November 2018

DVRPC

TECHNICAL MEMO

Energy Use and Greenhouse Gas Emissions Inventory for Greater Philadelphia: Methods and Sources

DELAWARE VALLEY REGIONAL PLANNING COMMISSION

The Delaware Valley Regional Planning Commission is the federally designated Metropolitan Planning Organization for a diverse nine-county region in two states: Bucks, Chester, Delaware, Montgomery, and Philadelphia in Pennsylvania; and Burlington, Camden, Gloucester, and Mercer in New Jersey.

DELAWARE VALLEY dvrpc REGIONAL PLANNING COMMISSION

DVRPC's vision for the Greater Philadelphia Region is a prosperous, innovative, equitable, resilient, and sustainable region that increases mobility choices by investing in a safe and modern transportation system; that protects and preserves our natural resources while creating healthy communities; and that fosters greater opportunities for all.

DVRPC's mission is to achieve this vision by convening the widest array of partners to inform and facilitate data-driven decision-making. We are engaged across the region, and strive to be leaders and innovators, exploring new ideas and creating best practices.

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DVRPC is funded through a variety of funding sources including federal grants from the U.S. Department of Transportation's Federal Highway Administration (FHWA) and Federal Transit Administration (FTA), the Pennsylvania and New Jersey departments of transportation, as well as by DVRPC's state and local member governments. The authors, however, are solely responsible for the findings and conclusions herein, which may not represent the official views or policies of the funding agencies.

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Introduction

This document provides an overview of the methods and sources used to produce DVRPC's *Energy Use and Greenhouse Gas Emissions Inventory for Greater Philadelphia*. That document, and additional information on DVRPC's inventory work, is available at www.dvrpc.org/EnergyClimate/Inventory

Tracking energy use, energy expenditures, and greenhouse gas (GHG) emissions is the first step toward developing informed regional and local policies to increase energy efficiency and reduce emissions.[1] The Delaware Valley Regional Planning Commission (DVRPC) periodically inventories Greater Philadelphia's energy use, energy expenditures, and GHG emissions. This inventory is allocated to the region's counties and municipalities. DVRPC's most recent inventory is for calendar year 2015, and updates previous inventories completed for 2010 and 2005.

DVRPC estimated energy use and GHG emissions associated with the residential, commercial, and industrial sectors, as well as transportation sectors (on-road transportation, passenger and freight rail, aviation, marine transportation, and off-road vehicles and equipment). DVRPC also included non-energy GHG emissions resulting from waste management (solid waste and wastewater), agricultural processes (animal- and plant-related), industrial processes, and fugitive and process emissions from natural gas and petroleum systems. DVRPC also estimated carbon dioxide (CO_2) taken up or released by the growth or loss of trees and forests.

Stationary Energy Use

Stationary energy use describes the energy used for all purposes other than transportation, including heating, cooling, and lighting buildings, and running machinery and appliances. This use category comprises both direct fuel consumption (e.g., burning of natural gas for home heating) and indirect fuel consumption (e.g., fuel consumed to generate electricity). Several generalized methods were applied to the residential and non-residential sectors to estimate energy use, GHG emissions, and fuel consumption.

Energy Use and Emissions from Electricity Generation

Generation of electricity for use in Greater Philadelphia consumes a variety of fuels, including fossil fuels. Combustion of fossil fuels for electricity generation causes emissions of the GHGs carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O).[2] DVRPC's process for estimating energy use and GHG emissions resulting from electricity generation included collection of consumption data, application of grid loss factors, application of average regional emissions factors, and fuel consumption and energy use estimates based on the electricity generation mix.

DVRPC obtained electricity consumption data from the region's electricity distribution companies and municipal utilities. Companies and municipal utilities that provided data included: PECO Energy Company (PECO), Public Service Enterprise Group (PSEG), PPL Electric Utilities Corporation, Metropolitan Edison, Atlantic City Electric, Jersey Central Power & Light (JCPL), Hatfield Borough, Lansdale Borough, Pemberton Borough, Perkasie Borough, and Quakertown Borough. These private and public utilities generally classified consumption as residential, commercial, or industrial, although some utilities combined commercial and industrial classifications to maintain customer confidentiality. The utilities aggregated consumption to either

[1] In the context of this document, "GHG emissions" or "emissions" will be used interchangeably to refer to greenhouse gas emissions, namely carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), and perfluorocarbons (PFCs).

[2] DVRPC did not estimate emissions from the electric power sector's use of SF_6, a potent GHG used as an insulator in high-voltage electrical equipment.

ZIP code areas or municipalities. DVRPC assigned consumption totals provided by ZIP code proportionally to municipalities based on 2010 U.S. Census Block populations.

To determine the amount of electricity generated to supply the DVRPC region, transmission and distribution losses must be taken into account. Thus, DVRPC multiplied electricity consumption in the region, as provided by the region's utilities, by an adjustment factor derived from the average of loss factors for the eastern grid provided by the U.S. Environmental Protection Agency's (U.S. EPA's) *Emissions & Generation Resource Integrated Database* (*eGRID*), eGRID2014 and eGRID2016 data.

Regional emissions rates are based on the mix of fuels used to generate electricity consumed in the region, which is located in the U.S. EPA's *eGRID* ReliabilityFirst Corporation (RFC) East subregion. This subregion comprises the eastern portion of the RFC's territory and contains much of Pennsylvania and New Jersey, and several other Mid-Atlantic states. For purposes of this analysis, the mix of fuels supplying the RFC East subregion is assumed to represent the generation mix supplying the DVRPC region. Thus, DVRPC determined GHG emissions by multiplying electricity generation in the DVRPC region by the RFC East subregion emissions rate for each GHG.

When electricity is generated, a large portion of the energy released from the combustion of fossil fuels and the fission of nuclear fuel is not converted into electricity. When DVRPC estimates energy use for the region, it considers all energy released by combustion or fission of a fuel, including both the energy that is converted to electricity and the energy that is not. In order to estimate energy use, DVRPC apportioned the total amount of electricity generated to source fuels according to the fuel mix identified for the RFC East subregion. For fossil fuels and biomass, DVRPC used the rate of electricity generation per energy unit released through combustion for fossil fuel steam-electric plants for 2015 as identified by the U.S. Energy Information Administration (U.S. EIA) in its *State Energy Data System* to determine the energy content of fossil fuels and biomass combusted. Similarly, DVRPC used the rate of electricity generation per energy unit release through fission for nuclear steam-electric plants as identified by the U.S. EIA to determine the energy content of fuel used in nuclear fission.

For fossil fuels for which the energy content per physical unit is documented in the U.S. EIA's *State Energy Data System* (i.e., coal, distillate fuel oil, and natural gas), DVRPC also calculated a total number of physical units consumed.

Energy Use and Emissions from Direct Fuel Consumption

Combustion of a variety of fuels, including natural gas, coal, distillate fuel oil, residual fuel oil, kerosene, liquefied petroleum gas (LPG; a.k.a., propane), motor gasoline, industrial petroleum feedstock, and other petroleum products, for heating and other purposes, causes emissions of CO_2, CH_4, and N_2O. DVRPC's process for estimating energy use and GHG emissions resulting from direct fuel consumption included collection of consumption data or development of consumption estimates, application of fuel physical unit-to-energy factors, and application of energy-to-emissions factors.

DVRPC obtained natural gas consumption data from natural gas utilities in the region. Companies that provided data included PECO, PSEG, Philadelphia Gas Works (PGW), South Jersey Gas, and AGL Resources (now Southern Company Gas). As with electricity, these utilities generally classified consumption as residential, commercial, or industrial, although some utilities combined commercial and industrial classifications to maintain customer confidentiality. The utilities aggregated consumption to either the ZIP code or municipal level. As with electricity, DVRPC assigned consumption totals provided by ZIP code proportionally to municipalities based on 2010 U.S. Census Block populations.

UGI Utilities, Inc., a natural gas provider with service territory in portions of Bucks, Montgomery, and Chester counties, did not provide data. To estimate residential consumption of natural gas in municipalities served by UGI in 2015, DVRPC calculated the natural gas usage per capita among municipalities for which natural gas consumption was available. Municipal populations were taken from DVRPC's *County and Municipal Population Forecasts, 2015-2045.* DVRPC then averaged this per capita consumption from three or more municipalities adjacent to municipalities served by UGI Utilities, Inc. DVRPC multiplied this average per capita natural gas consumption number to the population of the municipality served by UGI. DVRPC did not estimate non-residential natural gas consumption in UGI-served municipalities.

Procuring high-quality data regarding the direct consumption of fuels other than natural gas by residences and businesses is among the most challenging aspects of the regional inventory process. For these fuels (primarily heating oil, propane, kerosene, and coal), consumption data is not directly available. DVRPC estimated residential consumption for each fuel in each county by calculating the proportion of households in each county using a given fuel to the number of households in the state using that fuel according to the 2012–2016 *American Community Survey: 5-Year Estimates*. DVRPC then applied this proportion to total statewide residential consumption of that fuel to estimate county consumption. Statewide consumption totals were provided by the U.S. EIA's *State Energy Data System*. The same process was repeated at the municipal level.

For those commercial and industrial fuels that are also used in the residential sector (coal, distillate fuel oil, kerosene, and propane), DVRPC assumed the same level of use among businesses by employment as residences. For instance, if 3 percent of the households in a municipality used coal, it was assumed that 3 percent of total employment in commercial or industrial businesses used coal. The calculation was carried out statewide to determine the assumed proportion of the statewide employment using a given fuel. DVRPC then multiplied the proportion of employment within a municipality assumed to use a given fuel to statewide employment assumed to use a given fuel by total state usage of the given fuel by the commercial or industrial sectors, respectively.[3] This calculation provided an estimate of fuel consumption for a given fuel by the commercial and industrial sectors by municipality. Municipal totals were summed to determine county consumption totals. For fuels used in the industrial sector, but not in the residential sector (e.g., still gas, residual fuel oil), DVRPC estimated consumption based on the region, county, or municipality's share of overall employment.

To estimate energy use, DVRPC applied physical unit-to-energy factors for each fuel for 2015 derived from the U.S. EIA's *State Energy Data System*. DVRPC calculated emissions totals by multiplying these estimates of energy use by an energy-to-emission factor for each fuel from the U.S. EPA's *State Inventory Tool*.

Energy Use and Emissions from Steam Production

A steam loop in Center City Philadelphia and West Philadelphia, owned and operated by Veolia Energy, provides heat to a number of buildings, including Center City office buildings and the University of Pennsylvania. Facilities providing the steam to the system combust natural gas and distillate fuel oil to produce both steam and electricity. The U.S. EPA's *Greenhouse Gas Reporting Program (GHGRP)* provides emissions totals and subtotals for these facilities. DVRPC assumed any emissions reported as being from general stationary combustion (rather than from electricity generation) to be consumed in production of steam. However, this data did not allocate these emissions to fuel type.

In 2010, DVRPC received data from Veolia Energy via the City of Philadelphia of natural gas and distillate fuel consumption at the steam production facilities. However, these data were not available in 2015. Therefore, emissions by fuel type as well as energy and physical units of natural gas consumed were not available.

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[3] DVRPC used a slightly different method for the 2005 *Regional Greenhouse Gas Emissions Inventory*, one not indexed to an assumed level of statewide employment using a given fuel.

Results: Residential GHG Emissions, Energy Use, and Fuel Consumption

Total GHG Emissions:	15.4 Million Metric Tons of CO_2 Equivalent ($MMTCO_2e$)
	20.4 Percent of Gross GHG Emissions
Total Energy Use:	325,564 Billion British Thermal Units (BBTUs)
	27.7 Percent of Energy Use
Total Direct Fuel Consumption:	Electricity—17,033,400,457 Kilowatt Hours (kWh) (17,878,838,748 kWh generated)
	Natural Gas—115,884,602 Thousand Cubic Feet (MCF)
	Coal—Zero Short Tons
	Distillate Fuel Oil—4,967 Thousand Barrels
	Kerosene—67 Thousand Barrels
	Liquefied Petroleum Gas (Propane) — 1,233 Thousand Barrels

Results: Non-Residential GHG Emissions, Energy Use, and Fuel Consumption

Total GHG Emissions:	28.0 $MMTCO_2e$
	37.1 Percent of Gross GHG Emissions
Total Energy Use:	541,975 BBTUs
	46.2 Percent of Energy Use
Total Direct Fuel Consumption:	Electricity—34,910,791,941 kWh (36,643,559,298 kWh generated)
	Natural Gas—139,139,475 MCF
	Coal—278 Thousand Short Tons
	Distillate Fuel Oil—4,220 Thousand Barrels
	Kerosene—7 Thousand Barrels
	Liquefied Petroleum Gas (Propane) — 730 Thousand Barrels
	Residual Fuel Oil—42 Thousand Barrels
	Motor Gasoline—2,487 Thousand Barrels
	Petroleum Coke—15,067 Thousand Barrels
	Still Gas—25,629 Thousand Barrels
	Special Naphthas—74 Thousand Barrels

Mobile Energy Use

Mobile energy use describes the energy used for transportation and in other non-stationary applications, such as off-road vehicles and equipment. This use category comprises both direct fuel consumption (e.g., combustion of gasoline in vehicles) and indirect fuel consumption (e.g., fuel consumed to generate electricity for electric railways).

Energy Use and Emissions from On-Highway Vehicles

The combustion of petroleum-based fuels and natural gas in motor vehicles results in emissions of CO_2, CH_4, and N_2O. DVRPC used its regional travel demand model, the U.S. Federal Highway Administration's Highway Performance Monitoring System (HPMS), and the U.S. EPA's Motor Vehicle Emission Simulator (*MOVES2014a*) to calculate emissions. DVRPC's Office of Modeling and Analysis provided annual average daily vehicle miles traveled (VMT) by county and vehicle class for 2015 derived from the DVRPC regional travel demand model and scaled to match overall VMT calculated for the region by the HPMS. The Office of Modeling and Analysis then applied per VMT energy use and emissions factors from *MOVES2014a*. *MOVES2014a* uses a variety of factors, including vehicle age, activity, and fuel types to establish these factors. DVRPC used a similar method for the *Energy Use and Greenhouse Gas Emissions in Greater*

Philadelphia, 2010; however, DVRPC updated its travel demand model and the U.S. EPA updated its emissions simulator in the intervening years.

Energy use and emissions were allocated to counties and municipalities according to the end-points for the predicted trips. DVRPC allocated half of the VMT, and consequently half of the energy use and emissions, resulting from a particular trip to the municipality in which the trip began and half to the municipality where it ended. For trips beginning and ending in the same municipality, all energy use and emissions were allocated to that municipality. For trips that either begin or end out of region, DVRPC's travel demand model provides estimates of trip lengths. DVRPC allocated half of the emissions from these trips to the municipality of origin or destination in the region. DVRPC did not evaluate through trips (trips with an origin and destination outside of the region). County VMT, energy use, and emissions allocations are simply the sum of the VMT allocated to all the municipalities in each county.

DVRPC estimated fuel consumption using a distribution of energy use by fuel type available for each county in the region from *MOVES2014a* and energy-to-physical factors derived from the U.S. EIA's *State Energy Data System*.[4]

DVRPC did not include energy use and emissions from electricity generation for plug-in electric vehicles in this energy use and emissions category. Energy use and emissions from these vehicles were included in DVRPC's calculation of energy use and emissions from electricity generation for the residential ("at home" charging) and non-residential ("at work" charging) sectors (see the "Energy Use and Emissions from Electricity Generation" section).

Though vehicles could emit GHGs in the form of leaks of ozone-depleting substances substitutes from air conditioning systems, DVRPC did not include emissions from leakage of ozone-depleting substances substitutes in this energy use and emissions category. These emissions were included in DVRPC's general calculation of emission of ozone-depleting substances substitutes (see the "Emissions from Ozone-Depleting Substances Substitutes" section).

Results: On-Highway Vehicle GHG Emissions, Energy Use, and Fuel Consumption

Total GHG Emissions:	17.9 $MMTCO_2e$
	23.8 Percent of Gross GHG Emissions
Total Energy Use:	306,433 BBTUs
	26.1 Percent of Energy Use
Total Direct Fuel Consumption:	Motor Gasoline—36,010 Thousand Barrels
	Distillate Fuel Oil—8,646 Thousand Barrels
	Natural Gas—179,292 MCF

Energy Use and Emissions from Freight Rail

The combustion of petroleum-based fuel to power diesel locomotives used to transport goods and materials into and out of the nine-county DVRPC region causes emissions of CO_2, CH_4, and N_2O. DVRPC derived an estimate of regional GHG emissions from freight rail using the 2015 estimate of national freight rail emissions calculated by the U.S. EPA for its *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2016*. DVRPC attributed national emissions to the region in proportion to freight rail tonnage destined for and originating from the region. DVRPC used a similar method for its 2010 *Regional Greenhouse Gas Emissions Inventory*.

[4] Subdivisions of the three fuels into their petrochemical and biodiesel or ethanol components were not available.

DVRPC obtained estimates of freight flow tonnage from the *Freight Analysis Framework Version 4* (FAF), which provides estimated tonnage of goods shipped by type of commodity and mode of transportation between 132 geographic areas in 2015. Data from the 2012 *Commodity Flow Survey* and other components of the *Economic Census* underlie this estimate. From the total U.S. freight rail tonnage estimates provided by the FAF, DVRPC selected those attributable to the Greater Philadelphia region (those originating in or destined for the region).[5] To avoid double counting flows attributed to the region using this calculation, DVRPC halved the resulting regional total freight tonnage, attributing half to the region and half to regions containing the trips' other end-points. DVRPC divided regional tonnage by total national tonnage to determine a regional proportion of total national freight flows via rail. DVRPC then multiplied total GHG emissions estimates resulting from freight rail as reported in the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2016* by this proportion to estimate emissions from freight rail attributable to the region.

To estimate energy use attributable to this activity, DVRPC used the emissions-to-energy conversion factor for diesel fuel derived from the U.S. EPA's *State Inventory Tool*. DVRPC used the energy-to-physical unit conversion factor derived from the U.S. EIA's *State Energy Data System* to estimate the total barrels of diesel fuel consumed.

These estimates do not include any emissions resulting from through traffic. DVRPC did not allocate freight rail energy use, fuel consumption, or emissions to counties or municipalities.

Results: Freight Rail GHG Emissions, Energy Use, and Fuel Consumption

Total GHG Emissions:	0.3 $MMTCO_2e$
	0.3 Percent of Gross GHG Emissions
Total Energy Use:	3,525 BBTUs
	0.3 Percent of Energy Use
Total Direct Fuel Consumption:	Distillate Fuel Oil—611 Thousand Barrels

Energy Use and Emissions for Intercity Passenger Rail

Generation of electricity consumed by electric locomotives used to move passengers into and out of the region results in emissions of CO_2, CH_4, and N_2O. Combustion of fuel by diesel locomotives and by associated support equipment also causes emissions of CO_2, CH_4, and N_2O. For purposes of this inventory, intercity passenger travel (defined as travel into and out of the region) is distinguished from transit (defined as entirely or mostly within the region). For purposes of this inventory, Amtrak is considered the sole provider of intercity passenger rail service, while all non-Amtrak service in the DVRPC region is considered transit (see the "Energy Use and Emissions from Transit Rail" section). DVRPC derived a regional estimate of energy use, fuel consumption, and GHG emissions due to intercity rail from data on diesel and electricity consumption provided by Amtrak.

Amtrak provided DVRPC with the total annual 2015 electricity consumption for its service in the Northeast Corridor (from New York's Penn Station to Washington, DC's Union Station, and from Philadelphia's 30th Street Station to the Amtrak station in Harrisburg, Pennsylvania). Using train schedules for 2015 and regional mapping of rail lines, DVRPC determined the proportion of route miles operated within DVRPC's region (using electric traction) in 2015 to those operated in the broader Northeast Corridor. DVRPC multiplied this

[5] The Philadelphia PA-NJ-DE-MD Combined Statistical Area (CSA), the FAF geographic division most similar to DVRPC's nine-county region, was used for this analysis. This CSA, which includes counties in Maryland, Delaware, New Jersey, and Pennsylvania not otherwise part of the DVRPC region, likely results in an overestimate of freight flows destined for and originating from the nine-county region.

proportion by Amtrak's total annual electricity consumption amount for its service in the Northeast Corridor to determine a regional portion.

DVRPC estimated energy use and emissions resulting from electricity generation using the same methods described previously (see the "Energy Use and Emissions from Electricity Generation" section).

Amtrak also provided an estimate of diesel consumed per mile for its diesel locomotives engaged in intercity passenger rail service nationwide. For each train using diesel traction, DVRPC multiplied total route miles that trains operated in the DVRPC region in 2015 to determine diesel fuel consumption. Amtrak also provided an estimate of fuel consumed by diesel switchers operated in the region on a per hour basis. DVRPC multiplied this fuel consumption factor by the number of switchers operating in the region in 2015 and the average number of hours each of those switchers operated.

DVRPC calculated energy use and emissions from diesel consumption using fuel consumption-to-energy content factors derived from the U.S. EIA's *State Energy Data System* and energy-to-emissions factors derived from the U.S. EPA's *State Inventory Tool*.

DVRPC did not further allocate emissions, fuel consumption, and energy use due to intercity passenger rail activity to counties and municipalities in this inventory.

Results: Intercity Passenger Rail GHG Emissions, Energy Use, and Fuel Consumption

Total GHG Emissions:	Less than 0.1 $MMTCO_2e$
	Less than 0.1 Percent of Gross GHG Emissions
Total Energy Use:	971 BBTUs
	Less than 0.1 Percent of Energy Use
Total Direct Fuel Consumption:	Electricity—93,510,560 kWh (99,203,409 kWh generated)
	Distillate Fuel Oil—Three Thousand Barrels

Energy Use and Emissions from Transit Rail

Generation of electricity used to power electric locomotives used to transport passengers within the region results in emissions of CO_2, CH_4, and N_2O. Combustion of petroleum-based fuels to power diesel locomotives used to transport passengers within the region also causes emissions of CO_2, CH_4, and N_2O. For purposes of this inventory, transit (defined as within region or regionally based rail travel) is distinguished from intercity rail (defined as travel into and out of the region). DVRPC derived a regional estimate of energy use and GHG emissions due to transit rail from data on fuel consumption available via the National Transit Database. DVRPC used a similar method for the *Energy Use and Greenhouse Gas Emissions in Greater Philadelphia, 2010*.

The National Transit Database provides fuel consumption data for each major transit rail operator in the nine-county DVRPC region. These are the Southeastern Pennsylvania Transportation Authority (SEPTA), the Port Authority Transit Corporation (PATCO), and NJ TRANSIT. For purposes of this inventory, NJ TRANSIT is considered to provide transit rail service, though it does provide some service from the DVRPC region to cities outside of the DVRPC region, such as Newark, New Jersey; and New York City. Similar to calculations for intercity passenger rail, DVRPC only calculates energy use and emissions for NJ TRANSIT's operations within the region.

Each of the transit agencies operates one or more modes tracked by the National Transit Database—including light rail, heavy rail, hybrid rail, streetcar rail, and commuter rail—and uses diesel or electric motive power or some combination of the two. DVRPC assumed all of SEPTA's and PATCO's operations to be within the DVRPC region (although one SEPTA line does run into Delaware). However, DVRPC used the following assumptions, provided by NJ TRANSIT, to calculate its fuel consumption in the DVRPC region:

- **6 percent of NJ TRANSIT's commuter rail electricity use occurs in the DVRPC region;**
- **0.5 percent of NJ TRANSIT's commuter rail diesel use occurs in the DVRPC region;**
- **0.0 percent of NJ TRANSIT's light rail electricity use occurs in the DVRPC region;**
- **0.0 percent of NJ TRANSIT's hybrid rail electricity use occurs in the DVRPC region; and**
- **100 percent of NJ TRANSIT's hybrid rail diesel use occurs in the DVRPC region.**

DVRPC estimated energy use and emissions resulting from electricity generation using the same methods described previously (see the "Energy Use and Emissions from Electricity Generation" section).

For diesel fuel consumption, DVRPC calculated energy consumption using fuel consumption-to-energy factors derived from the U.S. EIA's *State Energy Data System*. DVRPC calculated emissions using energy-to-emissions factors derived from the U.S. EPA's *State Inventory Tool*.

DVRPC allocated fuel consumption, energy use, and GHG emissions to municipalities based on the proportion of a municipality's rail transit users to all rail transit users in the region derived from estimates of workers 16 years and older using some sort of rail transit (e.g., streetcar, subway, railroad) to travel to work according to the 2012–2016 *American Community Survey: 5-Year Estimates*.

Results: Transit Rail GHG Emissions, Energy Use, and Fuel Consumption

Total GHG Emissions:	0.2 $MMTCO_2e$
	0.2 Percent of Gross GHG Emissions
Total Energy Use:	4,585 BBTUs
	0.4 Percent of Energy Use
Total Direct Fuel Consumption:	Electricity—447,249,502 kWh (469,448,350 kWh generated)
	Distillate Fuel Oil—18 Thousand Barrels

Energy Use and Emissions from Commercial Aviation

The combustion of jet fuel by commercial aircraft causes emissions of CO_2, CH_4, and N_2O. To estimate regional energy use and GHG emissions associated with commercial air traffic, DVRPC apportioned the national estimate of emissions due to commercial air traffic to the region in accordance with its share of total flight miles traveled. DVRPC used a similar method in DVRPC's *Energy Use and Greenhouse Gas Emissions in Greater Philadelphia 2010*.

The U.S. Bureau of Transportation Statistics maintains a database of commercial flights arriving at or departing from each of the nation's airports. For each airport pair, the database reports the number of flights in a selected year and the distance in flight miles between those airports. DVRPC calculated total flight miles associated with commercial flights arriving at or departing from airports in the DVRPC region in 2015 by selecting all flight pairings from that year that included these airports and multiplying the number of flights by the flight miles provided. In 2015, airports in the DVRPC region with commercial activity included Heritage Field (PTW), North Philadelphia (PNE), Philadelphia International (PHL), Toughkenamon (PA7), and Trenton-Mercer (TTN). DVRPC similarly calculated total national flight miles flown in 2015 by multiplying the number of flights between each airport pair in the database by the flight mile distance between them. DVRPC included both domestic and international flights beginning and/or ending in the United States.

For domestic flights, DVRPC halved the total number of flight miles associated with flights beginning or ending in the DVRPC region, so as to equally attribute these flight miles between the DVRPC region and the origin or destination regions of these flights. DVRPC then multiplied the proportion of DVRPC region flight miles to national flight miles by total national CO_2, CH_4, and N_2O emissions from commercial aircraft as reported for 2015 in the U.S. EPA's *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2016* to determine the DVRPC region's share of emissions resulting from commercial aircraft activity.[6]

For international flights, the U.S. EPA's *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2016* only estimates emissions from commercial aviation bunker fuels loaded in the United States, presumably for flights departing the United States. The U.S. EPA estimates commercial aviation bunker fuels loaded elsewhere, presumably on flights bound for the United States. Thus, DVRPC did not halve the total number of flight miles with international flights beginning or ending in the DVRPC region. DVRPC assumed fuel consumed on inbound flights would be roughly equal to fuel consumed on outbound flights, thus the lack of this data negated the need to attribute half of all flight miles to the region of origin and half to the region of destination. DVRPC then multiplied the proportion of DVRPC region international flight miles to nationwide international flight miles by total national CO_2, CH_4, and N_2O emissions from commercial aviation bunker fuels loaded in the United States as reported for 2015 in the U.S. EPA's *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2016* to determine the DVRPC region's share of emissions resulting from commercial aircraft activity.[7]

To estimate energy use attributable to this activity, DVRPC used an emissions-to-energy conversion factor for jet fuel from the U.S. EPA's *State Inventory Tool*. DVRPC used a heat-to-physical unit conversion factor for jet fuel from the U.S. EIA's *State Energy Data System* to estimate the total number of barrels of jet fuel consumed.

DVRPC did not allocate energy use or GHG emissions from commercial aircraft activity to counties or municipalities.

Results: Commercial Aviation GHG Emissions, Energy Use, and Fuel Consumption

Total GHG Emissions:	3.71 $MMTCO_2e$
	4.9 Percent of Gross GHG Emissions
Total Energy Use:	50,857 BBTUs
	4.3 Percent of Energy Use
Total Direct Fuel Consumption:	Jet Fuel—8,969 Thousand Barrels

Energy Use and Emissions from General Aviation

The combustion of jet fuel and aviation gasoline used by general aviation aircraft results in emissions of CO_2, CH_4, and N_2O. To estimate regional energy use and GHG emissions associated with general aviation activity, DVRPC apportioned the national estimate of emissions from general aviation aircraft to the region in accordance with its share of general aviation take-offs and landings. DVRPC used the same method in DVRPC's *Energy Use and Greenhouse Gas Emissions in Greater Philadelphia, 2010*.

DVRPC carries out an aircraft counting program that measures activity at the region's non-towered airports. In combination with data provided by the region's towered airports (Philadelphia International Airport and Trenton–Mercer Airport), the aircraft counting program allows for an estimate of all general aviation take-

[6] As a result of this inventory's use of national commercial aviation CO_2, CH_4, and N_2O emission totals, local factors (which could include in-air or on-the-ground aircraft congestion and long taxiing times or the lack thereof) are not considered except insofar as they affect national totals.

[7] As a result of this inventory's use of national commercial aviation CO_2, CH_4, and N_2O emission totals, local factors (which could include in-air or on-the-ground aircraft congestion and long taxiing times or the lack thereof) are not considered except insofar as they affect national totals.

offs and landings in the region.[8] Using counts like DVRPC's along with data from towered airports, the Federal Aviation Administration estimates total national general aviation take-offs and landings. The U.S. EPA, in its *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2016*, provides nationwide estimates of CO_2, CH_4, and N_2O emissions from general aviation aircraft using jet fuel and aviation gasoline. By multiplying these nationwide estimates of emissions by the proportion of regional landings and take-offs to national landings and take-offs, DVRPC calculated a regional share of general aviation emissions from each fuel source.

To estimate energy use attributable to this activity, DVRPC used an emissions-to-energy conversion factor for each fuel type derived from the U.S. EPA's *State Inventory Tool*. DVRPC used an energy-to-physical unit conversion factor for each fuel from the U.S. EIA's *State Energy Data System* to estimate the total number of barrels of jet fuel and aviation gasoline consumed.

DVRPC did not allocate energy use and GHG emissions from general aviation activity to counties or municipalities.

Results: General Aviation GHG Emissions, Energy Use, and Fuel Consumption

Total GHG Emissions:	0.2 $MMTCO_2e$
	0.3 Percent of Gross GHG Emissions
Total Energy Use:	2,691 BBTUs
	0.2 Percent of Energy Use
Total Direct Fuel Consumption:	Jet Fuel—447 Thousand Barrels
	Aviation Gasoline—31 Thousand Barrels

Energy Use and Emissions from Marine and Port-Related Activities

For the 2005 *Regional Greenhouse Gas Emissions Inventory,* DVRPC estimated the physical units of fuel consumed, energy used, and GHGs emitted by marine vessels and associated port activities in the DVRPC region using results of an unpublished survey developed by the U.S. EPA.[9] For the 2010 inventory*,* DVRPC adjusted these 2005 estimates in proportion to the overall change in ship arrivals between 2005 and 2010. For 2015, DVRPC adjusted these values again based on the difference in ship arrivals between 2010 and 2015. This category of the inventory includes fuel consumption, energy use, and emissions estimates for ocean-going vessels, harbor craft, port-side cargo-handling equipment, and heavy trucks idling in the port area. In addition to emissions directly within a port area, DVRPC also included fuel consumption, energy use, and emissions of ships in transit within the Delaware Bay area.

Between 2010 and 2015, ship arrivals at the region's ports increased from 1,757 to 1,965 or by 11.84 percent.[10] The 2005 inventory calculated the energy content of the fuel consumed by ocean-going vessels, harbor craft, cargo-handling equipment, and idling heavy trucks. To determine emissions produced, energy generated, and number of physical units combusted, DVRPC assumed energy use by these vehicles and equipment will increase or decrease based on the percentage change between years. Since ship arrivals

[8] DVRPC's Aircraft Operations Counting Program performs counts at the region's 17 non-towered airports on a rotating basis. Each cycle takes approximately three years to complete. For the purposes of this inventory, the landing and take-off counts for years closest to 2015 were used to estimate general aviation emissions attributable to the region.

[9] While the U.S. EPA has not published its 2005 estimate of emissions for marine vessels and associated activity in the DVRPC region, this unpublished data is the most comprehensive effort to estimate emissions from the region's ports.

[10] Maritime Exchange for the Delaware River and Bay, *Annual Summary of Cargo and Piers (2015)* (Philadelphia: Maritime Exchange for the Delaware River and Bay, 2016).

increased by 11.84 percent between 2010 and 2015, DVRPC assumed proportional increases in fuel consumed and emissions produced.

DVRPC used energy-to-physical unit conversion factors for distillate fuel oil and residual fuel oil from the U.S. EIA's *State Energy Data System* to estimate the total number of barrels of these fuels consumed. DVRPC used an energy-to-emissions conversion factor for each fuel type derived from the U.S. EPA's *State Inventory Tool* to calculate CO_2, CH_4, and N_2O emitted.

In the absence of more detailed data, this method assumes a direct relationship between the arrival of ocean-going vessels at the region's ports and energy use. A more detailed analysis could reveal changes in ship types, engine efficiency, and other factors that could affect this relationship. This method also assumes a direct relationship between ocean-going vessel arrival activity and the activity of harbor craft, cargo-handling equipment, and idling heavy trucks.

Results: Marine and Port-Related Activities GHG Emissions, Energy Use, and Fuel Consumption

Total GHG Emissions:	0.3 $MMTCO_2e$
	0.4 Percent of Gross GHG Emissions
Total Energy Use:	4,076 BBTUs
	0.3 Percent of Energy Use
Total Direct Fuel Consumption:	Distillate Fuel Oil—321 Thousand Barrels
	Residual Fuel Oil—353 Thousand Barrels

Energy Use and Emissions from Off-Road Vehicles and Equipment

Combustion of petroleum-based fuels by off-road vehicles and equipment produces emissions of CO_2, CH_4, and N_2O. Off-road vehicles and equipment are vehicles and equipment operating in areas other than the region's public roadways. These can include off-road recreation vehicles, for instance, as well as equipment used for lawn and garden care. DVRPC derived a regional estimate of energy use and GHG emissions from the U.S. EPA's *MOVES2014a*. This differs from the method used for the 2005 *Regional Greenhouse Gas Emissions Inventory* and the *Energy Use and Greenhouse Gas Emissions in Greater Philadelphia, 2010,* both of which used the 2008 edition of the U.S. EPA's *Nonroad Emissions Model* (*NONROAD2008*). *NONROAD2008* has now been incorporated into *MOVES2014a*.

MOVES2014a estimates CO_2 exhaust emissions along with several other pollutants based on estimates of the number of vehicles and equipment in the region and a set of parameters that describe fuel and weather statistics for the time period of interest. DVRPC calculated emissions estimates for each county by vehicle and equipment type. DVRPC included in these estimates off-road recreation vehicles, lawn and garden equipment, and pleasure craft. DVRPC excluded agriculture equipment, airport support equipment, commercial equipment, construction equipment, industrial equipment, logging equipment, oil field equipment, railway equipment, and underground mining equipment, as energy use and emissions for these categories are included in the commercial, industrial, and freight/passenger rail sections of the inventory.

DVRPC ran *MOVES2014a* using default fuel parameters provided by the program.

Using the CO_2 emissions output from the *MOVES2014a,* DVRPC estimated energy use using emissions-to-energy factors derived from the U.S. EPA's *State Inventory Tool*. DVRPC estimated physical units of fuel consumed and emissions produced using energy-to-fuel consumption factors derived from the U.S. EIA's *State Energy Data System*. Lastly, DVRPC estimated CH_4 and N_2O emissions using fuel consumption-to-emissions factors derived from the *State Inventory Tool*, which allowed a conversion from physical units of fuel consumed to CH_4 and N_2O emitted. These were added to CO_2 emissions to calculate total emissions. County totals were added to get a regional total.

Results: Off-Road Vehicles and Equipment GHG Emissions, Energy Use, and Fuel Consumption

Total GHG Emissions:	0.52 $MMTCO_2e$
	0.7 Percent of Gross GHG Emissions
Total Energy Use:	6,962 BBTUs
	0.6 Percent of Energy Use
Total Direct Fuel Consumption:	Motor Gasoline—1,194 Thousand Barrels
	Distillate Fuel Oil—154 Thousand Barrels
	Liquefied Petroleum Gas (Propane)—9 Thousand Barrels

Other Emissions and Sequestration Sources

Other emissions and sequestration sources include sources of emissions and sequestration not related to energy use. This emissions category comprises emissions from industrial processes, fuel refining and distribution, agriculture, and waste decomposition. It also includes emissions and sequestration resulting from changes in the amount of the region's forested acres and the year-on-year sequestration of carbon in growing trees.

Though some facilities producing emissions as a result of industrial processes and fuel refining also produce emissions as a result of fuel combustion, these two types of emissions are classified separately in this inventory. Methods and sources for estimating emissions from combustion are described in the "Stationary Energy Use" section. Methods and sources estimating emissions from industrial processes and refining are described below.

Emissions from Natural Gas Transmission and Distribution

The production, transmission, and distribution of natural gas result in CH_4 emissions. This includes so-called "fugitive" emissions from leaks in drilling apparatus, processing, and pipelines. Minimal natural gas production occurs in the DVRPC region, so DVRPC considers only transmission and distribution in this inventory. To estimate emissions in the DVRPC region, DVRPC divided total national emissions from transmission and distribution of natural gas as reported in the U.S. EPA's *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2016* by national consumption as reported by the U.S. EIA. This provides an implied emission factor of CH_4 emitted per million cubic feet of natural gas consumed, which DVRPC applied to natural gas consumption totals for the region, counties, and municipalities.[11] DVRPC used the same method in *Energy Use and Greenhouse Gas Emissions in Greater Philadelphia, 2010.*

Results: Natural Gas Transmission and Distribution GHG Emissions

Total GHG Emissions:	0.4 $MMTCO_2e$
	0.6 Percent of Gross GHG Emissions

[11] An alternative approach would calculate process emissions from distribution of natural gas using data on the total length of pipeline by type within a given natural gas distribution utility's distribution network and emission factors for these pipeline types. DVRPC did not adopt this approach due to the difficulty of assembling region wide comprehensive pipeline data.

Emissions from Hydrogen Production

Depending on the raw material used, the production of hydrogen for subsequent production of ammonia and other chemicals or for use in petroleum refining, metals treating, and food processing, results in the emission of CO_2 and other greenhouse gases.[12]

DVRPC estimated direct emissions of GHGs associated with hydrogen production in the DVRPC region using data from the U.S. EPA's *GHGRP*.[13] This program requires emitters from a variety of industrial sectors to report annual GHG emissions and then makes this information available publicly.

To determine total regional emissions, DVRPC tallied hydrogen production emissions reported in the *GHGRP* database for each reporting source within the DVRPC region. DVRPC allocated emissions from hydrogen production to the region's counties and municipalities in accordance with the physical locations of the facilities and their emissions as reported by the *GHGRP*.

The 2015 energy use and greenhouse gas emissions inventory is the first to include emissions from hydrogen production, though the estimation method used is very similar to the method used to estimate emissions from petroleum refining and iron and steel production in 2010.

Results: Hydrogen Production GHG Emissions

Total GHG Emissions:	0.01 $MMTCO_2e$
	0.01 Percent of Gross GHG Emissions

Emissions from Iron and Steel Production

The production of iron and steel causes emissions of CO_2 and CH_4. A variety of individual manufacturing processes are responsible for these emissions, including the production of pig iron in blast furnaces or through direct reduction, sintering, production of steel in basic oxygen furnaces and electric arc furnaces, and consumption of process byproducts for various purposes.[14]

DVRPC estimated direct emissions of GHGs associated with iron and steel production processes in the DVRPC region using data from the U.S. EPA's *GHGRP*. For iron and steel production this includes all facilities producing 25,000 metric tons of CO_2e per year.[15]

To determine total regional emissions, DVRPC tallied iron and steel production emissions reported in the *GHGRP* database for each reporting source within the DVRPC region. DVRPC allocated emissions from iron and steel production to the region's counties and municipalities in accordance with the physical locations of the facilities and their emissions as reported by the *GHGRP*.

DVRPC used the same method for its 2010 estimate of emissions from iron and steel production, but this method differs from that used in DVRPC's 2005 *Regional Greenhouse Gas Emissions Inventory*. For 2005, DVRPC calculated emissions from iron and steel production by multiplying total national emissions due to iron and steel production by the proportion of regional firms to national firms in this sector according to the

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[12] U.S. Department of Energy Fuel Cell Technologies Office, "Hydrogen Production: Natural Gas Reforming", https://energy.gov/eere/fuelcells/hydrogen-production-natural-gas-reforming and U.S. Environmental Protection Agency, *2013 GHGRP Industrial Profiles: Chemicals* (Washington, DC: U.S. Environmental Protection Agency), 19.
[13] More information about the U.S. EPA's *GHGRP*, as well as associated data sets, is available at: www.epa.gov/ghgreporting/index.html.
[14] U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2010*, 4-42, 4-43.
[15] U.S. Environmental Protection Agency, *Greenhouse Gas Reporting Program*, "Who Reports," www.ccdsupport.com/confluence/pages/viewpage.action?pageId=93290546 (accessed September 28, 2012).

U.S. Census Bureau's *County Business Patterns* database. The U.S. EPA *GHGRP* was not in place when DVRPC's 2005 inventory was completed.

Results: Iron and Steel Production GHG Emissions

Total GHG Emissions: 0.05 $MMTCO_2e$
0.1 Percent of Gross GHG Emissions

Emissions from Petroleum Refining

The production, refining, and transportation of petroleum products result in the emissions of CO_2 and CH_4. A variety of processes are responsible for these emissions, including the venting CH_4 and CO_2. Emissions also result from equipment leaks and evaporation ("fugitive" emissions) and disruptions to production and manufacturing processes that cause unintentional releases.[16]

Of the main petroleum system activities, only refining is likely to result in emissions in the DVRPC region.[17] DVRPC estimated direct emissions of GHGs associated with petroleum refining processes in the DVRPC region using data from the U.S. EPA's *GHGRP*.[18] This program requires emitters from a variety of industrial sectors to report annual GHG emissions and then makes this information available publicly.

To determine total regional emissions, DVRPC tallied petroleum refining emissions reported in the *GHGRP* database for each reporting source within the DVRPC region. DVRPC allocated emissions from petroleum refining to the region's counties and municipalities in accordance with the physical locations of the reporting facilities and their emissions as reported by the *GHGRP*.

DVRPC used the same method for its 2010 estimate of emissions from petroleum refining processes, but this method differs from that used in DVRPC's 2005 *Regional Greenhouse Gas Emissions Inventory*. For 2005, DVRPC calculated emissions from petroleum systems by multiplying total national emissions from petroleum systems by the proportion of regional refining capacity to national refining capacity as reported in the U.S. EIA's *Refining Capacity Report*. The U.S. EPA's *GHGRP* was not in place when DVRPC's 2005 inventory was completed.

Results: Petroleum Refining GHG Emissions

Total GHG Emissions: 2.45 $MMTCO_2e$
3.2 Percent of Gross GHG Emissions

Emissions from Ozone-Depleting Substances Substitutes

The *Montreal Protocol on Substances that Deplete the Ozone Layer* and the *Clean Air Act Amendments of 1990* have caused several classes of ozone-depleting substances to be phased out and made others subject to production and trade restrictions and eventual phase-out. Replacements for these substances, while not harmful to the stratospheric ozone layer, do have strong global warming effects.

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[16] U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2010* (Washington, D.C.: U.S. Environmental Protection Agency, 2012), 3-50, 3-51.

[17] Fugitive emissions from natural gas distribution systems are accounted for in the natural gas systems process emissions portion of the inventory.

[18] More information about the U.S. EPA's *GHGRP*, as well as associated data sets, is available at: www.epa.gov/ghgreporting/index.html.

These replacements, widely used in refrigerators, air conditioners, fire extinguishers, foams, aerosols, and other products, include HFCs and PFCs.[19] Emissions can be released during the manufacturing, testing, use, and disposal of these products. Because their use is widespread and the methods and data needed to estimate emissions from this sector on the national level are complex, DVRPC used a population-based model to allocate national emissions to the region.

DVRPC allocated total national ozone-depleting substances substitute emissions to the region in proportion to the region's proportion of national population. The U.S. EPA suggests a similar methodology in its *State Inventory Tool*.[20] DVRPC calculated county allocations based on county populations and municipal allocations based on municipal populations. DVRPC used the same method in to estimate emissions from ozone-depleting substances in 2005 and 2010.

Results: Ozone-Depleting Substances Substitutes GHG Emissions

Total GHG Emissions: 3.0 $MMTCO_2e$
4.0 Percent of Gross GHG Emissions

Emissions from Municipal Solid Waste Landfilling

Municipal solid waste management in landfills can result in the emission of CH_4 due to the anaerobic decomposition of the organic matter in waste that takes place in landfills. Landfill decomposition also produces CO_2 as carbon is released from organic materials. This CO_2 is considered biogenic, resulting from the Earth's natural carbon cycle, and not a result of the release of long-sequestered carbon in fossil fuels like coal, petroleum, and natural gas. Consistent with national and international conventions, DVRPC does not include these CO_2 emissions from decomposition of waste in landfills in its calculation of emissions.

Incineration of waste also results in emissions, especially of CO_2. However, all waste incineration in the DVRPC region is used to produce electricity and thus those emissions are accounted for in the portions of the inventory which consider emissions due to electricity generation. DVRPC estimated landfill CH_4 emissions using the first order decay equation presented in the U.S. EPA's AP-42 guidance and implemented in the U.S. EPA's *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2010* and *State Inventory Tool*. DVRPC used the same method in the 2005 *Regional Greenhouse Gas Emissions Inventory.*

The first order decay equation is:

$$Q_{Tx} = A \times k \times R_x \times L_o \times e^{-k(T - x)}$$

Where:

- Q_{Tx} = Amount of CH_4 generated in year T by the waste R_x,
- T = Current year,
- x = Year of waste input,
- A = Normalization factor, $(1-e^{-k})/k$,
- k = CH4 generation rate (yr^{-1}),
- R_x = Amount of waste landfilled in year x,
- L_o = CH_4 generation potential.

[19] U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2010*, 4-70.
[20] U.S. Environmental Protection Agency, "Industrial Process Module," in *State Inventory Tool* (October 1, 2017).

This model functions by estimating annual landfill deposits for the time period 1960–2010 to predict resulting emissions. DVRPC estimated annual landfill deposits based on population counts provided by the U.S. Census Bureau and per capita waste generation factors provided by the *State Inventory Tool*.[21,22]

Many of the region's landfills are equipped with landfill gas-management systems. DVRPC used the U.S. EPA's *Landfill Methane Outreach Program* database to determine emissions avoided in 2015 based on projects that were collecting landfill gas at that time in the DVRPC region. DVRPC subtracted this amount from total potential CH_4 generation to determine net estimated regional landfill CH_4 emissions.

To allocate landfill emissions to the counties, DVRPC assumed emission reductions due to landfill gas-management systems were shared in proportion to a county's portion of regional landfill CH_4 emissions. Thus DVRPC subtracted this offset from each county's gross estimated landfill CH_4 emissions. DVRPC based municipal allocations on the proportion of each municipality's population to county populations.[23]

It is important to note that this overall approach estimates current emissions due to historical solid waste generation. This is appropriate because as solid waste decomposes over time it releases CH_4, and the purpose of this inventory is to calculate current emissions due to activity, both current and historic, in the DVRPC region. However, an alternative approach could calculate future emissions due to current solid waste generation.

Results: Municipal Solid Waste Landfill GHG Emissions

Total GHG Emissions: 2.0 $MMTCO_2e$
2.7 Percent of Gross GHG Emissions

Emissions from Wastewater Treatment

Wastewater treatment causes emissions of CH_4 and N_2O. CH_4 emissions result from anaerobic treatment of organic matter and N_2O emissions result from centralized wastewater treatment processes and from the effluent of centralized treatment systems discharged into aquatic environments. Though CO_2 is also produced during wastewater treatment, consistent with national and international conventions DVRPC does not include these CO_2 emissions from decomposition of waste in its calculation of emissions.

For counties other than Philadelphia, DVRPC estimated emissions for wastewater treatment using a variety of factors, including population, fraction of population not on septic, per capita BOD_5,[24] fraction of

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[21] In DVRPC's 2005 *Regional Greenhouse Gas Emissions Inventory* the estimated 2005 population of each county was used irrespective of year. Starting with the 2010 inventory, a population estimate was determined for every year from 1960 to 2010. These populations were multiplied by the disposal rate for those years to determine total amount of waste landfilled.

[22] An alternative approach would have used data on solid waste generation by county of origin available from the Pennsylvania Department of Environmental Protection Bureau of Waste Management's Division of Reporting and Fee Collection. This data would have been used in place of estimates derived from *State Inventory Tool* factors. DVRPC did not adopt this approach due to the lack of data on solid waste generation prior to 1988 from this source.

[23] This allocation approach does not take into account local efforts to reduce waste disposed of in landfills, such as aggressive recycling programs or waste reduction efforts, except insofar as they affect the overall state per capita waste generation factors. Municipal staff or citizens with access to historical waste generation data from local billing records, for instance, could replicate the first order decay equation method using local data to estimate their community's contribution to emissions from municipal solid waste.

[24] BOD (biological oxygen demand) represents the amount of oxygen that would be required to completely consume the organic matter contained in the wastewater through aerobic decomposition processes. A standardized measurement of BOD is the "5-day test" denoted as BOD_5.

wastewater treated anaerobically, and annual protein consumption. DVRPC used the same methods in the 2005 *Regional Greenhouse Gas Emissions Inventory* and the *Energy Use and Greenhouse Gas Emissions in Greater Philadelphia, 2010*; the U.S. EPA suggests these methods in its *State Inventory Tool* and uses these methods in the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2010*.

To estimate CH_4 emissions from anaerobic treatment of organic matter, DVRPC multiplied county populations by an average per capita BOD_5 and scaled this product by the fraction of wastewater anaerobically treated. DVRPC derived these factors from the *State Inventory Tool.* DVRPC multiplied the resulting level of BOD_5 treated anaerobically by an emission factor from the *State Inventory Tool*, which provided the total amount of the CH_4 resulting from anaerobic treatment of organic matter.[25] This method provided both a regional estimate and county estimates. DVRPC allocated the county estimates to municipalities by population.

To estimate N_2O emissions, DVRPC performed similar population-driven calculations. DVRPC used other factors, again derived from the *State Inventory Tool*, such as average protein consumption, the nitrogen content of protein, and conversion factors of N_2 to N_2O, to calculate N_2O emissions. This method again provided both regional estimates and county estimates. DVRPC allocated the county estimates to municipalities by population.

For the City of Philadelphia, CH_4 and N_2O emissions estimates were provided by the Philadelphia Water Department and take into account the factors listed above as well as specific treatment methods, including CH_4 capture and combustion.

Results: Wastewater Treatment GHG Emissions

Total GHG Emissions:	0.5 $MMTCO_2e$
	0.6 Percent of Gross GHG Emissions

Emissions from Agriculture

A variety of agricultural activities and processes result in the production of CH_4 and N_2O. Enteric fermentation, the digestion of carbohydrates by microorganisms present in the digestive systems of ruminant animals such as cows and sheep, causes CH_4 emissions. Manure management results in both CH_4 and N_2O emissions. Agricultural soil management, including fertilization, results in N_2O emissions. DVRPC developed emissions estimates for each of these activities and processes by applying the percentage changes of greenhouse gas emissions in enteric fermentation, manure management, and agricultural soils from 2010 to 2015 in the U.S. EPA's *State Inventory Tool* to the county-level greenhouse gas emissions estimates from DVRPC's *Energy Use and Greenhouse Gas Emissions in Greater Philadelphia, 2010*. This differs from the method used in 2005 and 2010 as the Census of Agriculture has yet to be released.

This method provides county estimates, which DVRPC summed to produce a regional estimate. For N_2O emissions from agricultural soil management, DVRPC calculated municipal allocations by multiplying the proportion of agricultural land located in each municipality to that located in the county in which the municipality is located by the total N_2O emissions from agricultural lands in that county.

Results: Agricultural GHG Emissions

Total GHG Emissions:	0.4 $MMTCO_2e$
	0.5 Percent of Gross GHG Emissions

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[25] DVRPC has been alerted to CH_4 capture and combustion operations at some wastewater treatment plants throughout the region. DVRPC will seek additional data on these operations and estimate effects on total emissions from wastewater treatment in future inventories.

Sequestration by Urban Trees

Through photosynthesis, plants convert CO_2 into carbohydrate and sugar molecules which are incorporated into the plants' physical structures while oxygen is released back into the atmosphere. Trees are significant users of the carbon in CO_2 and continue to accumulate carbon for as long as they continue to grow. Through this process trees sequester carbon by removing it from the atmosphere. When a tree dies or is removed and either decays or is combusted, this accumulated carbon is released and can again form CO_2. Under certain conditions, CH_4 and N_2O can also be released, but consistent with national and international conventions, DVRPC does not include these emissions in estimates of total emissions from urban trees and forests.

To estimate sequestration of CO_2 in urban trees outside of the City of Philadelphia, DVRPC used data on the region's total urbanized acreage outside of Philadelphia from the U.S. Census Bureau along with state-specific data on tree coverage ratios and net sequestration rates from the *State Inventory Tool.* With these, DVRPC developed a regional estimate of net annual sequestration by trees located in urbanized areas (so-called "urban trees") outside of Philadelphia. DVRPC also developed county and municipal allocations based on the extent of urban acreage located in these geographic areas. This is a different method than DVRPC used in its 2005 *Regional Greenhouse Gas Emissions Inventory* and the *Energy Use and Greenhouse Gas Emissions in Greater Philadelphia 2010*.

To estimate net annual sequestration by urban trees in Philadelphia, DVRPC used specific data on tree coverage and annual sequestration rates available from a study carried out by the U.S. Forest Service using their Urban Forest Effects model. From this model, DVRPC estimated an average tree cover ratio for the city, as well as a net annual sequestration rate expressed in terms of carbon sequestered per area of tree cover. DVRPC calculated total net annual sequestration by multiplying total urban tree acreage in Philadelphia by the net annual sequestration rate. This, too, is the same method DVRPC used for the 2005 *Regional Greenhouse Gas Emissions Inventory* and *Energy Use and Greenhouse Gas Emissions in Greater Philadelphia, 2010*.

Results: Urban Trees GHG Sequestration

Total GHG Sequestration: 1.0 $MMTCO_2e$

Emissions from and Sequestration by Forests

Estimating the net change in forest carbon is a difficult process. For this inventory, DVRPC calculated per acre carbon storage factor for forests in New Jersey and Pennsylvania from statewide forest acreage and carbon storage estimates in the U.S. Forest Service's *Forest Inventory Analysis* database. DVRPC then applied this per acre carbon storage factor to 2010 and 2015 forest acreage in the region's counties and municipalities as determined from DVRPC's estimation of "wooded" areas in its comprehensive land use files for 2010 and 2015. DVRPC assumed the difference between carbon stored in 2010 and 2015 divided by five to be the average annual carbon loss or gain due to decreased or increased carbon acreage in the given county or municipality. DVRPC assumed forest loss to result in a complete release of carbon stored therein.

This method differs greatly from that used in the 2005 *Regional Greenhouse Gas Emissions Inventory*, in which carbon storage factors were calculated by forest type and then applied to acreage estimates for those specific forest types. For 2010, DVPRC determined that the levels of uncertainty associated with the data underlying these calculations were unacceptable and has continued with this determination for 2015.

To determine annual carbon sequestration in existing forests, DVRPC divided the carbon stored on a per acre basis in a 100-year-old forest in New Jersey and Pennsylvania as estimated by the U.S. Forest Service's *Carbon OnLine Estimator* by 100 to determine an average annual sequestration factor. DVRPC multiplied

2015 forest acreage as determined from DVRPC's estimation of "wooded" areas in its comprehensive land use files for 2015 by this annual sequestration factor to determine annual carbon sequestration within each of the region's counties and municipalities.

In 2005, DVRPC did not estimate annual sequestration in existing forests.

Results: Forest GHG Emissions/Sequestration

Total Net GHG Sequestration: 0.7 $MMTCO_2e$

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ABSTRACT

Title: Energy Use and Greenhouse Gas Emissions in Greater Philadelphia, 2015: Methods and Sources

Publication Number: TM18023

Date Published: November 2018

Geographic Area Covered:
Nine-County Greater Philadelphia region, comprised of Bucks, Chester, Delaware, Montgomery, and Philadelphia counties in Pennsylvania, and Burlington, Camden, Gloucester, and Mercer counties in New Jersey

Key Words:
Energy, Greenhouse Gas, Emissions, Climate Change, Inventory, Methods, Fuel, Consumption, Electricity, Natural Gas, Fossil Fuels

Abstract:
This document provides an overview of the methods and sources used to produce DVRPC's *Energy Use and Greenhouse Gas Emissions in Greater Philadelphia, 2015*. The inventory itself may be found at: www.dvrpc.org/EnergyClimate/Inventory.htm

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