San Diego County Greenhouse Gas Inventory

A Summary of the Methods Used

Prepared by

Energy Policy Initiatives Center

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EXECUTIVE SUMMARY

The San Diego Association of Governments (SANDAG) and the California Energy Commission (Energy Commission) entered into a multiyear agreement entitled *Regional Energy Strategies* that assisted SANDAG with enhancing its regional energy planning program in order to meet mutual state and regional energy goals. SANDAG also was tasked with developing transferable tools and resources for similar regional government entities based on integrating its existing energy planning efforts with its cutting edge smart growth and transportation planning. The *Regional Energy Strategies* partnership comprised four main components:

1. Update the SANDAG *Regional Energy Strategy*
2. Develop a regionally-focused *Climate Action Strategy*
3. Expand the Sustainable Region Pilot Program for local governments
4. Develop a regional alternative transportation report

In concert with development of its *Climate Action Strategy*, SANDAG prepared a *Regional Climate Strategy How-To-Guide (Guide).* The purpose of the *Guide* was to explain how Metropolitan Planning Organizations (MPO) and Councils of Government (COG) in California can begin to address long-term climate change planning in their respective jurisdictions. As of March 31, 2010, the *Climate Action Strategy*, the *Guide,* and this methodology report will be available at www.sandag.org/energy.

A regional climate strategy can provide a foundation for integrating energy and climate change issues into existing plans as they are updated, such as the *Regional Transportation Plan*, regional blueprint plan (e.g., SANDAG *Regional Comprehensive Plan*), and local General Plans. In general, updates to these types of existing policy documents and related regulatory mechanisms are opportunities to implement a regional climate strategy.

The first step in preparing a climate strategy is to inventory the sources of greenhouse gas emissions. SANDAG contracted with the Energy Policy Initiative Center at the University of San Diego Law School (EPIC), which had begun a regional greenhouse gas inventory through a grant from the San Diego Foundation. Rather than duplicate efforts, SANDAG chose to leverage the work already underway by contracting with EPIC to extend the inventory forecast from 2020 to 2030 and to provide additional analysis for the transportation, natural gas, and electricity sectors. In addition, SANDAG asked EPIC to prepare a detailed methodology report on the methods and sources used for the forecast.

The purpose of this methodology report is twofold: 1) to provide a transparent documentation of the sources and methods used to develop the San Diego County Greenhouse Gas Inventory, and 2) to provide other metropolitan planning organizations, councils of government, and other regional entities with the rationale behind the San Diego regional inventory and a starting point if they choose to undertake a similar effort. The published report, *San Diego County Greenhouse Gas Inventory*, is available on the Energy Policy Initiatives Center website at http://www.sandiego.edu/epic/.

Summary of the Methods and Sources for San Diego County Greenhouse Gas Inventory

Inventory Catetory	Method	Data Sources
ON-ROAD TRANSPORTATION	CARB EMFAC Model, mass balance calcualtions to determine CO_2E emissions (Modified CARB Method)	1990-2006 CO_2E Emissions from CARB On-Road EMFAC Model 2007-2020 CO_2E Emissions from SANDAG (via EMFAC)
ELECTRICITY	Fuel-based, CARB emissions factors (lbs/MWh) and average emisions for power suppliers used where fuel data unavailable (CARB Method)	FERC FORM 1, CEC Energy Forecast 2008-2018, SEC Form 10-K, EIA Form 861
NATURAL GAS END USES	Fuel-based (CARB Method)	FERC FORM 1, CEC Energy Forecast 2008-2018, EIA Form 861
OFF-ROAD EQUIPMENT AND VEHICLES	CARB OFFROAD Model	CO2E Emissions from CARB OFFROAD Model
CIVIL AVIATION	Fuel-based (Average of jet fuel sold and passenger miles traveled methods), interstate emissions included (Modified CARB Method)	Two main jet fuel and aviation gas suppliers to San Diego Int'l Airport, Bureau of Transportation Statistics Department (BTS RITA), San Diego Air Pollution Control District (natural gas)
WASTE	IPCC Mathmatically Exact First Order Decay Model (CARB Method)	CARB (waste water factors) , City of San Diego (waste disposed), San Diego County Public Works Department, CARB (waste disposed), CIWMB, USD EPA
INDUSTRIAL PROCESSES AND PRODUCTS	Source-based, some scaled from statewide inventory data (CARB Method)	CARB, US EPA, US Census Bureau, US Geological Survey, CA Dept. of Transportation, CEC
WATER-BORNE NAVIGATION	Based on CARB estimate (CARB Method)	CARB estimate
RAIL TRANSPORTATION	Scaled from statewide inventory (CARB Method)	CARB statewide GHG inventory, US Census Bureau (economic data)
OTHER/OTHER FUELS	Scaled from statewide inventory (CARB Method)	CARB statewide GHG inventory, US Census Bureau (economic data)
AGRICULTURE (LIVESTOCK)	Scaled from statewide inventory (CARB Method)	CARB statewide GHG inventory, US Department of Agriculture, and San Diego County (crop reports)
EMISSIONS FROM DEVELOPMENT (Loss of Vegetation)	GIS analysis of developed areas from 1990-2007 (Modified CARB)	SANDAG and CA Dept of Forestry and Fire Protection (GIS data), Winrock International and C. Wiedinmyer paper (biomass data)
WILDFIRES	GIS analysis of burned areas from 1990-2007 (Modified CARB)	SANDAG and CA Dept of Forestry and Fire Protection (GIS data), Winrock International and C. Wiedinmyer paper (biomass data), SANGIS (GIS burn areas)
SEQUESTRATION FROM LAND COVER	GIS analysis of San Diego County vegetation 1990-2007 (Modified CARB)	SANDAG and CA Dept of Forestry and Fire Protection (GIS data), Winrock International and C. Wiedinmyer paper (biomass data), SANGIS (GIS burn areas), H. Luo paper (carbon uptake by chaparral)

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1. Introduction

The published report, *San Diego County Greenhouse Gas Inventory*, is available on the Energy Policy Initiatives Center website at http://www.sandiego.edu/epic/.

In 2006, California Governor Arnold Schwarzenegger signed the Global Warming Solutions Act (AB 32), which seeks to reduce statewide greenhouse gas emissions to 1990 levels by the year 2020. This bill has raised the importance of developing and adopting measures to mitigate emissions among all sectors of the economy, including local and regional government agencies. While federal and state initiatives are critically important to reducing emissions of greenhouse gases, local governments will play a key role. Local governments have primary jurisdiction over several significant areas that relate to climate change, including land use and transportation planning. Climate planning has become a major issue for local governments.

Many local governments around California and the nation have already conducted inventories to determine the sources and levels of emissions for their own operations and the community at large. A few regions, including San Diego County, have conducted region wide inventories. These inventories are the critical first step in conducting climate planning. To the extent that you can't manage what you don't measure, data from a GHG inventory can help cities and counties can begin to develop GHG reduction plans and prioritize actions.

This report provides a summary of the methods and data sources used to develop the San Diego County Greenhouse Gas Inventory. It provides more details for the largest emitting categories – on-road transportation, electricity, and natural gas end uses – which account for nearly 80% of all regional emissions, but includes information about all the categories included in the regional estimate.

1.1. Organization of the Report

Section 2 of the report provides background on regional inventories, including information on why to conduct a regional inventory, which is the appropriate entity to conduct an inventory, and what methodologies are available. In Section 3, the report provides a brief summary of the San Diego County GHG Inventory, including key findings and an overview of the methods used. The next four sections (4-7) provide a more detailed discussion of the methodologies used to estimate emissions from the 4 categories that comprise nearly 85% of all emissions – on-road transportation (46%), electricity (25%), natural gas end uses (9%), and civil aviation (5%). Section 8 briefly discussed the methods use for the remaining categories of the inventory, including: Industrial Processes and Products, Other Fuels/Other– including fuels like propane, kerosene, wood, etc, Off-road Equipment and Vehicles, Waste, Agriculture/Forestry/Land Use, Rail, and Water-Borne Navigation.

2. General Regional GHG Inventory Background

2.1. Why Conduct a Regional Inventory?

Comprehensive greenhouse gas inventories serve several purposes, including to: develop a baseline against which to measure changes, characterize the emissions by sector and subsector, help develop and prioritize mitigation policies, and focus actions on the most worthwhile sectors. Many cities in California and the nation have completed greenhouse gas inventories for their own facilities and for their entire population within their jurisdiction, so why conduct regional inventories?

There are several advantages to developing regional inventories. In many cases, the data needed to conduct an inventory is collected at the county level, such as vehicle miles travelled (VMT), a significant driver of emissions. In the case of VMT, disaggregating the data to the city level could increase the level of uncertainty, as many models used to generate VMT typically are designed to work at the county or multi-county level. One significant exception to this is that electricity and natural gas data are not typically broken down by county. It would be necessary to obtain data from the utility or utilities that serves a given region.

Regional (county or multi-county) inventories also may capture more emissions. For example, many city inventories do not include emissions associated with highways or civil aviation (5% of San Diego County's GHG emissions). If city inventories were aggregated to develop a county or multi-county emissions estimate, significant categories would be missing and emissions would be underestimated. By contrast, regional inventories can be aggregated to regional inventories that correspond to metropolitan planning organizations (MPO) or regional transportation agencies (RTA), which have land use and transportation expertise that is directly related to the largest emissions source in California: on-road transportation.

Another advantage is that many of the highest emitting sectors are by definition regional in nature and their solutions will require regional planning and action. For example, on-road transportation is by far the largest emitting category in the San Diego region. Mitigation strategies at the city level are necessary but not sufficient to capture regional strategies like transit and other demand management strategies, which address the issue more comprehensively.

It may also be possible to develop individual community-scale city inventories based on regional inventories. This approach may prove more cost and time efficient than having each city conducts its own inventory. This also has the benefit of a unified methodology. Although, the CARB is developing a guidance document of accepted protocols, no such standard exists currently. To the extent that cities in a region use the same methodology, meaningful comparisons can be made. And if regional inventory methodologies follow those used by the California Air Resources Board (CARB) in developing the statewide inventory, comparisons can be made between regions and between regions and states.

2.2. Who Should Conduct Regional Greenhouse Gas Inventories?

There are several entities that could conduct or coordinate regional inventories, including:

- **Metropolitan Planning Organizations** – MPOs could conduct inventories in cooperation with the included counties.[1] MPOs already perform similar analytical work related to their transportation and land use functions. And given the emissions prominence of on-road transportation, and the MPOs familiarity with vehicle miles travelled modeling, at a minimum they would have to be involved in the on-road portion of the analysis.

- **Air Pollution Control Districts** – Districts or air quality management districts also could perform this function. These entities likely have the best available fuel use and emissions data for stationary sources within their districts and are generally familiar with mobile emissions models, such as those used by CARB.

- **California Air Resources Board** (CARB)– As part of developing a statewide greenhouse gas inventory, CARB already has some of the data that would be needed to conduct county level inventories. CARB will be determining regional transportation and land use emissions targets, which presumably will be based on county data, as part of the statutory requirements under SB 375.

Given the complexity of greenhouse gas accounting, local governments and agencies may not have the technical resources or staff time available to conduct emissions inventories. In such cases, it may be necessary to hire technical consultants to complete the task. Another option is to work with organizations like Local Governments for Sustainability (ICLEI). Through its Cities for Climate Protection Program, ICLEI helps local governments develop climate action plans, including greenhouse gas emissions inventories. ICLEI is a partner with the Clinton Climate Initiative in developing the online emissions tracking site Project 2 Degrees, which allows cities to track emissions.[2] Further, ICLEI is working in partnership with CARB, and the California Climate Action Registry to develop protocols for communitywide inventories that capture all emissions within a jurisdiction. As discussed below in Section 2.4, ICLEI plans to modify its emissions inventory software to incorporate the community scale protocols established by CARB.

2.3. Considerations for Conducting Regional Inventory

When planning an accounting of emissions, tradeoffs may exist between and among the desired characteristics of a regional inventory. There is no perfect combination and the desired outcome will be determined in large part by local capacity. The following are the characteristics that may be considered:

- **Completeness** – How many categories and subcategories should an inventory include? To be complete, an inventory should include as many categories as possible. The CARB statewide inventory, which is based on the

Intergovernmental Panel on Climate Change (IPCC) categories, is a good guide as to the total possible categories that should be considered. Including all the CARB categories could increase cost and time to complete, but would yield a comprehensive inventory.

- **Comparability** – At present there are several different methods available, though there is an effort to develop common protocols. Choosing a methodology that allows results to be compared across jurisdictions (i.e., city to city, city to county, county to county, county to state) is desirable, but could affect the other considerations listed here, depending on which methodology is chosen. A related consideration is to develop an inventory that could be used for regulatory compliance. There is no general standard for this, other than CARB's mandatory reporting regulations for high emitting entities, but this should be a consideration.[3]

- **Accuracy** – Finding data and using accepted calculation methods to allow the most accurate results is important; however, it might not be worth the time or cost to add incremental levels of precision.

- **Time to Conduct** – The time needed to complete an inventory is an important consideration. It may be more useful to have results in a timely fashion that are not perfectly complete or accurate but that are sufficient for purposes of characterizing the emissions and developing mitigation strategies. On the other hand, if time is not a critical factor, it might be worth taking more time to develop a comprehensive and accurate inventory

- **Cost** – In many cases, cost will be a consideration that underlies all others. Pursuit of a complete and precise inventory that is compatible to other inventories may be too costly.

- **Geographical Scope –** What jurisdictions to include in a regional inventory is an important question. In the case of the San Diego Regional GHG Inventory, this was an easy consideration as the region consists of one county. Other regions in California include multiple counties. The geographical scope of an inventory should correspond to other defined boundaries such as MPOs or RTAs for which the results will be useful for planning or policy development purposes.

2.4. Regional Inventory Methodologies

At the time this report was written, no accepted protocol existed for regional greenhouse gas inventories. On September 25, 2008, CARB adopted The Local Government Operations Protocol, which "is designed to provide a standardized set of guidelines to assist local governments in quantifying and reporting GHG emissions associated with their government operations."[4] CARB will be developing protocols to assist local governments to develop community-scale GHG emissions inventories, which capture all emissions within a given jurisdiction. It is anticipated that this protocol will be completed and available to the public toward the end of

2009. Even though these protocols will focus on city-level inventories, they should be applicable to county or multi-county emissions inventories.

ICLEI and California Climate Action Registry (California Registry) worked with CARB to develop their Local Government Operations Protocol. Each organization also has developed tools to assist local governments estimate greenhouse gas emissions for their own operation and their community as a whole. As part of their Cities for Climate Protection® campaign, ICLEI assists cities conduct climate planning to reduce greenhouse gas emissions and improve livability within their jurisdictions.[5] Specifically, ICLEI has developed Five Milestones to assist US local governments conduct mitigation activities. These are to: conduct a baseline emissions inventory and forecast; adopt an emissions reduction target; develop a Local Climate Action Plan; implement policies and measures; and, monitor and verify results. As part of its membership services, ICLEI provides technical support and software to assist local governments conduct inventories of their operational greenhouse gas emissions and those of the broader community, which includes all the residents and economic activity within the entire jurisdiction. ICLEI plans to update its community scale inventory model to embody the protocols developed by CARB.

The California Climate Action Registry (California Registry), founded in 2001 as a result of AB 1171, has developed a tool – CARROT – to assist organizations conduct voluntary greenhouse gas inventories for their operations, including local governments.[6] The California Registry assisted CARB in the development of the local government operations protocols and will apply its expertise in verified, operational level inventories assist in developing CARB's community-scale protocols. The California Registry is transitioning away from work in voluntary inventories as its sister organization the Climate Registry develops. The Climate Registry is a "nonprofit collaboration among North American states, provinces, territories and Native Sovereign Nations that sets consistent and transparent standards to calculate, verify and publicly report greenhouse gas emissions into a single registry. The Registry supports both voluntary and mandatory reporting programs and provides comprehensive, accurate data to reduce greenhouse gas emissions."[7] Instead, the California Registry through its Climate Action Reserve will transition into more work developing standards for the national voluntary carbon reduction market.[8]

3. Overview of San Diego Regional Greenhouse Gas Inventory

The San Diego Greenhouse Gas Inventory project developed a greenhouse gas inventory for San Diego County to better understand the emissions sources in the region and to serve as a resource for local and regional decision makers as they consider ways to reduce emissions at the local and regional levels.[9] To that end, the project team calculated historical greenhouse gas emissions from 1990 to 2006 using the best available data, and then estimated future emissions to 2020. Using emissions reduction targets codified in California's Global Warming Solutions Act of 2006 (AB 32) as a guide, the study also sought to establish emissions reductions targets for the region. Although AB 32 does not require individual sectors or jurisdictions (e.g., cities and counties) to reduce emissions by a specific amount, the study calculated the theoretical emissions reductions necessary in each emissions category (e.g., transportation, electricity, etc.) for San Diego County to reduce emissions to 1990 levels by 2020—the statewide statutory target under AB 32.[10]

The inventory includes the entire population and all economic sectors of San Diego County, with the exception of some military activities.[11] To the extent possible, the study followed the same calculation methodology used by the California Air Resources Board (CARB) to develop the statewide greenhouse gas inventory. In some instances, when doing so could yield a more accurate or precise result or when data were unavailable, the project modified the CARB method.

3.1. Key Findings from the San Diego Regional Greenhouse Gas Inventory

The following are among the key findings from the San Diego regional greenhouse gas inventory:

- San Diego County emitted 34 million metric tons of carbon dioxide equivalent (MMTCO2E) in 2006 – an 18% increase over 1990 levels, commensurate with population growth during the same period.
- In 2006, per-capita emissions for San Diego County were 12 metric tons CO2E, which is slightly lower than California as a whole (13) and significantly lower than the U.S. levels (24). California's lower per capita emissions can be attributed mostly to weather but also include the effects of the stat's comparatively aggressive efficiency programs since the 1970s.[12]
- In 2006, emissions from cars and light-duty trucks represented 46% of total greenhouse gas emissions in San Diego County.
- By 2020, under a business-as-usual scenario, regional greenhouse gas emissions are expected to be 43 MMT CO2E, an increase of 9 MMT CO2E (26%) over 2006 levels and 14 MMT CO2E (48%) over 1990 levels.
- To meet AB 32 emissions reduction targets (1990 levels by 2020), San Diego County would have to reduce emissions by 14 MMT CO2E (33%) below projected business-as-usual levels in 2020.

Figure 1 summarizes the results of the San Diego regional greenhouse gas inventory. It shows the relative contribution of emissions from each sector analyzed.

Figure 1. San Diego County GHG Emissions by Category (2006)

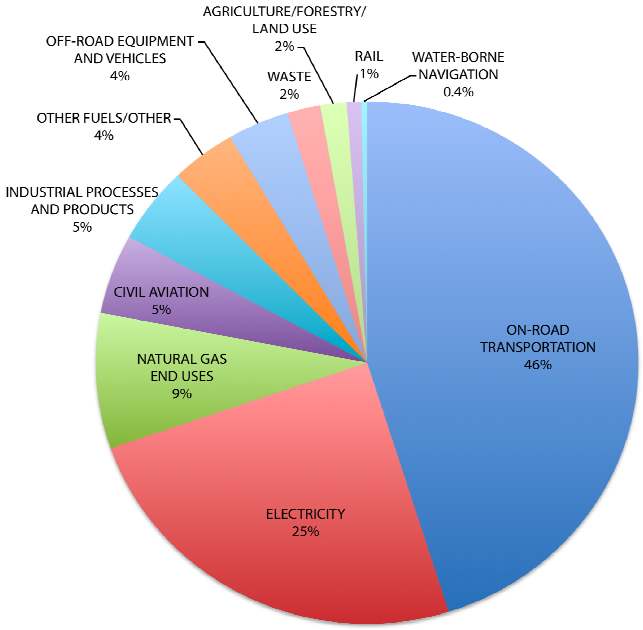

Table 1 shows the 19 broad emissions reduction strategies identified in the inventory report that in combination could achieve AB 32 targets.

Table 1 Emissions Reduction Strategies for SD County to Meet Hypothetical AB 32 Targets by 2020

CATEGORY	REDUCTION AMOUNT (MMT CO_2E)	PERCENTAGE OF TOTAL
ON-ROAD TRANSPORTATION	**6.8**	**46%**
2005 CAFE Standard	2.3	15%
Low-Carbon Fuel Standard	1.6	11%
Reduce Vehicle Miles Traveled by 10%	1.4	9%
Pavley Standard (Incremental to CAFE)*	0.9	6%
Light/Heavy Vehicle Efficiency/Hybridization	0.6	4%
ELECTRICITY	**5.4**	**36%**
Renewable Portfolio Standard 20%	2.0	13%
Reduce Electricity Consumption 10%	1.1	7%
Renewable Portfolio Standard 33% (Incremental)	1.0	7%
Cleaner Electricity Purchases (≤1100 lbs/MWh)	0.6	4%
Replace Boardman Contract	0.3	2%
400 MW of Distributed Photovoltaics	0.2	1%
Increase CHP by 200 MW	0.2	1%
INDUSTRIAL PROCESSES AND PRODUCTS	**1.3**	**9%**
Phase out of HFCs	1.3	9%
OFF-ROAD EQUIPMENT AND VEHICLES	**0.7**	**4%**
Reduce Fuel Consumption by 15%	0.4	3%
Low-Carbon Fuel Standard	0.2	1%
Reduce Pleasure Craft Fuel Use by 35%	0.1	1%
NATURAL GAS END-USE	**0.3**	**2%**
Reduce Natural Gas Consumption 8%	0.3	2%
CIVIL AVIATION	**0.3**	**2%**
Civil Aviation Low-Carbon Fuel Standard	0.3	2%
WASTE	**0.3**	**2%**
Capture 80% of Landfill Gas	0.3	2%
AGRICULTURE/FORESTRY/LAND USE	**0.05**	**0.3%**
Urban Tree Planting / Preservation	0.02	0.1%
Tree Preservation during Development	0.03	0.2%
Total	**15.0**	**100%**

*The entire reduction attributable to Pavley is 3.2 MMT CO_2E (CAFE + Pavley).

3.2. Regional Greenhouse Gas Methodology Overview

In general, the San Diego Greenhouse Gas Inventory followed the same methodology used by CARB to develop the statewide inventory, which is based on the IPCC protocols. Even though our regional inventory uses the same categories included in the CARB statewide inventory, the organization and presentation of data differ slightly from CARB's approach. For example, natural gas end uses are broken out as a separate category. This decision was based in part on the format of our natural gas data and it seemed to be a more intuitive breakdown that highlighted the sources of emissions rather than the economic sectors of emissions. Emissions from natural gas end uses are further broken down into economic sectors, so the data also can be presented in this format. When calculating emissions for each category, some subcategories included in the CARB inventory were excluded from the San Diego County inventory because no similar activity occurs in San Diego County. For example, no petroleum refining occurs in San Diego County. Table 2 shows the categories and subcategories included in the inventory. It is possible to map emissions in these categories to the IPCC categories used by CARB.

Table 2. Emissions Inventory Categories

AGRICULTURE
- Enteric Fermentation
- Manure

CIVIL AVIATION
- Interstate Flights
- Intrastate Flights

ELECTRICITY
- Residential
- Commercial
- Industrial
- Mining
- Agricultural
- Telephone, communications, utilities (TCU)
- Street Lighting

DEVELOPMENT
- Loss of farmland
- Loss of native vegetation

INDUSTRIAL PROCESSES AND PRODUCTS
- HFC refrigerants
- Sulfur hexafluoride
- Other

NATURAL GAS END USES
- Residential
- Commercial
- Industrial
- Mining
- Agricultural

OFF-ROAD EQUIPMENT AND VEHICLES
- Construction and Mining Equipment
- Pleasure Craft
- Industrial Equipment
- Agriculture Equipment
- Other

ON-ROAD TRANSPORTATION
- Passenger Vehicles
- Light-Duty Trucks
- Heavy-Duty Trucks and Vehicles
- Motorcycle

OTHER FUELS/OTHER
- Manufacturing
- Transport
- Residential
- Commercial
- Non-Specified
- Agriculture
- Cogeneration Thermal Emissions

RAIL TRANSPORTATION

SEQUESTRATION FROM LAND COVER
- Forest growth
- Woodland growth
- Chaparral, scrub, and grasslands

WASTE
- Landfills
- Wastewater Treatment

WATER-BORNE NAVIGATION
- Ocean Going Vessels (OGV)
- Harbor Craft

WILDFIRES
- Forest
- Woodlands
- Chaparral, scrub, and grasslands

We calculated the emissions of dioxide, methane, nitrous oxide and specific hydrofluorocarbons (HFCs) in terms of carbon dioxide equivalent (CO_2E). The project team reviewed the formula and data source documentation for the statewide inventory that were available during the project to determine if similar data were available for the San Diego region. As shown in Table 3, which illustrates the methods and data sources used for each category of the regional inventory, emissions levels for nearly all categories were determined using the same methods as CARB or a similar proxy. In some cases, based on data availability, the project team slightly modified the CARB method or conducted more detailed calculations. For example, the project team developed a method to calculate emissions for electricity imports that may be more detailed than what CARB has done for the statewide inventory. In the civil aviation category, we included emissions associated with interstate travel, which is calculated but not included in the statewide GHG totals.

We used six general approaches to calculate GHG emissions.

- **Fuel- based** - This approach, which calculated GHG emissions directly from fuel burned, was used to calculate emissions for a significant portion of electricity, natural gas, civil aviation, and to some extent industrial processes and products.

- **CARB Emissions Models** – In the case of on-road and off-road transportation categories, the project team used CARB emissions models to estimate CO_2 emissions. For their statewide GHG inventory, CARB had access to actual fuel sold data for these sectors, and scaled EMFAC results to obtain more accurate emissions data at the state level. Similar fuel sold data was not available at the county level.

- **Source-based Model** – Waste category emissions were based on calculations using the IPCC Mathematically Exact First Order Decay Model to estimate emissions from landfills. We used waste (source) data for San Diego County in the model.

- **Scaled CARB Data** – Where fuel or source data were not available, the project team scaled CARB statewide emissions for a particular category to San Diego County using relevant factors like economic activity or population. This approach was used for rail transportation, some industrial process emissions and the "Other fuels" category.

- **CARB Regional Data** - In the case of water-borne navigation, we directly used CARB's calculations for our regional emissions though forecasts were adjusted using locally developed growth projections.

- **CARB Emissions Factor** - In limited cases, the project team used emissions factors provided in CARB's state inventory documentation to calculate GHG emissions for a particular category. In the agriculture category, for example, an emissions factor for each greenhouse gas is available per head of each type of livestock. We obtained county livestock population data and

multiplied that by the per head emissions factor to determine total emissions.

Table 3 Summary of Methods and Data Used in San Diego Regional GHG Inventory

Inventory Catetory	Method	Data Sources
ON-ROAD TRANSPORTATION	CARB EMFAC Model, mass balance calcualtions to determine CO_2E emissions (Modified CARB Method)	1990-2006 CO_2E Emissions from CARB On-Road EMFAC Model 2007-2020 CO_2E Emissions from SANDAG (via EMFAC)
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NATURAL GAS END USES	Fuel-based (CARB Method)	FERC FORM 1, CEC Energy Forecast 2008-2018, EIA Form 861
OFF-ROAD EQUIPMENT AND VEHICLES	CARB OFFROAD Model	CO2E Emissions from CARB OFFROAD Model
CIVIL AVIATION	Fuel-based (Average of jet fuel sold and passenger miles traveled methods), interstate emissions included (Modified CARB Method)	Two main jet fuel and aviation gas suppliers to San Diego Int'l Airport, Bureau of Transportation Statistics Department (BTS RITA), San Diego Air Pollution Control District (natural gas)
WASTE	IPCC Mathmatically Exact First Order Decay Model (CARB Method)	CARB (waste water factors) , City of San Diego (waste disposed), San Diego County Public Works Department, CARB (waste disposed), CIWMB, USD EPA
INDUSTRIAL PROCESSES AND PRODUCTS	Source-based, some scaled from statewide inventory data (CARB Method)	CARB, US EPA, US Census Bureau, US Geological Survey, CA Dept. of Transportation, CEC
WATER-BORNE NAVIGATION	Based on CARB estimate (CARB Method)	CARB estimate
RAIL TRANSPORTATION	Scaled from statewide inventory (CARB Method)	CARB statewide GHG inventory, US Census Bureau (economic data)
OTHER/OTHER FUELS	Scaled from statewide inventory (CARB Method)	CARB statewide GHG inventory, US Census Bureau (economic data)
AGRICULTURE (LIVESTOCK)	Scaled from statewide inventory (CARB Method)	CARB statewide GHG inventory, US Department of Agriculture, and San Diego County (crop reports)
EMISSIONS FROM DEVELOPMENT (Loss of Vegetation)	GIS analysis of developed areas from 1990-2007 (Modified CARB)	SANDAG and CA Dept of Forestry and Fire Protection (GIS data), Winrock International and C. Wiedinmyer paper (biomass data)
WILDFIRES	GIS analysis of burned areas from 1990-2007 (Modified CARB)	SANDAG and CA Dept of Forestry and Fire Protection (GIS data), Winrock International and C. Wiedinmyer paper (biomass data), SANGIS (GIS burn areas)
SEQUESTRATION FROM LAND COVER	GIS analysis of San Diego County vegetation 1990-2007 (Modified CARB)	SANDAG and CA Dept of Forestry and Fire Protection (GIS data), Winrock International and C. Wiedinmyer paper (biomass data), SANGIS (GIS burn areas), H. Luo paper (carbon uptake by chaparral)

3.2.1. Carbon Dioxide Equivalent and Emissions Factors

We converted all greenhouse gas emissions to carbon dioxide equivalents based on the global warming potential (GWP) of each greenhouse gas. Table 4 provides the GWP factors for the three main greenhouse gases used to calculate regional GHG emissions. Additional GWP factors were used for the industrial processes and products category.

Table 4. Global Warming Potential (GWP) Factors

Greenhouse Gas	Symbol	GWP
Carbon Dioxide	CO_2	1
Methane	CH_4	21
Nitrous Oxide	N_2O	310
Sulfur Hexafluoride	SF_6	23,900

Source: Intergovernmental Panel on Climate Change (IPCC) Second Assessment Report (1996)

3.2.2. Overall Limitations of the Methodology

The IPCC document on General Guidance and Reporting states that: "Uncertainty estimates…. should be derived for both the national level and the trend estimate, as well as for the component parts such as emission factors, activity data and other estimation parameters for each category."[13] The San Diego Regional GHG Inventory is based on the best available estimates using conceptual models and data collected by the state as fair representation of the real situation in the state and we attempt to reduce the errors associated with using the state inventory data and methods by adjusting the input parameters, whenever possible, to local conditions. In some cases of the use of model outputs, such as in the transportation category, we can identify uncertainties based analogous empirical data available at the state level but in most categories, model outputs have not been confirmed by actual measurement.

The use of proxies in some cases introduces uncertainties, especially for interpolated and extrapolated data. Activity data are often linked to economic data in the absence of alternative data. Though economic data have usually undergone rigorous statistical analysis for economic models, these have not generally been used to estimate GHGs. Whenever we have been unable to obtain quantitative estimates of uncertainty, good practice requires that we qualitatively identify potential sources of uncertainty.

Further limitations to the results occur from the lack of data for certain portions of some categories. For example, it was not possible to obtain fuel use data for most private jets and watercraft and neither is it possible at this time to quantify what percentage of the total fuel use this might constitute.

The overall uncertainty level for the San Diego Regional GHG Inventory is approximately 4%, based on the inputs used.

4. On-Road Transportation Methodology

On-road transportation is a significant source of greenhouse gas (GHG) emissions. In San Diego County, emissions from on-road vehicles account for about 46% of regional GHG emissions. This total is slightly higher than the 38% contribution of on-road transportation to total statewide greenhouse gas emissions. The on-road transportation methodology includes analysis of most motorized vehicles that travel San Diego County freeways, highways, streets, and roads. All vehicle types were analyzed: passenger cars; light-, medium-, and heavy-duty trucks; buses; motor homes; and motorcycles.

Table 5 presents a summary of the methods and data sources used to estimate emissions from the on-road transportation category.

Table 5 Summary of On-Road Transportation Method and Data Sources

Method	Data Sources
CARB EMFAC Model, mass balance calcualtions to determine CO_2E emissions (Modified CARB Method)	1990-2006 CO_2E Emissions from CARB On-Road EMFAC Model 2007-2020 CO_2E Emissions from SANDAG (via EMFAC)

4.1. Computation, Process, and Data

The on-road transportation GHG emissions were computed in two steps. First, emissions data specific to San Diego County from on-road transportation were obtained using the CARB on-road emissions modeling tool, EMissionsFACtor or EMFAC. Second, using the methodology provided by CARB in their statewide inventory data documentation pages,[14] this output was further refined to obtain emissions values for the three main GHGs associated with vehicles - carbon dioxide, methane and nitrous oxide.

4.1.1. The EMFAC Model for Calculating Emissions for On-Road Transportation

The EMFAC2007 is the most recent model for calculating tailpipe pollutant emissions in California.[15] The user can select an area of California from a list of 15 air basins, 35 air pollution districts, and 58 counties. The default models for each of these units have been developed using local data provided to CARB by the local transportation agency, in this case, SANDAG. The model uses emissions rate and local vehicle activity data to compute on-road vehicle emissions. Vehicle activity can be either vehicle miles traveled, number of trips, or total number of vehicles. The emission rate is computed in grams per mile, grams per trip, or grams per vehicle. Vehicle activity requires estimates of vehicle population and age, vehicle miles traveled (VMT), vehicle type and weight, fuel type and consumption, vehicle technology, and emissions reduction technology.

The basic calculation equation used in EMFAC is:

Emissions factor *correction factor * vehicle activity = emissions in tons per day.

The model calculates emissions factors and inventories for the pollutants hydrocarbons, carbon monoxide, nitrogen oxides, carbon dioxide, particulate matter, sulfur oxides, and lead. The model also generates fuel consumption based on the emissions of carbon monoxide, carbon dioxide, and total hydrocarbons (THC) using the carbon balance. The amounts of pollutants vary depending on the stage of vehicle activity, and the EMFAC default model sums up tailpipe emissions due to the normal running, idling and starting phases, those due to diurnal temperature variations, emissions from the resting and hot soak phases as well as running and resting losses.

Separate calculations are performed for thirteen classes of vehicle by fuel type and technology type (Table 6). The vehicle population is generally obtained from the historical CA Department of Motor Vehicle (DMV) database and forecast from 2005 vehicle population data to 2040 and back cast to 1970. Fuel emissions factors are based on EPA empirical vehicle test data.

Table 6. Vehicle Classes Modeled by EMFAC[16]

Vehicle Class	Fuel Type	Code	Description	Weight Class (lbs)	Abbr.
1	All*	PC	Passenger Cars	All	LDA
2	All*	T1	Light-Duty Trucks	0-3,750	LDT1
3	Gas, Diesel	T2	Light-Duty Trucks	3,751-5,750	LDT2
4	Gas, Diesel	T3	Medium-Duty Trucks	5,751-8,500	MDV
5	Gas, Diesel	T4	Light-Heavy-Duty	8,501-10,000	LHDT1
6	Gas, Diesel	T5	Light-Heavy-Duty	10,001-14,000	LHDT2
7	Gas, Diesel	T6	Medium-Heavy-Duty	14,001-33,000	MHDT
8	Gas, Diesel	T7	Heavy-Heavy-Duty	33,001-60,000	HHDT
9	Gas, Diesel	OB	Other Buses	All	OB
10	Diesel	UB	Urban Buses	All	UB
11	Gas	MC	Motorcycles	All	MCY
12	Gas, Diesel	SB	School	All	SBUS
13	Gas, Diesel	MH	Motor	All	MH

*Gas, Diesel, Electric

EMFAC calculates VMT based on local vehicle population and vehicle mileage accrual. However, VMT is also produced as output from regional transportation models for certain planning years. The regional VMT estimates are matched in the EMFAC model by modifying either or both the local vehicle population and accrual estimates. Therefore the VMT data produced by EMFAC when running the default model is the same as that produced by the regional transportation model. In our case, the default EMFAC provided VMT data from 1990 to 2005.

While the EMFAC model *can* produce forecasts of all its output parameters based on the historical data, more accurate forecasts of VMT, trips or numbers of vehicles can be obtained by the regional (SANDAG) transportation model. This regional

transportation model projects monitored data (which originally comes from the DMV as well as other monitoring databases) based on a complex set of assumptions, inputs and four model components. The four components are: 1) a demographic and economic model, 2) an interregional commute model, 3) an urban development model, and 4) a transportation forecasting component. The current SANDAG regional transportation model forecast (Series 11-2030 San Diego Regional Growth forecast update) is the 11th such forecast completed by SANDAG beginning in the late 1970s. Note that this model now incorporates the contribution made by interregional commuting.

For the period 2006 to 2020, SANDAG provided EPIC with annual EMFAC output forecast data sheets containing all primary pollutants, fuel combustion, trips, vehicle population and VMT based on its regional transportation model outputs.

4.1.2. Calculating GHG Emissions from EMFAC Output

The EMFAC outputs for CO_2, CO, THC and nitrogen oxides (NOX) are converted to CO_2 and N_2O using the equations provided by CARB in its 2007 statewide on-road transportation GHG emissions inventory data documentation page (Table 7).[17] The model provides CH4 emissions directly. In the statewide inventory, CARB reports that it currently uses the EMFAC model only to obtain emissions and total fuel consumption data but then scales these values to the actual fuel sold data available to the state through the Board of Equalization. At the county level, we currently do not have total fuel consumption data, much less according to vehicle class. Therefore at the county level, we must rely on the EMFAC emissions results. The difference at the state level between the EMFAC total fuel combustion and the actual fuel sold data averaged approximately 5% in the period 1990-2004. We would expect a similar difference between the EMFAC computed total fuel combusted and fuel sold data at the county level.

Table 7. Equations Used for the Calculation of GHG Emissions using EMFAC Output Data

CO_2
Mass of CO_2 emission = ([EMFAC output CO_2Emission] + ([EMFAC output CO Emission] * [Molecular weight ratio of CO_2 to CO]) + ([EMFAC output THC Emission] * [Molecular weight ratio of CO_2 to CH2]))
N_2O: Distillate
Mass of N_2O emitted = [EMFAC output Fuel Combustion] * [Fuel N_2O emission] where [Fuel N_2O emissions] = 0.332 g/gal of distillate
N_2O: Gasoline
Mass of N_2O emitted = ([Vehicle miles traveled] * (0.0318 * ([EMFAC output NOx Emission] / [Vehicle miles traveled]) + 0.0167))
CH_4
Mass of CH_4 emitted = [EMFAC output CH4 Emission]

The EMFAC emissions output is generated in tons per day. This daily emissions rate was converted to an annual emissions rate based on the annual usage and vehicle type (noncommercial or commercial). Noncommercial vehicle annual emissions were calculated on the basis of 347 effective days per year and included passenger cars, light-duty trucks, and motorcycles. Commercial vehicles included heavy-duty trucks and buses and their annual output was calculated on the basis of 327 effective days per year, on the assumption that vehicle activity and miles traveled decrease on weekends. GHG emissions from buses and motor homes were also included in this inventory. Owing to their similar gross vehicle weights, their respective emissions were included in the heavy-duty truck category.

4.2. Limitations to the Methodology

As explained above, it was not possible to calculate GHG emissions using from fuel sold data at the County level. The project team had to rely on existing models and methods to estimate the GHG emissions from the on-road transportation sector. Based on the significant reliance on EMFAC and data produced by the Regional Transportation Model, much of the uncertainty is related to the models and their methods and data inputs. Technical documents on the EMFAC model and the Regional Transportation Model indicate that of the basic model inputs - vehicle population, the number of trips, the vehicle miles traveled (VMT), and the emissions factors associated with each class of vehicles - there is no significant uncertainty in the vehicle population as these are based on the historical DMV registrations.[18] The VMT data is based on actual numbers from the DMV. The number of trips is both estimated by the regional transportation model and tested empirically by surveys. The main uncertainties for historical emissions therefore arise from the assumptions made in the model regarding the running time, the idling time, start time, as well as in the EPA emissions factor measurements for each type of vehicle, which we were unable to quantify within the timeframe of the project.

An alternative way to assess uncertainty in on-road transportation emissions estimates is to compare the results for total fuel use from EMFAC to actual fuel sold data at the state level. This shows that the statistical error in EMFAC total fuel combusted versus actual fuel sold is 4% for the years 1990-2004. Assuming there are no additional sources of error at the county level, and as CO2E emissions are directly proportional to fuel combusted, the uncertainty in the emissions from this sector is 4%.

Forecast emissions have greater uncertainties. Limited literature research indicates that the main limitation to the above method lies in the accuracy of projected VMT data (as an input to the regional transportation model, including the work mode split allocation), the fuel economy of the existing fleet, and how the fleet should be aged for the future. Discussions are on going between VMT modelers, regional planners and NGO groups on these issues.[19] (Sparks, 2007; Bartholomew and Ewing, 2009).

5. Electric Sector Emissions Inventory Methodology

Determining greenhouse gas emissions for the San Diego region is perhaps more straight forward than other regions because the political boundaries of San Diego County are very similar to the boundaries of the service territory of the local utility, San Diego Gas & Electric. With the exception of a small portion of Orange County, which represents about 9% of total sales, all of SDG&E's service territory falls within San Diego County.

To calculate GHG emissions from electricity generation in the San Diego region, the project team estimated the total amount of electricity consumed in the region and determined the type and amount of fuel used to generate electricity. When no fuel data were available, we used an accepted standard emissions rate (lbs/MWh) or developed a proxy emissions rate based on similar fuel data. Table 8 provides a summary of the methods and data used to estimate emissions from this category.

Table 8 Electricity Category Method and Data Sources

Method	Data Sources
Fuel-based, CARB emissions factors (lbs/MWh) and average emisions for power suppliers used where fuel data unavailable (CARB Method)	FERC FORM 1, CEC Energy Demand Forecast 2008-2018, SEC Form 10-K, EIA Form 861

This section describes the data categories that make up total electricity supply for the region, data sources, and a detailed discussion of how the project team calculated greenhouse gas emissions estimates for each electric data category.

5.1. Total Electric Energy Supply

To determine the greenhouse gases associated with electricity generation, it is necessary to estimate total electricity supplies for the region; that is, the quantity of electricity needed by customers. In the case of the San Diego Regional Green House Gas Inventory, this total included electricity from SDG&E-owned generation assets, electricity purchased by SDG&E, electricity sold to customers who get electricity from a provider other than SDG&E (i.e., direct access), electricity associated with the California Department of Water Resources contracts issued during the 2000-2001 California electricity crisis, and on-site electricity generation used to offset customer load (self-serve). In addition to these sources, the calculation included transmission and distribution losses as well as electricity produced at the customer's site. Since this project focused on San Diego County, the electricity associated with the small portion of Orange County that SDG&E serves, which was about 9% in 2006, was subtracted from the totals.

Total electric supply comprises the following categories:

- **SDG&E Net Generation**: the total amount of electricity generated by SDG&E-owned assets.

- **Total Power Purchased**: the total purchased by SDG&E to supplement its own generation.
- **Sales for Resale**: energy purchased and then resold, typically a negative number.
- **Net Exchanges**: contractual exchanges of electricity between two entities.
- **Transmission Losses by Others**: losses associated with electricity wheeled across the SDG&E's transmission system, counted as supply since they serve on-system demand.
- **Direct-Access Sales**: electricity supplied to customers from suppliers other than SDG&E. Direct-access totals include transmission and distribution losses of approximately 7.5%.[20]
- **Department of Water Resources Contracts**: energy associated with DWR contracts assigned to the SDG&E territory. No public data were available, but energy totals were derived from EIA data. These also included transmission and distribution losses of 7.5%.[21]
- **Self-Serve Energy**: total energy generated on the customer's premises to serve on-site load was included in the energy supply total. Only non-photovoltaic self-serve energy was included.

Table 9 provides a sample calculation of total electric energy supply for the San Diego Gas & Electric service territory for 2006. It also includes data sources for the components of the total electricity supply.

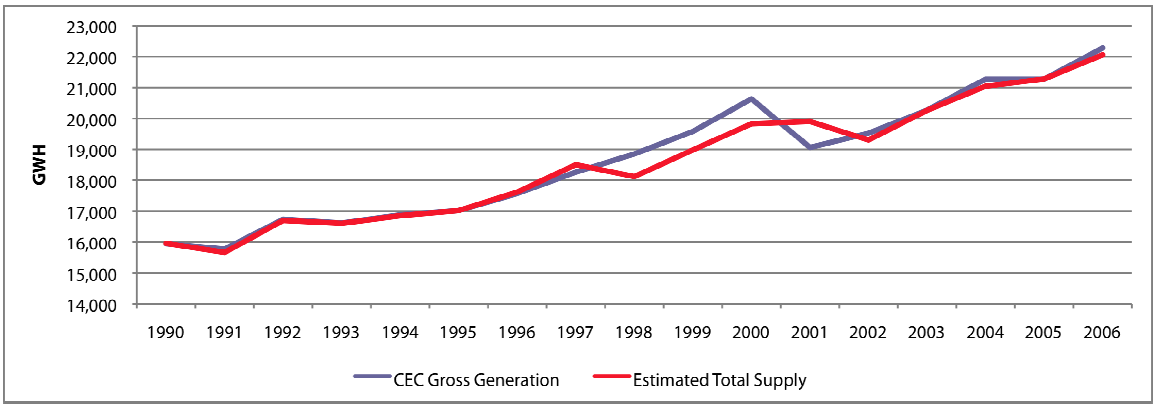
Table 9 Total Electric Energy Supply Components and Data Sources, 2006

Total Energy Supply Component	MWh	Source
SDG&E Net Generation	5,203,402	FERC Form 1 - Steam-Electric Generating Plant Statistics (Large Plants)
Direct Access Sales +Transmissions Losses	3,644,250	Sempra Energy SEC Form 10-K, Table 5
DWR Contracts +Transmissions Losses	7,888,953	FERC Form 1 / EIA Form 861
Total Power Purchased	5,086,291	FERC Form 1 - Account 555
Self Serve	709,766	CEC Electric Energy Forecast 2008-2018 - Net Energy for Load
Sales for Resale (FERC FORM 1)	(474,587)	FERC Form 1 - Electric Energy Account
Net Exchanges (FERC FORM 1)	0	FERC Form 1 - Electric Energy Account
Transmission Losses by Others	0	FERC Form 1 - Electric Energy Account
Total Supply	**22,058,075**	

5.1.1. Comparison to California Energy Commission Gross Generation

To determine if our estimate of total electricity supply for San Diego County was accurate, we compared it with the latest forecast for gross generation from the California Energy Commission (CEC).[22] The estimate matched up very well for all years except 1998-2001, which varied by up to 5% at times (Figure 2). This mismatch is likely attributable to data-reporting inconsistencies during the California electricity restructuring period and the energy crisis of 2000-2001. For the purposes of developing a greenhouse gas inventory, the middle years of the data set are not as important as 1990 and 2006, both of which match up very well.

Figure 2. Comparison of EPIC Total Supply Estimate and CEC Gross Generation



5.2. Emissions from SDG&E Net Generation

To calculate the total GHG emissions from SDG&E-owned generation assets, the project team used data from FERC Form 1 Electric Energy Account to determine the total amount of fuel combusted by each power plant.

For this and all other calculations to estimate GHG emissions from electricity production, fuel data, heat content, CARB emissions factors for CO_2, CH_4, and N_20, and global warming potential (GWP) factors were used to calculate carbon dioxide equivalent. The basic equation for this calculation follows.

CO_2 Equivalent = [(Amount of fuel consumed) x (average heat content of fuel) x (CARB Emissions Factor – for CH_4, CO_2, and N_2O) x (GWP factor)]

Table 10 provides an example of this calculation for the Encina power plant in 1990.

Table 10. 1990 Encina Power Plant Emissions – Sample Calculation

Fuel Type	Fuel Consumed	Average Heat Content (BTU/Unit)	Greenhouse Gas	CARB Emissions Factor (grams/BTU)	Global Warming Potential Factor	Total CO_2 Equivalent (grams)	Total CO2 Equivalent (MMT)
Natural Gas (mcf)	15,524,550	1,035,000	CH_4	0.000001	21	337,426,094	0.0003
Natural Gas (mcf)	15,524,550	1,035,000	CO_2	0.053		851,599,190,250	0.85
Natural Gas (mcf)	15,524,550	1,035,000	N_2O	0.0000001	310	498,105,187	0.0005
Distillate Fuel Oil (bbl)	700,969	6,203,694	CH_4	0.000003	21	273,961,622	0.0003
Distillate Fuel Oil (bbl)	700,969	6,203,694	CO_2	0.073		317,882,453,820	0.32
Distillate Fuel Oil (bbl)	700,969	6,203,694	N_2O	0.0000006	310	808,839,075	0.0008
Total						**1,171,399,976,049**	**1.2**

5.3. Emissions from Total Purchased Power

SDG&E purchases a significant portion of electricity each year to supplement the amount they generate; therefore, this is an important component of the inventory. We used FERC Form 1 Purchased Power (Account 555) data from 1990 through 2007 to identify all entities that sold energy to SDG&E. These data were used to create a database that enabled us to see how much each supplier sold to SDG&E each year and to identify which suppliers sold the most electricity to SDG&E over the period studied.

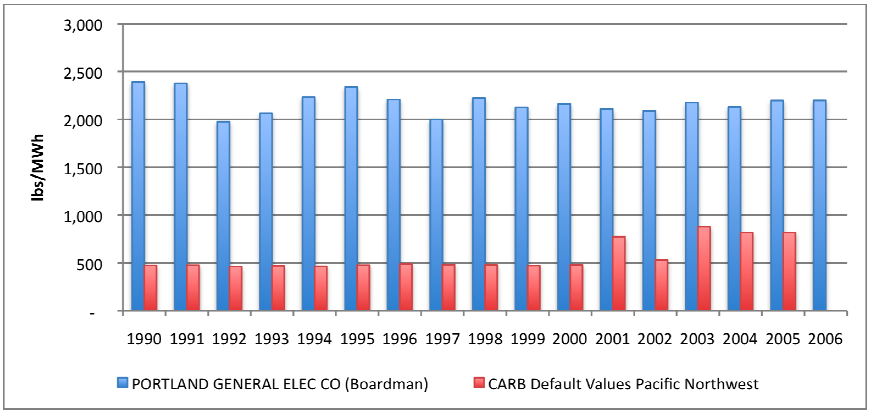
The project team categorized each supplier by fuel and location. For location, we indicated if the information was available whether the energy producer was located in the Pacific Northwest (PNW); Pacific Southwest (PSW); San Diego County; California; or an unspecified location. For fuel source, we used the following categories: unspecified, natural gas, coal, nuclear, digester gas, landfill gas, biomass, wind, and hydro. To be consistent with the method used by CARB and to account for transmission and distribution losses, we added a 7.5% loss factor to purchases that we knew originated outside the region. Because this project focused on San Diego County, electricity use associated with Orange County (approximately 9%) was omitted.

We used three different methods to calculate emissions levels, depending on the level of information available about the supplier and power plant: calculations based on actual fuel data, calculations based on default CARB multiplier, or calculations based on an average emissions profile of the entity selling power to SDG&E.

In the case of known locations and fuels, such as the Boardman coal-fired plant owned by Portland General Electric in Oregon, we knew the fuel and amount of energy sold, so we could use actual fuel and heat content data from EIA to calculate emissions levels for each year SDG&E purchased electricity from this power plant. Figure 3 shows the results of calculations to determine historical emissions rates from the Boardman plant and compares them to the default emissions factors developed by CARB for unspecified electricity purchased from the Pacific

Northwest. Had we used the CARB default value for the energy associated with the Boardman plant instead of the actual emissions, the results would have underestimated the emissions. Portland General's Boardman plant was the eighth-largest supplier, providing about 4% of the power purchased by SDG&E during this period.

Figure 3. Emissions Rate for Boardman Plant



In cases where we did not have complete information about the location and fuel, we multiplied the energy values (MWh) by CARB emissions rates (lbs/MWh) for each category:

- Unspecified Geography/Unspecified Fuel: CARB value of 1100 lbs/MWh.
- PNW, unspecified fuel: CARB default value for PNW for each year.
- PSW, unspecified fuel: CARB default value for PSW for each year.

In the third method, we calculated average emissions profiles for the utilities that sold the most electricity to SDG&E over the period 1990-2007. For six of the top known suppliers, we developed an average emissions rate (lbs/MWh) based on actual fuel, heat content, and net energy generation data. These included PacifiCorp, Public Service Company of New Mexico, Salt River Project, Portland General Electric, Arizona Public Service, and Tucson Electric Power Company. Combined, these utilities supplied 26% of SDG&E's total purchased power between 1990 and 2007 Figures 4 and 5 show the average greenhouse gas emissions for the entire fleet of power plants for a sample of utilities analyzed compared to the CARB default emissions rate for that region. Note that the figure title is followed by the rank of the supplier and the percent of purchased power supplied during this period.

The CEC has recommended a method to account for emissions from imports using a dispatch approach, assuming a utility supplier would use its inexpensive electricity (coal and nuclear) to satisfy its own needs and sell higher cost – and less polluting – electricity (natural gas) to others.[23] In the case of Pacificorp, whose actual emissions were significantly higher than the default CARB value, the energy generation portfolio was dominated by coal and there was little natural gas to sell. In the case

of the suppliers from the Pacific Southwest, the difference in emissions rates was not significant – in the case of Arizona Public Service the average emissions rate was lower than the CARB default value.

Figure 4. Average Emissions Rate for Pacificorp (3, 7%)[24]

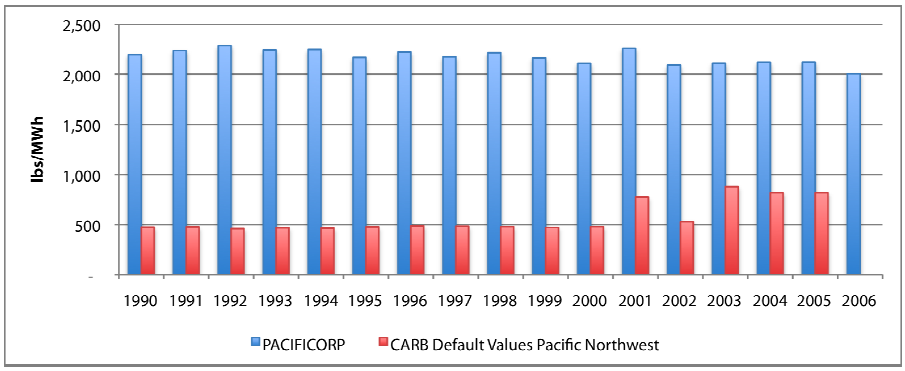
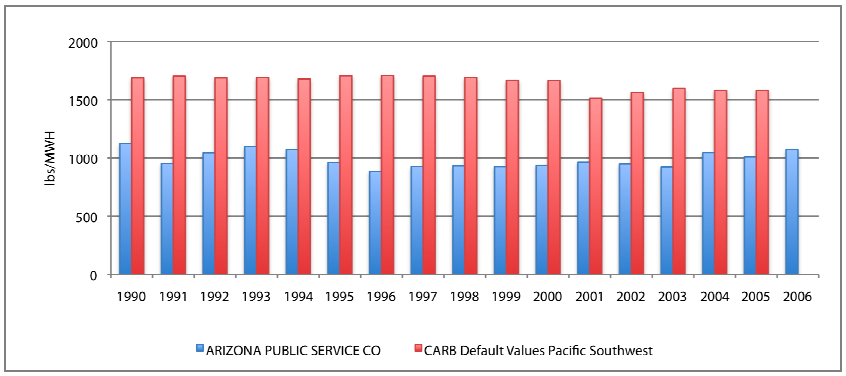


Figure 5. Average Emissions Rate for Arizona Public Service (9, 3.2%)



5.4. Cogeneration

Taken together, all cogeneration purchases make up the largest electric energy supplier to SDG&E over the 17-year period covered in the inventory. It was possible to determine the location of several cogeneration suppliers outside the region, such as Yuma Cogeneration Associates. For these facilities, actual fuel data was available to calculate GHG emissions levels. The simplifying assumption that all other cogeneration was located in the region was applied to the inventory.

While we had data on fuel use for some of the cogeneration plants located in the region, the FERC Form 1 data only provide an aggregated energy number. To determine GHG emissions, we multiplied this by a representative emissions rate (lbs/MWh) calculated using actual fuel and energy data for a sample of cogeneration systems of different sizes.

Emissions from cogeneration facilities are split into those associated with the production of electricity and those associated with the production of useful heat. Such an allocation depends on the specific equipment used, but for regional inventories this information is typically not available. When only energy production values are known a general allocation can be used. Based on the CARB methodology used for mandatory emissions reporting, it is reasonable to allocate 70% of emissions to the electricity category and 30% to thermal category.[25] If emissions inventory results are organized according the IPCC categories used by CARB, electricity emissions should be allocated to the electricity section, while thermal emissions should be allocated the thermal section.[26]

5.5. Other FERC Form 1 Categories

We included several other categories of FERC Form 1 data in our calculations, as follows:

- Sales for Resale: we calculated the emissions using average overall SDG&E emissions rate (lbs/MWh) for each year and then subtracted it from the total emissions for the region.
- Net Exchanges: we used average overall SDG&E emissions rate (lbs/MWh) for each year and then added/subtracted it from the total emissions for the region, depending on whether net exchanges were positive or negative.
- Transmission Losses by Others: we used average overall SDG&E emissions rate (lbs/MWh) for each year and then added it to the total emissions for the region. There were only "losses by others" in 1990 and 1992, and their emissions contribution to the total was minimal.

5.6. Direct-Access Sales

Data for direct-access sales were derived from Sempra Energy SEC Form 10-k, Table 5, for 1990-2006.[27] Consistent with CARB's method, we added a 7.5% transmission and distribution loss factor to this energy.[28] Since no public data are available on the amounts and sources of specific transactions, we calculated emissions using the default CARB rate of 1100 lbs/MWh.

5.7. Department of Water Resources Contracts

No historical data were available for the actual quantity of energy purchased as a result of ongoing Department of Water Resources contracts. We estimated energy levels by using FERC Form 1 Purchased Power data and EIA wholesale purchase data from Form 861.[29]

For several years, the FERC Form 1 data on purchased power varied significantly from the EIA Form 861 data for wholesale purchases. The difference was assumed to be the Department of Water Resources Contracts, as shown in Table 11.

Table 11. Estimated Department of Water Resources Contract Energy Totals

Data Source	2001	2002	2003	2004	2005	2006
Wholesale Purchases EIA Form 861	13,568,541	10,935,412	12,075,204	13,109,328	12,856,203	12,424,852
Purchased Power FERC FORM 1	6,549,941	3,823,022	7,079,998	5,471,401	5,015,197	5,086,291
Difference	7,018,600	7,112,390	4,995,206	7,637,927	7,841,006	7,338,561

Data were available for estimated energy from the DWR contracts in the future. SDG&E's long-term procurement plan includes an energy-balance estimate that forecasts energy associated with the DWR contracts.[30] We used these data to develop approximate energy supplies from each contract. We added transmission and distribution losses of 7.5% to those sources we knew originated outside the region.

For the largest contract, Sunrise, we estimated energy purchased and then used EIA fuel, heat content, and net energy generation data to develop an emissions rate (lbs/MWh). We multiplied that by the estimated energy supply from the plant. The second-largest contract was the Williams B contract; here, we used the CARB unspecified default value of 1100 lbs/MWh.

5.8. Business as Usual Electricity and Greenhouse Gas Emissions Projections

As mentioned above, our total energy supply calculation matched the CEC calculation very well for most of the 1990-2006 period. To project into the future, we chose to use the CEC demand forecast data for 2008-2018. We used a linear projection of the CEC estimate for gross generation until 2020. To capture all the energy uses that create GHG emissions, we added total private supply, including both photovoltaic and non-photovoltaic self-generation. This became the basis for calculating the business-as-usual GHG emissions projections.

The CEC forecast incorporates the effects of the 2005 building standards and currently funded energy efficiency programs through 2008.[31] This is particularly relevant to the wedge that reduces electricity consumption by 10%.

5.9. Limitations of the Methodology

In general, the methodology used to estimate total GHG emissions for the electricity category could be improved by access to more relevant data, particularly fuel and DWR contract energy data. In many cases, fuel data were available, but in the cases of much of the electricity purchased by SDG&E to supply the region, the California Department of Water Resources contracts, and all of the energy associated with direct access, no data exist on the actual source of the electricity. Thus no data are available on the amount of fuel used. The total electricity supplied from these sources was approximately 30% of total energy supplies to the region: 11% from purchased power, 17% from direct access, and a fraction from unspecified DWR contracts. To overcome this data gap, CARB, the CEC, and the

CPUC have developed default emissions factors for energy originating in the Pacific Northwest, Pacific Southwest, and from unknown origins. In at least one case shown here, use of the default factor resulted in significant underestimation of emissions.

- Where possible, the project team used actual data, but in cases where data were not available, we used CARB default emissions rates (e.g., for unspecified electricity imports) or we developed a proxy rate based on actual data. For example, between 1990 and 2006 about 45% of the GHG emissions estimate associated with purchased power was derived using CARB default emissions values, 30% was derived using actual fuel consumption data, and about 15% was calculated using a proxy emissions rate developed with actual fuel consumption data. By definition, this introduces some uncertainty into the estimate.
- As indicated above, we developed an estimate for the total annual energy associated with the DWR contracts. We used several data sets to develop the estimate, but to estimate emissions more accurately, actual fuel and energy generation data would be necessary.

The greatest uncertainty in the CO_2E emissions arises from about 35% of supply coming from unknown locations and unknown fuel sources. To overcome this data gap also at the state level, CARB, the CEC, and the CPUC have developed default emissions factors for energy originating in the Pacific Northwest, Pacific Southwest, and from unknown origins. A comparison of average historic emissions rates from several plants based on actual fuel use compared with the default emissions rates developed by CARB for the default unspecified electricity and that purchased from either the Pacific Northwest or Pacific Southwest showed that the uncertainty on the default rates vary from 0% (hydropower) to 500% (coal based). Use of the default factors for that portion of electricity supply where fuel type and amounts were unknown resulted in an uncertainty of approximately 12% on the GHG emissions.

6. Natural Gas End Use Methodology

The method for calculating greenhouse gas emissions from natural gas end use is relatively straightforward. Greenhouse gas emissions correlate directly to consumption, so the team estimated emissions on the basis of historical and projected consumption data provided by the California Energy Commission (CEC).[32] In addition to the aggregated data in the staff forecast, the CEC provided detailed consumption data that allowed the project team to analyze consumption trends for each sector and subsector of the economy. The method and data sources used to estimate emissions from natural gas end uses are summarized in Table 12.

Table 12 Natural Gas End Uses Category Method and Data Sources

Method	Data Sources
Fuel-based (CARB Method)	FERC FORM 1, CEC Energy Forecast 2008-2018, EIA Form 861

6.1. Natural Gas GHG Emissions Calculation

The project team calculated total GHG emissions (measured in carbon dioxide equivalent, CO_2E) by aggregating emissions of CH_4, CO_2, and N_2O, according to the following formula:

Greenhouse gas emissions (grams of CO_2E) = (standard cubic feet of natural gas) x (heat content in BTU/scf) x (fuel emission factor g/BTU) x (global warming potential [GWP] factor)

Each part of the equation is described in more detail below.

Heat Content

The heat content of natural gas is a significant factor in determining emissions. On the basis of actual fuel use data from both the Federal Energy Regulatory Commission (FERC) Form 1 and the Energy Information Administration (EIA), the project team calculated weighted averages of the heat content of the natural gas consumed in the region for electrical generation during the period 1990-2006 (Table 13). By comparison, the heat content used by CARB for 1990, 1995, and 2000 was 1,027 BTU/scf. In 2004, the last year of the statewide inventory, CARB used 1,002 BTU/scf.

Table 13. Weighted Average Heat Content for Selected Years (BTU/scf)

Year	1990	1995	2000	2005	2006
Heat Content	1,032	1,019	1,017	1,020	1,020

Fuel Emissions Factors

The project team used the fuel emissions factors for natural gas combustion provided by CARB.

- CH_4 - 1.00E-06 g/BTU
- CO_2 - 0.053 g/BTU
- N2O - 1.00E-07 g/BTU

7. Civil Aviation Methodology

Even though civil aviation accounts for about 5% of overall greenhouse gas emissions in the San Diego region, this category is often not captured in city level inventories. This omission is ostensibly due to the difficulty in assigning emissions from a regional airport to specific cities. Emissions from this category comprise those associated with flights into and out of the major airports in the region but not emissions associated with operational activities at regional airports. The latter emissions are captured in the other categories of this regional inventory.

To estimate total greenhouse gas emissions from this category, the project team used two different methods: a fuel-based method using actual jet fuel and aviation gas data (method 1), and a second top-down approach used departing flight mileage with fleet efficiency data available from a national mileage database to estimate jet fuel use (method 2). Because the jet fuel sold does not reflect the emissions caused by departing flights that *do not* fuel up during a stopover in San Diego, this alone would underestimate flight emissions from the region. The top-down method provides an estimate for the maximum jet fuel use from departing flights and therefore provides an upper limit for emissions. An average of the two methods thus provides a better estimate for regional aviation emissions. Table 14 provides a summary of the methods and data sources used to calculate emissions from this category.

Table 14 Civil Aviation Method and Data Sources

Method	Data Sources
Fuel-based (Average of jet fuel sold and passenger miles traveled methods), interstate emissions included (Modified CARB Method)	Two main jet fuel and aviation gas suppliers to San Diego Int'l Airport, Bureau of Transportation Statistics Department (BTS RITA) San Diego Air Pollution Control District (natural gas)

In its statewide GHG inventory CARB only included emissions from intrastate flights although interstate flight emissions are listed as a separate item. The San Diego Regional GHG inventory also includes interstate flights to provide a more complete estimate of emissions associated with regional civil aviation activity.

This section includes an overview of these two methods and the limitations of each.

7.1.1. Jet Fuel Emissions Using Fuel Sold (Method 1)

Estimating GHG emissions from civil aviation activity is relatively straightforward. The equation used to calculate the emissions is:

greenhouse gas emissions = fuel gallons x emissions factor,

where the emissions factors for commercial jet fuel and aviation gasoline were obtained from the CARB GHG inventory (Table 15).

Table 15 CARB Emissions Factors for Commercial Jet Fuel and Aviation Gasoline[33]

Fuel type	Methane (grams/gallon)	Nitrous Oxide (grams/gallon)	Carbon Dioxide (grams/gallon)
Jet fuel	0.3	0.3	9,570
Aviation gasoline	7.1	0.11	8,310

Limitations of Method 1

The annual fuel data used to estimate emissions from civil aviation in San Diego County represents the jet fuel sold to commercial operations and some private flights departing from San Diego International Airport only. As such, these data do not represent all flights departing from the region since there is one other regional airport offering commercial flights and several small private airports. On the other hand, San Diego International Airport represents over 95% of the commercial flights from the County. The second limitation of this method is that, according to airport personnel, not all flights refuel while stopping over in San Diego; therefore, calculations based solely on fuel sold to flights departing from San Diego will underestimate greenhouse emissions associated with departing flights.

7.1.2. Passenger Miles Traveled Method (Method 2)

Passenger miles flown out of San Diego International Airport were used in combination with fleet energy intensity data to estimate fuel use. This method would capture the emissions caused by all passenger flights departing the San Diego International Airport. However, because this method is based on passenger activity, emissions due to cargo (mail and freight) flights are not captured, whereas Method 1 includes all types of domestic commercial flights.

Passenger miles traveled from San Diego International Airport were extracted from the Bureau of Transportation Statistics Department (BTS RITA) database for each year from 1990 to 2007.[34] The energy intensity for a range of the total US commercial aircraft fleet over the past 20 years is also available in the same database and is shown in modified version in Table 16.

Table 16 Aircraft Fleet Fuel Intensity

Year	Passenger Miles (millions)	Fuel Consumed (million gallons)	Intensity (mpg)
1960	30,557	1,954	16
1965	51,887	3,889	13
1970	104,147	7,857	13
1975	131,728	7,558	17
1980	200,289	8,519	24
1985	270,584	10,115	27
1990	340,231	12,323	28
1991	332,566	11,506	29
1992	347,931	11,763	30
1993	354,177	11,959	30
1994	378,990	12,384	31
1995	394,708	12,672	31
1996	425,596	13,217	32
1997	450,612	13,563	33
1998	463,262	13,335	35
1999	488,357	14,402	34
2000	516,129	14,845	35
2001	486,506	14,017	35
2002	482,310	12,848	38
2003	505,158	12,959	39
2004	557,893	13,623	41
2005	584,996	13,789	42
2006	591,834	13,458	44

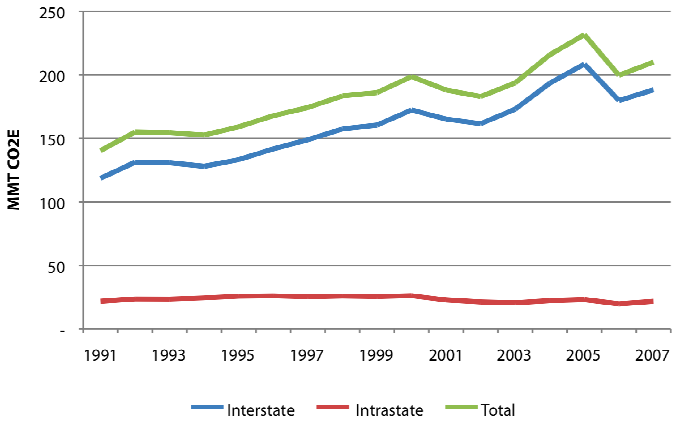
Note that the US fleet fuel efficiency has improved significantly since 1960. The Table 2 data was used to calculate energy intensity or fuel efficiency range *per passenger mile* of 0.036 gallons in 1990 to 0.023 gallons in 2006. Assuming the same fleet mix in San Diego as in the United States[35], multiplication of the fuel efficiency by the passenger miles gives jet fuel consumption for all domestic passenger departures from San Diego as follows:

Fuel efficiency (gallons/passenger mile) x passenger miles = gallons total.

As the miles traveled data can be separated into intrastate and interstate flights, this method allows calculation of the jet fuel used and GHG emissions for each type of passenger flight.

The results of Method 2 show a trend in the last 15 years towards decreasing intrastate miles and increasing interstate miles (Figure 6). Therefore in these years, the driving force for aviation emissions has been interstate miles flown.

Figure 6: Fuel Use Trends based on Passenger Miles Departed, San Diego, 1991-2007 (Method 2)

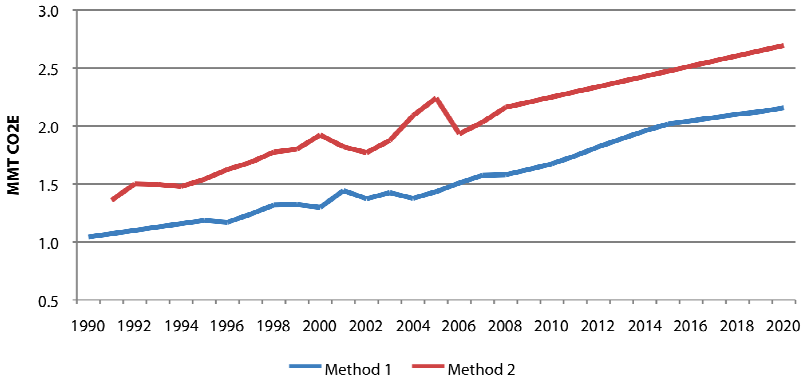


Limitations

The emissions calculated by this method are necessarily greater than that calculated by the fuel sold (Method 1) since not all aircraft fuel in San Diego. With this method, however, it is possible to distinguish between intrastate and interstate emissions, which is not possible with the jet fuel sold method, as the data provided could not be separated. It is clear that intrastate emissions are significantly lower than interstate emissions, and that intrastate flights are the driving force for civil aviation emissions.

The difference in emissions between the fuel-sold method (Method 1) and the passenger miles departed method (Method 2) ranges from 300,000 to 800,000 metric tons, or from 30-50% of the emissions based on the fuel sold (Figure 7).

Figure 7: Difference in Emissions based on the Two Methods of Calculation



Although the emissions trend is positive and rising in both cases, the fuel sold method indicates a slower rate of increase than the passenger miles method, resulting in a gradually increasing gap between the two. One possible explanation for this difference, which has not been further examined, may be a tendency to reduce fueling at San Diego International Airport.

Because of the large difference in results of the two methods, an average of the results of the two methods reduces the error in the emissions estimates. The average values differ from the results of either method by about 20%. These averaged jet fuel emissions were used in the total aviation sector emissions presented above.

7.1.3. Aviation Gasoline and Natural Gas

In addition to jet fuel, the project team calculated the greenhouse gas emissions from aviation gasoline and natural gas. Only one of the fuel suppliers sells aviation gasoline at the San Diego International Airport. This data was available from 1996-2007. Only the fuel-sold method (Method 1) could be used to calculate emissions as the miles departed data for flights using aviation gasoline is not available.

Natural gas used in the aviation sector for ground transportation purposes at the San Diego International Airport is included in this section. The data were provided by the San Diego County Air Pollution Control District (APCD).[36]

8. Methodologies for Other Categories

This section includes brief summaries of the methods used for the remaining categories of the San Diego County Greenhouse Gas Inventory. More detailed discussions are included in detailed reports for each category available at the EPIC Website.[37]

8.1. Industrial Products and Processes

GHG emissions from Industrial Products and Processes accounted for about 5% of overall regional emissions in 2006. In general, the project team used the categories contained the CARB 2007 Greenhouse Gas Emissions Inventory and either calculated emissions directly from primary data using the same method used by CARB or scaled down statewide emissions based on a ratio of industrial activity in San Diego County and the state as a whole using appropriately related data, such as population and economic data from the US Census Bureau. In some cases, several IPCC categories as used in the CARB GHG inventory were excluded from the inventory total because Economic Census data from 1997 and 2002 from the US Census Bureau indicated no economic activity in San Diego County.

The most significant limitation to the analysis of industrial processes and products included in the inventory was availability of relevant data. In particular, this analysis could be improved by the addition of data on the industrial consumption of the following materials at the county level: liquefied petroleum gas (LPG), petroleum feedstocks, lubricants, naphtha, other petroleum products, and carbon dioxide.

Table 17 presents the method and data used to calculate emissions from the industrial products and processes category.

Table 17 Industrial Products and Processes Method and Data Sources

Method	Data Sources
Source-based, some scaled from statewide inventory data (CARB Method)	CARB, US EPA, US Census Bureau, US Geological Survey, CA Dept. of Transportation, CEC

8.2. Other Fuels

The Other Fuels category contributed approximately 4% to overall regional emissions in 2006. To estimate emissions from Other Fuels – such as propane, kerosene, and wood – the project team scaled the values contained in the CARB statewide inventory to San Diego County using data on relevant economic activities.[38] The following categories are included in the Other Fuels emissions estimate: household use; energy - petroleum marketing; manufacturing for non-metallic minerals, oil and natural gas, construction, and non-specified; transportation for rail and non-specified; commercial non-specified; agriculture

energy use; and non-specified Industry. Emissions associated with rail are accounted for in a separate category and described in Other Transportation Report.

Similar to the industrial processes and products section of the inventory, several categories were included in the CARB statewide inventory but not included in our estimate for San Diego County because Economic Census data from 1997 and 2002 from the US Census Bureau indicated no economic activity in San Diego County.

Table 18 provides a summary of the method and data sources used to estimate emissions from this category.

Table 18 Other / Other Fuels Method and Data Sources

Method	Data Sources
Scaled from statewide inventory (CARB Method)	CARB statewide GHG inventory, US Census Bureau (economic data)

8.3. Off Road Equipment and Vehicles Methodology

The data for this sector, which accounted for 4% of emissions in 2006, was generated with the California Air Resource Board's (CARB) emission modeling tool, OFFROAD. The computations from this model were based on three main factors: equipment population, activity, and emission factors. These factors account for variables such as: equipment type, technology, age and horsepower, as well as the amount and type of fuel consumed. Seasonal operating conditions and adjustments for ambient temperature are also included in the computation.[39] Table 19 shows the method and data sources used to estimate emissions from this category.

Table 19 Off-road Equipment and Vehicles Method and Data Sources

Method	Data Sources
CARB OFFROAD Model	CO2E Emissions from CARB OFFROAD Model

8.4. Waste

The waste category accounts for approximately 2% of regional emissions. It includes emissions from both domestic wastewater treatment and landfills. Table 20 includes the methods and data sources used to estimate emissions from the waste category. The method use to calculate emissions for each of these sources is described below.

Table 20 Method and Data Sources for Waste

Method	Data Sources
IPCC Mathmatically Exact First Order Decay Model (CARB Method)	CARB (waste water factors) , City of San Diego (waste disposed), San Diego County Public Works Department, CARB (waste disposed), CIWMB, USD EPA

8.4.1. Domestic Wastewater Treatment Emissions

The project team obtained an estimate for emissions from the domestic wastewater treatment by multiplying the region's population by the per capita emissions factors for nitrous oxide (N2O) and methane (CH4) provided by the California Air Resources Board.[40] The emissions per person for N2O have increased over the period of study (Table 21) while the methane emission factor per person has remained constant at 9,855 grams.[41]

Table 21: Waste Water Emissions Factors for Methane and Nitrous Oxide[42]

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
N2O emissions grams/person	89.3	91	91	91	94	92	92	93	94	96	95	95	95	95	95

The CH4 emissions factor is based on the Biochemical Oxygen Demand (BOD5)[43] production rate of 0.1 kg BOD5/capita/day and a methane production capacity for domestic wastewater of 0.6 kg CH4/kg BOD5. It also assumes an average CH4 correction factor for treatment, or the anaerobically degradable fraction, for all treatment systems of 0.5.

The Air Pollution Control District provided data on the amount of biogas removed for combustion in cubic feet of biogas produced per facility annually in the County. This was converted to mass of methane by assuming a density of biogas of 0.7

kg/m3, as provided by CARB. The data for biogas removed was available from 1997 to the present.

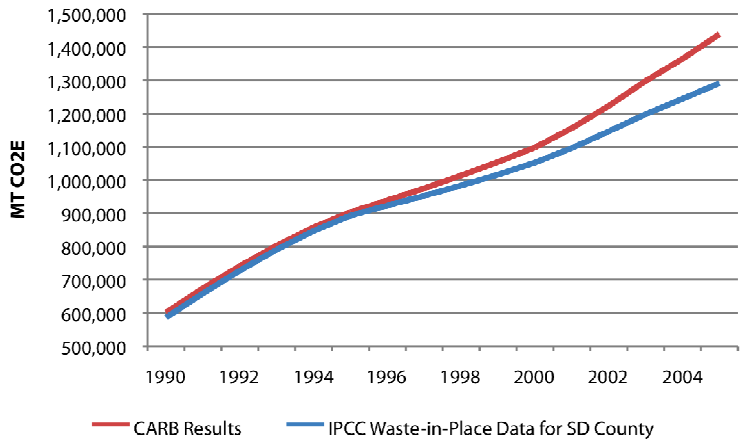
8.4.2. Landfill Gas Emissions

We used the Mathematically Exact First Order Decay Model (FOD) from the IPCC Solid Waste Guidance Document.[44] This model requires input of the amount disposed from 1950. Not all 26 landfills in the County existed in 1950, and even if they did, the data available does not go back as far as 1950. Some landfills opened and closed within the 1950 to 2005 time frame and others were open for waste disposal for less than a decade. The City of San Diego provided waste disposed data for four city landfills (out of the total 26 County landfills), of which the Miramar landfill is the longest operating, with data available from 1960. However, the Miramar landfill has not always been the largest in the County. For other County landfills, only random spot data were found within site assessment reports available at the County Public Works Department. Therefore, it was not possible to use the local data available for the countywide amounts disposed.

The California Air Resources Board provided the waste disposed data for each of the 26 landfills in the County that it had obtained to carry out the statewide GHG inventory. The data available to CARB had been backcast and interpolated where there were data gaps using several complementary methods, as well as additional data available from CWIMB and US Environmental Protection Agency (US EPA) studies. The project team therefore used this countywide total disposal data as inputs to the IPCC model from 1950 to 2004. The CARB waste input data from 1990 to 2006 are the same as the waste input data available from CWIMB.

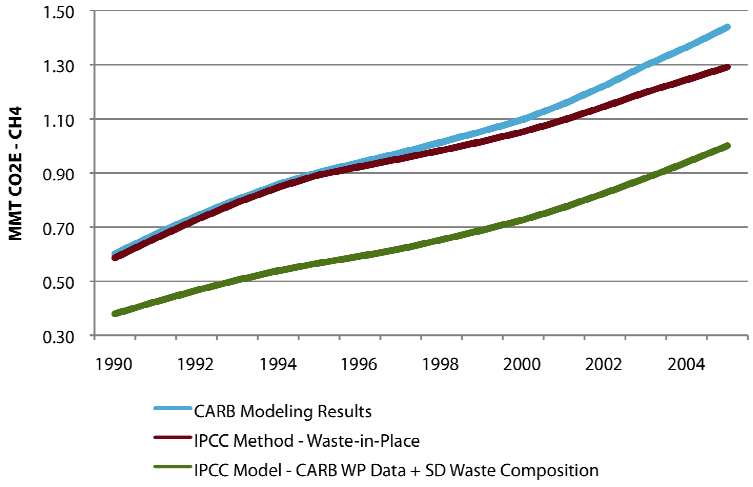
The project team tested the reproducibility of the CARB derived emissions for San Diego County with that of the IPCC Waste Model by using the CARB county waste input data and other parameters used by CARB for the state of California. For instance, the California average waste composition data was used, which is based on several EPA and CWIMB studies. The results of the IPCC Waste Model were found to be in close agreement with the results of raw methane emissions data provided by CARB (Figure 8) especially in the beginning years, but diverge up to 5% in the recent years. This variation may be attributable to the greater historical waste input data used by CARB, back to 1930. For the purpose of establishing the 1990 county level, this divergence is not of consequence but it will overestimate emissions of the forecasted values compared with any forecasts made by CARB.

Figure 8: Comparison of Methods for Landfill Gas Emissions, San Diego County



The City of San Diego provided the local waste composition from studies carried out in 1996 and 2000. These show that the San Diego County waste profiles differ from the US EPA and CWIMB California-wide profiles, mainly in the lower content of organic matter. To account for this difference, the project team ran the IPCC Waste Model with the San Diego waste composition data and the CARB waste disposed data to obtain the results shown in Figure 9. These emissions values were used to determine the total carbon dioxide equivalents emissions from the landfill sector presented here.

Figure 9: Landfill Methane Emissions Based on Local Waste Composition Data



8.4.3. Method Limitations

Studies comparing modeling results with whole site methane emission measurements, though few, have shown that large differences in results occur depending on the model and when relying on back cast and interpolated data sets

versus actual emissions.[45] Therefore it is important that at least the same model and default parameters are used for comparison purposes, as done here. Still, large errors in estimation occur because of the lack or variations of actual waste disposed data, and lack of testing of the model with real landfill gas monitoring data.

For example, a comparison of the waste disposed provided by CARB for three city landfills versus the data provided by the City of San Diego demonstrate this problem, as shown in Figure 10. The total waste in place in 2005 for the Miramar Landfill is only 10% different from that provided by CARB; however, the same comparison for the Chollas Landfill shows a difference of at least 50%. Other such comprehensive data was not available for the other landfills but similar differences might be expected.

Caution is needed even for this landfill specific comparison as *both* sets of data consist of back cast and interpolated values where there are data gaps. In this sense, a better comparison of the data differences may be obtained using the total waste disposed over the whole lifetime of any particular landfill, and not the distribution over the years or difference in any one year. A comparison of the total waste in place by 2005 for each of the city landfills showed that the total waste in place estimated by CARB versus that provided by the city, though both containing back cast and interpolated data, differ by only 10%. However, when the IPCC Waste Model is run with the CARB data and the City data, the annual differences flatten out, due to the nature of landfill degradation and long lag times. Therefore, further improvement of the total waste disposed data might be possible from the total capacity of the landfill as given in the permits with the assumption that when the landfill closes, all its capacity has been used. However, to be consistent with CARB methodology, and due to lack of time and resources in this phase of the project, this method was not further pursued.

A second limitation is that waste composition varies not only between the state averages and San Diego County averages but also locally, among the county landfills. During the time of this study, it was not possible to find waste profile data for even all the existing active landfills. In addition, waste composition would have changed over the more than 50 years of disposal, while only two local studies are available, from 1996 and 2000 on waste composition.

As water is the determining factor for anaerobic decomposition, more accurate results would also be obtained if annual rainfall averages were used in place of one average value for all the years. For such reasons, the waste sector emissions, especially those from landfills, may be under- or even overestimated.

A final limitation of the method is the lack of data for the amount of landfill and biogas captured from 1990. It appears from the data provided by CARB that at least one county landfill was combusting landfill gas in 1990 and some were operating from 1993. If similarly biogas were removed prior to 1996, the 1990 waste sector emissions value would be lower.

8.5. Agriculture, Forestry, and Land Use

Agriculture, forestry, and other land-based activities may both absorb and emit greenhouse gases (GHG). This category is one of the main categories used in the California Air Resources Board (CARB) statewide inventory and is responsible for about 2% of regional emissions. The San Diego County Greenhouse Gas Inventory provides an estimate of GHG emission from the following two subcategories:

- **Livestock Management**– This includes emissions from both enteric fermentation and manure management.

- **Sequestration by Land Cover** –This is the net level of greenhouse gas emissions from CO2 uptake by plant growth (sinks) and greenhouse gas releases from the destruction of existing land cover (vegetation). Our analysis includes the total amount of greenhouse gases sequestered by natural vegetation in San Diego County, the effects of development on sequestration, and emissions from wildfires during the period 1990 to 2007.

The subcategory of crop burning and soils management, which includes non-CO2 emissions from agricultural activities, is a component of the agriculture, forestry, and other land-based activities category in the CARB statewide inventory; however, due to a lack of data – and the likelihood that emissions will be relatively very small -- emissions from these activities are not included in the analysis here.

The methods and data used to estimates emissions from livestock, loss of vegetation, and wildfires, and the levels of sequestration from vegetation in the region are summarized in Table 22.

Table 22 Methods and Data Sources Used for the Agriculture, Forestry, and Land Use Category

Inventory Catetory	Method	Data Sources
AGRICULTURE (LIVESTOCK)	Scaled from statewide inventory (CARB Method)	CARB statewide GHG inventory, US Department of Agriculture, and San Diego County (crop reports)
EMISSIONS FROM DEVELOPMENT (Loss of Vegetation)	GIS analysis of developed areas from 1990-2007 (Modified CARB)	SANDAG and CA Dept of Forestry and Fire Protection (GIS data), Winrock International and C. Wiedinmyer paper (biomass data)
WILDFIRES	GIS analysis of burned areas from 1990-2007 (Modified CARB)	SANDAG and CA Dept of Forestry and Fire Protection (GIS data), Winrock International and C. Wiedinmyer paper (biomass data), SANGIS (GIS burn areas)
SEQUESTRATION FROM LAND COVER	GIS analysis of San Diego County vegetation 1990-2007 (Modified CARB)	SANDAG and CA Dept of Forestry and Fire Protection (GIS data), Winrock International and C. Wiedinmyer paper (biomass data), SANGIS (GIS burn areas), H. Luo paper (carbon uptake by chaparral)

8.5.1. Sequestration from Land Cover Methodology

Carbon uptake by vegetation was estimated using CARB methods (Winrock[46]) for forests, woodlands, and riparian environments, which are dominant in carbon uptake at the state level. However, because these ecosystem types are rare in San Diego County, other types of ecosystems that were ignored in the CARB California

statewide GHG inventory, namely scrub, chaparral, and grasslands, play a significant role here.

San Diego County vegetation data was downloaded as GIS shapefiles from the SANDAG website.[47] Data from outside the county border was removed. Data gaps in the eastern third of the county were filled in using 2002 raster data with 100 m resolution from the California Department of Forestry and Fire Protection.[48] Due to limited resolution, these data sets do not include information on urban trees unless they are in parks or open space preserves. The 130 vegetation types in the SANDAG dataset were re-categorized into the 7 classes. "Scrub" is a new class; other classes are used in the CARB (Winrock) study. Ecosystem types classified as scrub include coastal sage scrub and Sonoran desert scrub. Most of the classifications are either obvious or were specified in the CARB (Winrock) study. Other broadleaf ecosystems were classified as hardwood forest or woodland depending on typical tree size and density, with the higher woody biomass ecosystems classified as hardwood forest.

The uptake rates for hardwood forests, conifer forests, and woodlands were specified in the CARB (Winrock) study. Other uptake rates had to be estimated from other sources. Annual carbon uptake rates for chaparral and grassland ecosystems were estimated to be 0.9% and 1.2%, respectively, of the total carbon stock in each ecosystem type, estimated using biomass data taken from Wiedinmyer et al.[49] (2006) and shown in the fuel loading column. (Chaparral was assigned to the "shrubland" category. A 44.4% carbon content in shrubland and grassland biomass was taken from Wiedinmyer et al.) For chaparral, this amount of carbon uptake matches integrated field measurements performed on young and on mature local chaparral ecosystems by Luo.[50] Since grasslands reach maturity sooner, a slightly higher percentage (1.2%) of total carbon stock was used to estimate annual carbon uptake rates. Since scrub is in between grassland and shrub / chaparral in terms of the amount of biomass present, values for carbon uptake and biomass were selected that were in between the other two categories but closer to grasslands.

Annual carbon uptake by each type of land cover was calculated by multiplying its land area in a given year times the appropriate uptake rate listed in the table. We have assumed that over the period 1990 – 2007 developed lands and agricultural lands neither accumulated net carbon (because of regular harvesting) nor released greenhouse gases during wildfires in significant quantities. Thus, after land is developed or farmed it makes no further contributions to greenhouse gas uptake or release in this analysis.

Carbon dioxide emissions due to land use conversion were estimated for farmland development using reported declines in agricultural carbon stocks at the county level for 1987, 1992, and 1997 from the Winrock study (2004).

Carbon dioxide emissions caused by vegetation removal for the conversion of undeveloped lands into farmland or developed areas were quantified using GIS analyses of SANDAG land use data at the parcel level for 1990, 1995, 2000, 2004, 2007[51] and SANDAG projections for 2020.[52] Lands classified as preserve open space (7603), landscape open space (7606), and undeveloped (9101) were all considered undeveloped, while all other land uses were considered developed. The change in

developed land area was quantified by comparing 1990 and 2020 land use data and locating land parcels that had switched out of undeveloped designations. Intermediate year land use data was used to quantify the variability in rates of development during the 30-year period. Once "developing" land parcels were located in each period, they were overlaid with the county vegetation dataset described earlier to determine types and acreages of vegetation displaced. These acreages are multiplied by the biomass amounts ("fuel loading") listed in Table 3 and multiplied by 0.4 to determine the mass of carbon displaced. As recommended by the CARB (Winrock) study, we assume that the carbon stock from land that is developed is immediately released as carbon dioxide to the atmosphere. Thus, the displaced carbon is multiplied by the factor 44/12 to determine the mass of CO_2 released.

Emissions due to forestry from slash decomposition and fuel wood were assumed to be zero because of the negligible amount of forest harvest that currently occurs in San Diego County.

Fire burn areas downloaded from the SANGIS website[53] were overlaid on vegetation maps by GIS to determine types of ecosystems burned each year from 1990 – 2003 and 2007. (Burn areas for 2004 – 2006 are not yet available. Average burn areas for the non-firestorm years 1990 – 2001 were used for this period.) Carbon dioxide and methane emissions released by wildfires in San Diego County were estimated using the method of Wiedinmyer et al. (2006), who uses the equation:

$$Emission = AB\left(wE_w + hE_h\right)F \times GWP \qquad (1)$$

where A is the burn area of a given land cover class in hectares, B is the biomass per hectare ("fuel loading"), w is the woody fraction, h is the herbaceous fraction (where $w + h = 1$), E is the combustion efficiency of a given fraction, F is the emission factor for the greenhouse gas in question, and GWP is the greenhouse warming potential of the gas. Values for the variables B, w, E, and F (except F_{N2O}) are taken from Wiedinmyer et al. (2006) and are listed in Table 3. GWP is defined as 1 for carbon dioxide. We used a GWP of 21 for methane and 296 for nitrous oxide. The result of the calculation is in units of kg of CO_2 equivalents, which is multiplied by 10^9 to get MMT CO_2E.

Nitrous oxide (N_2O) emissions were estimated using the same method[54] as in the CARB inventory. This method, where both carbon and N_2O emissions are in the same mass units, is shown below (Eq 2). If the *carbon emitted* term is removed from the equation, the result is an emission factor for N_2O, which can be used in equation 1. This emission factor (after unit conversions) is listed in Table 6.

$$N_2O_{emitted} = \frac{Carbon_{emitted} \times 0.005 \times 0.01 \times 44}{28} \qquad (2)$$

Fire emissions calculated using these methods for the firestorm years 2003 and 2007 were consistent with the CARB (Winrock) method for fires with an intensity between medium and high, which seems appropriate.

Limitations of the Methodology / Error Analysis

Results using the Wiedinmyer method have lower uncertainties than the CARB (Winrock) method, which failed to distinguish between different fuel types. The Wiedinmyer method is reliable to within a factor of 2, but has not been directly validated due to a lack of measurements. Thus, our calculated emissions due to development and fire have the same level of uncertainty. The methods of the Winrock study for estimating CO_2 uptake by vegetation have an estimated reliability of ±38%. Since we have extended this method to include chaparral, scrub and grasslands (based on Luo's two 2007 measurements on chaparral ecosystems) our estimations of CO_2 uptake are also reliable only to within a factor of 2.

These uncertainties will be reduced only by measurements of biomass content, fire emissions, and CO_2 uptake in local ecosystems. Very few measurement studies have focused on the types of ecosystems that cover most of San Diego County due to their low biomass compared to forests.

8.5.2. Livestock Emissions Calculation Methodology

The project team used data from two different sources to calculate livestock emissions: the San Diego County Crop Report[55] and U.S. Department of Agriculture (USDA) National Agricultural Statistics.[56] Neither data set was complete and some interpolation and extrapolation was necessary to complete each set. The sets were then combined to serve as the basis for livestock emissions calculations. USDA data included information for the years 1990-1992 and 2001-2007, so we used a linear regression analysis to estimate livestock populations for the missing years, 1993-2000. USDA livestock population data included only the categories of dairy cows, beef cows, and all cattle. To determine the population of the "other cow" category, we subtracted data from the "milk (dairy) cows" and "beef cows" categories from the "all cattle" category included in the USDA data set.

The San Diego County Crop Report provided livestock population data for sheep and lambs, hogs, and chickens for the years 1995-2006. A linear regression analysis was used to back cast livestock population to 1990.

Emissions Calculations

To calculate livestock emissions, the project team used a direct calculation provided in the CARB statewide greenhouse gas inventory. For each sector CARB provides a 'per unit activity', which is based on the total emissions for that sector divided by the unit of activity. As an example, in 1990, California's 1,115,000 dairy cows emitted 143,547 tons of CH_4 (3,014,481 tons CO_2E), which yields per cow emissions of 128,741 g of CH_4 per head of Dairy Cows (2,703,571 g CO_2E per head of dairy cows). We multiplied the total head count for each animal type by this CARB activity factor to estimate emissions form livestock in San Diego County.

8.6. Rail

Activity data for rail transportation, which emits 1% of regional GHGs, were not available within the time frame of this project; therefore, GHG emissions for the County were scaled from the CARB GHG inventory using US Economic Census data. For this, the project team used data on the "total sales, shipments, receipts, revenue or business done by domestic establishments" for rail transportation. Table 23 includes the method and data used to calculate emissions from rail transportation.

Table 23 Method and Data Sources for Rail Transportation Category

Method	Data Sources
Scaled from statewide inventory (CARB Method)	CARB statewide GHG inventory, US Census Bureau (economic data)

8.7. Water Borne Navigation Methodology

Water borne navigation accounts for less than 1% of overall regional GHG emissions. Insufficient data was available to develop a fuels based estimate for this category, so the project team used the regional emissions data provided by CARB. This method includes emissions for ocean going vessels (OGV) and harbor craft. Table 24 shows the method and data sources for estimating emissions for water borne navigation in the region.

Table 24 Method and Data for Water Borne Navigation

Method	Data Sources
Based on CARB estimate (CARB Method)	CARB estimate

8.7.1. Ocean Going Vessel Emissions

The basic equation used by CARB for estimating emissions from OGVs is based on the following variables: pollutant specific emissions (tons per year of NOx, HC, CO2, SO2, and diesel PM), population of ocean-going vessels by vessel type, emission factor by engine type, operating mode, and fuel (units of g/kw-hr), average annual use in hours by operating mode and vessel type, average power by operating mode and vessel type, average engine load by operating mode and vessel type, inventory year, operating mode (transit, maneuvering, hotelling), vessel type (auto, container, bulk cargo, etc.), fuel (HFO or MGO/MDO, and engine type. Emissions factors are consistent with the emissions factors used by Starcrest in its San Diego Port emissions inventory of 2006.

The fuel consumption rates used by CARB for the different engines are given below. The equivalent values used by Starcrest is not available.

CARB assumed that the main engines and auxiliary boilers burned heavy fuel oil and that for auxiliary engines, 92% of cruise ships burned fuel oil and 8% distillate. For all other ships, the assumptions were 71% heavy fuel oil and 29% distillate. The equivalent information used by Starcrest was not available.

In their estimate, CARB used data from California Lands Commission for vessel population and number of port calls while berthing was obtained from the each California port. The vessel populations used by CARB are similar to that used by the San Diego Port Air Emissions Inventory 2007.

Historical trend data for OGV port calls was not available from the Port of San Diego or CARB. According to OGV port call data available at the U.S. Maritime Administration from 2002-2006, none of the OGVs indicate an increasing trend, although auto ship calls increased from 2005 to 2006. Cruise and auto ships make up the majority of the OGV calls in San Diego.

Scaling Statewide OGV Emissions to the County Level

OGV emissions for the County provided by CARB were already scaled according to the operating hours in the various modes and calculated on the basis of the route taken between ports. OGVs passing through but not calling at the Port were also included. Vessel traffic lanes and routes (Figure 5) for California versus the San Diego County area as defined above were used for the route calculations.

8.7.2. Harbor Craft Emissions

Harbor craft consist of tugboats, commercial and charter fishing boats, excursion boats, and government pilot boats. According to the 2007 CARB methodology on harbor craft emissions, as well as the San Diego Port Emissions Inventory (EI) of 2006, commercial and charter fishing boats make up the majority of the harbor craft. Although no data is available to compare the population of harbor craft in the same year, harbor craft vessel numbers data are available for 2004 and 2006 from the two sources, Starcrest and CARB. Large differences are observed between the number of harbor craft vessels provided in the Port EI for 2006 and the closest year for which CARB harbor craft numbers are available – 2004. The Port EI harbor craft population in 2006 was surveyed as 107 while the CARB 2004 allocation to the County was 307[57]. The largest difference lay in the number of commercial fishing and excursion vessels with the CARB number at 260 and the EI number at 72.

CARB also provided us with harbor craft emissions for the County and forecasts to 2020. However, the method of allocation of harbor craft and the emissions estimates from the state to county level may significantly overestimate harbor craft emissions, which would be of no significance in the calculation of the total *state* emissions for harbor craft. The allocation method does make a large difference when assigning emissions at the county level. We therefore based our harbor craft emissions (to a distance of 24 nm) on the one actual Starcrest EI survey obtained for 2006.[58] In that year harbor craft constituted 27% of the OGV number. With the assumption that the harbor craft use is proportional to the OGVs, the harbor craft emissions from 1990 to 2020 were estimated based on this percentage.

Limitations

The main limitation is the lack of local survey data on harbor craft population except for the year 2006. Especially the number of commercial fishing boats may have varied significantly based on fluctuations in the fishery populations in the county waters since 1990 in place of the constant 27% of OGV assumption. However, as the total water-borne emissions in San Diego are small, these variations would be of little significance for the overall countywide greenhouse gas emissions.

END NOTES

[1] Councils of Governments in California include: ABAG-Association of Bay Area Governments, BCAG-Butte County Association of Governments, COFCG-Council of Fresno County Governments, Council of San Benito County Governments, Coachella Valley Association of Governments, MCAG-Merced County Association of Governments, Kern Council of Governments, Kings County Association of Governments, Mendocino Council of Governments, Association of Monterey Bay Area Governments, Orange County Council of Governments, SACOG-Sacramento Area Council of Governments, San Bernardino Associated Governments, SANDAG-San Diego Association of Governments, SBCAG-Santa Barbara County Association of Governments, SCAG-Southern California Association of Governments, SGVCOG-San Gabriel Valley Council of Governments, SJCOG-San Joaquin Council of Governments, SLOCOG-San Luis Obispo Council of Governments, StanCOG - Stanislaus Council of Governments, WRCOG-Western Riverside Council of Governments, TCAG-Tulare County Association of Governments.

[2] http://www.project2degrees.org

[3] See REGULATION FOR THE MANDATORY REPORTING OF GREENHOUSE GAS EMISSIONS http://www.arb.ca.gov/regact/2007/ghg2007/frofinoal.pdf

[4] CARB, Local Government Operations Protocol: For the quantification and reporting of greenhouse gas inventories (Version 1.0). September 25, 2008. Available at http://www.arb.ca.gov/cc/protocols/localgov/pubs/final_lgo_protocol_2008-09-25.pdf

[5] http://www.icleiusa.org/programs/climate/mitigation

[6] http://www.climateregistry.org/resources/docs/legislation/SB1771.pdf

[7] http://www.theclimateregistry.org/

[8] http://www.climateregistry.org/reserve.html

[9] Electronic copies of the executive summary and 8 supplements sector reports are available on the EPIC website at http://www.sandiego.edu/epic/ghginventory/.

[10] To do this, we adapted the well-know approach used by Pacala and Socolow. See Pacala, S. and Socolow, R. (2004). Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technologies. Science, 305, 968-972.

[11] While emissions of some military activities are captured, not all activities are included in the inventory totals. For example, military aviation and ship activities are not included.

[12] The gap between California and the US average presented here have not been adjusted for weather, but it has been shown that the lower per capita energy use in California is due 2/3 to climate advantages and 1/3 to state energy efficiency measures since the 1970s. See Schipper, L and McMahon, J., 1995. Energy Efficiency in California: A Historical Analysis.

[13] Intergovernmental Panel on Climate Change. (2006) Guidelines for National Greenhouse Gas Inventories, General Guidance and Reporting, Vol.1, c.3 available from http://www.ipcc=nggip.iges.or.jp/public/gp/english

[14] California Air Resources Board, Greenhouse Gas Emissions Inventory: Index to the Documentation Pages, cited April 15, 2008. See http://www.arb.ca.gov/cc/inventory/doc/doc_index.php

[15] http://www.arb.ca.gov/msei/onroad/latest_version.htm'

[16] California Air Resources Board, EMFAC2007 version 2.30: Calculating emissions inventories for vehicles in California, User's Guide, p. 7. Available at http://www.arb.ca.gov/msei/onroad/downloads/docs/user_guide_emfac2007.pdf

[17] Ibid.

[18] Sparks, Jehan. (2007). Greenhouse Gas Emission Measurement in the Transportation Sector: Status, Problems and Possible Solutions, Climate Protection Campaign available at www.climateprotectioncampaign.org/reports/jehanrep07.pdf

[19] Sparks, Jehan. (2007). Greenhouse Gas Emission Measurement in the Transportation Sector: Status, Problems and Possible Solutions, Climate Protection Campaign available at www.climateprotectioncampaign.org/reports/jehanrep07.pdf. See also Bartholomew, K. and Ewing, R. (2009). Land Use-Transportation Scenarios and Future Vehicle Travel and Land Consumption, Journal of the American Planning Association, Vol 75, No 1, Winter 2009.

[20]Imported Electricity Methodology (Draft). California Air Resources Board. Personal communication with Larry Hunsaker, email May 14, 2008.

[21] Ibid.

[22] California Energy Commission. California Energy Demand 2008-2018 Staff Revised Forecast. November 2007, available at http://www.energy.ca.gov/2007publications/CEC-200-2007-015/CEC-200-2007-015-SF2.PDF

[23] A. Alvarado and K. Griffin, Revised Methodology to Estimate the Generation Resource Mix of California Electricity Imports: Update to the May 2006 Staff Report. March 2007, California Energy Commission.

[24] Formerly Pacific Power and Light.

[25] California Air Resources Board, Instructional Guidance for Mandatory GHG Emissions Reporting December 2008, Chapter 9: Cogeneration Facilities (Guidance for Regulation Section 95112). See http://www.arb.ca.gov/cc/reporting/ghg-rep/ghg-rep-guid/09_Cogen.pdf.

[26] California Air Resources Boars, Greenhouse Gas Inventory Data 1990-2004 (last reviewed December 22, 2008). See http://www.arb.ca.gov/cc/inventory/data/data.htm.

[27] http://www.shareholder.com/sre/edgar2.cfm

[28] Imported Electricity Methodology (Draft). California Air Resources Board. Personal communication with Larry Hunsaker, email May 14, 2008.

[29] http://www.eia.doe.gov/cneaf/electricity/page/eia861.html

[30] Exhibit IV-4: Electricity Resource Planning Energy Balance Resource Accounting Table (Preferred Resource Plan). Filed with the California Public Utilities Commission, San Diego Gas & Electric, in Rulemaking R.06-02-013 on December 12, 2006.

[31] California Energy Demand 2008-2018 Staff Revised Forecast. California Energy Commission (CEC) November 2007. Available from the CEC website at http://www.energy.ca.gov/2007publications/CEC-200-2007-015/CEC-200-2007-015-SF2.PDF (Last viewed 6-17-08).

[32] California Energy Demand 2008-2018 Staff Revised Forecast. California Energy Commission (CEC), November 2007. Available at http://www.energy.ca.gov/2007publications/CEC-200-2007-015/CEC-200-2007-015-SF2.PDF (last viewed June 17, 2008).

[33] http://www.arb.ca.gov/cc/inventory/data/data.htm.

[34] http://www.transtats.bts.gov/. The departure miles for 1990 are not available and were back cast from the 1991-2007 linear plot.

[35] A preliminary analysis for just one year, 1991, of the aircraft type mix in San Diego versus the aircraft type mix in California showed that San Diego had a more modern and therefore more fuel efficient fleet than the state. Time did not permit further evaluation to establish if this were true for all years to 2006. If it does hold true to the present day, then the emissions caused by the aircraft fleet in San Diego will be somewhat lower than the average of California.

[36] The project team submitted a detailed data request to the APCD for all fuel used in San Diego County. This included emissions from aviation activities.

[37] http://www.sandiego.edu/epic/ghginventory/

[38] Gross economic data for the agriculture sector is available at: http://www.energy.ca.gov/research/iaw/industry/agri.html. Economic Census data is available at: http://factfinder.census.gov/servlet/IBQTable?_bm=y&-geo_id=04000US06&-ds_name=EC0200A1&-_lang=en and http://factfinder.census.gov/servlet/IBQTable?_bm=y&-geo_id=31000US41740&-ds_name=EC0200A1&-_lang=en. Population data is available at: http://factfinder.census.gov/servlet/ACSSAFFPeople?_submenuId=people_1&_sse=on.

[39] California Air Resources Board, "Overview: OFFROAD Model" cited May 25, 2008. http://www.arb.ca.gov/msei/offroad/pubs/offroad_overview.pdf

[40] Personal communication with Mr. Lin Ying, CARB, 5 May 2008.

[41] The increase in N2O emissions has been attributed to the increase in consumption of red meat. See Volume 5, Waste, available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/

[42] The methane factor was the latest (May 2008) provided by CARB.

[43] The Biological or Biochemical Oxygen Demand is the amount of oxygen consumed by microbial oxidation of wastewater in a 5-day period. It is used as an indicator of wastewater "strength". The BOD5 is proportional to the amount of organic matter in the water, and varies from country to country based on the quantity of water as well as diet.

[44] IPCC waste model available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol5.html

[45] *Scharff, H., Jacobs, J.*, Applying Guidance for Methane Emission Estimation for Landfills, Waste Management, Volume 26, Issue 4, 2006, pp 417-429.

[46] Brown, S., T. Pearson, A. Dushku, J. Kadyzewski, and Y. Qi. 2004. *Baseline Greenhouse Gas Emissions and Removals for Forest, Range, and Agricultural Lands in California.* Winrock International, for the California Energy Commission, PIER Energy-Related Environmental Research. 500-04-069F.

[47] SANDAG GIS shapefiles download available at: http://www.sandag.cog.ca.us/resources/maps_and_gis/gis_downloads/senlu.asp

[48] Statewide vegetation data with 100 m resolution available from CA DFFP's Fire and Resource Assessment Program (FRAP) available at: http://www.frap.fire.ca.gov/data/frapgisdata/download.asp?spatialdist=2&rec=fveg02_2

[49] Wiedinmyer, C., et al., *Estimating emissions from fires in North America for air quality modeling.* Atmospheric Environment, 2006. **40**: p. 3419-3432.

[50] Luo, H., Carbon Dynamics and Its Environmental Controls over Southern California Chaparral Ecosystems Using Eddy Covariance Techniques., Ph.D. thesis in Ecology. 2007, San Diego State University.

[51] SANDAG GIS land use data downloaded at:
http://www.sandag.cog.ca.us/resources/maps_and_gis/gis_downloads/landHistorical.asp (1990 - 2000)
http://www.sandag.cog.ca.us/resources/maps_and_gis/gis_downloads/land.asp (2004 - 2007)

[52] Schafer, E., SANDAG, personal communication to D.O. De Haan. GIS-compatible files posted to SANDAG ftp website: ftp://ftpx.sandag.org/pub/DEHAAN/ (2008)

[53] http://www.sangis.org/

[54] Crutzen, P.J. and M.O. Andreae, Biomass burning in the tropics: impact on atmospheric chemistry and biogeochemical cycles. Science, 1990. **250**: p. 1669-1677.

[55] See http://www.sdcounty.ca.gov/awm/crop_statistics.html.

[56] U.S. Department of Agriculture National Agricultural Statistics Service
http://www.nass.usda.gov/QuickStats/Create_County_Indv.jsp#top

[57] CARB describes its allocation of harbor craft to the ports. The vessels with home ports far away from navigable waters were assigned to the nearest port. Those that did not have a home port were assigned the port of the owner or operator. Those that had a home port outside California were assigned the port at which they landed their catch. See Appendix B, Emissions Estimation Methodology for Commercial Harbor Craft operating in California, 2007, provided by CARB and available at http://www.arb.ca.gov/regact/2007/chc07/appb.pdf.

[58] See Port of San Diego 2006 Emissions Inventory, 2007 at
http://www.portofsandiego.org/environment/clean-air.html#doc