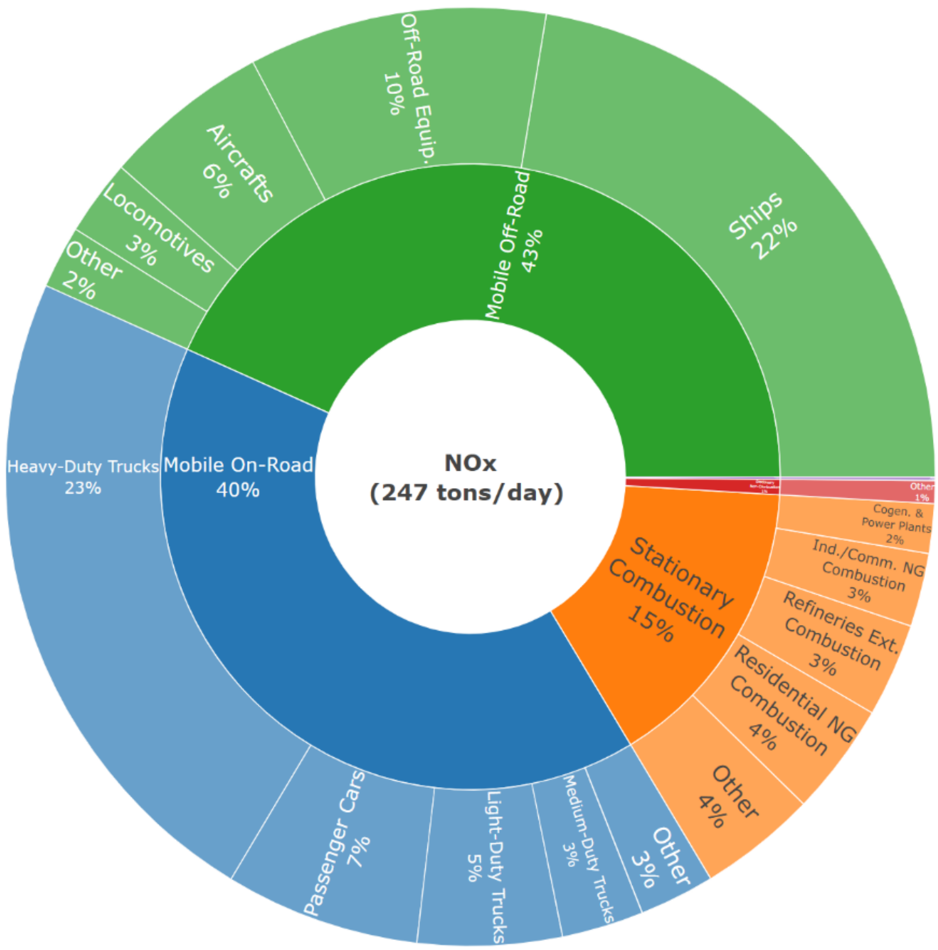


Figure 3e: Distribution of NO_x emissions by source sector and sub-sector.

- On-Road (40%) and Off-Road (43%) Mobile source sectors account for most of the total NO_x emissions.
- Heavy-duty trucks (23%) and ships (22%) are the largest sub-sectors contributing to NO_x emissions.
- Construction equipment (10%) has a larger contribution to NO_x emissions than passenger cars (7%).
- Stationary Combustion (mostly from natural gas use) accounts for the remaining 16%.

2.4.6 CO emissions by sub-sector

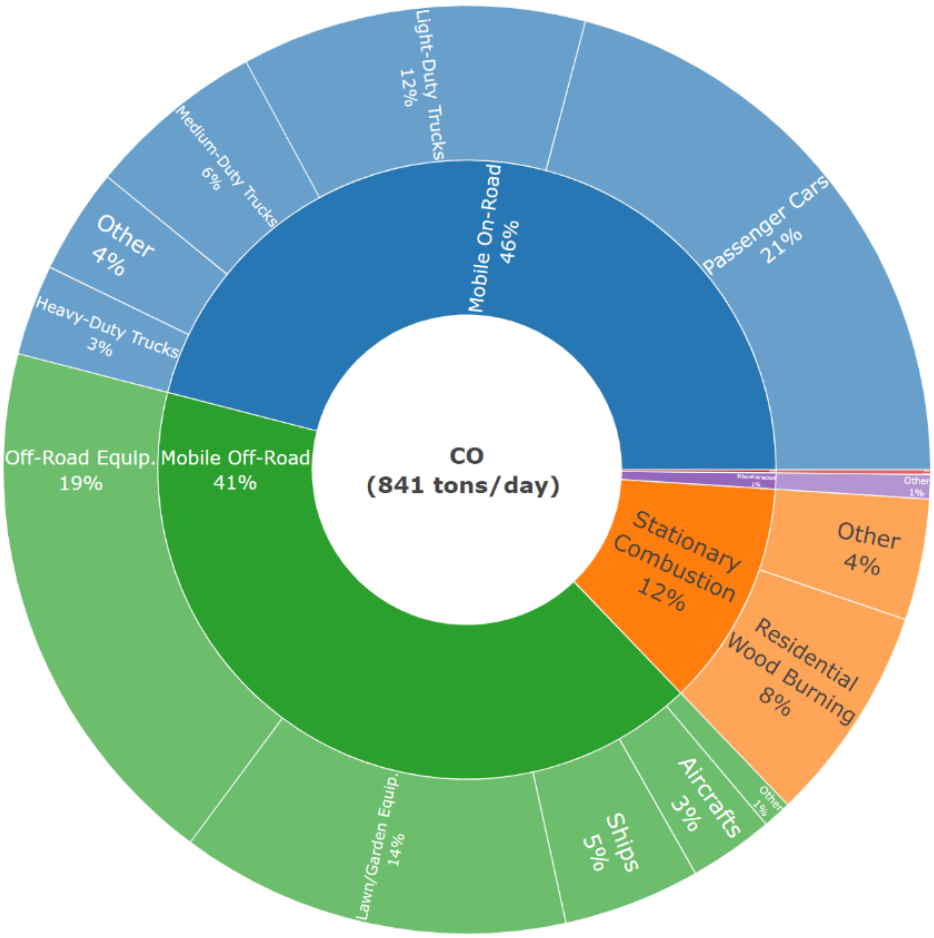


Figure 3f: Distribution of CO emissions by source sector and sub-sector.

- On-Road (46%) and Off-Road (41%) Mobile source sectors account for most CO emissions.
- Passenger cars are the single largest source (21%) of CO emissions, followed by off-road equipment (19%).
- Fuel-powered lawn and garden equipment is a large source of CO (14%).
- Residential wood burning is an important CO source and accounts for 8% of total CO emissions.

2.4.7 SO_2 emissions by sub-sector

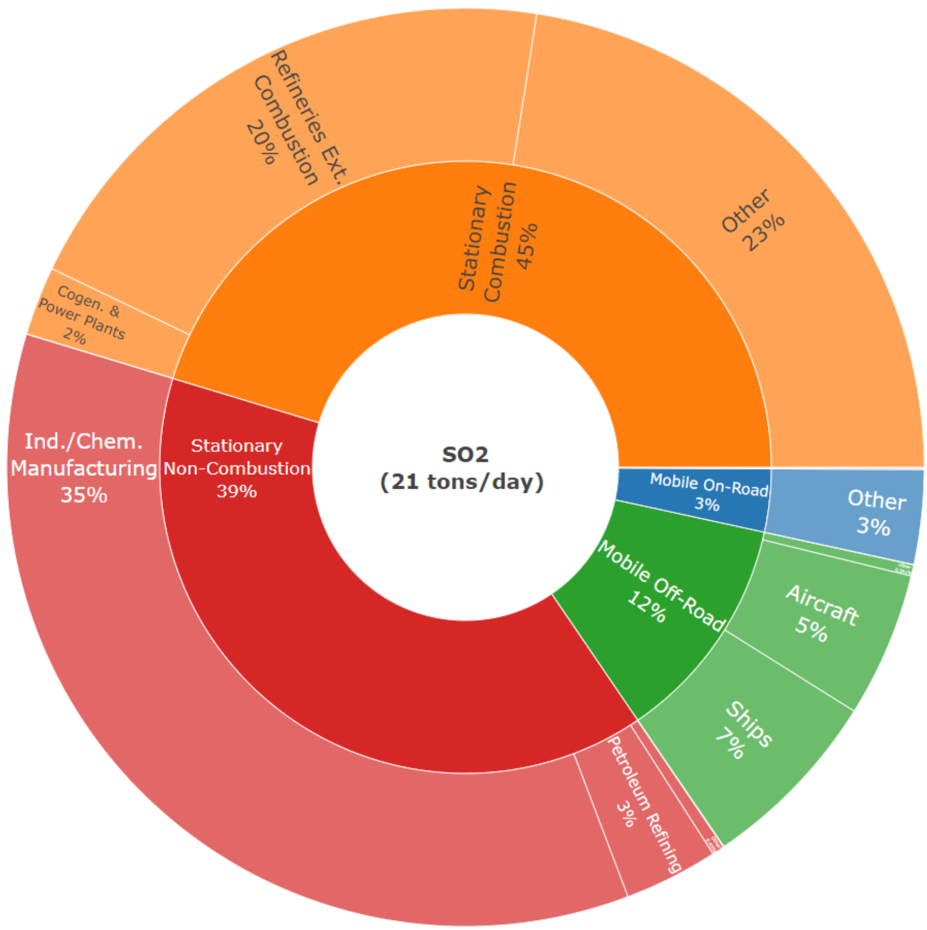


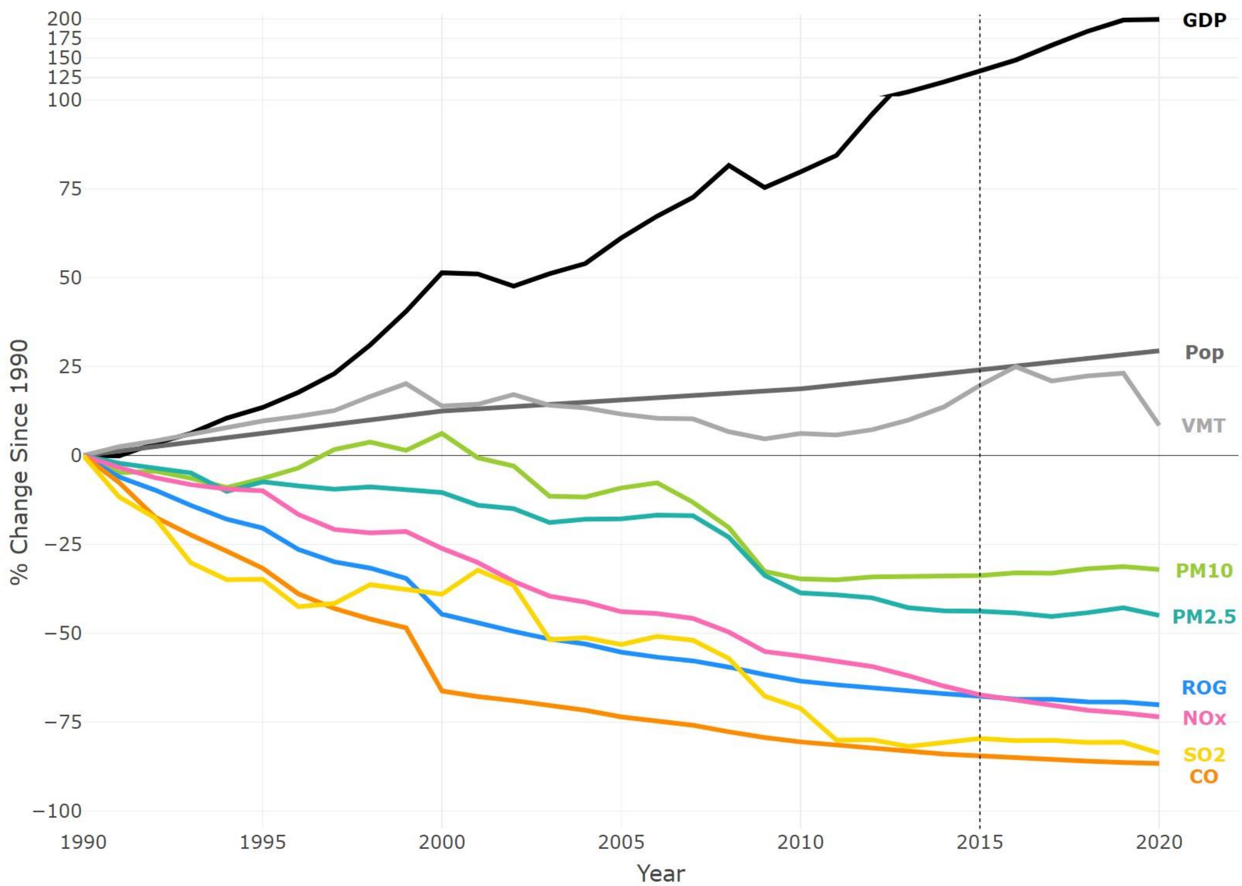
Figure 3g: Distribution of SO_2 emissions by source sector and sub-sector.

- The Stationary Combustion sector accounts for half of total SO_2 emissions, with combustion processes at refineries (20%) and fuel combustion at cement plants (13%; under the "Other" sub-sector) as the largest sources.
- The Stationary Non-Combustion sector emissions, including categories such as sulfur and sulfuric acid manufacturing, glass manufacturing etc., account for 39% of total SO_2 emissions.

2.5. Emissions by Time

In this section, several key socio-economic indicators are presented along with emissions estimates of criteria pollutants, by sector, from years 1990 to 2020. Given the increased uncertainty and constraints, caused by assumptions in forecasting emissions and socio-economic metrics beyond 2020, the discussion is focused on general trends during the past 30 years as opposed to the complete 50-year inventory estimates timeline (i.e., from 1990 to 2040). Specific methodology for backcasting and forecasting emissions is presented in *Chapter 3.4* of this report.

Figure 4 illustrates a timeseries of relative changes in emissions of various criteria pollutants against economic growth indicators and activity patterns, such as gross domestic product (GDP), population, and vehicle miles traveled (VMT) in the SFBA over a 30-year period (*ABAG, 2018; BEA, 2022; EMFAC, 2018*). As shown in the annual percent changes normalized against 1990 values, the SFBA's GDP and population have been constantly growing in the past three decades; VMT in the SFBA has also increased from 1990, although larger variations are observed (e.g., those associated with economic recession and the coronavirus pandemic). During the same period between 1990 and 2020, criteria pollutant emissions have continuously declined, with the largest percentage reduction (approximately 75%) in CO and SO_2 emissions. The reduction in SO_2 emissions can be largely attributed to the adoption of low-sulfur fuels and the implementation of regulations requiring heavy industries to install abatement devices. During this period, NO_x emissions have dropped by approximately 65%. The reduction in NO_x and CO emissions has been largely associated with on-road mobile sources, due to progressively improved pollution controls required for motor vehicles to meet increasingly stringent engine standards. The reduction in PM_{10} and $PM_{2.5}$ emissions is less substantial, compared to emission reductions of other pollutants, but the Air District continues to pursue regulations and require the use of controls on combustion sources to achieve greater PM reductions.



Data sources for socio-economic indicators:
Gross Domestic Product: Bureau of Economic Analysis, Real GDP in Chained Dollars. Due to data availability, different geographical regions are used to create a complete dataset from 1990-2020.

- *For years 2001-2020, the total GDP for the nine counties within BAAQMD's jurisdiction is used.*
- *For years 1997-2000, GDP for California is used.*
- *For years 1990-1996, GDP for the United States is used.*

Population: Association of Bay Area Governments
Vehicle Miles Traveled: EMFAC2021 (years 2017-2020), EMFAC2017 (years 2000-2016), EMFAC2011 (years 1990-1999)

Figure 4: Normalized time series of criteria pollutant emissions and major socio-economic indicators in the San Francisco Bay Area from 1990 to 2020.

The annual emissions by sector for each pollutant over a 50-year timeline (1990-2040) are presented in *Figures 5a* through *5g*. Each of the time series plots is accompanied by a pollutant-specific summary of highlights. The forecasted emissions in this report are generated using projections that rely on growth profiles typically representative of business-as-usual activity or throughput changes. It is important to note that not all potential emission reductions resulting from committed or proposed regulations have been incorporated into the forecasted emissions. Consequently, emissions estimates for 2020 to 2040 are subject to considerable uncertainties as they are based on forecasted data. When interpreting the projected trends of future emissions, it is advisable to exercise caution and consider the specific forecasting methodology applied to each source category. For a more detailed description of the methodology used, please refer to Chapter 3.1. Additionally, Chapter 4.2 provides a more comprehensive discussion on the limitations associated with these projections.

2.5.1 PM_{10} emissions trend

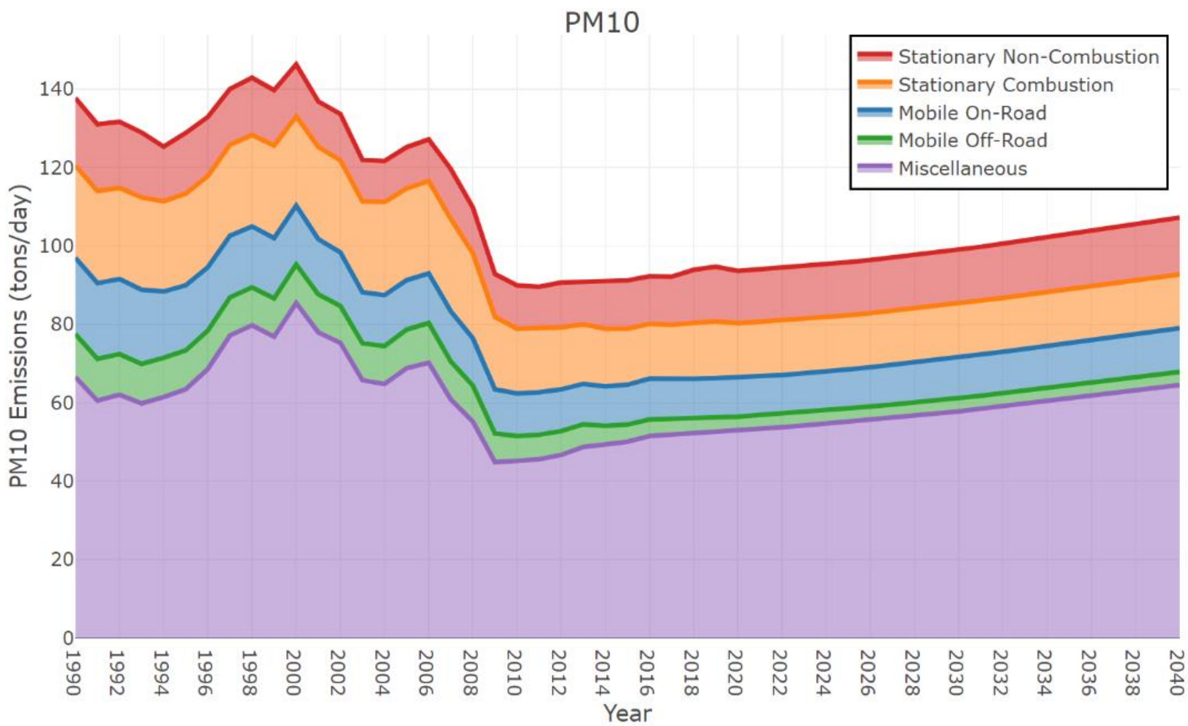


Figure 5a: Timeseries of PM_{10} emissions by source sector.

- Overall, PM_{10} emissions drop by 32%, from 139 to 95 tons/day, between 1990-2020.
- The Miscellaneous sector remains the largest sector for PM_{10} with a projected 23% decline in emissions by 2020.
- Fluctuations in PM_{10} emissions are mostly attributed to the Miscellaneous sector due to dust generated from construction activities. PM_{10} emissions trends align with fluctuations in the construction industry activity, peaking in the late-1990s, followed by a rapid decline in the late 2000s during the economic recession, then slightly increasing during the past decade.
- A large percent decrease in smaller sectors like On-Road Mobile sector (50%) and Off-Road Mobile sector (70%) are observed during the period from 1990 to 2020.

2.5.2 $PM_{2.5}$ emissions trend

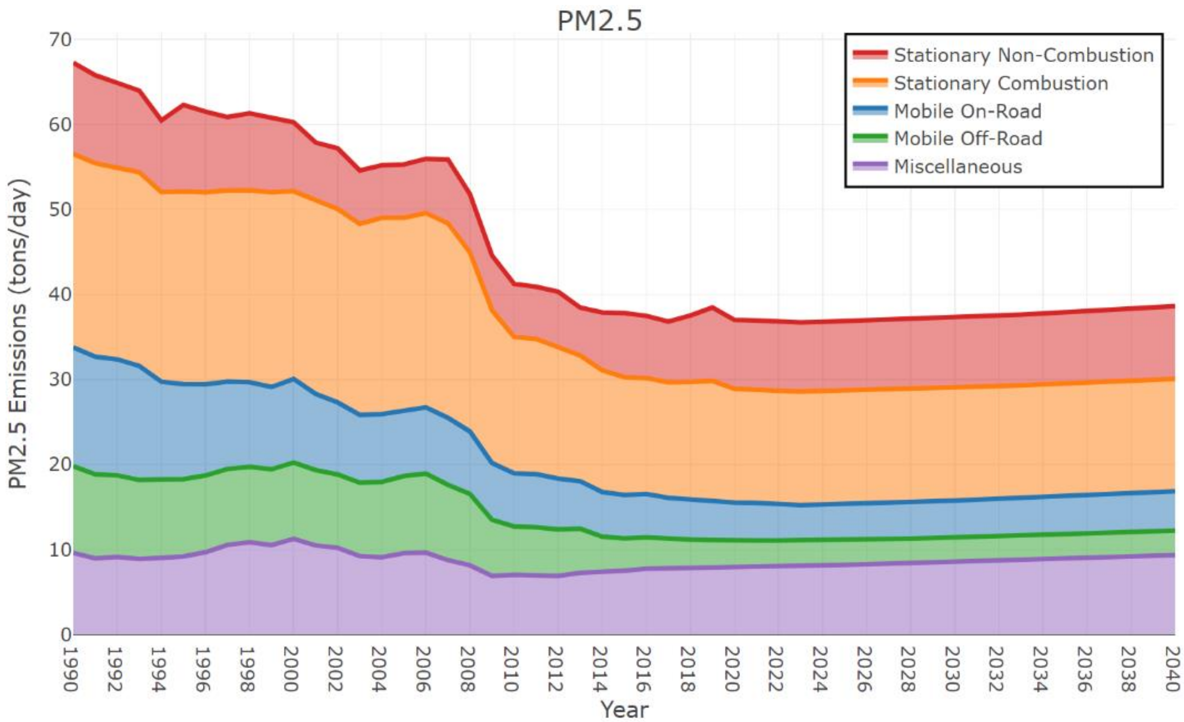


Figure 5b: Timeseries of $PM_{2.5}$ emissions by source sector.

- Overall, $PM_{2.5}$ emissions decrease by 44% between 1990-2020.
- The largest percentage reduction occurs in the Mobile Off-Road (69%) and On-Road (67%) sectors attributed to controls on mobile sources.
- Slight increase in the 2010s in the Stationary Non-Combustion sector.
- Stationary Combustion emissions had a 31% decline from 1990 to 2020 (propelled by the recession in the late 2000s) but remains the largest contributor to $PM_{2.5}$ among all source sectors.

2.5.3 TOG emissions trend

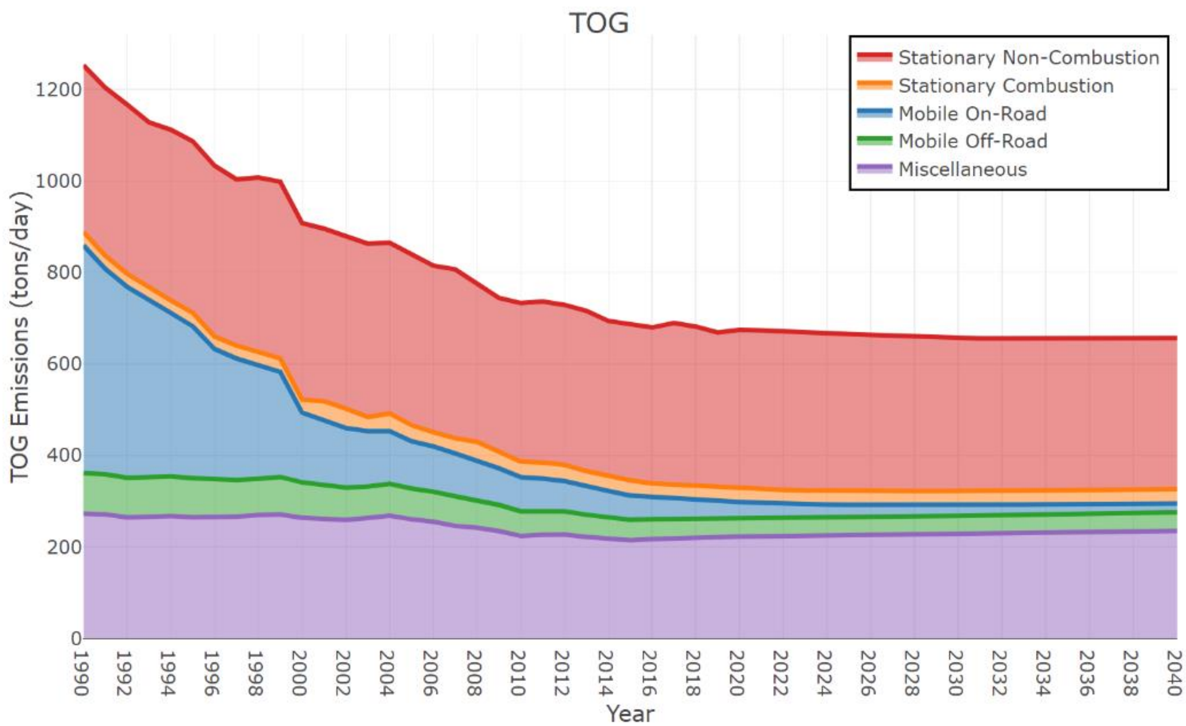


Figure 5c: Timeseries of TOG emissions by source sector.

- Overall, TOG emissions drop by 42% from 1990 (~1,200 tons/day) to 2020 (~700 tons/day).
- The largest decrease in emissions occur in the Mobile On-Road sector, primarily driven by pollution control of motor vehicles and use of reformulated fuels.
- The Stationary Non-Combustion sector (dominated by waste management and fuels distribution activities) is the largest contributor (~400 tons/day); emissions contribution generally remains steady over time.
- Emissions from the Miscellaneous sector also remain steady at approximately 200 tons/day.

2.5.4 ROG emissions trend

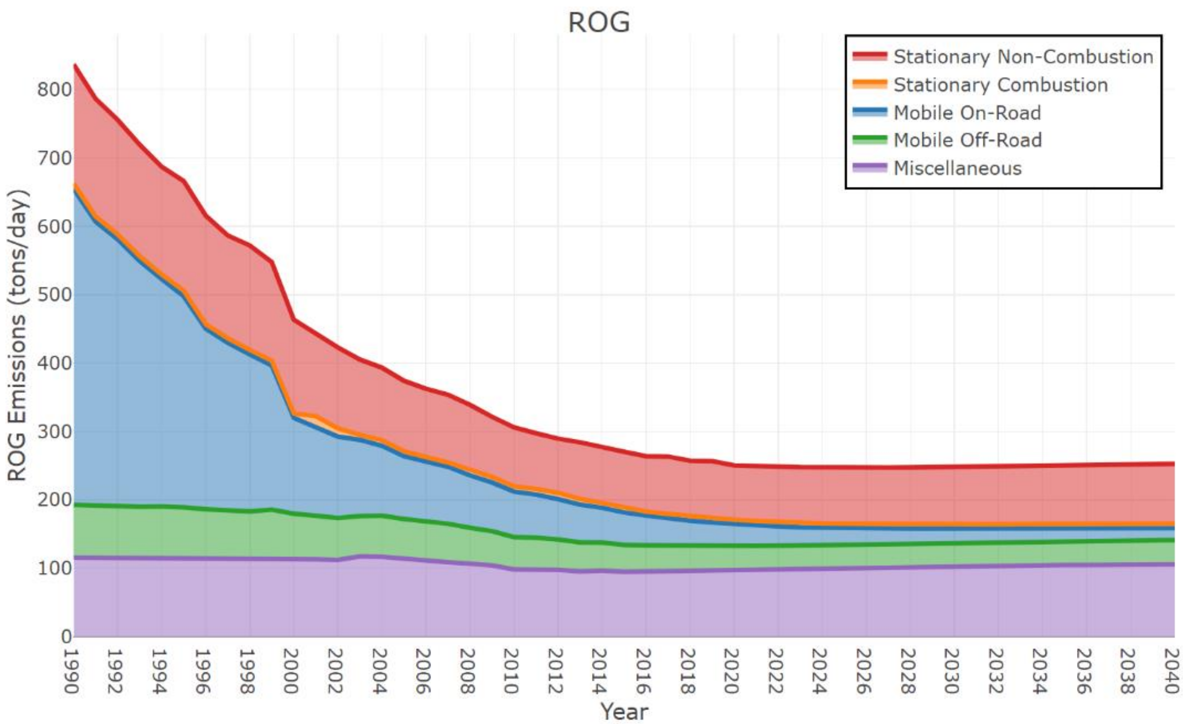


Figure 5d: Timeseries of ROG emissions by source sector.

- Overall, ROG emissions drop by 68% between 1990-2020.
- The Mobile On-Road sector has the largest change from ~450 tons/day to <50 tons/day due to fleet turnover with lower emitting vehicles and use of reformulated gasoline.
- The Stationary Non-Combustion sector had a 53% emissions reduction in the past three decades, largely driven by regulatory controls on organic compounds evaporation and other industrial sources, such as petroleum refining, surface coating, and solvent use.

2.5.5 NO_x emissions trend

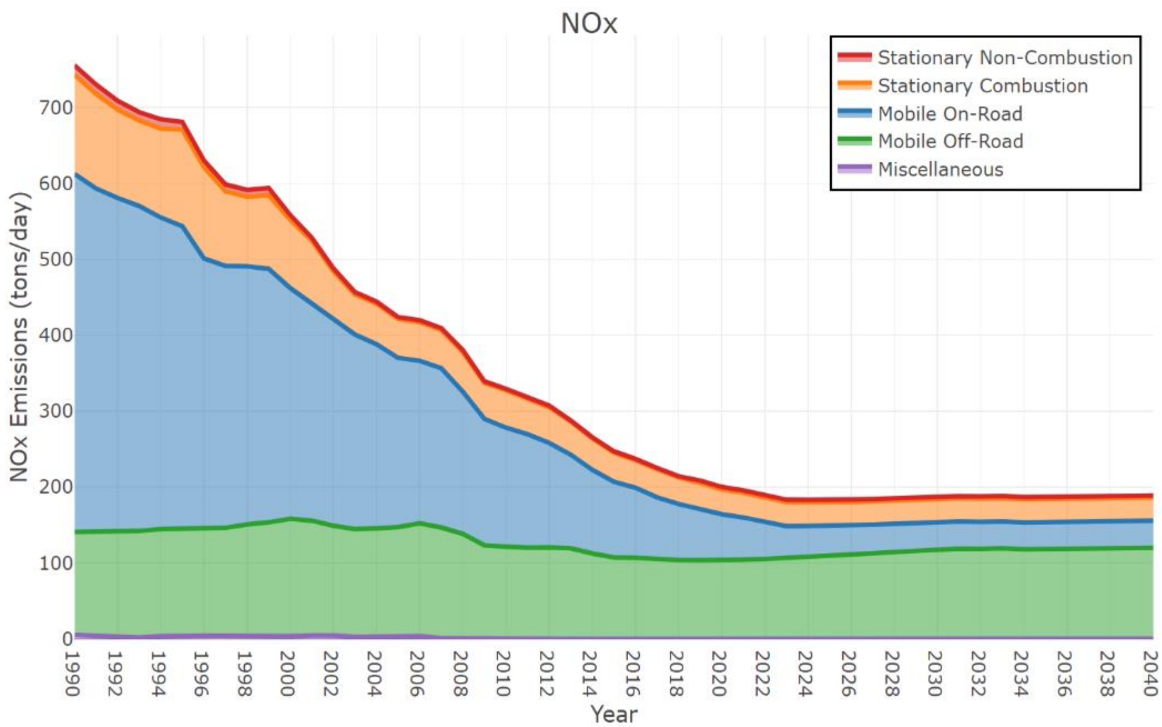


Figure 5e: Timeseries of NO_x emissions by source sector.

- NO_x emissions drop significantly from ~750 tons/day in 1990) to ~200 tons/day in 2020 (73% decrease).
- The largest reductions came from the Mobile On-Road sector (89% decrease) due to regulatory controls and fleet turnover of motor vehicles.
- The Stationary Combustion sector also had a substantial emissions reduction (83%) from 1990 (~120 tons/day) to 2020 (~20 tons/day) due to regulatory controls on various industrial, commercial, and residential combustion sources.
- Mobile Off-Road emissions decreased in the mid-2000s and remained steady in the next decade.

2.5.6 CO emissions trend

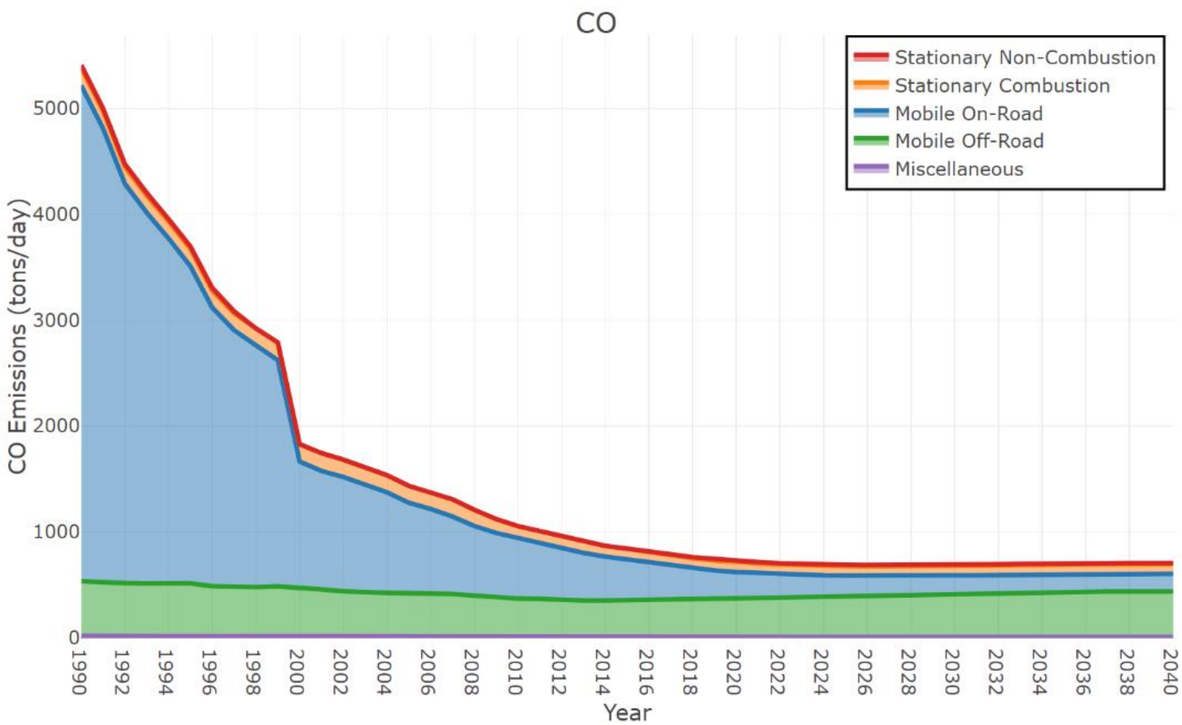


Figure 5f: Timeseries of CO emissions by source sector.

- CO emissions drop significantly by 85% from 5,300 to 800 tons/day between 1990-2020.
- The largest reduction comes from the Mobile On-Road sector (94% decrease) due to regulatory controls and fleet turnover of motor vehicles.
- The Mobile Off-Road sector's CO emissions indicate minimal variations during the past three decades and are projected to remain stable.

2.5.7 SO_2 emissions trend

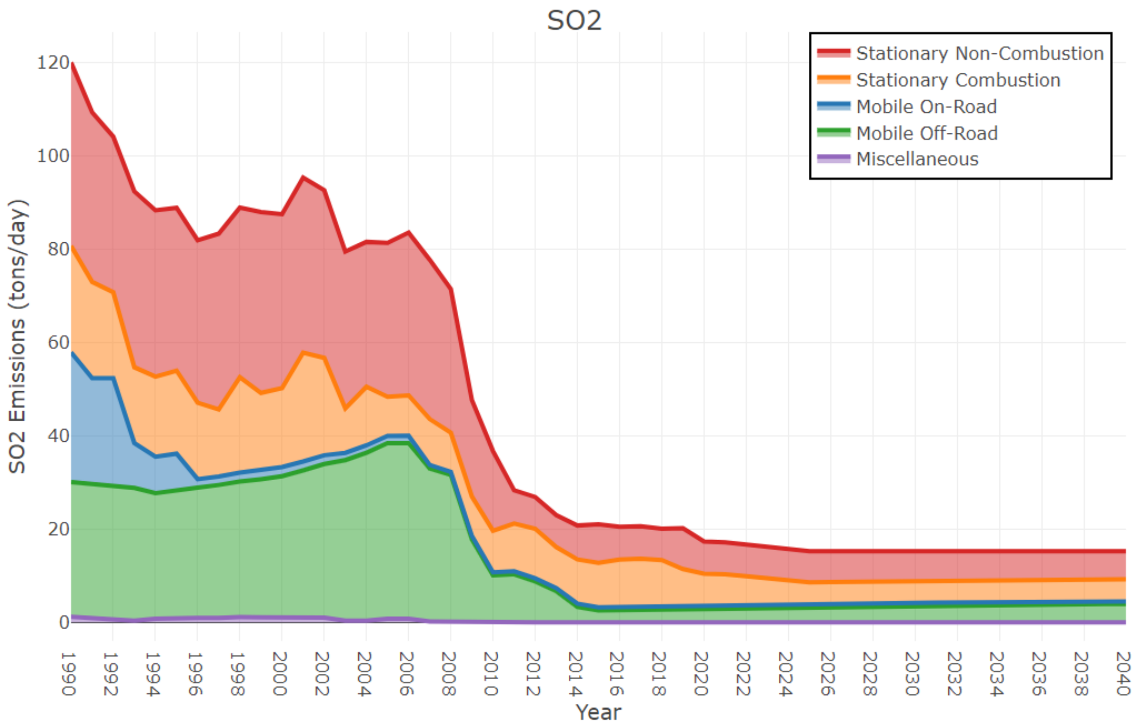


Figure 5g: Timeseries of SO_2 emissions by source sector.

- Overall, SO_2 emissions decrease by 81% between 1990 and 2020 (95 to 18 tons/day) with large temporal variations.
- Changes in SO_2 emissions were mainly associated with the Stationary Non-Combustion sector and the Mobile Off-Road sector in the 2000s, and the Mobile On-Road sector in the 1990s.
- The substantial reduction of SO_2 emissions in the 2000s from the Stationary Non-Combustion sector can be primarily attributed to the implementation of abatement devices, such as the wet gas scrubbers that effectively lowered sulfur emissions from the Fluid Catalytic Cracking Units (FCCUs) in refineries.
- The substantial reduction of SO_2 emissions in the late 2000s from the Mobile Off-Road sector can be largely attributed to the ocean-going vessel fuel regulation adopted by CARB in 2008, which set specific sulfur content limit in marine fuels.

3. INVENTORY METHODOLOGY OVERVIEW

This chapter presents an overview of the emissions accounting process. Before generating a sector-level summary of estimates, emissions are estimated at the category level by pollutant, following the methodology detailed in *Chapter 3.1* and illustrated in *Figure 6b*. The emissions categories are further classified based on the specific methods used to develop emissions, which are associated with the source types included in each category. *Chapter 3.2* provides a comprehensive description of the basic source types used to classify categories, including point sources, mobile sources, area sources, CARB sources, and special cases. The emissions calculation approach is summarized in *Chapter 3.3*. Typically, a recent year or Base Year (BY) is selected as the basis for projecting emissions for future years (after the base year) and backcasting emissions for historical years (before the base year), as described in *Chapter 3.4*. For this inventory, the base year varies depending on the category type (refer to *Chapter 3.4* for further details).

3.1. Emissions Categorization

In this summary report, emissions are distributed across five broad anthropogenic sectors that are further divided into pollutant-dependent sub-sectors. The high-level overview of the organization scheme is illustrated in *Figure 6a*. The scheme presented in *Figure 6a* is used to discuss emissions summaries and trends in *Chapter 2*.

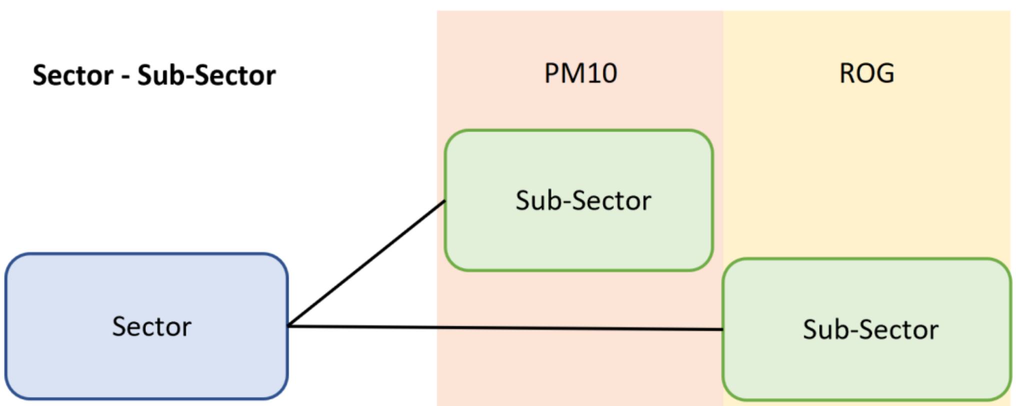


Figure 6a: Schematic illustration of Sector-Sub-sector organization of emissions summary in the Summary Report, with PM_{10} and ROG used as examples.

Emissions inventories are periodically updated to incorporate changes in activity data, emissions factors, and new or amended state and local regulations. In addition to this summary report, the Air District provides a companion document, "Bay Area Emissions Inventory: Source Category Methodologies" (herein referred to as the *Methodology Document*), with more details on the methods used to develop the EI by category (*BAAQMD, 2023*). As shown in *Figure 6b*, the *Methodology Document* provides an alternate view of the inventory, where sectors are divided into emission categories, rather than by pollutant-specific sub-sectors.

Within the Methodology Document, the category-level description of emissions includes a comprehensive discussion of various aspects of the inventory calculation approaches, such as throughputs and activity data, county distribution, emission factors, control factors, emissions trends (including the derivation of historical estimates and future projections), and uncertainties.

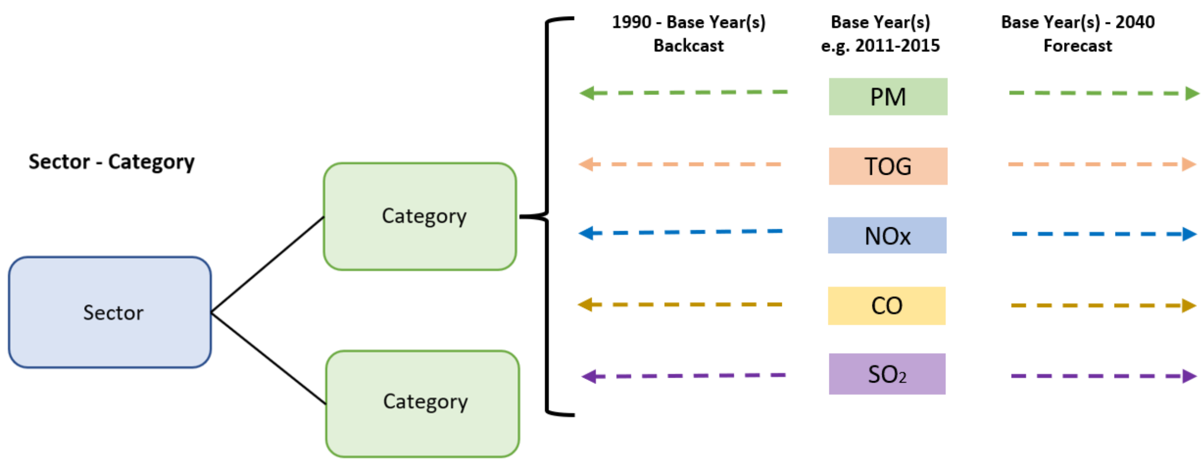


Figure 6b: Schematic illustration of Sector-Category organization of emissions summary in the Methodology Document, with backcasting and forecasting of emissions from the base year.

3.2. Source Categorization

Over one thousand categories are included in the base year emissions inventory and these categories are grouped into the following five major classes based on the type of sources, origin of the emission data, or complexity of emissions calculations/supporting data.

- Point Source Category: These are typically operations emitting air pollution into the atmosphere at a fixed location (or multiple fixed locations) within a facility for which the Air District has issued a permit to operate. These sources could also be a collection of similar permitted equipment (e.g., reciprocating engines) across multiple facilities. Emissions are estimated at the individual source level based on the specific characteristics of that source, such as operational information, emission factors, and applicable abatement equipment data, available via the Air District's internal database.
- Mobile Source Category: These are equipment, and combustion/non-combustion processes emitting air pollution into the atmosphere from sources that can move: motor vehicle or movable equipment with no static location. Examples include tailpipe emissions from cars, trucks, buses, and farm or construction equipment. On-road as well as off-road mobile source inventories are developed using data from CARB's EMission FACtor (EMFAC) system and other data sources (*EMFAC, 2018*).

- Area Source Category: These are equipment and/or operations emitting air pollution into the atmosphere from multiple locations through various release mechanisms. They are typically clustered into larger groups for which the overall source (rather than individual sources) activity or throughput information is available, and emissions are estimated based on a standard set of emission factors. Area sources include both permitted and unpermitted sources. Examples include residential combustion (e.g., water heaters and space heating devices), dairies, wind-blown dust, pesticides, and consumer products.
- CARB Source Category: These are a subset of Area Source categories and some Mobile Sources (e.g., lawn garden equipment and recreational boat etc.) with emissions data derived by CARB and directly used as inventory estimates. For the base year inventory, the CARB's 2016 State Implementation Plan database was used to obtain relevant emissions estimates (*CEPAM, 2018*). Examples of categories include ships and other marine sources, aircraft, mining equipment, and structures coatings, etc.
- Special Case Category: These are also a subset of Area Source categories that involve complex calculations and multi-level aggregation based on a non-standard calculation approach as described in *Chapters 3.3 and 3.4*. These source categories include atypical variables such as county-varying and time-varying emission factors and controls, weighted emission factors, disparate activity data sources, aggregation of emission from several constituent smaller area sources etc. Examples of Special Cases include road and agricultural dust, solvents, ozone-depleting substance substitutes, and certain aircraft categories.

3.3. Emission Estimation Methods

Emission inventories are estimated using either a bottom-up or a top-down approach. A bottom-up emission inventory involves estimating emissions using (1) emission factors (mass of pollutant emitted per unit of activity); (2) local activity or throughput information of the emission processes (e.g., number of events, duration of activity, duty cycle, and quantity of gallons consumed); and (3) estimated emissions reduction or control efficiency if an abatement device is installed or relevant regulation is applicable. For permitted sources under the Point Source category, the Air District uses source specific information submitted by the facility. Detailed activity data and emission factors are also available for some Mobile Source categories and many Area Source categories.

The following equation illustrates a general formula for estimating emissions following the bottom-up method:

$$E_i = A \cdot (1 - ER_i) \cdot EF_i$$

where

E_i = emissions of pollutant i
A = activity rate or throughput
ER_i = emission reduction efficiency of pollutant i
EF_i = emission factor of pollutant i

Emission factor (EF) is a value that reflects the quantity of pollutant emitted per activity or time/distance increment (e.g., grams per hour, grams per gallon of fuel consumed). EFs can be general or source specific. General EFs from published literature represent averages of similar operations, while specific EFs are derived from source-specific emission testing, mass balance, or chemical analysis. Specific EFs are typically more representative and can be self-reported by the facility/operator or compiled by the regulating agency.

Activity rate or throughput (A) data refers to the frequency and amount of pollution activities based on the operation of the source or facility. General activity data may be used for categories where minimal information is available, such as some area sources; for point source categories, activity data are based on reported source-specific information provided by the permitted facility.

Emissions reduction efficiency or control factors (ER) indicate the percent reduction in pollutant emissions if an abatement device is installed or specific regulations are applicable for the source. For example, if a baghouse on a cement silo serves as an abatement device that could reduce particulate emissions by 95%, then a control factor of 0.95 can be used for emissions estimation. Regulatory controls incorporated into the emissions calculation are discussed in the Methodology Document, which presents how emissions by category are adjusted to reflect control benefits.

The top-down emissions estimation approach is typically used for those sources or categories with limited source-specific information. A top-down emissions inventory can be developed from a larger-scale (e.g., state or county) emissions inventory using spatial surrogates and/or temporal profiles to disaggregate total emissions to finer spatiotemporal scales. A top-down emissions inventory was developed for some area and on-road or off-road mobile sources using county-level data obtained from CARB's State Implementation Plan (SIP) inventory (*CEPAM, 2018*). Surrogate activity data, such as fuel throughput, population growth, employment by job sector, and land use etc., are used to scale the CEPAM data to derive category-specific emissions. For example, county-based population data are used to assign statewide emissions for consumer solvent use to Bay Area counties.

3.4. Backcasting and Forecasting

This report presents a regional base year inventory that includes emissions trends from the years 1990 to 2040. The Air District applies backcast and forecast factors to data for certain base years to estimate emissions in past years and for future years. Future changes in the baseline emissions over time are dependent on two factors: (1) a growth profile based on socio-economic indicators, demographics, and activity parameters etc.; (2) a control factor based on federal, state, and local regulations. The following equation illustrates a general formula for projecting future year emissions:

$$PE_i = Gr \cdot C_i \cdot E_i$$

where

PE_i = projected emissions of pollutant i in a past or future year
Gr = growth rate by economic profile of industry or population
C_i = control factor based on adopted rules and regulations
E_i = base year emissions of pollutant i

This base year inventory only considers future impacts of category- or source-specific regulations that are currently adopted and enforced when estimating control factors (*C*). Anticipated emission reductions due to policy goals and executive orders, non-binding emissions targets, grants, and incentive programs are not reflected in projections of future emissions. The estimation of backcast emissions follows a similar approach with applied control factors reflecting impacts from historical regulations.

Specific backcasting and forecasting protocols applied to the different source category classes are highlighted in the following.

Point Source Category: For historical emissions, no backcasting was applied as emissions estimates were developed using the Air District's internal database for permitted facilities through 2020. In those cases where emissions are not available, linear interpolation was applied to replace missing values. Forecasted emissions were estimated using the above equation based on updated growth profiles with 2020 as the base year.

Mobile Source Category: Emissions for motor vehicles were estimated directly for each year between 1990 and 2040 using the EMFAC2017 model based on year-specific traffic activity and emission factors (*EMFAC, 2018*). For each year, the EMFAC model estimates vehicle population and VMT based on historical and the most recent vehicle registration data available, as well as new vehicle sales and activity growth rates derived from regression analysis of socioeconomic indicators, such as human population and unemployment rate. The emission factors generated by EMFAC reflect changes in emission standards, control technology penetration, and vehicle deterioration over time.

Area Source Category: For years 2011 through 2015, emissions for area source categories were estimated using category-specific activity data and emissions factors as detailed in the equation presented in *Chapter 3.3*. Historical and future emissions data are then derived using growth profiles as described earlier. For this base year inventory, backcast emissions for 1990 through 2010 were estimated using year 2011 data as the basis; forecast emissions for 2016 and onwards were developed using year 2015 data as the basis.

CARB Source Category: Emissions from years 2000 to 2035 for these categories were compiled by CARB. CARB's data were backcast to year 1990 from the base year 2000 using one of the following three methods, depending on the available data – scaling to historical emissions reported by CARB from 1990 to 1999 in the previous inventory, as shown in the equation below; or, linear extrapolation of year 2000 to 2008 emission data; or, using a specific category growth profile.

$$Emissions_{year\ X} = \frac{BY2015\ EI\ emissions_{year\ 2000}}{BY2011\ EI\ emissions_{year\ 2000}} \times BY2011\ EI\ emissions_{year\ X}$$

For each category, the regional emissions derived for the years 1990 through 1999 are apportioned across the nine counties in the same ratio as their distribution in year 2000. The specific approach applied to each category is described in more detail in the *Methodology Document* (*BAAQMD, 2023*). Forecasting of CARB source emissions is done by holding the base year 2035 emissions constant through year 2040.

Special Case Category: The backcasting and forecasting follows the same methodology that is applied to Area Sources. However, unlike for Area Sources, base year for projections vary by category, and projections use pollutant-specific growth profiles and time-varying emission factors.

4. INVENTORY UPDATES, LIMITATIONS, AND IMPROVEMENTS

An emissions inventory is constantly changing because it reflects emissions estimates that are developed under evolving data, assumptions, and methodology. The Air District routinely updates the emissions inventory by using new data (e.g., throughputs and emission factors), refining estimation assumptions (e.g., for backcasting and forecasting), and improving calculation methods. However, uncertainties are inherent in any emissions inventory and certain emission source categories may have higher uncertainties than other categories. Understanding the inventory features and limitations is necessary to properly use and interpret emissions inventory data.

4.1. Emissions Inventory Updates

Compared to prior versions of the SFBA regional emissions inventory (base year 2011 and earlier), the current regional emissions inventory incorporates several major methodological updates. More detailed technical documentation for inventory updates by emissions source category is presented in a separate *Methodology Document* (*BAAQMD, 2023*).

- A new emissions data organization schema has been developed to include five general source sectors with multiple sub-sectors. As presented in *Chapters 1* and *2*, these source sectors are consistent across various pollutants and cover all specific source categories.
- For point source categories, the current inventory methodology has improved data processing, using the Air District's internal data as a basis for historical and base year emissions estimates. Using this improved data method, as described in *Chapter 3*, data gaps or missing values between 1990 and 2020 presented in the previous point source inventory (*BAAQMD, 2014a;2014b*) have been updated through data filling or interpolation.
- Several important area source categories (e.g., composting, road dust, and industrial/commercial natural gas combustion) have been designated as special cases with improved estimation methodology incorporating county-level, time-varying emission factors and pollutant-specific growth profiles.
- In this inventory, efforts have been made to improve the estimation of TOG emissions across various categories. These efforts involved a systematic approach aimed at incorporating methane (CH_4) emissions by utilizing enhanced data sources and refined ROG to TOG ratios based on literature review and source test results. This stands in contrast to the previous inventory (BAAQMD, 2014a;2014b), where the ROG-to-TOG ratios did not consistently account for CH_4 emissions.
- For certain point and area source emissions categories, a set of updated growth profiles has been implemented to forecast future year emissions. These growth profiles were developed using the most recent population, household, and employment data obtained from the Association of Bay Area Governments (*ABAG, 2018*) to reflect the best available regional information.
- An improved backcasting approach has been developed for generating emission estimates prior to the year 2000 for certain area source categories based on data obtained from CARB. As

discussed in *Chapter 3.4*, this improvement addresses data gaps for some categories with missing inventory data for the years 1990 through 1999.

- Source categories have been refined, including newly added categories (e.g., ozone depleting substance substitutes and structures coatings), disaggregated categories (e.g., industrial wastewater treatment), combined categories (e.g., composting), and re-scoped categories (e.g., domestic natural gas combustion).

4.2. Limitations and Future Improvements

The emissions estimates presented in this summary report are annual totals aggregated at source sector and sub-sector levels; therefore, they are best used for planning and routine reporting purposes. For detailed inventory data analysis to meet statutory requirements, specific rules development support, and community-scale assessment, further refined emissions data by source category should be used and the *Methodology Document* (*BAAQMD, 2024*) serves as an appropriate reference. The development and maintenance of the regional emissions inventory is an ongoing work process, with necessary data updates being constantly identified and addressed.

Although the current base year inventory has incorporated substantial improvements, it still has important limitations in data completeness, assumptions, and uncertainty for some emissions categories. Examples of such data limitations are highlighted below and will be addressed in future inventory improvements. This list of data limitations is illustrative and not exhaustive.

- The current inventory focuses on stationary point, stationary areawide, and mobile sources. A complete emissions inventory (e.g., CARB's statewide inventory) for criteria pollutants also includes emissions from natural sources, such as vegetation (biogenic) and wildfires (*CEPAM, 2018*). The Air District has preliminary estimates for biogenic emissions and wildfires but has not relied on a well-documented inventory approach that includes recent regional activity data or modeling parameters; therefore, emissions summarized in this report cover anthropogenic sources only and do not reflect contributions from natural sources. For inventory completeness, the addition of a Natural Sources sector will be considered in future inventory updates.
- Emissions estimates for certain important categories are still based on old data approaches; however, updates based on new data and improved methodology are under development for these categories. For example, residential woodsmoke emissions from fireplaces and woodstoves were estimated using old annual telephone survey data (conducted each year since 2005-2006) to quantify wood burning activities. The Air District collected new survey data in 2022 and has been developing an improved modeling-based methodology to refine PM emissions estimates for residential woodsmoke, which will be incorporated in a future updated regional inventory.
- Emissions data for certain source categories (e.g., structure coating, construction and industrial equipment, and lawn and gardening equipment etc.) are dependent on data directly obtained from CARB's statewide inventory, which may not necessarily reflect the best local information for the San Francisco Bay Area. CARB's emissions data for these categories are still considered appropriate, but further assessment of the representativeness of these emissions for local conditions would be needed to improve their data quality.

- For $PM_{2.5}$, particles emitted from certain sources include filterable and condensable components. Recently, condensable particulate matter data became available for some industrial facilities (e.g., refineries and cement manufacturing) and were included in the base year inventory. However, some emissions categories in the inventory do not have estimates for condensable particulate matter due to data gaps and limited calculation methodology. In future base year inventory updates, condensable particulate matter emissions need to be estimated and assessed for certain important categories (e.g., refineries, combustion, and wood product sources) in a systematic manner, including estimation of historical emissions.
- This emissions inventory has used improved growth profiles for multiple area source categories; for example, the latest population, number of households, and employment forecasting data from a regional planning agency are used (*ABAG, 2018*). However, the impact of the COVID-19 pandemic during the years 2020 through 2022 on activity data for certain emissions categories (e.g., on-road mobile sources) is not reflected. Similarly, there are potentially significant emission changes resulting from recent and upcoming closures of large facilities including two refineries, a foundry, and a cement plant; such changes are not reflected but will be included in future inventory updates.
- The emissions impact of recently adopted rule amendments or anticipated upcoming regulations has not been fully reflected in this emissions inventory. For example, in March 2023, the Air District adopted Amendments to Regulation 9, Rule 4: Nitrogen Oxides from Fan Type Residential Central Furnaces, and Regulation 9, Rule 6: Nitrogen Oxides Emissions from Natural Gas-Fired Boilers and Water Heaters. With the introduction and phasing-in of a zero NO_x emission standard for natural gas-fired furnaces and water heaters sold and installed in the Bay Area, reductions in NO_x emissions are expected in future years. This inventory has not incorporated changes to emissions projections due to these rule amendments; however, the next version of the inventory with routine updates will reflect the expected emission reductions.
- For certain emissions processes, speciation data are used to estimate ROG based on TOG emissions, while size fraction partitioning is used to generate PM_{10} or $PM_{2.5}$ emissions using PM data. However, certain speciation and/or partitioning ratios currently in use may not necessarily reflect the most up-to-date organic and particulate matter profiles published by CARB. In future inventory updates, the Air District plans to improve ROG and PM emissions estimation for selected categories by incorporating the latest version of CARB's speciation and partitioning profiles.

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6. APPENDIX

Table 4a: Relative distribution (in percent) of annual PM_{10} daily average emissions (91 tons/day) by source sector and sub-sector.

Share of annual emissions (in percent, %)										
Sector	Stationary Non-combustion		Stationary Combustion		Mobile On-road		Mobile Off-road		Miscellaneous	
Sub-sector	Petroleum Refining	3.2	Residential Wood Burning	10.0	Passenger Cars	4.9	Ships	1.8	Road Dust	29.5
	Commercial Cooking	2.9	Refinery External Combustion	1.8	Light-Duty Trucks	2.1	Off-road Equipment	2.0	Other Dust	20.6
	Waste Management	2.2	Other: Coke / coal combustion	3.8	Heavy-Duty Trucks	2.8	Other	1.0	Agriculture Operations	2.4
	Industrial and Chemical Manufacturing	1.7			Other Vehicles	1.4			Other	2.4
	Concrete/ Cement/ Asphalt Processing	1.7								
	Other	1.8								
Total	13.5		15.6		11.2		4.8		54.9	

Table 4b: Relative distribution (in percent) of annual $PM_{2.5}$ daily average emissions (38 tons/day) by source sector and sub-sector.

Share of annual emissions (in percent, %)										
Sector	Stationary Non-combustion		Stationary Combustion		Mobile On-road		Mobile Off-road		Miscellaneous	
Sub-sector	Petroleum Refining	6.1	Residential Wood Burning	23.1	Passenger Cars	5.0	Ships	3.9	Road Dust	10.2
	Commercial Cooking	4.3	Refinery External Combustion	4.3	Heavy-Duty Trucks	4.9	Off-road Equipment	4.1	Other Dust	5.9
	Industrial and Chemical Manufacturing	3.7	Industrial / Commercial Natural Gas Combustion	3.0	Light-Duty Trucks	2.2	Other	2.0	Accidental / Planned Fires	1.6
	Waste Management	2.1	Cogeneration and Power Plants	2.3	Other Vehicles	1.4			Other	2.2
	Other	3.7	Residential Natural Gas Combustion	2.5						
			Other	1.4						
Total		19.9		36.6		13.5		10.0		19.9

Table 4c: Relative distribution (in percent) of annual TOG daily average emissions (688 tons/day) by source sector and sub-sector.

Share of annual emissions (in percent, %)										
Sector	Stationary Non-combustion		Stationary Combustion		Mobile On-road		Mobile Off-road		Miscellaneous	
Sub-sector	Waste Management	29.8	Other	4.8	Passenger Cars	3.0	Lawn and Garden Equipment	2.2	Animal Waste	16.5
	Fuel Distribution	9.3			Light-Duty Trucks	1.9	Ships	2.1	Consumer Products	6.8
	Organic Compounds Evaporation	7.7			Other Vehicles	2.8	Other	2.2	Industrial / Commercial Natural Gas Leakage	3.6
	Petroleum Refining	1.8							Residential Natural Gas Leakage	2.8
	Other	1.1							Other	1.6
Total		49.7		4.8		7.7		6.5		31.3

Table 4d: Relative distribution (in percent) of annual ROG daily average emissions (270 tons/day) by source sector and sub-sector.

<table>
<tr><th colspan="11">Share of annual emissions (in percent, %)</th></tr>
<tr><th>Sector</th><th colspan="2">Stationary Non-combustion</th><th colspan="2">Stationary Combustion</th><th colspan="2">Mobile On-road</th><th colspan="2">Mobile Off-road</th><th colspan="2">Miscellaneous</th></tr>
<tr><td rowspan="5">Sub-sector</td><td>Organic Compounds Evaporation</td><td>17.6</td><td>Other</td><td>2.8</td><td>Passenger Cars</td><td>6.9</td><td>Lawn and Garden Equipment</td><td>5.0</td><td>Animal Waste</td><td>18.9</td></tr>
<tr><td>Fuel Distribution</td><td>4.8</td><td></td><td></td><td>Light-Duty Trucks</td><td>4.3</td><td>Ships</td><td>4.6</td><td>Consumer Products</td><td>14.3</td></tr>
<tr><td>Petroleum Refining</td><td>3.9</td><td></td><td></td><td>Heavy-Duty Trucks</td><td>2.4</td><td>Off-Road Equipment</td><td>2.8</td><td>Other</td><td>1.9</td></tr>
<tr><td>Other</td><td>3.8</td><td></td><td></td><td>Medium-Duty Trucks</td><td>2.1</td><td>Other</td><td>2.2</td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td>Other Vehicles</td><td>1.9</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Total</td><td></td><td>30.1</td><td></td><td>2.8</td><td></td><td>17.6</td><td></td><td>14.6</td><td></td><td>35.1</td></tr>
</table>

Table 4e: Relative distribution (in percent) of annual NO_x daily average emissions (247 tons/day) by source sector and sub-sector.

Share of annual emissions (in percent, %)										
Sector	Stationary Non-combustion		Stationary Combustion		Mobile On-road		Mobile Off-road		Miscellaneous	
Sub-sector	Other	1.0	Residential Natural Gas Combustion	3.9	Heavy-Duty Trucks	23.1	Ships	22.4		
			Refinery External Combustion	3.2	Passenger Cars	6.8	Off-road Equipment	10.4		
			Industrial and Commercial Natural Gas Combustion	2.5	Light-Duty Trucks	5.0	Aircrafts	5.8		
			Cogeneration and Power Plants	1.7	Medium-Duty Trucks	2.9	Locomotives	2.5		
			Other	4.1	Other Vehicles	2.5	Other	2.2		
Total		1.0		15.4		40.3		43.3		0

Table 4f: Relative distribution (in percent) of annual CO daily average emissions (841 tons/day) by source sector and sub-sector.

Share of annual emissions (in percent, %)										
Sector	Stationary Non-combustion		Stationary Combustion		Mobile On-road		Mobile Off-road		Miscellaneous	
Sub-sector		0	Residential Wood Burning	7.6	Passenger Cars	20.9	Off-road Equipment	18.9	Other	1.0
			Other	4.2	Light-Duty Trucks	12.0	Lawn and Garden Equipment	13.6		
					Medium-Duty Trucks	6.2	Ships	4.8		
					Heavy-Duty Trucks	3.2	Aircrafts	3.0		
					Other Vehicles	3.7				
Total		0		11.8		46.0		41.2		1.0

Table 4g: Relative distribution (in percent) of annual SO_2 daily average emissions (20 tons/day) by source sector and sub-sector.

Share of annual emissions (in percent, %)										
Sector	Stationary Non-combustion		Stationary Combustion		Mobile On-road		Mobile Off-road		Miscellaneous	
Sub-sector	Industrial and Chemical Manufacturing	35.5	Refinery External Combustion	20.4	Passenger Cars	1.4	Ships	6.6	Other	0.1
	Petroleum Refining	3.3	Cogeneration and Power Plants	2.4	Other Vehicles	1.9	Aircrafts	5.1		
	Other	0.4	Other	22.5			Other	0.4		
Total		39.2		45.3		3.3		12.1		0.1