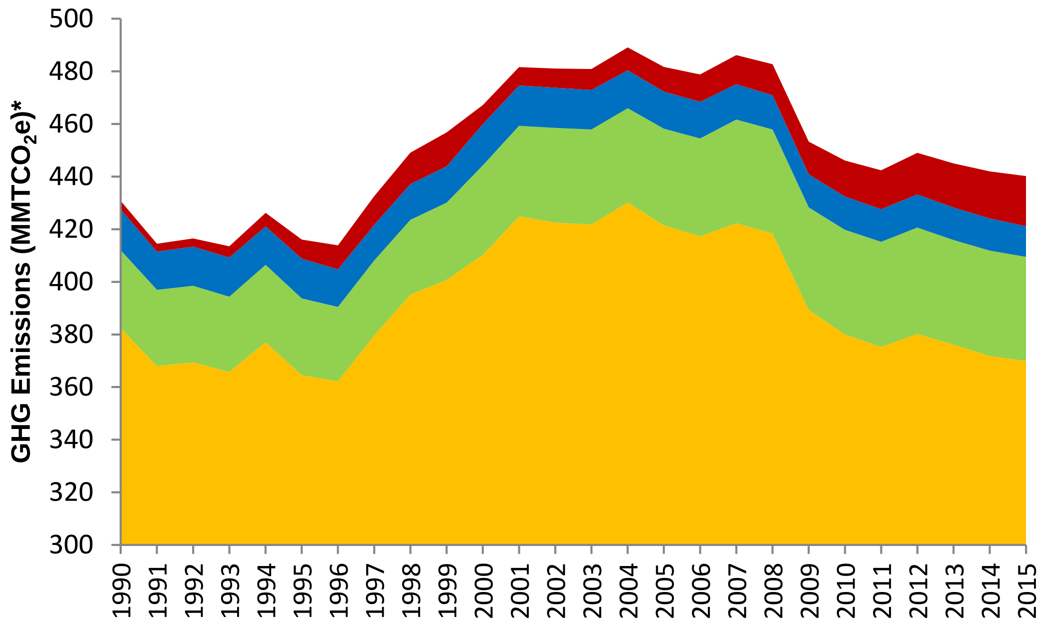
GREENHOUSE GAS EMISSIONS

Statewide emissions have increased since 1990, but have decreased by 10 percent since levels peaked in 2004. On a per capita and gross state product basis, emissions have steadily decreased.

Figure 1. Greenhouse gas emissions in California by pollutant: 1990-2015
(Based on IPCC Fourth Assessment Report 100-year global warming potentials)



*$\textbf{MMTCO}_2\textbf{e}$ = million metric tons of carbon dioxide equivalents

Source: CARB, 2007; CARB, 2017a

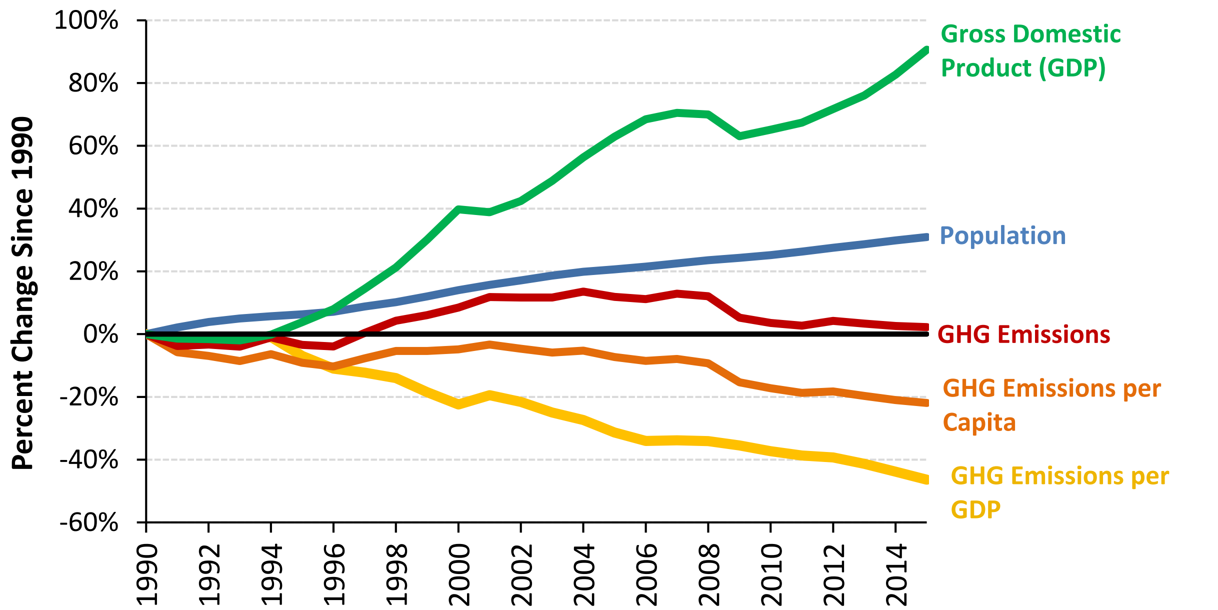
What does the indicator show?

California's combined emissions of the greenhouse gases (GHG) carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and high global warming potential (high-GWP) gases have increased since 1990, reaching peak levels in 2004, but have decreased by 10 percent since then (CARB, 2017a). GHG emissions are expressed in million metric tons (MMT) of carbon dioxide equivalents (CO_2e) based on 100-year Global Warming Potential values as specified in the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (IPCC, 2006).

> ***What are "CO_2 equivalents"?***
>
> Emissions of greenhouse gases other than carbon dioxide (CO_2) are converted to **carbon dioxide equivalents** or **CO_2e** based on their Global Warming Potential (GWP). GWP represents the warming influence of different greenhouse gases relative to CO_2 over a given time period and allows the calculation of a single consistent emission unit, CO_2e.

CO_2 accounts for the largest proportion of GHG emissions, making up 84 percent of total emissions in 2015. In comparison, CH_4 and N_2O account for 9 percent and 3 percent of total GHG emissions, respectively. The remaining GHG emissions consist of high-GWP gases including hydrofluorocarbons (HFC), perfluorocarbons (PFC), sulfur hexafluoride (SF_6), and nitrogen trifluoride (NF_3). Among these GHGs, methane and a subset of HFCs[1] are also considered short-lived climate pollutants (SLCPs), powerful climate forcers that remain in the atmosphere for a much shorter period of time than longer-lived climate pollutants such as CO_2. SLCPs are discussed further below (see *Why is this indicator important?*).

Figure 2. Trends in California's population, economy, and greenhouse gas (GHG) emissions since 1990

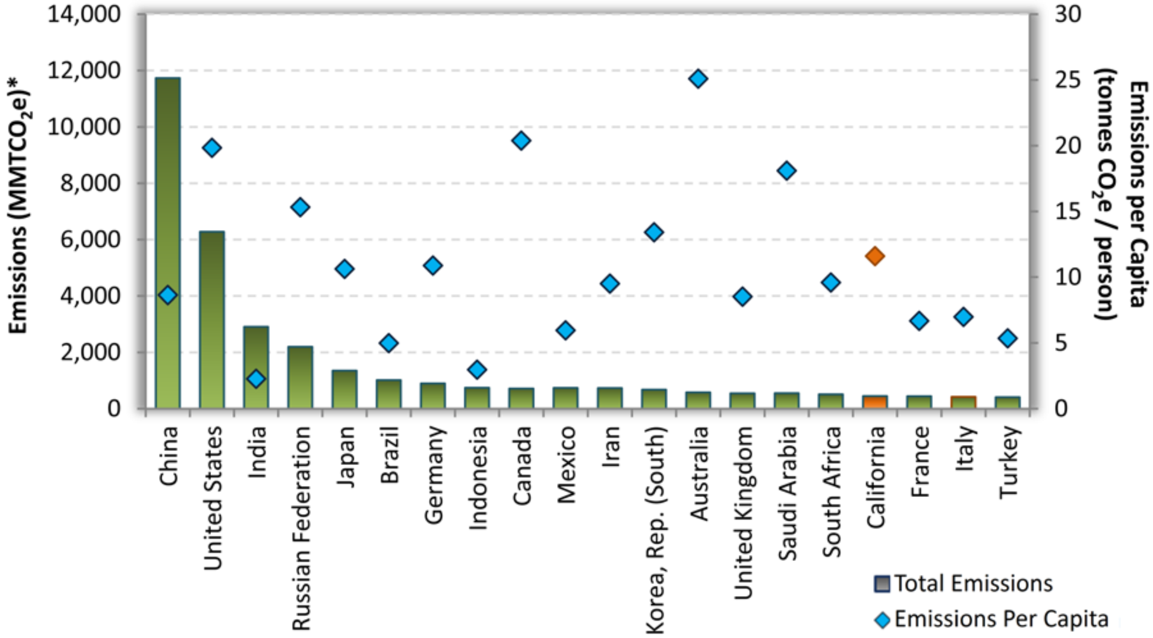


Source: Census, 1992; DOF, 2017a; DOF, 2017b; CARB, 2007; CARB, 2017a

GHG emissions per person (per capita) and per dollar of gross domestic product (GDP, a measure of the state's economic output) show declining trends between 1990 and 2015 (Figure 2). During the same period, the state's population and GDP increased by 31 percent and 91 percent, respectively. California's 2015 GHG emissions are 2 percent higher than in 1990, but emissions per capita have declined by 22 percent and emissions per dollar of GDP (carbon intensity) have declined by 46 percent. Total GHG emissions have also decreased from the peak in 2004 by 10 percent. A combination of factors contributed to this decrease in carbon intensity of the California economy. These factors include incrementally higher energy efficiency standards, growths in renewable energy sources, carbon pricing in the cap-and-trade program, improved vehicle fuel efficiency, and other regulations.

[1] These include HFC-152a, HFC-32, HFC-245fa, HFC-365mfc, HFC-134a, HFC-43-10mee, HFC-125, HFC-227ea, and HFC-143a.

Figure 3. 2013 Total (bars) and per Capita (markers) Emissions in California Compared to the Top 20 Emitting Nations



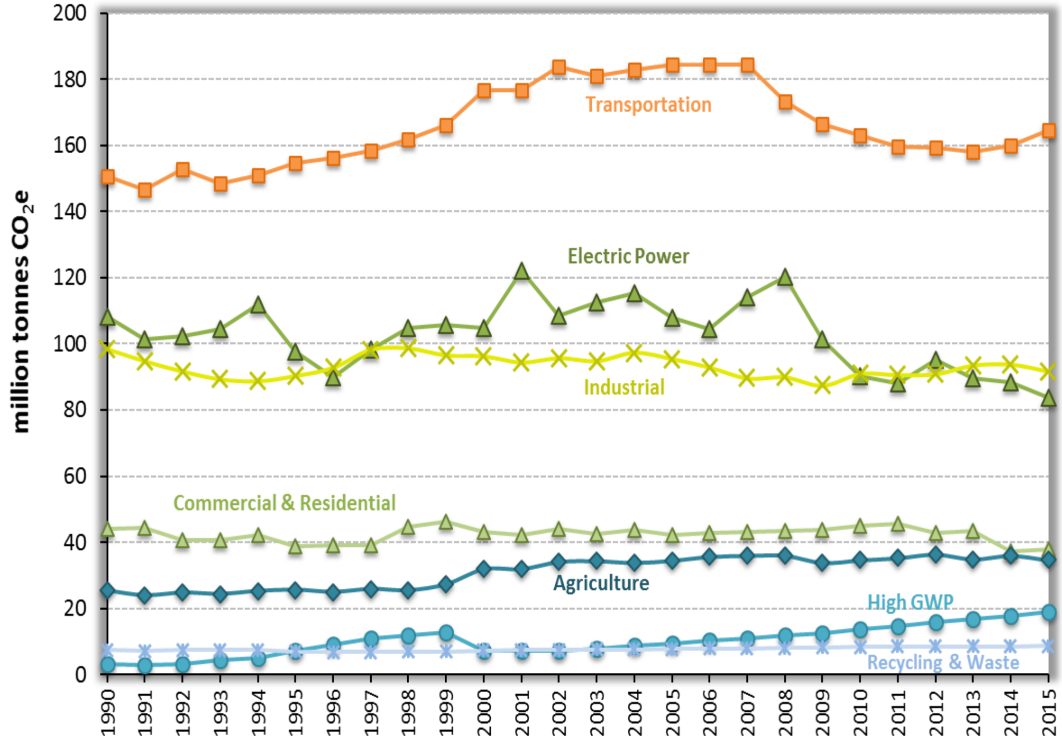
****MMTCO$_2$e** = million metric tons of carbon dioxide equivalents

Source: CARB, 2017b; WRI, 2017

California has been an international leader in reducing GHG emissions. Figure 3 shows 2013 total emissions and emissions per capita for California compared to the top emitting nations. If California were a country, it would rank 17th in total emissions and 7th in per capita emissions among the top 20 emitting nations. The state's 2013 per capita emissions are 42 percent lower than those of the United States (WRI, 2017).

Figure 4 shows emissions of GHGs from 1990 to 2015, organized by categories as defined in the California Air Resources Board's *Initial Scoping Plan* (CARB, 2008). The transportation sector and the electric power sector are the primary drivers of year-to-year changes in statewide emissions. Transportation sector emissions increased between 1990 and 2007, followed by a period of steady decrease through 2013, and then a slight increase in 2014 and 2015. Emissions from the electric power sector are variable over time but have decreased by about 30 percent since 2008. High-GWP gases, while not representing a typical "economic sector," are classified as such for purposes of organizing and tracking emissions, sources and emission reduction strategies. High-GWP gases make up a small portion of total emissions, but are steadily increasing as they replace ozone-depleting substances that are being phased out under international accord (UNEP, 2016). Emissions from the other sectors show some year-to-year variations, but their trends are relatively flat over time.

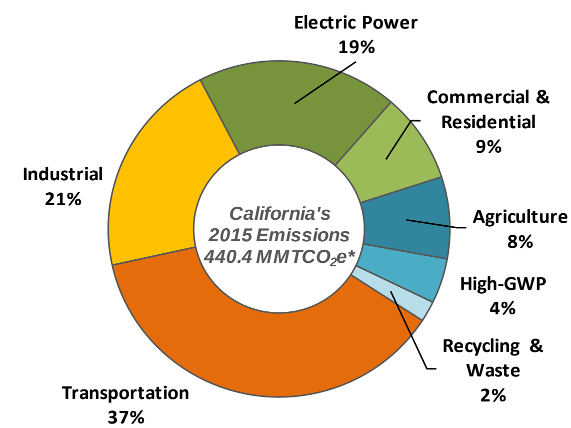
Figure 4. Greenhouse gas emissions in California by sector*: 1990-2015
(Based on IPCC Fourth Assessment Report 100-year global warming potentials)



* This figure uses sector categories as defined in the Initial Scoping Plan (ARB 2008) Emissions on million metric tons of carbon dioxide equivalents

Source: CARB, 2017a

Transportation is the largest source of GHGs, accounting for over a third of the total emissions in 2015 (Figure 5). Cars, light duty trucks, and sport utility vehicles (SUVs) are the most important contributors to transportation emissions. Industrial activities account for 21 percent of emissions, and include fossil fuel combustion and fugitive emissions from a wide variety of activities such as manufacturing, oil and gas extraction, petroleum refining, and natural gas pipeline leaks. Electricity generated both in and out of the state accounts for 19 percent of emissions, followed by commercial and residential sources at 9 percent. The commercial sector includes schools, health care services, retail, and wholesale. The residential sector includes emissions from households such as heating with natural gas furnaces and the use of nitrogen fertilizer



*$MMTCO_2e$ = million metric tons of carbon dioxide equivalents

on residential lawns. Emissions from the agricultural sector come from livestock, crop production, and fuel combustion. High-GWP gases are primarily used in refrigeration and air conditioning, as well as foams and consumer products. Recycling and waste includes emissions from landfills, wastewater treatment, and compost.

Why is this indicator important?

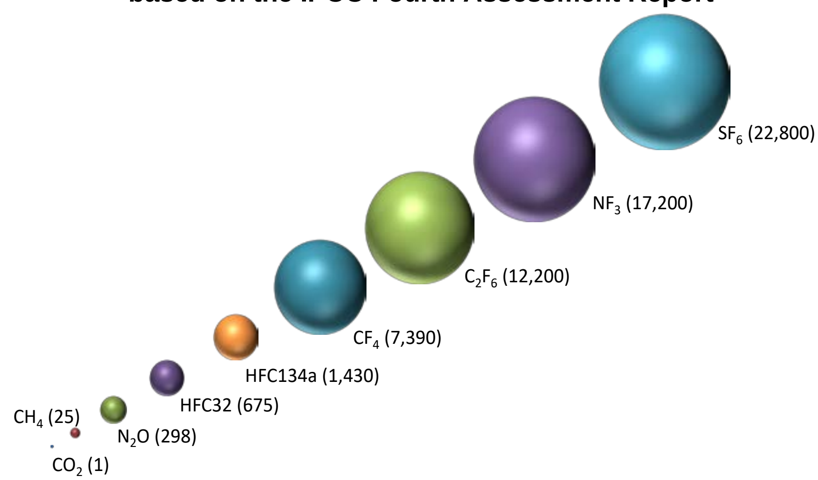
Atmospheric concentrations of GHGs have increased since the Industrial Revolution, enhancing the heat-trapping capacity of the earth's atmosphere. GHG emission reduction targets are intended to prevent atmospheric concentrations from reaching dangerous levels. Accurately tracking GHG emission trends in California provides critical information to policymakers as they assess climate change mitigation options and track the progress of GHG reduction programs. Businesses that track their GHG emissions can better understand processes that emit GHGs, establish an emissions baseline, determine the carbon intensity of their operations, and evaluate potential GHG emission reduction strategies.

The 2015 Paris Agreement aims to hold the increase in the global average temperature to well below 2°C above pre-industrial levels and to pursue efforts to limit the temperature increase even further to 1.5°C above pre-industrial levels (UNFCCC, 2016). These efforts would significantly reduce the risks and impacts of climate change (Xu and Ramanathan, 2017). Emissions scenarios leading to CO_2-equivalent concentrations of about 450 ppm or lower in 2100 are likely to maintain warming below 2°C over the 21st century relative to pre-industrial levels (IPCC, 2014).

Since each GHG pollutant absorbs energy and warms the atmosphere to a different degree, understanding the pollutants' relative effects on climate change is also important for setting priorities and meeting emission reduction goals. Current international and national GHG inventory practice, as defined by the IPCC Guidelines, uses 100 years as the standard timeframe for GHG inventories. (Other timeframes may be used for different purposes. For example, discussions related to SLCPs typically use the 20-year timeframe.)

As illustrated in Figure 6, in a 100-year timeframe, CO_2 has the lowest GWP of all GHGs reported in the statewide inventory. Non-CO_2 emissions are converted to CO_2 equivalents (CO_2e) using GWP, which is a measure of the extent to which a particular GHG can alter the heat balance of the Earth relative to carbon dioxide over a specified

Figure 6. 100-Year global warming potential of greenhouse gases based on the IPCC Fourth Assessment Report



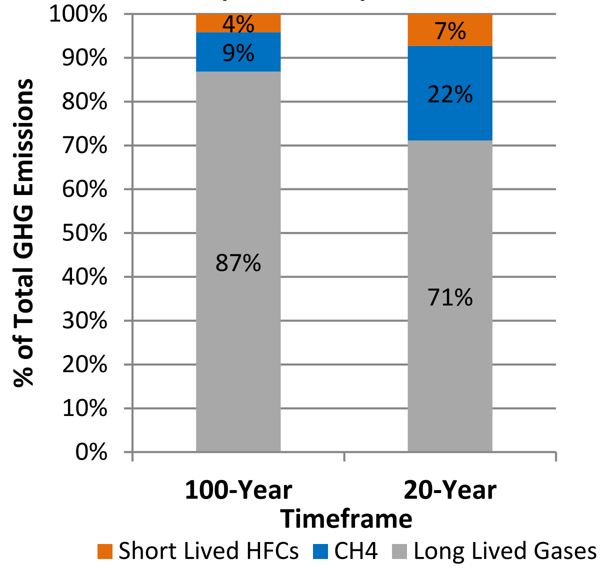
Source: IPCC, 2007

timeframe. For example, the GWP of SF_6 is 22,800, meaning that one gram of SF_6 has the same warming effect as 22,800 grams of CO_2.

Emissions of CO_2, the main contributor to climate change, stay in the atmosphere for hundreds of years. Reducing CO_2 emissions is critically important but will not result in near-term cooling. In contrast to CO_2, SLCPs remain in the atmosphere from days to decades; therefore, a reduction in these emissions can have more immediate effects. Moreover, their GWP values are tens to thousands of times greater than that of CO_2. Near-term reductions in SLCPs can help slow the rate of warming, providing additional time to reduce CO_2 emissions.

As noted earlier, GHG emissions are most commonly discussed using a 100-year timeframe. Because SLCPs do not persist in the atmosphere, however, it is useful to consider a 20-year timeframe when discussing their impacts on climate change and planning for mitigation measures. Figure 7 shows the contribution of SLCP emissions to total GHG emissions in 2015. This contribution is based on their effect on warming (GWP) and their atmospheric lifetime. Emissions of short-lived HFCs and methane in 2015 account for 13 percent of the total GHG emissions in a 100-year timeframe; however, when considering a 20-year timeframe, they account for 29 percent. In addition to methane and short-lived hydrofluorocarbons (HFCs), black carbon, a class of particulate matter, is also considered a SLCP (see *Atmospheric black carbon concentrations* indicator).

Figure 7. SLCP Contribution to total GHG emissions in 2015, Over a 100-year and 20-year timeframe



Source: CARB, 2017a

What factors influence this indicator?

Statewide GHG emissions reflect activities across all major economic sectors, which are influenced by a variety of factors including population growth, vehicle miles traveled, economic conditions, energy prices, consumer behavior, technological changes, drought, and regulations, among other things.

Because GHG emissions from each sector are simultaneously influenced by multiple factors, one-to-one attribution between these factors and their magnitude of influence can be difficult to quantify. For example, improved economic conditions can result in an increased number of motor vehicles per household, and can boost vehicle miles traveled thus increasing GHG emissions, while using more fuel efficient vehicles, public transportation, or driving less can reduce emissions.

GHGs are emitted from a variety of sources, but most notably from the combustion of fossil fuels used in the industrial, commercial, residential, and transportation sectors. GHG emissions also occur from non-combustion activities at landfills, wastewater treatment facilities, and certain agricultural operations. A discussion of trends in the certain economic sectors, sources of SLCPs, and the influence of regulatory requirements is presented in the following sections. Further information is provided in CARB (2017b).

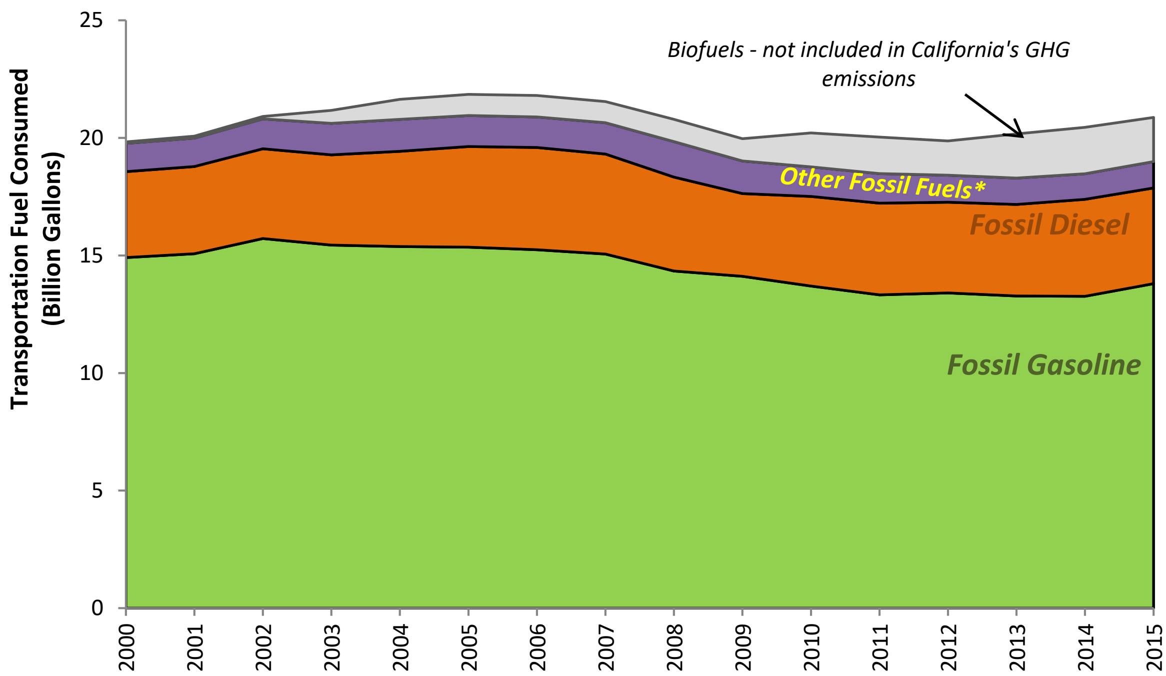
Transportation

Although California's population has grown by 31 percent since 1990 (Figure 2), GHG emissions from the transportation sector have grown by only 12 percent (Figure 4). Furthermore, transportation emissions in 2015 were 11 percent lower than the peak level in 2007. This decline in transportation emissions is likely due to a combination of improved fuel efficiency of the vehicle fleet, higher market penetration of alternative fuel and zero emissions vehicles, increased use of biofuels, the economic recession, and fluctuations in fuel prices. California is a world leader in the adoption of advanced alternative vehicles, such as plug-in electric and hybrid vehicles. The state is the world's largest market for zero emission vehicles (ZEVs). The US comprises about one-third of the world's ZEV market, and 47 percent of ZEVs in the US are in California (GIWG, 2016). Building consumer awareness and demand, providing incentives and enabling the necessary infrastructure to support ZEVs are among the steps the state has undertaken to bring California towards the goal set by Executive Order B-16-2012 of 1.5 million ZEVs on the road by 2025 (Brown, 2012; GIWG, 2016). More recently, a new target of 5 million ZEVs by 2030 was established by Executive Order B-48-18 (Brown, 2018).

Transportation emissions are related to the amount of fuel burned. Combustion of fossil fuels, such as gasoline and diesel, produces GHGs that are counted towards California's inventory. On the other hand, emissions from the combustion of biofuels such as ethanol and biodiesel, which are derived from carbon that was recently absorbed from the atmosphere as a part of the global carbon cycle, are not counted pursuant to international GHG inventory practices (IPCC, 2006). Thus, displacing fossil fuels with biofuels can reduce the climate change impacts of the transportation sector.

The trends in use of fossil fuels (colored) and biofuels (grey) are shown in Figure 8. Gasoline use is declining and biofuel use is increasing — trends contributing to the reduction in GHG emissions from transportation. Declining gasoline consumption is related to higher ethanol use, as well as to improved fuel economy or increased use of alternative fuel vehicles such as electric or hydrogen fueled vehicles. Biofuel diesel alternatives (i.e., biodiesel and renewable diesel) have been in use since 2010, and volumes are increasing rapidly. Between 2012 and 2015, biofuel diesel alternatives increased from 1 percent to 6 percent of the total transportation diesel use.

Figure 8. Trends in transportation fuel combustion, 2000-2015



*Other fossil fuels include: aviation gasoline, jet fuel, LPG, residual fuel oil, and natural gas.

Source: CARB, 2017a

<u>Residential and Commercial</u>

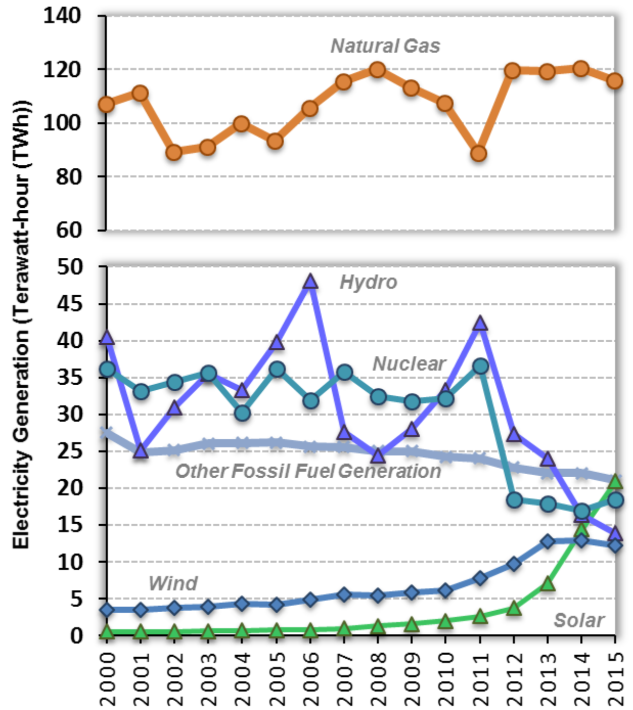
California's steady population growth from 1990 through 2015 has been accompanied by an increased demand for housing, among other things. More housing often means additional demand for residential energy and increased associated GHG emissions. Yet emissions from the residential and commercial sector have decreased in the same period. Residential and commercial building code standards are updated regularly to improve building efficiency (e.g., insulation thickness, window design, lighting systems, and heating/cooling equipment specification). These energy efficiency standards have saved Californians billions of dollars in reduced electricity bills (CEC, 2015), and have reduced the emissions of GHGs and other air pollutants. The per capita electricity consumption in California is near the lowest in the nation, primarily due to mild weather and energy efficiency programs (EIA, 2017).

Weather and precipitation can have notable influences on GHG emissions from the electricity sector. A warmer summer increases electricity demand for air conditioning, and consequently increases the emissions from power plants that must ramp up to meet the additional demand.

Electric Power

California's in-state electricity is derived from a variety of sources (see Figure 9). Natural gas, which is used to produce the majority of in-state electricity, accounted for 57 percent of the electricity production in 2015. Solar energy accounted for 10 percent, hydro accounted for 7 percent, and nuclear accounted for 9 percent. Nuclear power declined after the 2012 shutdown of the San Onofre Nuclear Generating Station. Hydro power reached historic lows in 2015 due to drought. An increase in solar and wind power has compensated for the decline in hydro power and nuclear generation in recent years. Wind, solar, hydro, and nuclear power are zero-emission sources. In 2015, California ranked first in the country in the production of solar energy, and second in net electricity generation from renewable resources (EIA, 2017).

Figure 9. In-State Electricity Generation by Source



Source: CARB, 2017b

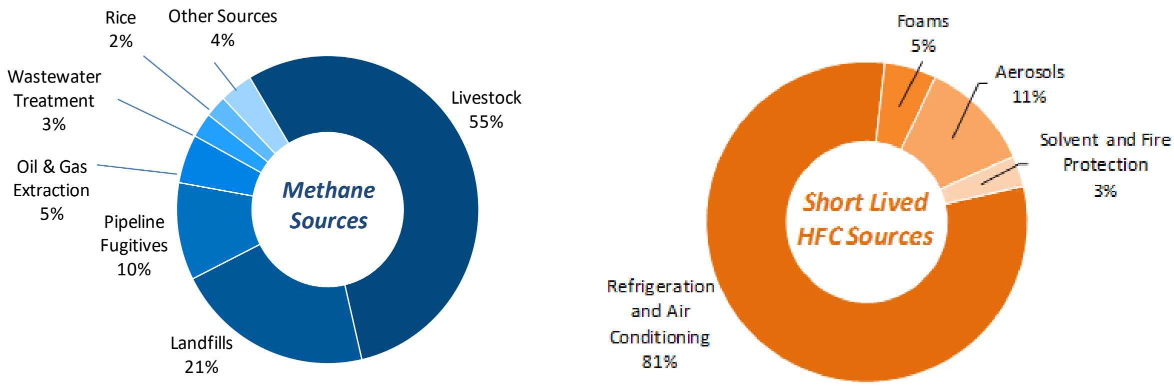
Weather can also have notable influences on GHG emissions from the electricity sector. A warmer summer increases electricity demand for air conditioning, and consequently increases the emissions from power plants that must ramp up to meet the additional demand.

Short-Lived Climate Pollutants

Sources of methane and short-lived HFCs in California are shown in Figure 10. Livestock represents the largest source of methane. Methane is produced from livestock manure management and directly by ruminant animals such as cows, sheep, and goats. Organic waste streams deposited in landfills or managed in wastewater treatment plants also produce methane emissions. As the primary component of natural gas, methane is emitted by oil and gas extraction and during its storage, processing, and transport. Natural gas is used for many purposes including electricity production and heating.

Short-lived HFCs are used as replacements for ozone-depleting substances that are being phased out under the Montreal Protocol (UNEP, 2016). The majority of HFC emissions comes from refrigeration and air-conditioning systems used in the residential, commercial, industrial, and transportation sectors. Foams, aerosols, solvents, and fire protection are other sources of HFCs.

Figure 10. 2015 Sources of short-lived climate pollutants*



*Based on the 2017 edition of the GHG inventory and 100-year GWP

Source: CARB, 2017b

Policies and Regulations

California's pioneering efforts in the adoption and implementation of policies designed to curb GHG emissions have clearly impacted emission trends. The California Global Warming Solutions Act of 2006 (Nuñez, Chapter 488, Statutes of 2006), also known as AB 32, established the nation's first comprehensive program of regulatory and market mechanisms to achieve real, quantifiable, cost-effective GHG reductions. A complete list of initial AB 32 measures can be found on the California Air Resources Board's Scoping Plan webpage at: https://www.arb.ca.gov/cc/scopingplan/scopingplan.htm. AB 32 is among a collection of laws, executive orders and regulations that address emission reductions and energy efficiency in the state. These policies are discussed in the Appendix. For a complete list of climate change legislation enacted in California, see: http://www.climatechange.ca.gov/state/legislation.html.

Technical Considerations

Data Characteristics

A GHG inventory is an estimate of GHG emissions over a specified area and time period from known sources or categories of sources. Emission inventories generally use a combination of two basic approaches to estimate emissions. The top-down approach utilizes nationwide or statewide data from various federal and state government agencies to estimate emissions. The bottom-up approach utilizes activity data (such as fuel quantity, animal population, tons of waste deposited in the landfill, etc.) to compute unit level emissions that are then aggregated to the state level for a particular source category. In either approach, calculation assumptions are made to estimate statewide GHG emissions from different levels of activity data. These calculations typically reference the 2006 IPCC Guidelines for National Greenhouse Gas Inventories or the US EPA's national GHG inventory, but also incorporate California-specific methods and considerations to the extent possible.

Strengths and Limitations of the Data
The methods used to develop the California GHG inventory are consistent with international and national inventory guidelines to the greatest extent possible. Emission calculation methodologies are evaluated over time and refined by incorporating the latest scientific research and monitoring activities.

The California GHG inventory includes emissions from anthropogenic sources located within California's boundaries, as well as GHG emissions associated with imported electricity. Pursuant to AB 32, California has gone beyond the international inventory guidelines defined by the IPCC in including imported electricity in GHG emission tracking. The inventory, however, excludes emissions that occur outside California during the manufacture and transport of products and services consumed within the State. On the other hand, California is a net exporter of multiple products, especially agricultural commodities. California exported about a quarter of all agricultural products (CDFA, 2014), but the state's GHG inventory does not discount the carbon sequestered in California-produced agricultural products that are exported and consumed outside of the state. In addition, GHG mitigation action may cross geographic borders as part of international and sub-national collaboration, or as a natural result of implementation of a state policy, but the inventory also does not account for emission reductions outside of its geographic border that may have resulted from California's adopted programs.

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APPENDIX. **California's Climate Change Policies**

California's climate program has evolved through a series of statutory requirements and executive orders over almost 30 years (beginning with the enactment of Assembly Bill 4420 in 1988, which directed the California Energy Commission to maintain a greenhouse gas emissions inventory and to conduct research on the impacts of climate change). Most notably, California established the nation's first comprehensive program of regulatory and market mechanisms to achieve real, quantifiable, cost-effective GHG reductions with the enactment of the California Global Warming Solutions Act of 2006 (Nuñez, Chapter 488, Statutes of 2006). Also known as AB 32, this law caps California's greenhouse gas emissions at 1990 levels by 2020. In 2016, emission reduction targets were extended through 2030 with the passage of Senate Bill (SB) 32 (Pavley, Chapter 249, Statutes of 2016), which requires a reduction of statewide GHG emissions to 40 percent below the 1990 level by 2030. The same year, SB 1383 (Lara, Chapter 395, Statutes of 2016) was passed to reduce emissions of short-lived climate pollutants by 2030. SB 1383 specified emission reduction targets of 40 percent for methane, 40 percent for hydrofluorocarbon gases, and 50 percent for anthropogenic black carbon. The California Air Resources Board (CARB) is working in collaboration with other state agencies in adopting plans and regulations to achieve GHG and short-lived climate pollutant emission reductions.

AB 32 has led to the adoption of a suite of GHG emission reduction measures. Among these, the Cap-and-Trade Regulation and the Low Carbon Fuel Standard (LCFS) are expected to achieve approximately half of the total reductions needed for California to meet its 2020 emission goal. The Cap-and-Trade Regulation is a market-based program that sets a limit on GHG emissions from capped sectors and allows trading of carbon permits (allowances). CARB is working with other states and provinces on linked cap-and-trade programs to form a larger regional trading program. In 2017, the California Legislature passed AB 398 and authorized extension of the Cap-and-Trade program beyond 2020. The LCFS was adopted in 2009 with the goal of reducing the carbon intensity of transportation fuels by at least 10 percent by 2020 (CARB 2016). The LCFS is based on the principle that each fuel has "lifecycle" greenhouse gas emissions associated with the production, transportation, and use of the fuel. By using a performance-based approach and allowing the market to determine how the carbon intensity of transportation fuels will be reduced, the LCFS provides incentives to diversify the fuel pool, and to reduce the lifecycle carbon intensity, emissions of other air pollutants, and California's dependence on fossil fuels.

SB X1-2 (Simitian, Chapter 1, Statutes of 2011) codified into law a renewable portfolio standard (RPS) which sets a target of 33% use of renewable energy by 2020. In 2015, SB 350 (De Leon, Chapter 547, Statutes of 2015) took the state's RPS one step further to 50 percent by 2030. It also doubled the energy efficiency of electricity and natural gas end uses by 2030. These legislations put California on a path to reduce the GHG emissions from the electric power, residential, and commercial sectors, which together make up almost a third of the state's total GHG emissions.

California has a history of adopting technology-advancing vehicle emission standards to protect public health. Assembly Bill (AB) 1493 (Pavley, Chapter 200, Statutes of 2002) requires CARB to develop and adopt regulations that achieve the maximum feasible reduction of GHG emitted by passenger vehicles and light-duty trucks for model years through 2016. In 2012, CARB approved a new emissions-control program for model years 2017 through 2025. The program combines the control of smog, soot and global warming gases and requirements for greater numbers of zero-emission vehicles into a single package of standards called Advanced Clean Cars.

Senate Bill 375 (Steinberg, Chapter 728, Statutes of 2008) supports the state's climate action goals to reduce GHG emissions through coordinated transportation and land use planning with the goal of more sustainable communities. It requires CARB to develop regional GHG emission reduction targets from passenger vehicle use. CARB established targets for 2020 and 2035 for each region covered by one of the State's 18 metropolitan planning organizations and will periodically review and update the targets as needed (https://www.arb.ca.gov/cc/sb375/sb375.htm).

For a complete list of climate change legislations enacted in California, see: http://www.climatechange.ca.gov/state/legislation.html. A complete list of initial AB 32 measures can be found on CARB's Scoping Plan webpage at: https://www.arb.ca.gov/cc/scopingplan/scopingplan.htm