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Puerto Rico Greenhouse Gases Baseline Report

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Executive Summary

Puerto Rico Executive Order (OE) 2013-018, dated February 28, 2013, requires "an inventory of greenhouse gases in Puerto Rico, including emissions current and future projections of emissions" and "In turn, after completing the inventory, the study will set aggressive goals to reduce gas emissions' greenhouse effect and increase in the absorption capacity environment so as to approach the goal of carbon neutral within a reasonable period of time to be established in the study." The Executive Order also calls for the establishment of carbon reduction strategies that advance "economic activity, sustainable results, attraction of investment, and the creation of jobs."

The Executive Order instructs the State Office of Energy Policy (SOEP) (former Puerto Rico Energy Affairs Administration), with the assistance of Environmental Quality Board and the Department of Natural and Environmental Resources, to design and execute the study. As an umbrella agency, the Puerto Rico Department of Economic Development and Commerce (DEDC) financed the report, in order to assist the SOEP in achieving full compliance with Executive Order OE-2013-018.

The Center for Climate Strategies (CCS) prepared this report for the DEDC and the SOEP. The report presents an assessment of the Territory's greenhouse gas (GHG) emissions and anthropogenic sinks (carbon storage) from 1990 to 2035. Emissions are evaluated in each sector and subsector activity area using standard principles and guidelines for national and state level analysis, including US EPA guidelines and best practices developed and deployed by CCS in over 40 similar assessments for US states.

Overall the report shows GHG emissions rising faster than the US average through 2005, then falling and stabilizing from there forward. Future emissions levels are, nonetheless, predicted to be significantly higher than 1990 levels in 2020 and beyond, and higher than many subnational, national, and international targets for emissions reductions.

In addition to establishing baselines, the report provides an evaluation of key Puerto Rico agency goals and recommended response strategies focused on the two primary emitting sectors, electric power generation (power) and transportation and land use (transportation). In particular it examines the likely impact of forthcoming US EPA goals for Section 111d GHG controls on existing power plants and compliance responses through expanded energy efficiency, renewable energy, and regional flexibility.

The report also examines the role of key transportation strategies in setting and achieving new goals for the sector through reduced demand and improved energy supply measures. Guidance for maximizing economic development potential is provided for each sector's compliance approach, as well as recommended next steps for GHG mitigation planning and analysis.

This report should be useful in expanding the understanding of Puerto Rico GHGs and carbon storage levels, trends, drivers, and potential mitigation response strategies, as well as future monitoring and evaluation programs.

Acknowledgements

We appreciate all of the time and assistance provided by contacts in Puerto Rico, as well as federal agencies. Thanks go to in particular the staff at several Puerto Rican Agencies for their inputs, in particular the Puerto Rican Department of Economic Development and Commerce, and to Erika Rivera Felicié and José G. Maeso González of the Puerto Rican State Office of Energy Policy who provided key guidance for this analytical effort.

We would also like to thank the Puerto Rican agencies that provided the Center for Climate Strategies (CCS) the data and assistance to prepare this report:

- Department of Transportation and Public Works
- Department of Agriculture
- Aqueducts and Sewer Authority
- Electric Power Authority
- The Environmental Quality Board
- State Office of Energy Policy
- Department of Natural and Environmental Resources
- Planning Board
- Solid Waste Authority
- Department of Consumer Affairs
- Institute of Statistics

Thomas D. Peterson and CCS, with its dedicated team of professionals, contributed extra ordinary amounts of time, energy, and expertise in providing technical analysis for the Puerto Rico Inventory and Forecast process. Special appreciation is recognized to CCS's Technical and Project Management Leads, Stephen Roe and Loretta Bauer, for their work throughout the process. Also, we acknowledge invaluable contributions of the following CCS technical team members to the project:

- Scott Williamson
- Holly Lindquist
- Arianna Ugliano
- Cassie Mullendore
- Juan Maldonado
- Jackson Schreiber

Acronyms and Abbreviations

AEO – EIA's Annual Energy Outlook
BAU – Business As Usual
Bbls – Barrels
Bcf – Billion Cubic Feet
BOD – Biochemical Oxygen Demand
BSER – Best System for Emissions Reduction
Btu – British Thermal Unit
C – Carbon
CAA – US Clean Air Act
CaCO3 – Calcium Carbonate
CAFE – Corporate Average Fuel Economy
CAR – Climate Action Reserve
CCS – Center for Climate Strategies
CFCs – Chlorofluorocarbons
CH_4 – Methane
CHP – Combined Heat and Power
CO – Carbon Monoxide
CO_2 – Carbon Dioxide
CO_2e – Carbon Dioxide equivalent
Cogen – Cogeneration Facilities
COP – United Nations Conference of Parties
CRP – Federal Conservation Reserve Program
DEDC – Puerto Rican Department of Economic Development and Commerce
DOE – US Department of Energy
DOT – US Department of Transportation
EIA – US DOE Energy Information Administration
EIIP – Emission Inventory Improvement Program
EISA – Energy Independence and Security Act
FAA – Federal Aviation Administration
FAO – United Nations Food and Agriculture Organization
FERC – Federal Energy Regulatory Commission
FHWA – Federal Highway Administration
FIA – Forest Inventory and Analysis (US Forest Service)
FOD – First Order of Decay
FS – Fuel Supply
GCU – Gross Calorific Value
Gg – Gigagrams
GHG – Greenhouse Gas
GIS – Geographic Information Systems
GRP – General Reporting Protocol
GWh – Gigawatt-hour
GWP – Global Warming Potential
HCFCs – Hydrochlorofluorocarbons
HFCs – Hydrofluorocarbons

Histosols - high organic content soils
HWP – Harvested Wood Products
HS – Heat Supply
I&F – Inventory and Forecast
IPCC – Intergovernmental Panel on Climate Change
km2 – Square Kilometers
K-nitrogen – Kjeldahl nitrogen
kWh – kilowatt-hour
lb – Pound
lbs - Pounds
LF – Landfill
LFG – Landfill Gas
LFGTE – Landfill Gas Collection System and Landfill-Gas-to-Energy
LMOP – US EPA Landfill Methane Outreach Program
LNG – liquefied natural gas
LPG – Liquefied Petroleum Gas
MATs – Mercury and Air Toxics Standards
Mg – Megagrams
MMBtu – Million British thermal units
MMt – Million Metric tons
$MMtCO_2e$ – Million Metric tons Carbon Dioxide equivalent
MOVES – EPA's Motor Vehicle Emissions Simulator
MSW – Municipal Solid Waste
MW – Megawatt
MWh – Megawatt-hour
N – Nitrogen
N_2O – Nitrous Oxide
NASS – National Agriculture Statistical Service
NEI – National Emissions Inventory
NF – National Forest
NF_3 – Nitrogen Trifluoride
NLCD – National Land Cover Database
ODS – Ozone-Depleting Substance
OE – Executive Order
OPS – Office of Pipeline Safety
PFCs – Perfluorocarbons
PM – Particulate Matter
ppb – parts per billion
ppm – parts per million
ppmv – parts per million by volume
PR- Puerto Rico
PRASA – Puerto Rico Aqueducts and Sewer Authority
PREPA –Puerto Rico Electric Power Authority
PREQB – Puerto Rico Environmental Quality Board
PS – Power Sector
PSC – Public Service Commission

RCII – Residential, Commercial, Institutional and Industrial
REMI – Regional Economic Models Inc.
REPS – Renewable Energy Portfolio Standards
RGGI – Regional Greenhouse Gas Initiative
SAR – Second Assessment Report (of the IPCC)
SCAP – State Climate Action Plan
SED – State Energy Data
SF_6 – Sulfur Hexafluoride
SIC – Standard Industry Classification Codes
SIP – State Implementation Plan
SIT – State Greenhouse Gas Inventory Tool (US EPA)
Sinks – Removals of carbon from the atmosphere, with the carbon stored in forests, soils, landfills, wood structures, or other biomass-related products.
SO_2 – Sulfur Dioxide*
SOEP – State Office of Energy Policy
SW – Solid Waste
SWMP – Solid Waste Management Profile
t – metric ton (equivalent to 1.102 short tons)
TAF – Terminal Area Forecast
tCO_2e – Metric Tons of Carbon Dioxide Equivalent
T&D – Transmission and Distribution
TCR – The Climate Registry
TAR – Third Assessment Report (of the IPCC)
TJ – Terajoule
TLU – Transportation and Land Use
UNFCCC – United Nations Framework Convention on Climate Change
US – United States
USBEA – United States Bureau of Economic Analysis
US DOE – United States Department of Energy
US EPA – United States Environmental Protection Agency
USDA – United States Department of Agriculture
USFS – United States Forest Service
USGS – United States Geological Survey
VMT – Vehicle Mile Traveled
VS – Volatile Solids
WM – Waste Management
WTE – Waste to Energy (Solid Waste Combustion Facility)
WW – Waste Water
yr – Year

I. Summary Findings

Introduction

The Center for Climate Strategies (CCS) prepared this report for the Puerto Rican Department of Economic Development and Commerce (DEDC). The report presents an assessment of greenhouse gas (GHG) emissions and anthropogenic sinks (carbon storage) from 1990 to 2035. The combined inventory (historic emissions) and forecast (I&F) is commonly referred to as a GHG baseline. This baseline and the information used in its construction provide the metrics needed to understand the important GHG contributors in Puerto Rico (PR) and indications of what types of mitigation strategies are needed to achieve future targets.

The baseline is structured by economic sector consistent with GHG reporting nationally and by many US States:

- "Energy" Sectors
  - *Energy Supply (ES):* addresses fuel combustion and non-fuel emissions in the Power Supply (PS), Heat Supply (HS), and Fuel Supply (FS) subsectors;
  - *Residential, Commercial, Institutional, & Industrial (RCII):* fuel combustion and process emissions. Industrial non-fuel (process) emissions are broken out separately;
  - *Transportation:* fuel combustion in on road vehicles and nonroad engines (including aircraft and water craft);

- "Non-Energy" Sectors
  - *Agriculture:* emissions from livestock management and crop production;
  - *Forestry & Other Land Use (FOLU):* primarily carbon sequestration in forests and urban trees;
  - *Waste Management (WM):* emissions from wastewater treatment and solid waste management.

Historical Emissions and Business as Usual (BAU) Forecast

Prior to this report, Puerto Rico completed two GHG inventory reports. The first report was completed in 1996. The 1996 I&F established an inventory for both 1990 and 1994. The Inventory report established a total of 38,035,932.94 tons of CO_2e in 1990 and 30,006,600.80 tons of CO_2e in 1994. The second report was a State Action Plan to Reduce Greenhouse Gas Emissions. This report used the 1994 Inventory as a baseline to establish a reduction of emissions to 10 percent above 1990 levels or a reduction of 10.438 million tons of CO_2e.[1]

To build upon the past two reports, this I&F estimates Puerto Rico's anthropogenic GHG emissions and anthropogenic sinks (carbon storage) for the period from 1990 to 2035. Historical GHG emission estimates (1990 through 2013 for most sources) were developed using a set of generally accepted principles and guidelines for State GHG emissions inventories, as described

[1] [1] E. Rivera, AAE, personal communication and data file to S. Roe, CCS, August 7, 2014

in the "Approach" section below and detailed in the appendices to this report. The emission estimates rely to the extent possible on Puerto Rican-specific data and inputs. The initial BAU forecast (2013 - 2035) are based on a compilation of various projections of electricity generation, fuel use, and other GHG-emitting activities for Puerto Rico, along with a set of transparent assumptions (see report appendices for details).

The inventory and projections cover the seven gases included in the U.S. Greenhouse Gas Inventory: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulfur hexafluoride (SF_6), and nitrogen trifluoride (NF_3). Emissions of these GHGs are presented using a common metric, carbon dioxide equivalence (CO_2e), which indicates the relative contribution of each gas, per unit mass, to global average radiative forcing on a global warming potential- (GWP-) weighted basis.[2] For consistency with US national and international reporting methods, 100-yr GWPs from the Intergovernmental Panel on Climate Change (IPCC) Second Assessment Report (SAR) were used:

- Carbon dioxide: 1
- Methane: 25
- Nitrous Oxide: 310
- Sulfur hexafluoride: 23,900
- Nitrogen trifluoride: 17,200
- Hydrofluorocarbons: a class of compounds with GWPs ranging from 140 to 11,700
- Perfluorocarbons: a class of compounds with GWPs ranging from 6,500 to 17,700.

More detailed breakdowns of emissions by GHG can be found in later sections of this report and in the final appendix: 2013 Greenhouse Gas Inventory Summary. The term "net emissions" means that both GHG sources and sinks are included.

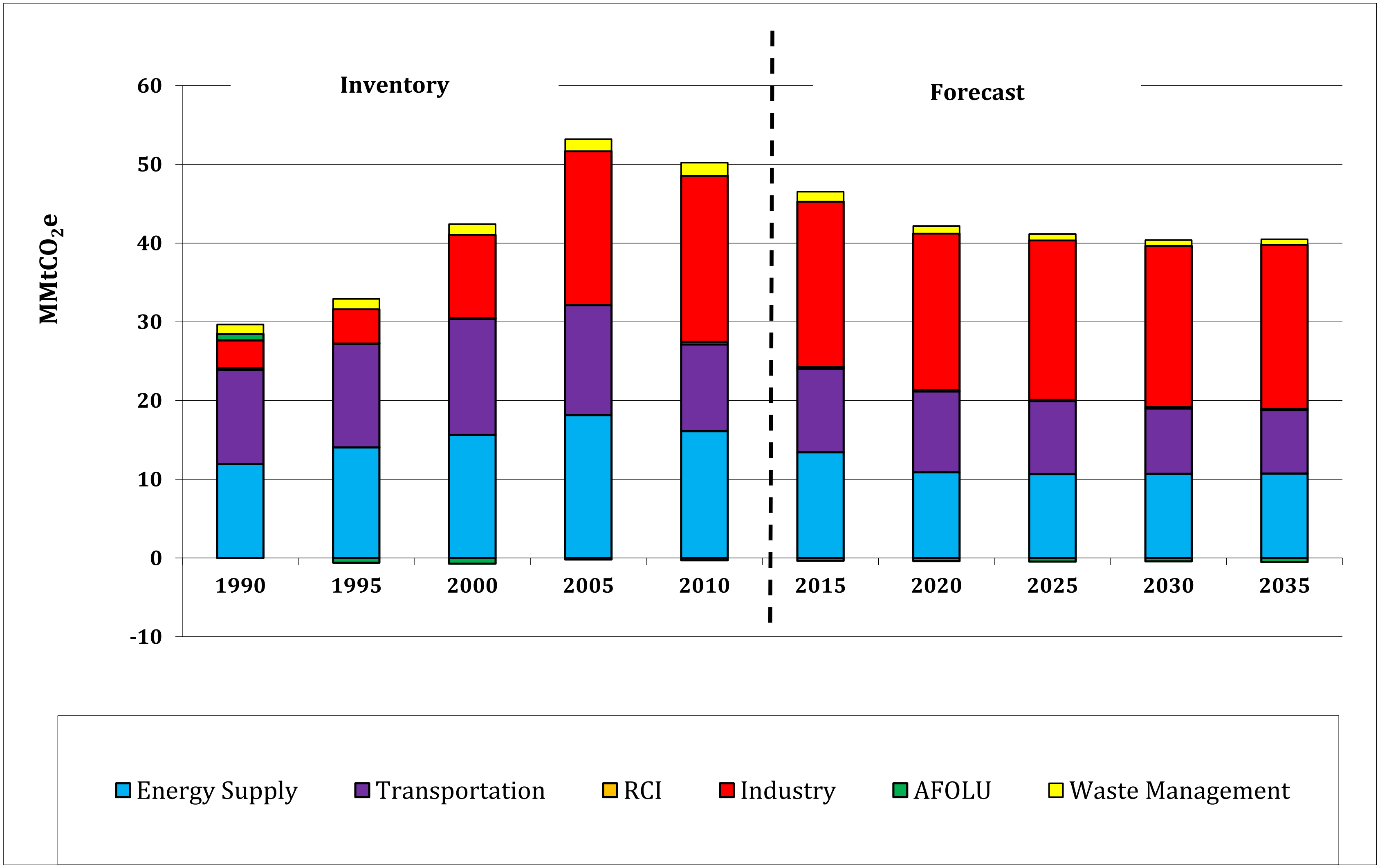
Figure I-1 is a bar chart of the baseline results. It is clear from this figure that the primary contributors to PR emissions are the ES (power supply subsector), Transportation, and Industrial sectors. ES emissions are primarily those from fuel combustion to produce electricity; transportation emissions mainly from on road vehicle fuel combustion; and for Industry, emissions are mostly from coal and natural gas combustion. Based on available data, historical emissions were calculated through 2013 for most sectors.

Table I-1 provides the values associated with Figure I-1 in five-year increments. Emissions are summarized in million metric tons (MMt) of carbon dioxide equivalents (CO_2e). Use of CO_2e emissions allows for the summation of mass emissions for each of the seven GHGs recognized

[2] Changes in the atmospheric concentrations of GHGs can alter the balance of energy transfers between the atmosphere, space, land, and the oceans. A gauge of these changes is called radiative forcing, which is a simple measure of changes in the energy available to the Earth-atmosphere system (IPCC, 2001). Holding everything else constant, increases in GHG concentrations in the atmosphere will produce positive radiative forcing (i.e., a net increase in the absorption of energy by the Earth), See: Boucher, O., et al. "Radiative Forcing of Climate Change." Chapter 6 in *Climate Change 2001: The Scientific Basis.* Contribution of Working Group 1 of the Intergovernmental Panel on Climate Change Cambridge University Press. Cambridge, United Kingdom. Available at: http://www.grida.no/climate/ipcc_tar/wg1/212.htm.

by the Intergovernmental Panel on Climate Change (IPCC). Industry sector emissions grew significantly beginning in the late 1990's with the introduction of both natural gas and coal-fired cogeneration sources. GHG emissions from the useful thermal output of these facilities are allocated to the industry sector. ES sector emissions decline in the forecast period; however, it should be noted that some of the industrial natural gas consumption emissions are tied to power supply. This is because natural gas is used in that sector to condition liquefied natural gas (LNG) to the compressed natural gas (CNG) used by power plants, as well as in a desalination plant that provides some of the water produced for use in power plants.

Figure I-1. Net GHG Baseline for Puerto Rico



Note: RCI – residential, commercial & institutional; AFOLU – agriculture, forestry & other land use.

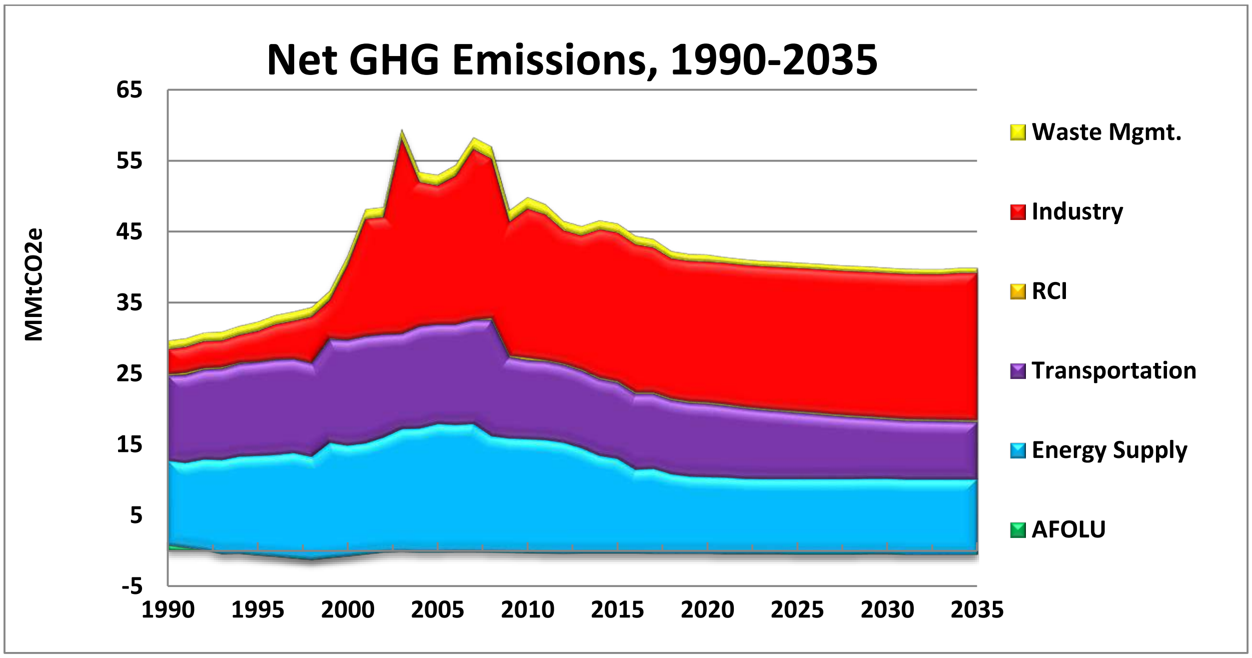
Table I-1. Net GHG Baseline for Puerto Rico

Sector	MMtCO$_2$e									
	1990	**1995**	**2000**	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**
Energy Supply	12	14	16	18	16	13	11	11	11	11
Transportation	12	13	15	14	11	11	10	9.3	8.3	8.0
RCI	0.23	0.04	0.05	0.01	0.32	0.18	0.17	0.18	0.18	0.18
Industry	3.5	4.4	11	20	21	21	20	20	20	21
AFOLU	0.82	(0.58)	(0.72)	(0.18)	(0.29)	(0.34)	(0.39)	(0.45)	(0.41)	(0.53)
Waste Management	1.2	1.3	1.4	1.5	1.6	1.3	1.0	0.8	0.7	0.7
TOTAL NET Emissions	**30**	**32**	**42**	**53**	**50**	**46**	**42**	**41**	**40**	**40**

II. Puerto Rico GHG Emissions: Sources and Trends

Figure II-1 provides a summary of GHG emissions estimated for Puerto Rico by sector from 1990 through 2035. As shown in this figure, Puerto Rico is estimated net GHG emissions peaked at around 60 MMtCO_2e in the early to mid-2000s. Net emissions for the most recent historical year, 2013, were 46 MMtCO_2e. The Energy Supply sector (power supply subsector), Transportation, and Industry produced most of the emissions historically and are expected to remain the primary sectors in the future. Puerto Rico's forested landscape, urban forestry, crop cultivation serve as sinks of CO_2 emissions (removal of emissions, or negative emissions). However, these are fairly modest as compared to the GHG sources (current and forecast estimates are in the 0.3 MMtCO_2 range). Puerto Rico's net emissions reflect a subtraction of carbon sinks from the gross GHG emission totals. The following sections discuss GHG emissions sources and sinks, trends, projections, and uncertainties.

Figure II-1. Puerto Rico Historic and BAU Forecasted GHG Emissions



Historical Emissions

Overview

In 2013, activities in Puerto Rico accounted for approximately 47 million metric tons (MMt) of *gross* CO_2e emissions. Through the mid-2000s, Puerto Rico's gross GHG emissions were rising at a faster rate than those of the United States as a whole (gross emissions exclude carbon sinks, such as forests). Puerto Rico's gross GHG emissions increased by about 80% from 1990 to 2005, while national emissions rose by 16% from 1990 to 2005.

The growth in Puerto Rico's emissions through the historical period up to 2013 is primarily associated with fuel consumption for the production of power (ES sector) and industrial use (Industry sector). Notably, beginning in the late 1990's, two cogeneration plants (AES and EcoElectrica) began operations. The AES coal-fired cogeneration plant initially provided process steam for a nearby chemical plant; however that plant shut down in 2011. So currently, AES is essentially operating as a power station. For the natural gas-fired EcoElectrica cogeneration plant, useful thermal output is used for conditioning LNG for use in power generation and for a desalination plant. Since, some of the water output from the desalination plant is used by power plants, then some of the useful thermal output of EcoElectrica is indirectly tied to power production (although all GHG emissions have been allocated to the Industrial sector).

The rest of the emissions growth for Puerto Rico through the mid-200s is from transportation fuels. Emissions increased by about 17% from 1990-2005. Most of these emissions are from gasoline and diesel combustion in the on road subsector.

The next largest contributor of gross GHG emissions in 2013 is the Waste Management (WM) sector, accounting for about 3% of the 2013 net GHG emissions in Puerto Rico. The waste management sector is dominated by CH_4 emissions from landfills, but also includes emissions from waste composting and wastewater management. Waste Combustion emissions from Waste-to-Energy (WTE) combustion facilities come online in 2016; however these are allocated to the ES sector.

Based on available data, the agriculture sector produces very little GHG emissions in Puerto Rico. In 2013, the agriculture sector actually accounted for net emissions of -0.3 $MMtCO_2e$. The net reduction occurs as a result of carbon sequestration in perennial crops, which more than offset emissions associated with livestock and crop production. It should be noted that emissions from fuel combustion in the agriculture sector are accounted for within the RCI sector totals, since the details available to disaggregate agriculture fuel use are not available. This sector includes non-energy methane (CH_4) and nitrous oxide (N_2O) emissions from both livestock and crop production and emissions and sinks of carbon dioxide (CO_2) in agricultural soils and vegetation. The primary GHG sources and sinks from livestock production and crop production. If only the GHG sources were considered, the agriculture sector would contribute a little over 1% to the gross emissions for Puerto Rico in 2013.

Other than perennial crops in agriculture, other carbon sinks in Puerto Rico include forests and urban forests. Forests and urban forests are estimated to be small net sinks of GHG emissions in all years, except 1990-1993, when losses of forest cover resulted in net CO_2 emissions. The current estimates indicate that about 0.33 $MMtCO_2$ were stored in Puerto Rico biomass in 2013.

On a per capita basis in 2011, Puerto Rican residents emitted about 13.5 metric tons (t) of net CO_2e compared to the US national per capita emissions of 21.0 tCO_2e/capita (2011 was the most recent historical year for comparison). Figure II-2 provides a comparison of per capita based carbon intensity for Puerto Rico and the US. Unlike the national per capita emissions which declined slightly from 1990 to 2005, the Puerto Rican per capita emissions increased by 68% from 1990 to 2005. The principal sources of Puerto Rico's GHG emissions are electricity production/consumption; industrial fuel consumption; and on road transportation fuels consumption.

Figure II-2. Population-Based Emissions Intensity Comparison: Puerto Rico and the US

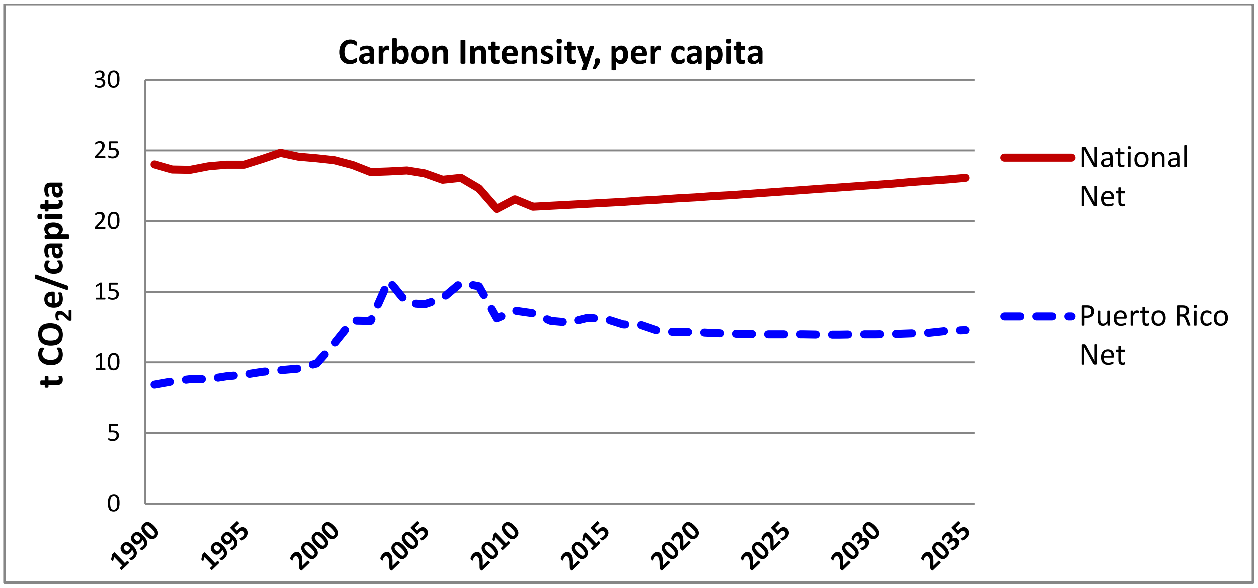


Figure II-3 provides another emissions intensity comparison based on economic output. The metrics charted are gross grams of CO_2e emissions per $2010 of economic output (gross emissions excludes carbon sinks). The data show that emissions intensity fell steeply for both the US and PR economies through 2010. Additional declines are expected for both economies through the forecast period based on forecasted emissions estimates and economic growth.[3]

[3] Both the US and PR intensity estimates use economic activity (gross GDP and GSP) in constant 2010 dollars (1990-2014) provided by the USDA-ERS (updated 8/25/2014) with the primary data source listed as Source: World Bank World Development Indicators, International Financial Statistics of the IMF, IHS Global Insight, and Oxford Economic Forecasting, as well as estimated and projected values developed by the Economic Research Service all converted to a 2010 base year. USDA-ERS contact: M. Shane (mshane@usda,ers.usda.gov). The PR annual growth rate through 2035 was calculated from the 1999-2014 growth rate provided in these USDA-ERS data. US GDP growth rates taken from the Congressional Budget Office: http://www.cbo.gov/sites/default/files/45010-Outlook2014_Feb_0.pdf.

Figure II-3. Economic Output Intensity Comparison: Puerto Rico and the US

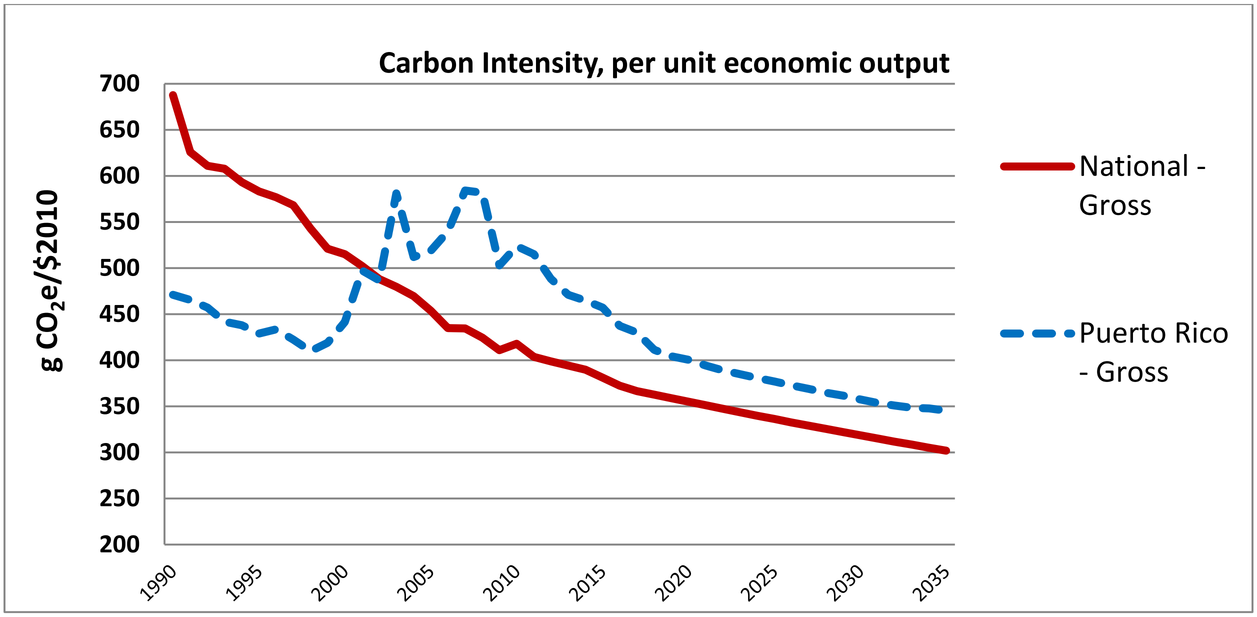
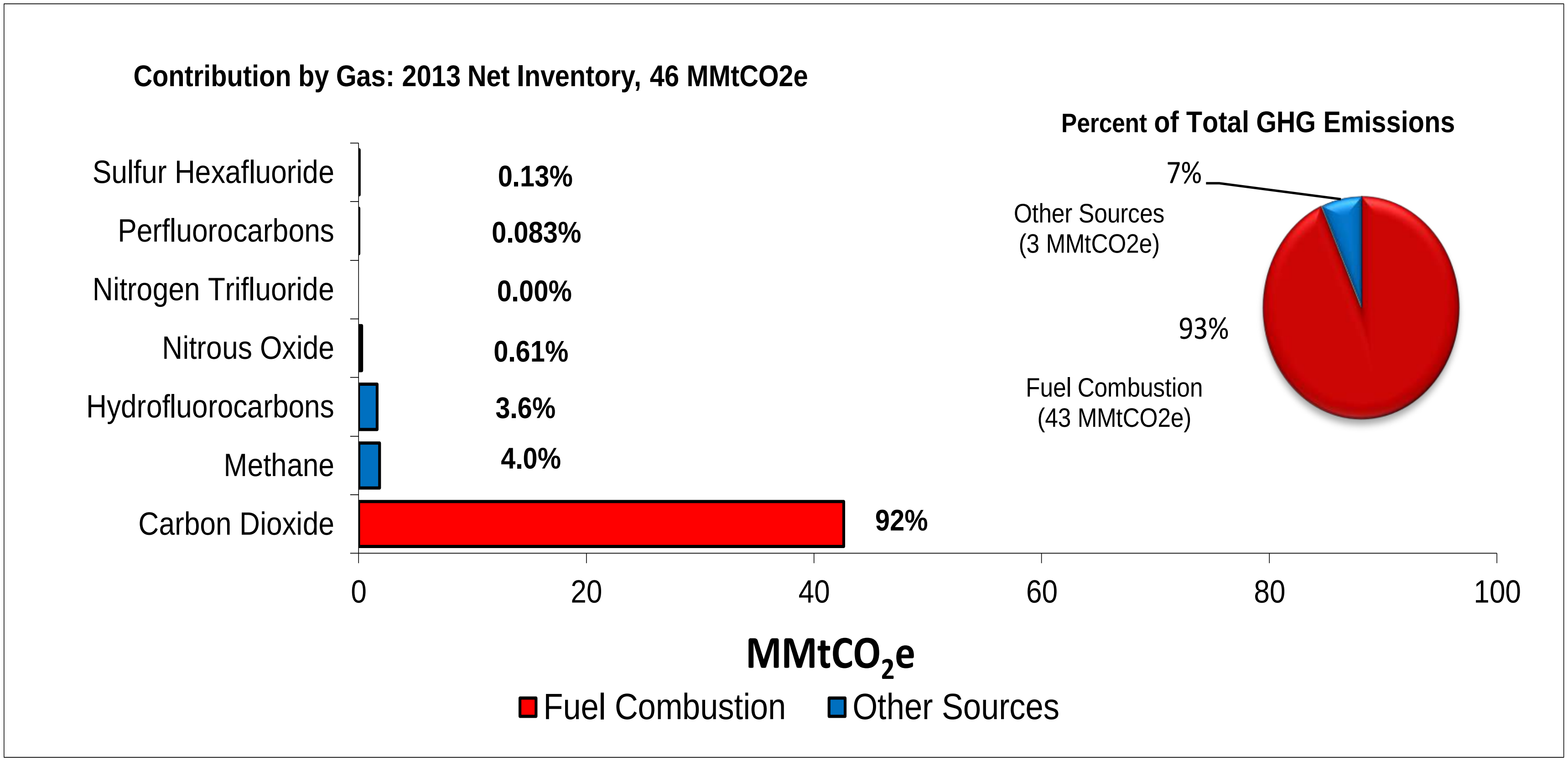


Figure II-4 provides information on the contribution by each GHG to total 2013 CO_2e emissions. It also provides an indication of the 2013 CO_2e contribution by fuel combustion sources versus non-combustion sources. As is typical in many regional to national scale inventories, carbon dioxide contributes most of the CO_2e emissions at over 90%. Methane contributes about 4%. Importantly, hydrofluorocarbons contribute nearly as much to the CO_2e total as methane and are expected to grow significantly in the future due to expected increases in refrigerant use (expected contributions by 2035 are nearly 5% of the net GHG total). CCS did not find any data on NF_3 emissions for PR; however, it is possible that some use of this compound in the electronics industry occurs.

Figure II-4 also shows that 93% of the 2013 emissions are contributed by fuel combustion sources, primarily in the power supply, industry, and transportation sectors. The remaining 7% include CH_4 and N_2O emissions from waste management and agricultural activities, industrial process emissions, and refrigerant use among other sources.

Figure II-4. Contribution by GHG and Combustion vs. Non-Combustion Sources



Business As Usual (BAU) Forecast

Relying on a variety of sources for forecasting, as detailed in the appendices, CCS developed a BAU forecast of GHG emissions through 2035. As illustrated in Figure II-1 above and numerically in Table II-1 below, Puerto Rico's net GHG emissions decline steadily to about 40 $MMtCO_2e$ by 2035, about 33% below peak levels in 2003.

Table II-1. Puerto Rico Net GHG Emissions by Sector, 1990-2035

Sector	$MMtCO_2e$									
	1990	1995	2000	2005	2010	2015	2020	2025	2030	2035
Energy Supply	12	14	16	18	16	13	11	11	11	11
Transportation	12	13	15	14	11	11	10	9.3	8.3	8.0
RCI	0.23	0.04	0.05	0.01	0.32	0.18	0.17	0.18	0.18	0.18
Industry	3.5	4.4	11	20	21	21	20	20	20	21
AFOLU	0.82	(0.58)	(0.72)	(0.18)	(0.29)	(0.34)	(0.39)	(0.45)	(0.41)	(0.53)
Waste Management	1.2	1.3	1.4	1.5	1.6	1.3	1.0	0.8	0.7	0.7
TOTAL NET Emissions	**30**	**32**	**42**	**53**	**50**	**46**	**42**	**41**	**40**	**40**

In the ES sector, emissions show a declining trend based on a variety of factors. First, the electricity demand in PR is expected to rise slightly in the next few years before tapering off to an essentially flat forecast at roughly 2013 levels of demand. Changes to the power generation fleet include a conversion of residual and distillate oil fired units to natural gas, which will largely be complete by 2020. Finally, a waste to energy (WTE) plant that will burn municipal solid waste (MSW) is included in the forecast with initial start-up assumed for 2016 and full capacity reached in 2017. It should be noted that there is uncertainty as to whether this facility will be constructed and operated on this schedule. See Appendix A for more details.

Industry is the largest contributing sector in the GHG forecast. Over 80% of the emissions are contributed by the EcoElectrica cogeneration plant for use in LNG conditioning and a desalination plant. Hence, since an undetermined portion of this fuel use is tied to natural gas consumption and cooling water for power generation, then some of these emissions could be considered to be indirectly tied to electricity supply. The forecast for industry sector emissions overall is essentially flat which is consistent with the flat forecast of electricity demand. Details on fuel use in the industry sector can be found along with the rest of RCII fuel use in Appendix B.

In the transportation sector, there is also a declining trend in overall GHG emissions, which is primarily associated with the on road vehicles subsector. The primary factor contributing to this declining trend is a growing efficiency of the on road fleet. Secondary factors include a fairly low growth rate in on road vehicle use and higher levels of biofuel consumption. In particular, the growth rate in vehicle-miles traveled (VMT) is only 11% from 2010 – 2040. See Appendix D for more details.

Key Uncertainties and Next Steps

Some data gaps exist in this inventory and forecast which can be found at the end of each appendix. Each sector appendix outlines specific key uncertainties and additional research needs.

Approach

The principal goal of compiling the historical inventories and BAU forecast presented in this document is to provide Puerto Rico with a general understanding of the Territory's historical, current, and projected (expected) GHG emissions, their drivers, comparison to other jurisdictions, and GHG and economic development goal setting. The following sections explain the general methodology and the general principles and guidelines followed during development of this GHG baseline for Puerto Rico.

General Methodology

CCS prepared this analysis in consultation with Puerto Rican agencies, in particular, with the staff at State Office of Energy Policy (SOEP). The overall goal of this effort is to provide straightforward estimates, with an emphasis on robustness, consistency, and transparency. As a result, we rely on historical and forecast data from best available Puerto Rican agency and regional sources where possible. Where reliable existing forecasts are lacking, we use straightforward spreadsheet analysis and constant growth-rate extrapolations of historical trends rather than complex modeling based on agency conferral and assistance.

In most cases, we follow the same approach to emissions accounting for historical inventories used by the US EPA in its national GHG emissions inventory[4] and its guidelines for States.[5]

These inventory guidelines were developed based on the guidelines from the IPCC, the international organization responsible for developing coordinated methods for national GHG inventories[6] as well as US EPA principles and guidelines and their application to US states. The inventory and forecast methods provide flexibility to account for local conditions.

General Principals and Guidelines

A key part of this effort involves the establishment and use of a set of generally accepted accounting principles for evaluation of historical and projected GHG emissions, as follows:

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[4] *Inventory of US Greenhouse Gas Emissions and Sinks: 1990-2012, Executive Summary*, *http://www.epa.gov/climatechange/Downloads/ghgemissions/US-GHG-Inventory-2014-Chapter-Executive-Summary.pdf*.
[5] http://yosemite.epa.gov/oar/globalwarming.nsf/content/EmissionsStateInventoryGuidance.html.
[6] http://www.ipcc-nggip.iges.or.jp/public/gl/invs1.htm.

- **Transparency:** CCS reports data sources, methods, and key assumptions to allow open review and opportunities for additional revisions later based on input from others. In addition, CCS reports key uncertainties where they exist.
- **Consistency:** To the extent possible, the inventory and projections were designed to be externally consistent with current or likely future systems for State and national GHG emissions reporting. CCS has used the EPA guidance for State inventories as a starting point. These initial estimates were then augmented and/or revised as needed to conform to State-based inventory and BAU forecast needs. For consistency in making BAU forecasts, we define BAU actions for the purposes of forecasting as those *currently in place or reasonably expected (i.e. planned) over the time period of analysis.*
- **Priority of Existing State/Territory and Local Data Sources:** In gathering data and in cases where data sources conflicted, CCS placed highest priority on local and State/Territory data and analyses, followed by regional sources, with national data or simplified assumptions such as constant linear extrapolation of trends used as defaults where necessary.
- **Priority of Significant Emissions Sources:** In general, activities with relatively small emissions levels may not be reported with the same level of detail as other activities.
- **Comprehensive Coverage of Gases, Sectors, Activities, and Time Periods:** This analysis aims to comprehensively cover GHG emissions associated with all activities in Puerto Rico. It covers all seven GHGs covered by US and other national inventories: CO_2, CH_4, N_2O, NF_3, SF_6, HFCs, and PFCs. The inventory estimates are for the year 1990, with subsequent years included up to most recently available data (typically 2013), with forecasts annually through 2035.

Details on the methods and data sources used to construct the inventories and forecasts for each source sector are provided in the following appendices:

- Appendix A. Energy Supply
- Appendix B. Residential, Commerical, Institutional & Industrial Fuel Combustion
- Appendix C. Industrial Process Emissions
- Appendix D. Transportation
- Appendix E. Agriculture
- Appendix F. Forestry and Other Land Use
- Appendix G. Waste Management

Goal Setting

Executive Orders on Climate Change

As noted, Puerto Rico Executive Order (OE) 2013-018 requires "an inventory of greenhouse gases in Puerto Rico, including emissions current and future projections of emissions" and "In turn, after completing the inventory, the study will set aggressive goals to reduce gas emissions' greenhouse effect and increase in the absorption capacity environment so as to approach the goal of carbon neutral within a reasonable period of time to be established in the study."

The Executive Order also calls for the establishment of carbon reduction strategies that advance "economic activity, sustainable results, attraction of investment, and the creation of jobs."

OE 2013-018 cites US and global greenhouse gas (GHG) benchmarks for consideration, including the Kyoto Protocol targets requiring signatories to reach 1990 levels or lower by 2020; a series of economy wide and sector specific goals and standards for US States; and the Costa Rica "National Strategy for Climate Change… allowing this Central American nation to accelerate decision-making, setting priorities and determine monitoring mechanisms to meet its primary objective of being the first country to reach the goal of "carbon neutral" by 2021."

Additionally, four related Executive Orders on climate change that were released concurrent with OE 2013-018 identify additional climate change goals and objectives, including integration of climate change with land use (OE 2013-015), increased adaptive capacity and resilience (OE 2013-016), sustainability (OE 2013-017), and coastal demarcation (OE-019).

When considering objectives of all of the executive orders, as well as the specific OE 2013-018 mandate for GHG goals, the goals establish the need for quantified targets and timetables for GHGs and consideration of other goals and objectives at the sector and agency level, including advancements of macro economic goals, sector based goals and priorities, sustainability, resource use, and climate resilience. Benchmarking of goals from other jurisdictions is also important at both the national and subnational levels.

The Puerto Rico GHG inventory and forecast (baseline) established by this report documents historical and expected GHG trends and their underlying activity drivers (energy and land use, economic growth, etc.). This baseline can be used to establish base years (index points) for GHG targets, as well as baselines (index trends) for GHG targets in future time periods. It also provides underlying baseline data for energy, economic, and other activities that can support goal setting for other objectives, and at the sector level.

Baselines support the development of "beyond baseline" or "baseline plus" actions and incremental impact (or feasibility) analysis of new or enhanced actions for subsequent development of climate mitigation strategies in each sector.

Goal Setting Methods

A number of methods have been used and are available for establishing economy wide and sector based goals and targets in Puerto Rico. They include:

1. Establishment of GHG targets with absolute tonnage reduction targets (tons CO2) or rate and intensity based targets (e.g. GHG per GDP or unit of energy output). Tonnage and rate based approaches can be combined and are mathematically linked.
2. Adoption of international standards as applied to individual nations, such as the Kyoto Protocol targets of GHGs at or below 1990 levels by 2020. These targets vary under a "common but differentiated" framework and by national circumstance. Generally, the goal of 1990 levels or lower by 2020 is recognized as an international benchmark from the United Nations Framework Convention on Climate Change (UNFCCC). New international targets are in the negotiation process for the commitment period that follows the Kyoto Protocol. Currently nations are assembling "national contribution" estimates or pledges for action for the upcoming Conference of the Parties (COP) 20 in Lima, Peru, with expected concurrence on new targets at COP 21 in Paris, France. These new contribution and commitment estimates are not yet available. In general they are being developed through feasibility analysis of sector specific actions that meet economic development, and sustainable energy and environmental objectives.
3. Adoption of President Obama's US GHG reduction goal of 17% reduction below 2005 levels by 2020. This goal is similar to the UNFCCC Kyoto Protocol. This goal is implemented through a series of sector-based actions, both existing and new. For instance, the Clean Air Act (CAA) Section 111d guidelines for carbon reductions from existing power plants are expected to provide significant reductions toward the President's goals. Current and future corporate average fuel economy (CAFÉ) standards provide significant reductions as well. A series of other actions within sectors are expected to help achieve the President's goal through existing or new authority at the federal, state, and local levels.
4. Adoption of other national goals, such as the Costa Rica carbon neutrality by 2021 goal. A variety of national approaches exist and have been developed by a variety of methods and under varying circumstances.
5. Adoption of subnational goals by US states, including 30 voluntary and or mandatory targets established by US states through comprehensive planning. These targets vary by time period, levels, coverage, and conditions (economic and energy constraints, etc.) but general follow a framework of base year emissions (such as 1990, 2005, or 2012) followed by percent reductions of GHGs in short term (2015-2020), mid term (2025-2035) and long term (2050-2080) periods. The short and medium term goals were typically set to meet GHG reductions and other public objectives (e.g. economic and energy improvements) through feasibility analysis and stakeholder consensus building. Some of these targets are mandatory at the full economy level (e.g. California, Maryland) but most are achieved through a combination of mandatory and voluntary measures at the sector level without binding economy wide targets.

6. Adoption of US local government goals established by many US cities and counties. These also vary by structure and circumstance. Many have simply adopted Kyoto Protocol goals.
7. Adoption of subnational goals in other nations. These vary, and this is an active area of policy development worldwide.
8. Adoption of near term and long-term goals consistent with global trajectories of emissions needed to hold GHG concentrations to "safe" levels in the future. The specific GHG concentration levels vary from 300 to 400 parts per million (PPM) but generally correspond with a 50 to 80 percent drop in global GHG emissions from current levels by 2050, 2080, or 2100. These are often described as "science based standards."
9. Feasibility ("bottom up") analysis of sector based and economy wide reductions of GHGs. Feasibility may include a range of factors such as economic, social, market, technical, institutional, and political constraints. Feasibility analysis is called for in the next phase of OE 2013-018 and can draw upon existing and new analysis of policy options relevant to Puerto Rico through a climate mitigation actions planning process. Typically feasibility analysis is limited to short and intermediate time periods due to long-term uncertainty.
10. Visioning, or back casting, from desirable future conditions to current stepwise paths required for achievement can be used for very long target setting. For instance, a question asked regards 2050 might be "where will our future energy come from if we are carbon neutral." A future snapshot will imply attainment pathways that progress from present to each decade forward, working backwards from the end points desired in 2050. Shorter-term feasibility analysis (bottom up forecasting) and visioning/back casting may be combined for development of short, medium and long-term targets.
11. Multi objective, integrated planning for a series of specific sector based and economy wide actions designed to reduce GHGs but also achieve positive performance metrics for other key goals at the same time, such as economy, energy, resources, health, resilience, and equity. This process goes beyond consideration of other criteria to be considered during carbon reduction planning, and establishes these as a series of co objectives. The weighting of each objective and method of application varies. These processes are often described as comprehensive climate action planning, comprehensive energy planning, low carbon development, low emissions development strategies, green growth, integrated resource management, and sustainability and security planning.
12. Planning processes designed to reduce GHGs but also meet or expand specific agency goals and priorities at the federal, state or local level. This could include federal clean air act compliance, utility sector investment targets, energy efficiency standards, renewable energy standards, land use regulations, waste reduction requirements, etc.
13. Hybrid procedures that combine one or more aspects of the above set of options as needed to meet Puerto Rico leadership needs.

Often climate action planning processes establish draft goals to support launch of a planning and analysis process, followed by finalization of goals and targets through feasibility analysis and consensus building.

Puerto Rico Climate Mitigation Goals

Through conferral, Puerto Rico agencies have indicated a preference for GHG goal setting through focus on two primary objectives:

1. Economic development
2. Government mandates for specific agencies and sectors, including US EPA Clean Air Act (CAA) Section 111d guidelines (hereafter referred to as 111d)

To address these objectives, this memo outlines key goals and strategies for electricity (power) generation and transportation and land use (transportation), the two primary GHG emitting sectors in Puerto Rico. Additionally, the memo provides framework guidance for action planning in waste management, industry, agriculture, and forestry that may provide supplemental benefits, including carbon storage, along with benchmark comparisons at the sector and economy wide levels with other jurisdictions.

Guidance on general strategies in each sector is based on the results of Puerto Rico baselines, local studies, and results of over 20 comprehensive, multi sector climate action plans in US states. Based on this experience, we know that specific approaches to policy selection and design can maximize both the economic and environmental benefit of climate mitigation actions at the sector specific and cross cutting levels.

Comparative research of US state climate action plans conducted by CCS through meta analysis of macroeconomic modeling of US state climate action plans using the REMI model (Rose and Dormandy, 2011) has shown that the following actions maximize macroeconomic performance (jobs, income, economic growth) of alternate policy options:

1. Cost effective (lower than norm) approaches that increase economic efficiency and expansion
2. Energy savings that cut energy costs, free up capital, and stimulate labor investment
3. Shifts to indigenous vs. imported resources that cut job outflows and capture multiplier effects of resource use within the jurisdiction
4. Actions supported by local supply chains that cut job outflows and similarly capture multiplier effects of resource use within the jurisdiction
5. New investment from outside sources that stimulates labor investment and growth at home
6. Labor intensive activities (compared to norm) that create more jobs even if at higher cost (up to a point)

Based on CCS experience in designing and evaluating successful macroeconomic design approaches in different states and sectors (e.g. Florida Climate and Energy Plan and Macroeconomic Analysis of 2008), we suggest GHG mitigation and economic development strategies for power and transportation in Puerto Rico that are likely to maximize macroeconomic output (i.e. cut carbon, save cash, create jobs).

The recommended GHG targets for Puerto Rico sectors and the full economy are recommended for baseline years that correspond to US EPA mandates as well as forecast periods in the study, and are indexed against base years. For instance, 111d targets call for baseline reductions in 2020 and 2030 against a 2012 base year; the Kyoto Protocol calls for a 1990 base year.

Results and Recommendations

A. Overview of Puerto Rico GHG Emissions

The aggregate and sector level breakdowns of GHG baselines in Puerto Rico from 1990 to 2035 shows an increase at rates faster than US average through 2005, then a decline to relatively flat growth in GHGs in the future that remain above 1990 levels.

Emissions from power generation are expected to decline and level off in the future, but also remain above 1990 levels by 2020, and below 2012 levels by 2020 and 2030 (111d compliance years). Emissions from transportation are similarly expected to decline and level off in the future, but remain above 1990 levels by 2020. Other sectors generally follow this trend.

Puerto Rico’s GHG baselines are unique but also similar to many US states that now show declining or stable GHG levels in future years but are, nonetheless, still higher than 1990 levels or more recent base year periods, and still much higher than 2050 and 2100 emissions levels suggested by scientists (50-80% below current levels).

B. Power Sector

Puerto Rico’s power generation sector faces two main federal mandates at present that are carbon related. The first is the US Environmental Protection Agency (EPA) Mercury and Air Toxic Standards (MATS) rule of 2011. This baseline study includes compliance with this standard in its forecasts already through reductions at the Aguirre plant.

The second is the 111d rule, which requires reductions of GHG emissions from existing power plants in each state that average 30 percent lower in 2030 than 2012 nationwide. The EPA has not yet proposed guidelines for Puerto Rico but is expected to do so in the next few months. We are calculating a likely Puerto Rico 111d goal in this memo for use in setting climate goals and general strategies for the Commonwealth, and to support development of a State Implementation Plan (SIP).

By June 2016 states, tribes, and territories must submit a SIP and Best System for Emissions Reduction (BSER) for EPA regional office approval to meet final 111d guidelines expected next year. If they chose a regional mechanism, the deadline is extended one year to June 2017.

EPA provides a goal setting formula that can be used to determine a likely goal for Puerto Rico when combined with baseline data from this study and additional information regarding Puerto Rico energy efficiency program levels, renewable energy standards (including waste energy), coal and oil conversion to natural gas, and nuclear Power (not relevant to Puerto Rico).

This memo provides a 111d goal analysis for Puerto Rico, compares the results to emissions for the base year of 2012 and business as usual (BAU) baselines through 2030 from this study, and recommends potential response actions (a BSER) that will meet 111d compliance and maximize macroeconomic growth. We further recommended more detailed policy design and analysis in a subsequent planning process to develop the best BSER for Puerto Rico.

Puerto Rico has substantial flexibility in developing a BSER to meet its likely 111d goals. It can draw upon energy efficiency; renewable energy (including waste energy); fuel switching from high carbon fossil energy (oil and coal) to lower fossil energy (liquid natural gas and natural gas); and regional mechanisms (such as opting to the Regional Greenhouse Gas Initiative (RGGI) cap and trade program). The proportions of each response strategy are flexible to EPA but must meet overall 111d goals. EPA regions must also must approve estimate methods and modeling provided to support proposed BSERs and SIP compliance plans.

Currently Puerto Rico has a Renewable Energy Portfolio Standard (REPS) that mandates a significant share of retail sales of power coming from renewable energy sources (12% in 2015, 15% in 2020, and 20% by 2035), and is implementing a series of energy efficiency measures in sectors. Under 111d EPA requires compliance with existing renewable energy standards that are at least as stringent as the best standards in the region. Puerto Rico, like other non-contiguous US states, represents its own region and can use its REPS standards for this purpose.

EPA also requires annual growth of energy efficiency at 1.5% per year following a ramp up period starting in 2016 or 2017. This will exceed Puerto Rico's current energy efficiency programs and require expansion of residential, commercial, and industrial energy efficiency. Puerto Rico must expand both renewable energy and energy efficiency programs to meet 111d goals.

Actions taken to expand BAU levels of renewable energy and energy efficiency are linked due to simultaneous effects on supply demand in the sector. The policy design and impact estimation of new policies and programs in these areas must be approached at both a stand alone and aggregate level to capture the full effects of program implementation.

Puerto Rico Preliminary 111d Goal Analysis

The 111d State GHG intensity goal is a pollution-to-power ratio determined by dividing the amount of GHG emitted in the power sector (in pounds) by the megawatt-hours of electricity generated from fossil-fuel fired power plants and certain low- or zero-emitting power sources (lbs GHG/MWh). For this study, 2012 data are used as the most current information available. EPA identified four building blocks for the 111d BSER that represent GHG abatement measures that can provide cost-effective emission reductions:

- Heat rate improvements to reduce the carbon intensity of generation (a 6% improvement is assumed that directly translates to a 6% reduction of coal emission rate)
- Conversion to low-emitting power sources such as natural gas

- Renewable energy as a combination of existing renewable generation and target renewable energy levels informed by existing REPS
- Demand-side energy efficiency programs (based on an incremental 0.2% of energy efficiency growth per year until the goal of 1.5% per year is reached and then held constant until 2030).

For the purpose of this study, we based our preliminary 111d goal analysis for Puerto Rico on this baseline and additional information such as the existing REPS, as well as on the following assumptions:

- Puerto Rico energy efficiency growth rate in 2017 (the first implementation year provided under the 111d rules) is equal to zero;
- The existing coal power plant will be subject to efficiency improvements equal to a 6% heat rate improvement. Based on our experience, we estimated that such upgrade takes place by 2020.

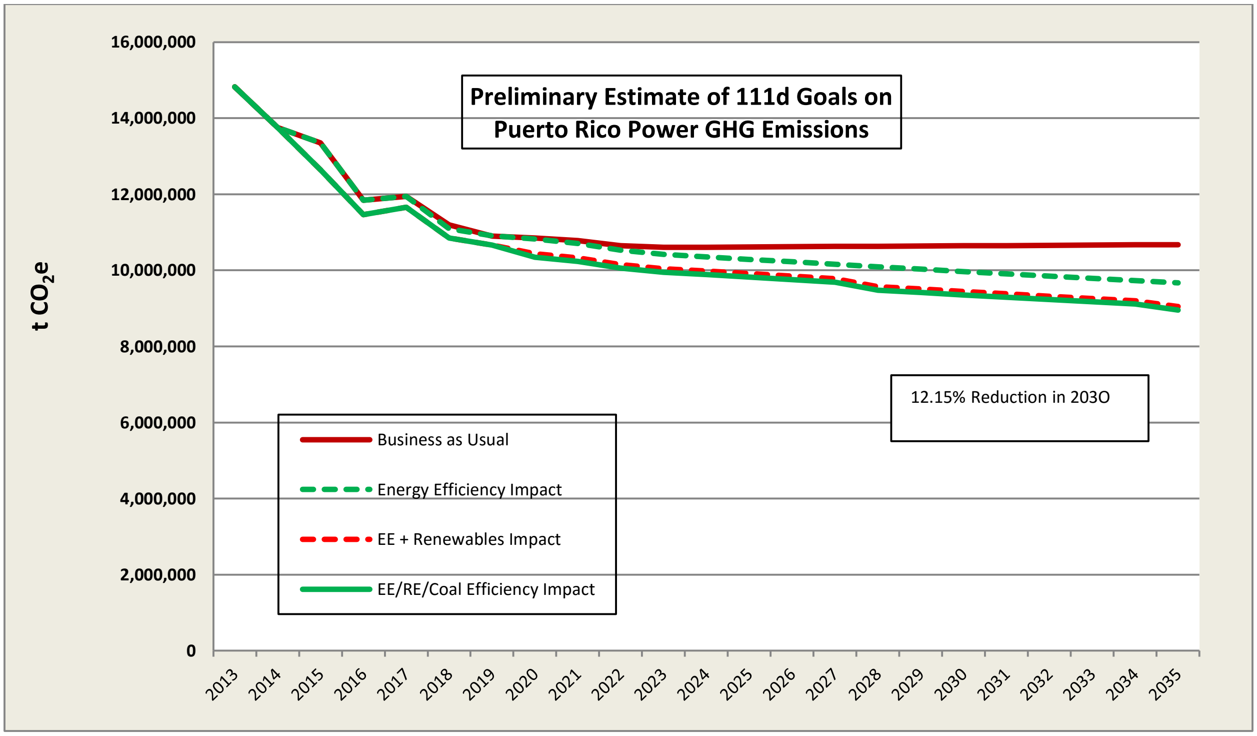
We constructed a potential BSER for Puerto Rico under the 111d scenario:

- First, by factoring into the baseline retail electricity sales savings from energy efficiency starting from 2017 and based on zero energy eficiency growth rate followed by an incremental 0.2% growth per year until the goal of 1.5% per year is reached and then held constant until 2030 (EE Scenario);
- Second, by factoring into this adjusted baseline target renewable energy levels by 2030 informed by existing REPS (EE+RE Scenario);
- Third, based on the assumption that natural gas will be the likely resource to be backed down to accommodate the resulting lower electricity demand and the change in fuel mix due to the increase in renewables, by calculating the resulting amount of "avoided" emissions; and
- Then, by factoring into the adjusted GHG emission levels a lower coal emission rate based on a 6% efficiency improvement starting from 2020 onward.

The result of our analysis shows a 4.64% GHG emissions reduction below baseline in the power sector by 2020, and 12.14% below baseline in 2030 using the US EPA Option 1 goal setting method. We did not evaluate Option 2, but this can be readily evaluated using information in this study.

Figure 1 below compares the power sector GHG emission levels under the EE scenario, the EE/RE scenario and the EE/RE/Coal efficiency scenario to BAU baselines from this study, assuming that natural gas generation only is backed down.

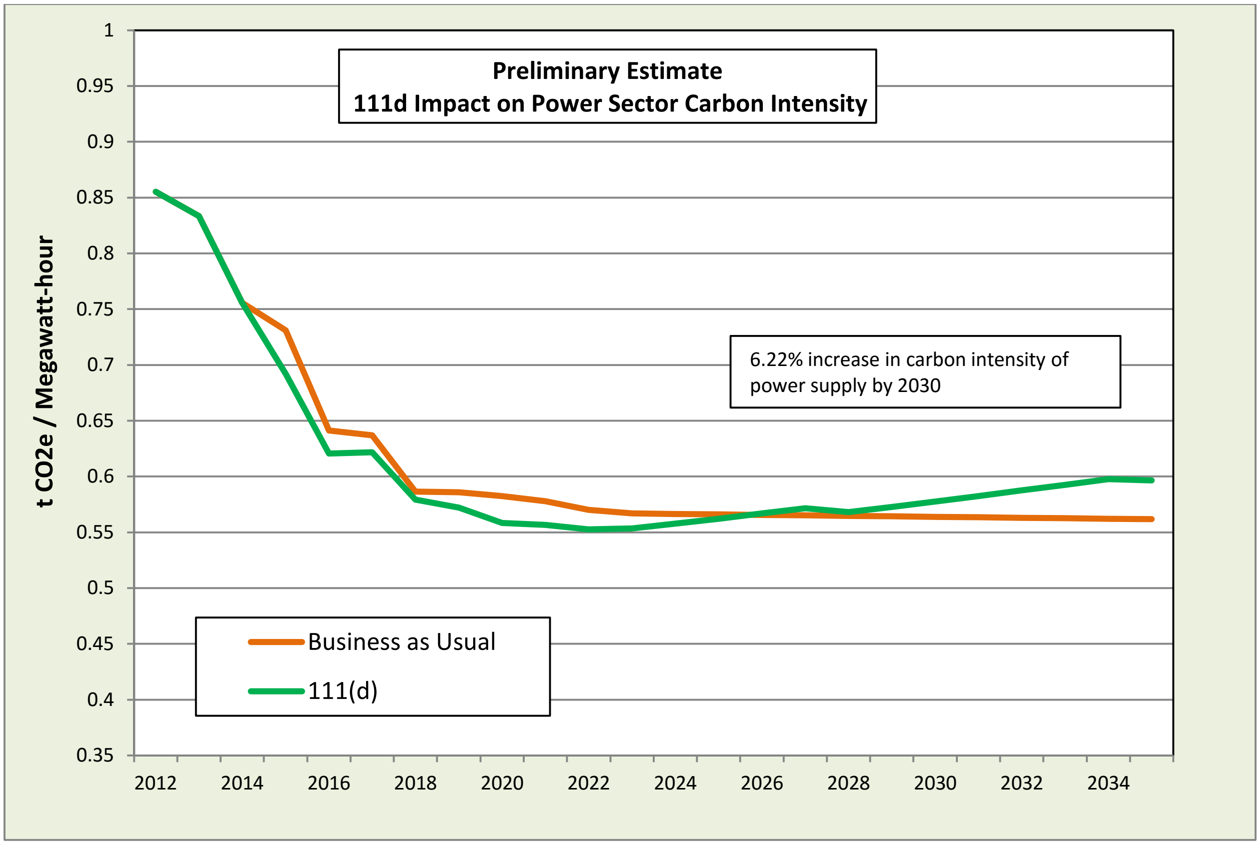
Figure 1. Preliminary Estimate of 111d Goals on the Puerto Rico Power Emissions



The above result translates in a 4.15% reduction in carbon intensity (tCO2e/MWh) in the power sector by 2020, and a 6.22% increase in 2030 compared to baseline.

Figure 2 below compares the power sector carbon intensity levels under the EE/RE/Coal efficiency scenario to BAU baselines from this study, assuming that natural gas generation only is backed down.

Figure 2. Preliminary Estimate of 111d Goals on Puerto Rico Power GHG Intensity



Future Compliance Pathways for Renewable Energy

Our analysis shows that Puerto Rico's compliance with 111d will be driven by implementation of its current REPS and a combination of existing and new energy efficiency programs (see discussion below). We also believe that Puerto Rico could join RGGI or another regional cap and trade program and potentially capture additional flexibility and allowance auction revenues for reinvestment.

Puerto Rico's most viable options for future renewable energy include solar and waste energy, and to a limited extent wind, based on current projections and feasibility. Based on past experience, particularly in Florida, solar power has a high potential for job creation and economic growth. Sensitivity analysis across a range of 50 percent plus/minus cost assumptions showed that macroeconomic gains are robust for solar power expansion (Florida REMI Analysis, CCS, 2008).

The economic development potential of renewable energy, such as solar, is particularly strong if:

- Local energy supplies replace imports
- Local supply chains are developed to replace imports
- Outside investment is mobilized to support solar and other renewable energy installations

- Energy production shifts to higher labor intensity approaches (such as wind and solar)
- Health improvements can be realized from reduced fossil energy generation in order to improve local economic productivity through reduced illness, fatigue, and related business and medical expenses

To build a sustainable economic system for renewable energy in Puerto Rico and to meet SIP compliance needs, sustained and targeted policy and investment will be needed through 2030. The economic development rewards of this strategy would likely be significant.

Future Compliance Pathways for Energy Efficiency

Energy efficient technologies and practices that are cost effective and provide short payback periods demonstrate strong economic growth, income, and job creation potential in previous macroeconomic analyses of state climate action plans (CCS). Provided these actions are not cost prohibitive and attract necessary investment, they are expansionary for a number of reasons:

- Energy efficiency cuts costs and frees up funds for local reinvestment in labor
- Energy efficient technology production and practices are more labor intensive than alternative spending
- Energy efficient technologies can ultimately support local supply chains that establish local growth economies
- Like renewable energy, health improvements from reduced fossil energy generation improve local economic productivity

For the purpose of this memo we did not scope a detailed set of energy efficiency policy options and approaches by sector, but recommend that a subsequent policy development process accomplish this subject to the economic development guidelines above. However, the baselines in this study show that end-use of energy is dominated by the residential and commercial sectors. Industrial applications may also be important contributors to energy efficiency, such as through water treatment and management, and industrial process improvements may also contribute to competitiveness and economic growth. A full range of energy efficiency and process improvement technologies and practices should be reviewed as options for a BSER in the development of Puerto Rico's SIP.

Combined Approaches

To address SIP compliance and economic development needs, renewable energy and energy efficiency should be integrated into a combined approach for the power sector, possibly also with a regional approach such as RGGI or some other regional market mechanism. The integration of multiple approaches provides a broader choice of technologies and implementation instruments, and a greater economic efficiency efficiency horizon.

For instance, the use of a price instrument, such as an auction based emissions allowance system for cap and trade, could be combined with non price instruments, such as codes and standards, to capture the relative efficiency of each at stimulating actions that vary in terms of price responsiveness. Supply side actions such as renewable energy tend to be more price sensitive than demand side actions such as renewable energy. An integrated approach avoids "one size fits all" inefficiencies.

For a Puerto Rico SIP, we recommend designing and evaluating two scenarios:

1. Integration of energy efficiency expansion to the 1.5% level concurrent with full REPS compliance (111d Option 1 goal), through:
    a. Expansion of energy efficiency programs in the residential, commercial and industrials sectors to meet EPA mandated levels. This would include detailed evaluation of the optimal mix of efficiency technologies, practices, and investment instruments in each sector, designed to reduce GHGs and expand macroeconomic output.
    b. Full compliance with the Puerto Rico REPS. This would include detailed evaluation of the optimal mix of renewable technologies, practices, and investment instruments designed to reduce GHGs and expand macroeconomic output.
2. Integration of Scenario 1 above (REPS and energy efficiency expansions at Puerto Rico and EPA mandated levels) with a regional cap and trade approach (such as RGGI) that includes allowance auction and reinvestment. Reinvestment should be targeted to an optimal combination of renewable energy and energy efficiency financing needs, plus economic needs of consumers and businesses.

Even though Puerto Rico 111d goals and final guidelines have not been issued by EPA, we recommend that a proactive approach be taken immediately to inform EPA's goal setting and guidelines. This will enable input from Puerto Rico, build capacity for long-term implementation, and capture early financing options for renewable energy and energy efficiency. Realistically, the planning, evaluation, and early stage implementation process to meet new 111d goals for Puerto Rico (including project financing) will be time consuming and difficult. Time is of the essence to avoid suboptimal outcomes. We recommend that this evaluation be conducted with expert assistance to support agency and stakeholder collaboration.

C. Transportation and Land Use Sector

Puerto Rico Transportation Baseline

The forecast for emissions reductions from the transportation sector is encouraging, even before concerted policy action at the territorial level. Emissions from the on-road fleet (light-duty cars and trucks as well as heavy-duty freight trucks) hit peak levels during the 2000-2010 decade, and are projected to fall over time.

Two major factors are responsible for this. The first is the expectation that the total amount of driving (referred to as "vehicle-miles traveled", or VMT) has been holding steady but not growing in recent years. This is consistent with a nationwide trend across the United States, as higher fuel prices and greater levels of urbanization (both by individuals and by entities) have broken the decades-long linkage between economic growth and VMT growth.

The second factor is the expected dramatic improvement in fuel efficiency of light-duty vehicles. While light-duty vehicles don't burn nearly the fuel per mile that heavy-duty trucks do, their far greater number establishes them as the primary source of on-road fuel use and on-road-generated greenhouse gas emissions. The efficiency of light-duty vehicles is forecast to comply with recent changes to the federal corporate average fuel economy (CAFE) standard, which will require that new vehicles average the emissions equivalent of 54.5 miles driven per gallon of gasoline combusted by the year 2025. Heavy-duty trucks are also forecast to achieve efficiency gains, though they will be more moderate.

As a consequence, the forecast of on-road emissions reflects a relatively flat level of activity and a dramatic improvement in fuel efficiency, leading to steadily falling greenhouse gas emissions. By the end of the forecast (the year 2030), emissions are expected to be on the order of 20% lower – around 2 million metric tons of carbon dioxide-equivalent lower – than they were measured to be in 2011.

Other forms of transportation associated with significant GHG emissions are also forecast to have flat or slightly falling emissions levels over the forecast period. Emissions from marine transportation is projected to fall slightly, while rail emissions are forecast to hold steady, with air transportation emissions rising, but only slightly.

Needs for Further Reductions

As noted earlier, while these reductions are heartening and a sign of the ability of policy to achieve significant reductions, they are not sufficient. Global goals for limiting the rise in global temperatures to 2 degrees centigrade call for reducing emissions in 2020 to levels equal to those in 1990, and reducing emissions in 2050 to a level 80% below the 1990 baseline. While the 2020 target (getting below 12 million metric tons per year) looks feasible, the long range target (getting Puerto Rico's transportation sector emissions down to no more than 2.4 million metric tons by 2050) is still far away.

The major driver of reductions, the new fuel-efficiency standards, is not expected to drive significant reductions past the year 2035 or so. This means that the expected trend of emissions reductions through 2030 cannot be assumed to continue to 2050, much less be assumed to reach such a dramatically low level, without significant new policy intervention.

Goal-Setting Strategy

Puerto Rico's business-as-usual forecast anticipates a drop in the transportation sector from a 1990 level near 11.5 million metric tons of greenhouse gases to about 7.5 million metric tons in 2035. This is a drop of nearly one third. However, as light-duty emissions level out, further reductions will not be at the rate necessary to hit key international targets. Achievable policies can steepen the decline of greenhouse gas emissions from the transportation sector, however. Emissions from on-road vehicles are driven by three main elements:

1. Vehicle design (specifically, the amount of fuel the power plant is designed to burn per mile of travel),

2. Fuel carbon intensity (the amount of greenhouse gases produced by the combustion of a liter or gallon of fuel), and
3. Travel volume (the total amount of miles or kilometers traveled by the fleet using the power plants and fuel described above).

These are referred to as the “three legs of the stool” of transportation emissions. Strategies for emissions reduction in this sector tend to target these three elements. A reduction in the intensity of any of these three elements will cause emissions reductions, and reductions in all can produce very significant emissions reductions.

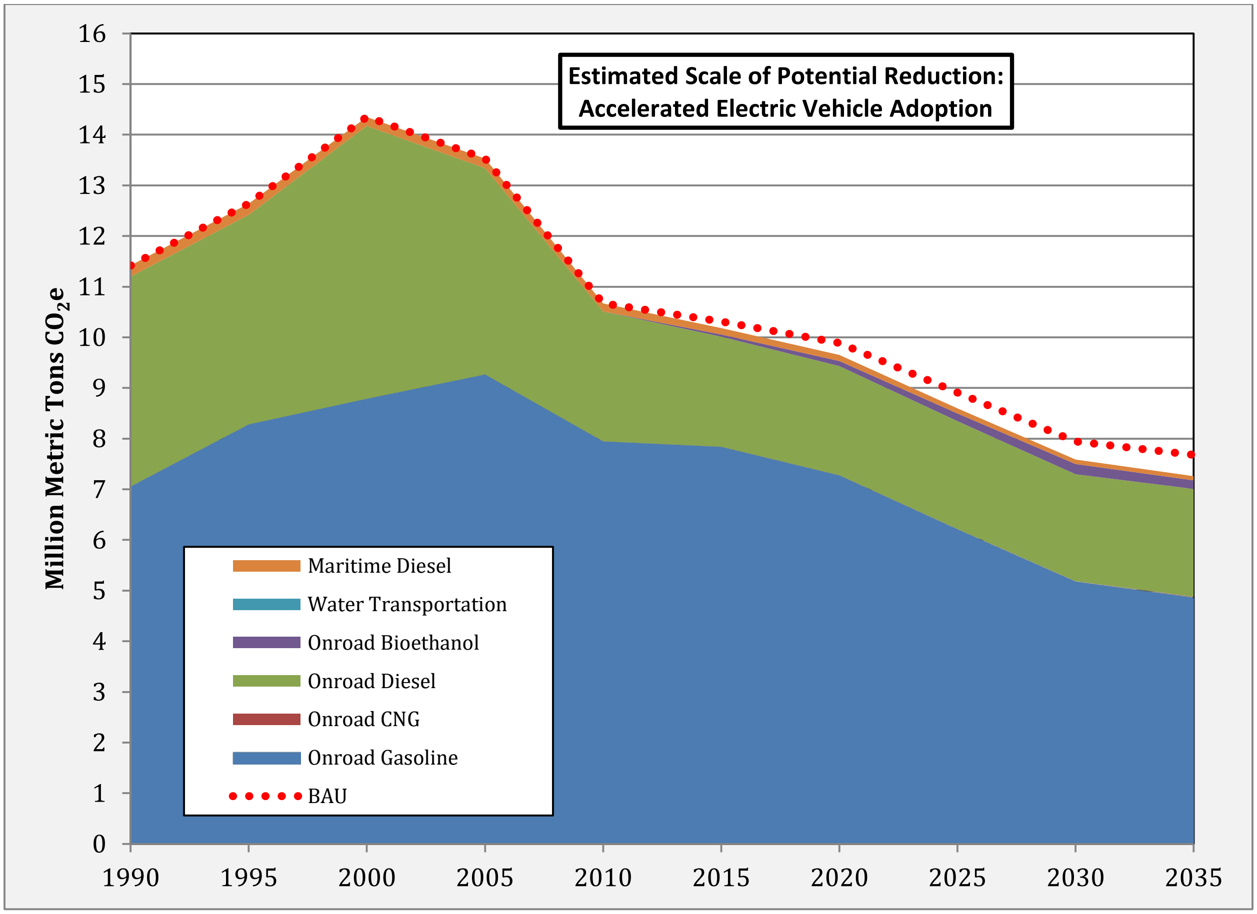
Vehicle and Fuel Approaches

While most policy regarding the efficiency of vehicles and the type of fuel used is carried out at the national level, there is some scope for sub-national policy that can produce emissions reductions. One example is the encouragement of conversion of the auto fleet to electric vehicles. Policies to do this tend to include several tactics, such as expanding the availability of vehicle charging infrastructure, easing the process permitting for construction of private charging facilities, establishing or enhancing subsidies for charging equipment and/or vehicles, and offering tax credits for electric vehicles.

Electric energy for transportation offers two unique benefits, in that it is capable of greater efficiency than combusted liquid fuels and it tends to be significantly cheaper per unit energy than liquid fuels. As a result, even when drawn from fossil-fuel-powered electricity generation sources, there are potential emissions reductions of 35% per vehicle. These can rise to over 50% per vehicle as electric supply gets cleaner through changes to power grid fuel sources.

To get an estimate of the potential reduction, consider a 20% turnover of the light-duty fleet to electric vehicles over time, and assume approximately 40% reduction in GHG emissions from these vehicles. In this scenario, such a change could reduce GHG from light-duty fleet by 8%, as shown in Figure 3 below. Economic benefits from such policies have been assessed to be good as well – there are jobs and spending from installation, which are offset by a lower cost per unit energy allowing vehicle operators to retain more money and redirect it to other uses.

Figure 3. Impact of Electric Vehicle Adoption in Puerto Rico



Puerto Rico has already taken some actions in this direction. See http://www.caribbeanbusinesspr.com/news/all-electric-nissan-leaf-debuts-in-pr-98780.html.

Heavy-duty Vehicle Approaches

Heavy trucks and buses typically require their own set of policies, as the options for light-duty vehicles are less available and usage patterns for these vehicles are very different. Voluntary programs focus on reduction of idling for heavy trucks and buses, as well as utilization of aerodynamic features that can save 10% of fuel use on long-haul trips.

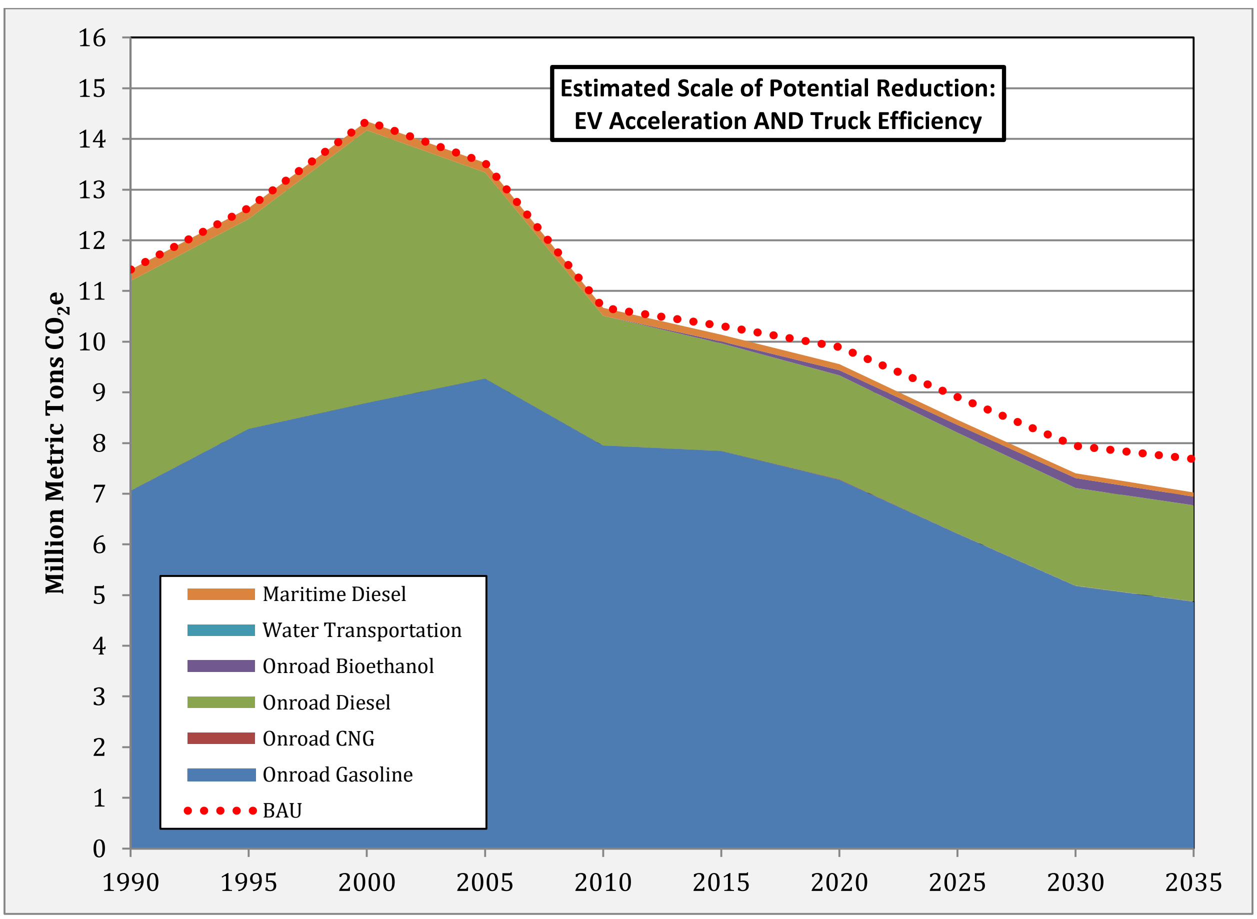
To understand the potential for emissions reduction, consider that if forty percent of truck VMT is long-haul or inter-city, the usage of such aerodynamic assistance could reduce total truck emissions 4% without affecting the number of trips. Idling large trucks can burn a gallon per hour, which can represent anywhere between 1% and 5% of emissions depending on the usage (overnight idling to power climate control in the cabin for resting drivers is the largest basis for idling).

Because both of these strategies cause no reduction in the amount of freight moved or people moved, they do not suppress economic activity, and the resulting fuel savings again tends to free up more money in the economy for use in other forms of saving and spending.

Turnover programs are also an option for sub-national actors who wish to see a more efficient fleet but lack the practical power to unilaterally mandate changes to vehicles. Because newer trucks and school buses are far cleaner in terms of local air pollution than their counterparts built just a decade ago, accelerating the turnover of vehicles before they would otherwise be taken out of service is a good tool for achieving near-term reductions of emissions. Using vehicle turnover or other efficiency incentives and requirements, accelerating fuel efficiency to a level 5% higher than the business-as-usual (another 0.2 kilometers per liter, or 0.5 miles per gallon) is a benchmark could reasonably be achieved using just the forecasts for efficiency already in the fleet.

Figure 4 below shows the additional possible impact from policies of such a scale on the Puerto Rico forecast, when added on top of the light-duty vehicle policies described above. The margin is now over a half million metric tons in 2035 – nearly 10% below the already-falling baseline forecast:

Figure 4. Impact of Electric Vehicle Adoption and Truck Efficiency in Puerto Rico



Puerto Rico has worked with EPA on heavy-duty vehicle emissions programs: http://yosemite.epa.gov/opa/admpress.nsf/cafbebb41895f4a9852572a000657b5c/20052b0463cc28c5852572d800584182!OpenDocument and http://yosemite.epa.gov/opa/admpress.nsf/d0cf6618525a9efb85257359003fb69d/e1e666f1cf7b69e08525795d0065da58!OpenDocument

These programs create sometimes-onerous up-front costs as vehicles can be quite expensive, and the time for fuel savings to pay back even a significant share of that cost may be quite long. However, the fuel savings and emissions reductions can be sizable.

Travel Demand Approaches

The third leg of the transportation strategy tool include a wide range of policy options. Smart growth and urban design patterns allowing for high levels of mode choice (the ability to choose among many transportation options based on the trip at hand) give people many alternatives to single-occupancy vehicle travel for a wide range of trips.

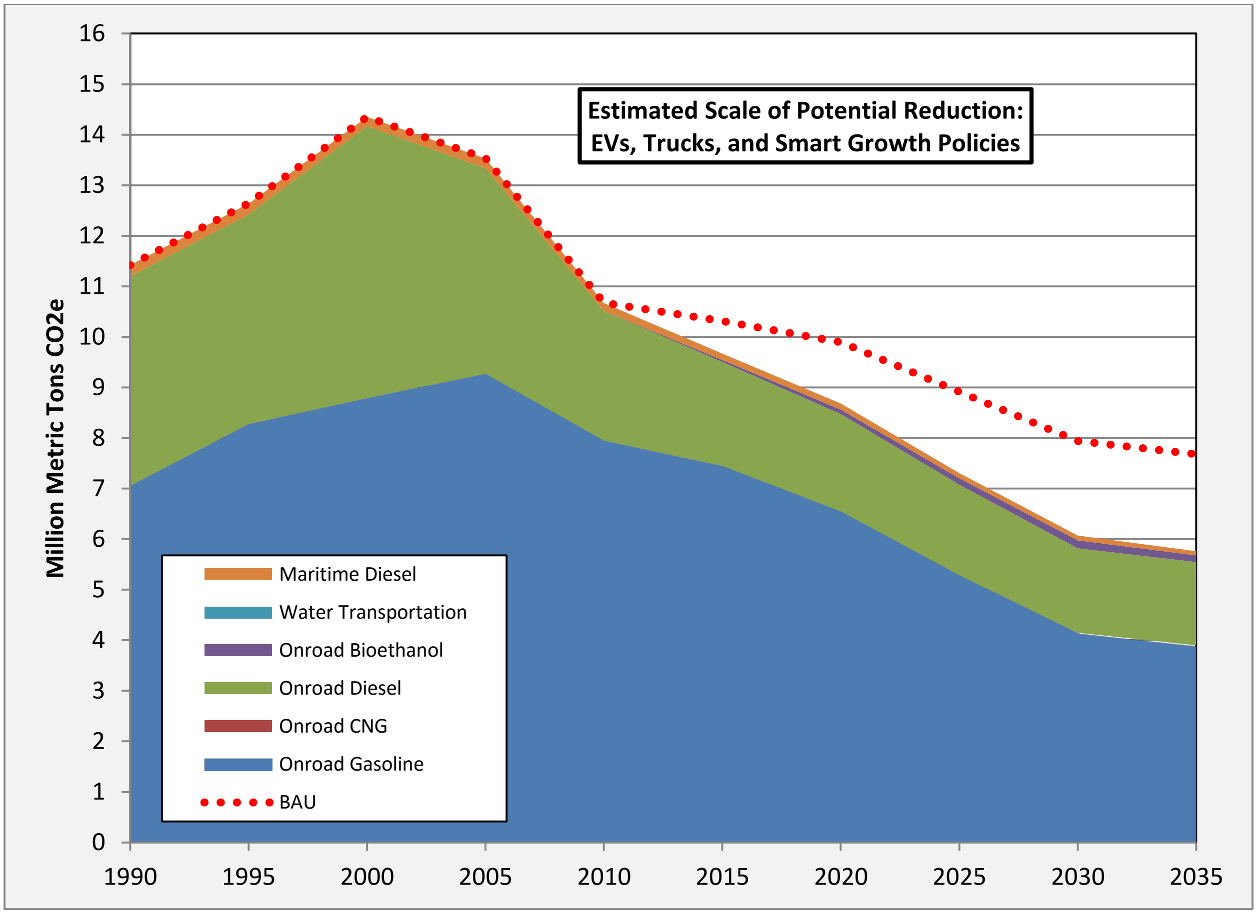
These forms of urban design can reduce VMT significantly by reducing the requirement for single-occupancy vehicle trips. Denser design also shortens trips by bringing start and end points closer together and allowing the co-location of multiple points of interest so that single trips can meet multiple needs. The value of transit service improves as more destinations are within short distances to its stops. Improved ridership means more passenger trips on the same amount of transit operation.

The economic benefits of smart-growth urban design can be high, as urbanized land use and transit very often create big gains in property value, a deeper tax base with less upward pressure on tax rates to cover municipal spending, greater access to jobs and employees for both people and businesses. Smart growth policy is complex, but it is closely connected to a wide range of crucial goals far beyond environmental policy such as access to jobs, preservation and growth of cultural and artistic communities, and access to schools and other public services as well.

Based on evaluation of transportation sector climate strategies and estimated impacts in US state climate action plans, as well as local government evaluations, we recommend considering scenarios for GHG reductions in this sector of ten percent below 2020 baseline levels by 2020 and twenty percent by 2030. Based upon our review, we believe that at least 60% of those targets can be reached through policies that actually save substantially more money than they cost (through efficiency gains or cost reductions, or shifts to less expensive travel patterns and energy sources). The full targets can be reached with an overall set of policies that produce significant new employment and economic activity, and lower costs to households and businesses.

The environmental goal of reducing the emissions from goods transportation is especially salient for Puerto Rico, which could see significant economic gains by reducing the fuel costs and imported-fuel consumption borne by homes and businesses, leaving that money free to circulate within the local economy rather than flowing overseas. Figure 5 below shows the potential reductions from adding these emissions reductions to the electric-vehicle and truck-efficiency impacts described above. The change from business as usual is now dramatic – over 25% lower emissions by 2035, and approximately half the 1990 levels rather than only one third below that mark in the baseline forecast:

Figure 5. Impact of Electric Vehicle Adoption and Truck Efficiency in Puerto Rico



In this memo, our purpose was to identify bases upon which ambitious but achievable goals for long-term emissions reductions could be established. We did not scope a detailed set of transportation and land use policy options and approaches by sector, but recommend that a subsequent policy development process accomplish this, and do so subject to the economic development principles and guidance above.

Specifically, we recommend evaluating specific policy options the following strategy areas at a standalone and integrated (aggregate) level with in the sector and across other sectors, including evaluation of the optimal mix of efficiency technologies, practices, and investment instruments in each sector, designed to reduce GHGs and expand macroeconomic output:

1. Expansion of travel demand reduction programs
2. Prioritization of land-use planning that facilitates trips by other modes than single-occupancy vehicle, through greater density, co-location of multiple land uses, transit and transit-oriented development, and improved walking and bicycling infrastructure.

3. Expansion of low carbon fuel/power programs for vehicles, including liquid fuels and electricity, and provision of key fueling/charging infrastructure to enable free use of low-emissions technologies by both households and businesses
4. Expansion of low carbon, high efficiency off road vehicle programs for vehicles
5. Expansion of low carbon, high efficiency freight programs, and overcoming the incentive gap for investments in low-cost aerodynamics that results from the use of rented truck and trailer equipment.
6. Expansion of low carbon, high efficiency marine transportation programs, including port operations fuel reduction programs, local air-quality efforts, and hoteling practices
7. Expansion of low carbon, high efficiency aviation programs, including airports
8. Integration of a regional cap and trade approach that includes allowance auction and reinvestment in renewable energy and energy efficiency plus targeted economic needs of consumers and businesses to offset negative distributional impacts that might exist.

We further recommend that this evaluation be conducted with expert assistance to support agency and stakeholder collaboration.

D. Additional Sectors

While Puerto Rico's emissions are dominated by the power and transportation sectors, other sectors have the potential reduce GHGs or store carbon for long periods, as well as economic development potential. This includes waste management, agriculture, forestry, and water management.

We recommend that Puerto Rico establish a planning goal to support a subsequent climate mitigation planning process. As in the power and transportation sectors, we recommend evaluating specific policy options the following strategy areas at a standalone and integrated (aggregate) level with in the sector and across other sectors, including evaluation of the optimal mix of efficiency technologies, practices, and investment instruments in each sector, designed to reduce GHGs and expand macroeconomic output. This should specifically include actions that can support power and transportation sector goals, including bio energy and energy efficiency, as well as actions within the sectors to promote carbon storage, efficiency management practices, and conservation actions.

Appendices

A. Energy Supply

Overview

This appendix describes the data sources, key assumptions, and the methodology used to develop the GHG baseline for the Energy Supply (ES) sector. The ES sector consists of three subsectors:

- **Electric Power Supply (PS):** use of fossil and renewable fuels to generate electricity for use by residential, commercial, institutional and industrial customers. This includes an accounting of overall GHG emissions from the use of all energy sources by power stations and cogeneration facilities. Fugitive emissions of sulfur hexafluoride (SF_6) from transmission & distribution (T&D) systems are also included. Additional sources not addressed in this project are described in the Key Uncertainties and Additional Research Needs section at the end of this appendix;
- **Heat Supply (HS):** use of fuels to produce heat for space heating or other non-industrial process needs (e.g. district heating). This is not a source subsector for Puerto Rico. Use of fuels for industrial process needs, including useful thermal energy from cogeneration plants, is addressed in the Industrial sector; and
- **Fuel Supply (FS):** fuel consumption and process emissions for fuel extraction, processing/refining, storage, transmission, and distribution. Sources in this subsector are expected to be minor contributors to GHG emissions in Puerto Rico given the lack of fossil fuel extraction, processing/refining, and transmission/distribution infrastructure. There is some natural gas infrastructure located at the EcoElectrica cogeneration facility in Penuelas. This includes regasification of liquefied natural gas (LNG) received at the terminal, including storage tank and associated transmission pipelines. Data required for quantifying emissions (e.g. length of pipelines, studies of equipment leak rates, etc.) were not identified. Therefore, this subsector was not addressed in this study.

Based on the above discussion, the focus for the ES sector was on characterizing the PS system and the associated energy use and GHG emissions. The following topics are covered in this Appendix:

- *Data Sources:* This section provides an overview of the data sources that were used to develop the inventory and forecast, including publicly accessible websites where this information can be obtained and verified.
- *Greenhouse Gas Inventory Methodology:* This section provides an overview of the methodological approach used to develop the Puerto Rico GHG inventory for the PS subsector.
- *Greenhouse Gas Forecast Methodology:* This section provides an overview of the methodological approach used to develop the Puerto Rico GHG forecast for the electric supply sector.
- *Greenhouse Gas Inventory Results:* This section provides an overview of key results of the Puerto Rico GHG inventory for the PS subsector.

- *Greenhouse Gas Forecast Results:* This section provides an overview of key results of the Puerto Rico GHG forecast for the PS subsector.

Data Sources

Most of the data for this assessment came from the Puerto Rico Electric Power Authority (PREPA)[7]. Included are the following:

- *Electricity consumption (sales and demand forecast):* historic data from 1990 – 2013 were available. A near-term forecast of 2014 – 2018 was also provided.
- *Electricity generation:* as with the consumption data, historic data for gross and net generation for each power generation resource was provided from 1990 – 2013. The near-term forecast runs from 2014 – 2018.
- *Primary energy use for electricity generation:* this information was also provided for the same time periods mentioned above.
- *Combined heat and power (CHP) production characteristics:* this included data on gross and net generation and heat rates for both of the CHP units (AES and EcoElectrica) for the same time periods listed above. Primary fuel consumption was provided by the PR Environmental Quality Board (EQB)[8].
- *Renewable energy data:* this was provided by PREPA along with the rest of the generation data mentioned above. It covers hydroelectric generation, wind, solar, landfill gas to energy, and the planned waste to energy (WTE) facility[9].
- *Carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) emission factors:* for all fuels, these emission factors are taken from The Climate Registry's (TCR's) database: http://www.theclimateregistry.org/resources/protocols/general-reporting-protocol/. For CO_2, the emission factors assume 100% oxidation of carbon.

Greenhouse Gas Inventory Methodology

The GHG inventory period was considered to be 1990-2013. The methodology used to develop the Puerto Rico inventory of GHG emissions associated with electricity production and consumption is consistent with the methods developed by the IPCC and used by the US EPA in the development of the US GHG inventory. It involved applying GHG emission factors to annual fuel consumed in PR for the production of electricity at power stations and CHP facilities.

The GHG inventory was estimated based on emissions at the point of electric generation only. That is, GHG emissions associated with upstream energy cycle processes such as primary fuel extraction, transport to refinery/processing stations, refining, beneficiation, and transport to the power station are not included as these are accounted for in this sector. Most of these emissions occur outside of PR and any additional processing or transport emissions are accounted for in other sectors of the GHG inventory (e.g. Industry).

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[7] R. Marrero, PREPA, personal communications with S. Roe, CCS, May-September, 2014.
[8] L. Fernandez, PR EQB, spreadsheets provided to CCS, August 25, 2014.
[9] The "Energy Answers, Inc. facility will combust municipal solid waste and is planned for start-up in 2016 based on information provided by PREPA.

Since Puerto Rico has no electricity imports or exports, then there is no differentiation of production versus consumption-based power sector emissions (i.e. no need to net out exports and add in the imports). A summary of Puerto Rico's expected generation resources in 2017 is provided in Table A-1 below.

Table A-1. Summary of Puerto Rico's 2017 Electric Generation Resources

Plant	Capacity (MW)[1,2]
Power Stations	
Palo Seco: residual oil fired steam plant scheduled for conversion to natural gas in 2017.	602
San Juan: Residual oil fired steam plant scheduled for conversion to natural gas in 2017.	400
Costa Sur: Residual oil and natural gas fired steam plant scheduled for complete conversion to natural gas after 2018.	900
Aguirre: Residual oil fired steam plant scheduled for conversion to natural gas in 2015.	900
Combined-Cycle Aguirre: distillate-oil fired conversion to natural gas complete by 2016.	592
Combined-Cycle San Juan: distillate-oil fired conversion to natural gas complete by 2018.	440
Cambalache: distillate-fired combustion turbine.	248
Mayaguez/Other Gas Turbines: distillate-fired combustion turbines.	578
Cogeneration Stations	
AES – Cogeneration[3]	454
EcoEléctrica - Cogeneration	507
Renewable Resources	
Hydro-electric	100
Solar Photovoltaic	427.6
Wind	101
Waste to Energy: "Energy Answers, Inc." municipal solid waste to energy plant.	67
Landfill Gas	11.5

Notes:
1. There are five diesel units in the Municipality of Culebra and two in the Municipality of Vieques with an aggregate dependable capacity of approximately 8 MW held on standby reserve.
2. The renewable capacity increases year by year through the study period up to the value on the table. This value corresponds to the year 2017.
3. AES power plant sells steam to Chevron Phillips Chemical; however Chevron closed. For this reason, PREPA buys up to 14 MW of excess energy from AES.

The assumptions and calculation process is briefly summarized below. Key Outputs for the most recent historical year of 2013 are summarized in Table A-2.

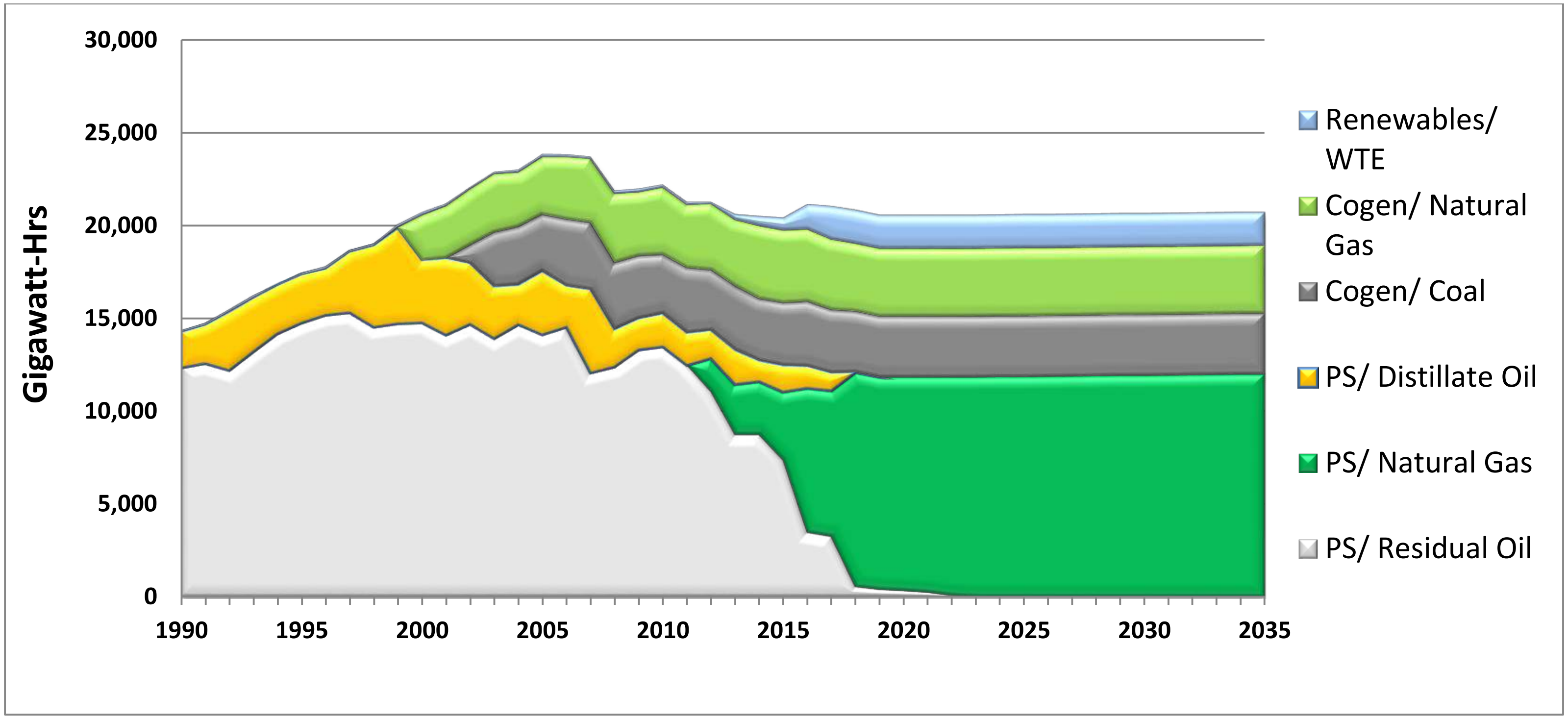
1. Determine annual primary energy consumption by Puerto Rico power and CHP stations by plant and fuel type. For coal, PREPA indicates that all coal consumed for power generation is bituminous coal.
2. For the CHP facilities, break out the energy consumed for useful thermal output, and allocate that fuel use to the Industrial sector. For both cogeneration facilities, the plant heat rates and gross power generation data supplied by PREPA were used to calculate the amount of fuel used to produce electricity. The remainder of the total plant energy use (provided by PREQB) was allocated to useful thermal output. The energy associated with useful thermal output was then allocated to the Industrial sector for GHG emissions accounting purposes.
3. Multiply annual primary energy consumption by Puerto Rico power and CHP stations by the appropriate GHG emission factors. For MSW WTE, adjust the CO_2 emissions to only account for fossil-based carbon (note this only affects the forecasted emissions, since this facility is planned to go on-line in 2016. PREPA provided a characterization of the MSW expected to be combusted by the facility indicating that fossil-based energy content (e.g. plastics, rubber, other petroleum-based synthetics) will make up 42% of the waste.
4. Adjust the GHG emissions to a CO_2e basis by multiplying by their global warming potential.

Table A-2. Summary of Puerto Rico Electric Generator Characteristics for 2013

Energy Source	**Gross Generation (GWh)**	**Net Generation (GWh)**	**Fuel Use (Terajoules)**	**Heat Rate (kJ/kWh)**
Cogeneration Facilities				
Coal	3,433	3,514	35,529	10,350
Natural Gas	3,574	3,570	29,135	8,151
Power Stations				
Residual Oil	9,361	8,728	99,922	10,674
Natural Gas	2,915	2,720	30,643	10,514
Distillate Oil	1,915	1,870	17,439	9,108
Hydroelectric	83	83	N/A	N/A
Solar/PV	173	173	N/A	N/A
Wind	40	40	N/A	N/A
MSW	0	0	0	0
Landfill gas	0	0	0	0
Exports	***N/A***	***N/A***	***N/A***	***N/A***
Imports	***N/A***	***N/A***	***N/A***	***N/A***
Total	***21,493***	***20,697***	***212,669***	***9,895***

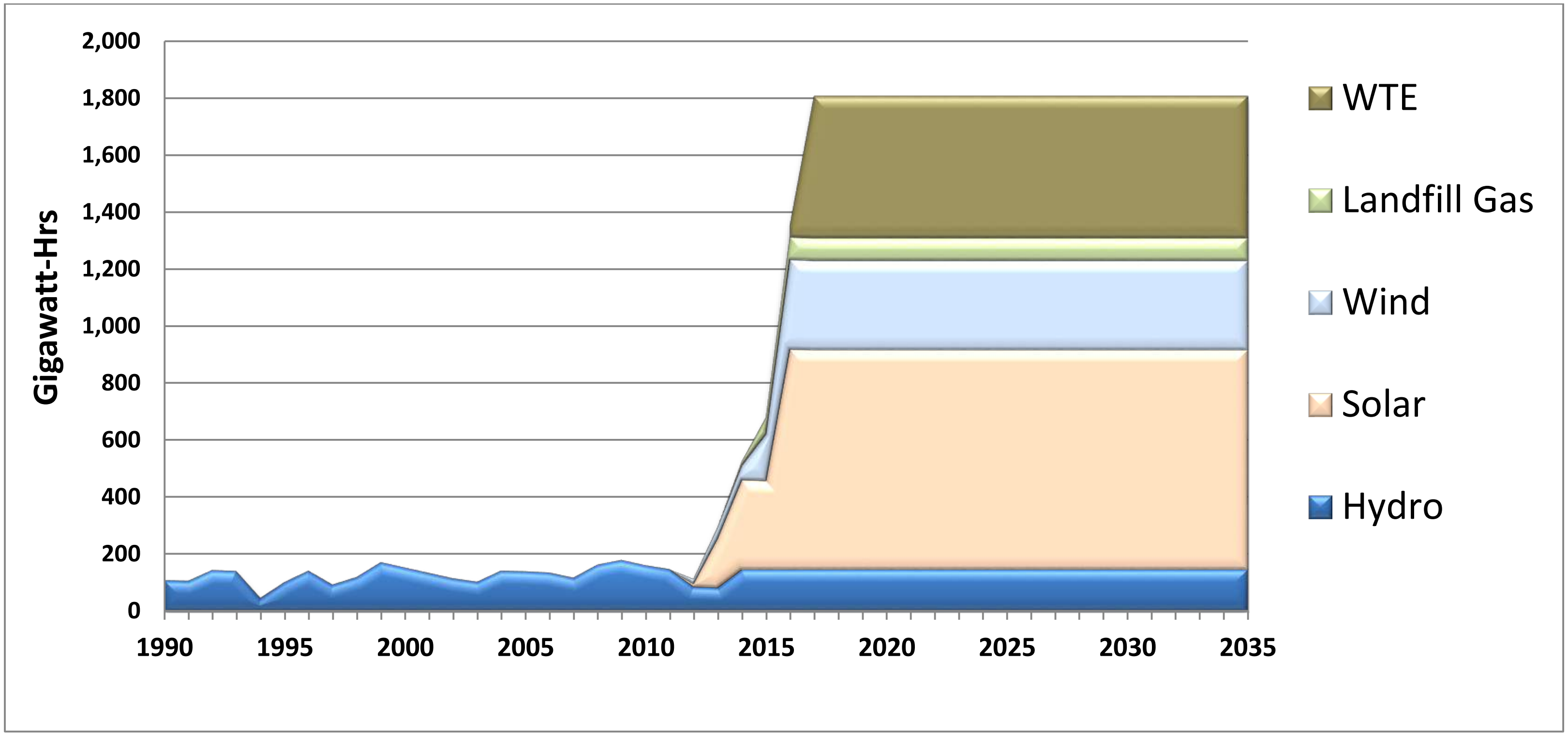
Figure A-1 provides the net generation baseline for Puerto Rico. This covers generation by power stations (PS), cogeneration facilities (cogen), and renewable resources. The renewables category includes hydroelectric, solar, wind, landfill gas, and a planned waste to energy (WTE) facility that will combust municipal solid waste (MSW). This facility is planned to begin operations in 2016. Figure A-2 provides a break-out of the generation baseline for renewables. Details for the forecasting methods are provided in the next section.

Figure A-1. Net Generation Baseline



Resource/Fuel Type	1990	1995	2000	2005	2010	2015	2020	2025	2030	2035
PS/Residual Oil	12,332	14,737	14,754	14,109	13,463	7,377	324	0	0	0
PS/Natural Gas	0	0	0	0	0	3,665	11,523	11,874	11,941	12,008
PS/Distillate Oil	1,950	2,630	3,372	3,417	1,799	1,449	0	0	0	0
Renewables	108	100	151	138	158	659	1,787	1,787	1,787	1,787
Cogen/Coal	0	0	0	3,063	3,190	3,374	3,279	3,279	3,279	3,279
Cogen/Natural Gas	0	0	2,450	3,120	3,609	3,895	3,656	3,656	3,656	3,656
Total (GWh)	**14,390**	**17,467**	**20,727**	**23,846**	**22,219**	**20,418**	**20,570**	**20,596**	**20,664**	**20,731**

Figure A-2. Net Generation Baseline – Renewables Only

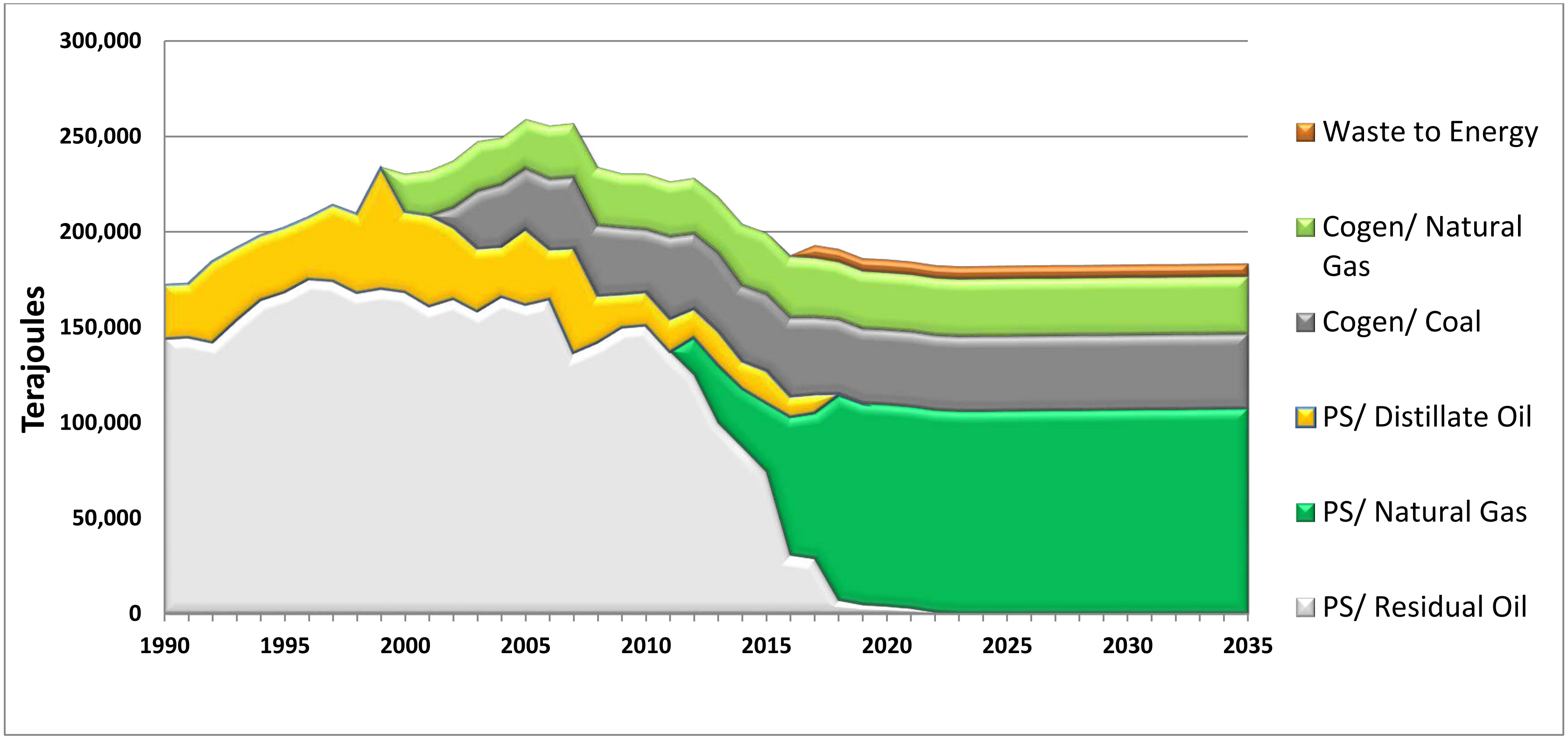


Resource/Fuel Type	1990	1995	2000	2005	2010	2015	2020	2025	2030	2035
Hydro	108	100	151	138	158	126	126	126	126	126
Solar	0	0	0	0	0	312	769	769	769	769
Wind	0	0	0	0	0	163	313	313	313	313
Landfill Gas	0	0	0	0	0	58	81	81	81	81
WTE	0	0	0	0	0	0	499	499	499	499
Total (GWh)	**108**	**100**	**151**	**138**	**158**	**659**	**1,787**	**1,787**	**1,787**	**1,787**

Figure A-3 provides the baseline energy consumption for electricity generation based on partial implementation of the Puerto Rico Renewable Energy Portfolio Standard (and also assumed in goal setting for US EPA Section 111d). For the cogeneration facilities, this includes just the energy used in the generation of electricity. The remaining energy use is allocated to the Industrial sector. For the AES facility, the heat host shut down in 2011[10], so from then on all fuel is allocated to power production.

[10] L. Vazquez, PREPA, personal communication with S. Roe, CCS, September 29, 2014.

Figure A-3. Primary Energy Consumption Baseline



Resource/Fuel Type	1990	1995	2000	2005	2010	2015	2020	2025	2030	2035
PS/Residual Oil	144,114	168,568	168,734	161,884	151,133	74,196	3,816	0	0	0
PS/Natural Gas	0	0	0	0	0	36,483	105,737	106,339	106,940	107,541
PS/Distillate Oil	28,019	33,424	23,219	25,472	20,935	16,536	0	0	0	0
Cogen/Coal	0	0	0	32,078	33,015	40,590	39,453	39,453	39,453	39,453
Cogen/Natural Gas	0	0	20,106	25,572	29,067	31,903	29,948	29,948	29,948	29,948
Waste to Energy	0	0	0	0	0	0	6,610	6,610	6,610	6,610
Total (TJ)	**172,133**	**201,993**	**212,059**	**245,006**	**234,151**	**199,709**	**185,565**	**182,351**	**182,952**	**183,553**

GHG emissions are calculated from primary energy consumption. Table A-3 summarizes the emission factors used to generate the emission estimates. These emission factors were taken from TCR's General Reporting Protocol (GRP)[11].

Table A-3. GHG Emission Factors for Electricity Generation

Fuel Type	(kg GHG/MMBtu)		
	CO2	CH4	N2O
Bituminous Coal	93.4	0.00070	0.0014
Fuel Oil #1	73.25	0.00020	0.0004
Fuel Oil #2	73.96	0.00020	0.0004
Fuel Oil #3/4	73.96	0.00020	0.0004
Fuel Oil #5	75.04	0.0030	0.0003
Fuel Oil #6	72.93	0.0030	0.0003
Liquefied Petroleum Gas	62.98	0.00090	0.0040
Natural Gas	53.02	0.0010	0.00010
Municipal Solid Waste	90.7	0.0093	0.0059

In addition to the GHG emission factors, additional inputs required for estimating emissions from the MSW WTE facility include an assumed heat content and the fraction of heat input derived from non-biogenic (i.e. fossil-based) materials. Biogenic carbon in the waste is assumed to be derived from sustainable sources and, therefore, the CO_2 is excluded from the calculation of carbon dioxide equivalent emissions. Emissions of CH_4 and N_2O are included in the CO_2e totals based on 100% of the MSW input. The non-biogenic fraction of MSW was assumed to be 41.8% for all years in the forecast, and the heat content was assumed to be 11.97 MMBtu/ton[12]. Mass emissions estimates for each GHG were then transformed into CO_2 equivalents using IPCC 100-yr global warming potentials from the Second Assessment Report[13]:

Gas	CO_2	CH_4	N_2O	SF_6
GWP	1	21	310	23,900

[11] TCR, GRP, 2013; http://www.theclimateregistry.org/resources/protocols/general-reporting-protocol/.
[12] R. Marrero, PREPA, personal communication with S. Roe with waste characterization break-down for the Energy Answers, Inc. facility, September 24, 2014.
[13] http://www.ipcc.ch/publications_and_data/publications_and_data_reports.shtml.

Energy and Greenhouse Gas Forecast Methodology

The GHG forecast period was considered to be 2014 – 2035. Ideally, constructing a GHG forecast should be based on detailed system planning information for PR over the entire planning period, including information such as projected sales, gross in-state generation, supply-side efficiency improvements, planned capacity additions and retirements by plant type/vintage, and changes over time regarding losses associated with on-site use and transmission and distribution (T&D). These details have been incorporated to the extent of available data from PREPA.

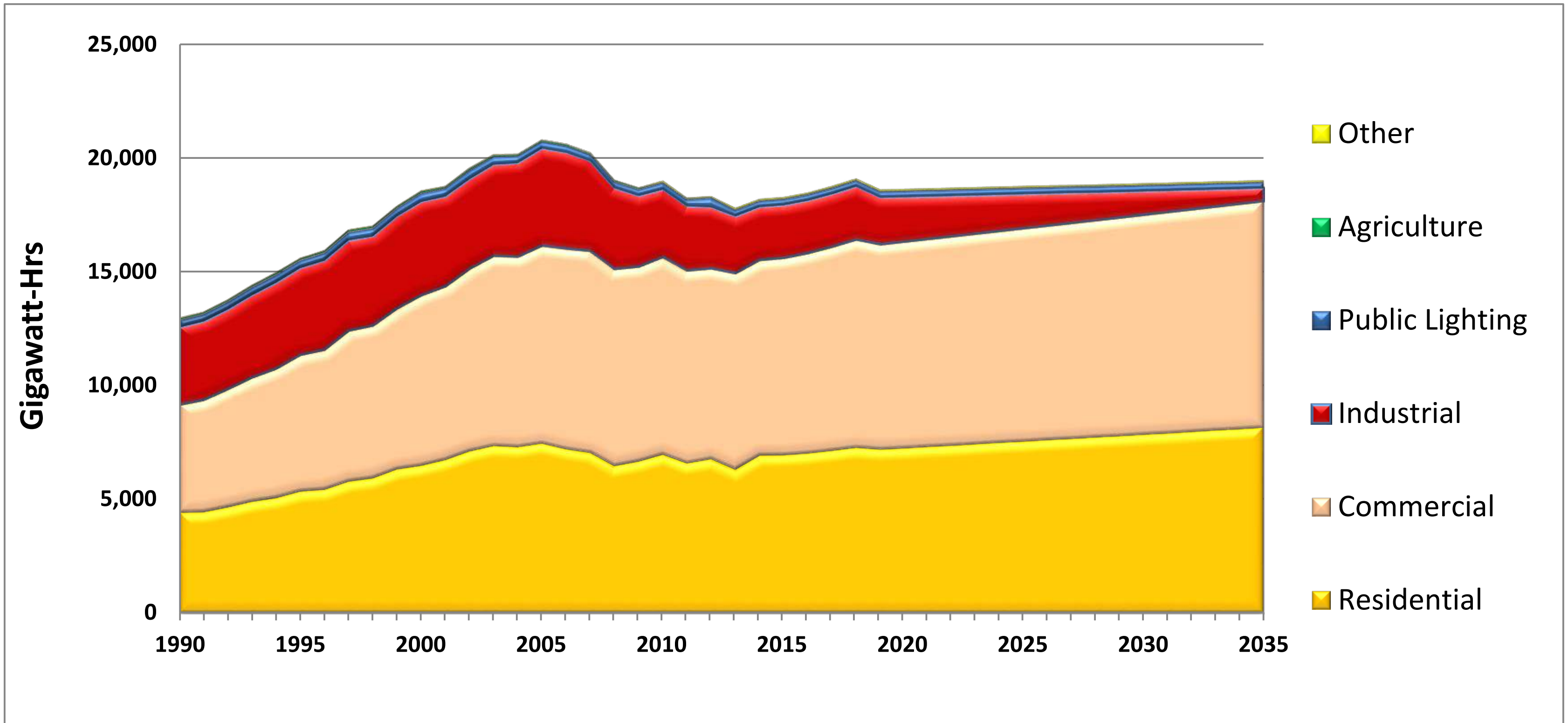
PREPA was able to provide near-term forecasts (2014-2018) on electricity demand, gross and net generation, and primary fuel use. The long-term forecast is based on simple trending of the historical and near-term forecast data through 2035. The electricity demand baseline is shown in Figure A-4 below. The long-term forecast is based on trending the 2009-2018 demand through 2035. As seen in this figure, the residential and commercial sectors dominate the historical and forecast electricity demand in Puerto Rico.

Coal quality. It was assumed that the coal quality used in the AES Puerto Rico cogen plant was the same as in the historical period (sub-bituminous coal).

Gross generation. Gross generation was calculated using the following assumptions:

- The growth rate for gross generation on a production basis (i.e., net generation plus on-site electricity use for all in-state units) was assumed to grow at the same rate as in-state sales.
- The resource mix remained the same in all forecast years as in the Base Year.
- Transmission and distribution (T&D) and theft losses were assumed to be equal to the average calculated for the 2009-2013 historical period (14% total).

Figure A-4. Electricity Demand Baseline



End Use Sector	1990	1995	2000	2005	2010	2015	2020	2025	2030	2035
Residential	4,426	5,364	6,482	7,460	6,975	6,942	7,252	7,551	7,850	8,149
Commercial	4,744	5,996	7,498	8,693	8,677	8,668	9,068	9,359	9,651	9,942
Industrial	3,400	3,822	4,101	4,258	2,968	2,317	1,966	1,503	1,039	575
Public Lighting	313	325	362	293	285	250	250	250	250	250
Agriculture	65.5	68.1	75.8	61.4	30.0	26.6	26.6	26.6	26.6	26.6
Other	34.9	36.3	40.4	32.7	57.6	64.4	64.4	64.4	64.4	64.4
Total (GWh)	**12,983**	**15,612**	**18,560**	**20,798**	**18,993**	**18,268**	**18,627**	**18,754**	**18,881**	**19,007**

Combustion efficiency. Fuel-specific heat rates held constant from the most recent near-term forecast year (2018). For the WTE plant, an average U.S. value was taken from an Oak Ridge National Laboratory database[14] (20,046 kJ/kWh) and used throughout the forecast period.

Primary energy use. A simple 2-step process was used to forecast primary energy use. First, the near-term forecasts by PREPA and then trended to follow gross generation. The forecast indicates that both residual and distillate oil combustion will be supplanted by natural gas combustion sources by 2020. Therefore, for the second step, natural gas use was constrained by forecasted electricity demand (i.e. cogeneration facilities and renewable resources were assumed to be operated at their full capacity). T&D loss rates were held constant at historical levels and power plant own use levels were also assumed to remain constant.

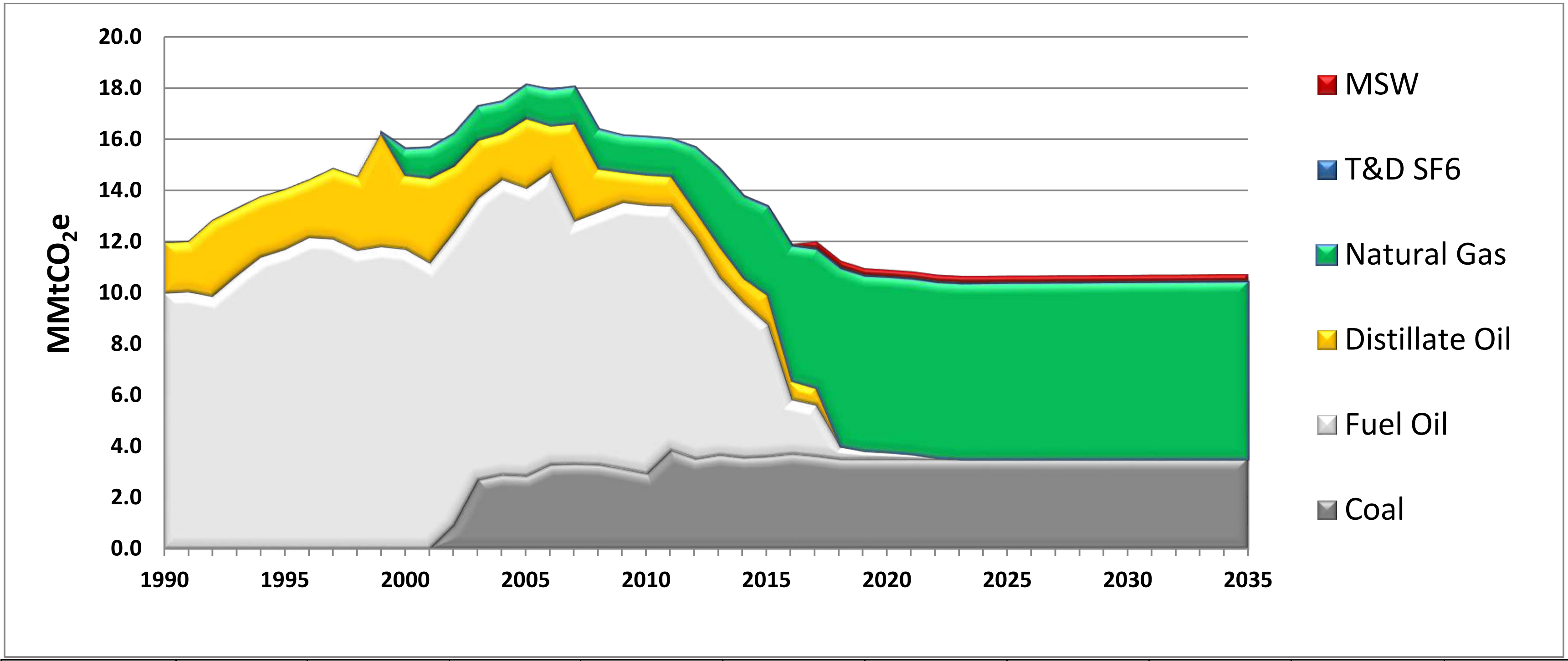
GHG Results

Figure A-5 provides the GHG baseline for electricity supply. In addition to the fuel combustion emissions at the power stations and cogeneration facilities, SF_6 emissions from T&D equipment leaks are also included. PREPA provided annual leakage estimates for 2011-2013[15]. Emissions were back-casted to 1990 using the 2011 annual leakage rate and forecasted to 2035 using the 2013 leakage rate.

Total GHG emissions were about 16.1 $MMtCO_2e$ in 2010 and are projected to decline to about 10.5 $MMtCO_2e$ in 2035, representing an overall decrease of almost 35% during this 25-year period. The decline is a function of an expected flattening in electricity demand, as well as an increasingly cleaner power supply over this period. The decrease in carbon intensity (GHGs per GW) of electricity supply is shown in Figure A-6. The primary drivers of this trend are a transition away from residual and distillate oil based production replaced primarily by natural gas-fired units (see Figure A-5). New energy efficiency and renewable energy requirements associated with US EPA Section 111d standards could drive this carbon intensity index even lower.

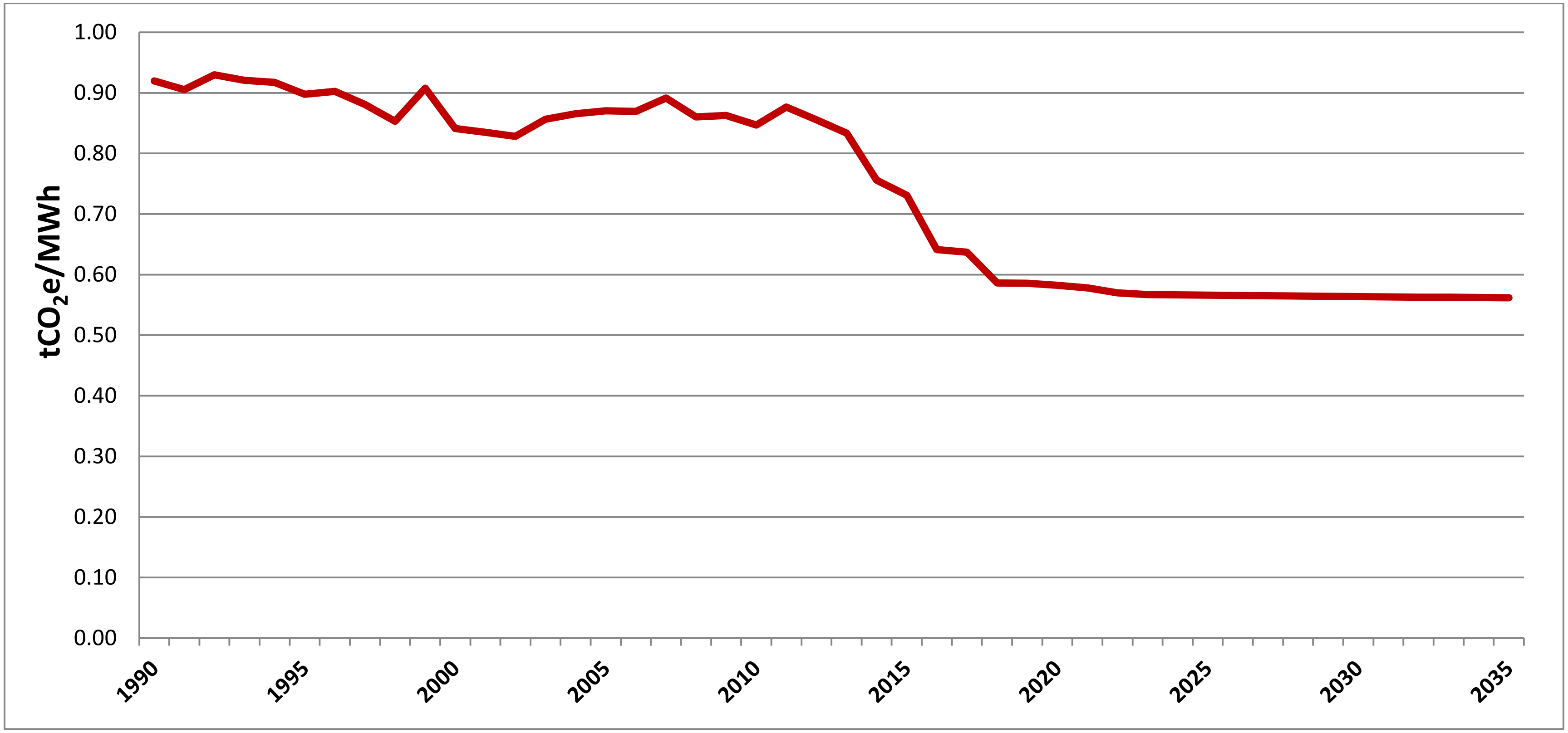
[14] cta.ornl.gov/bedb/biopower/Current_MSW_Power_Plants.xls.
[15] R. Marrero, PREPA, personal communication with S. Roe, CCS, September 24, 2014.

Figure A-5. GHG Emissions from Puerto Rico Electricity Production



Source	1990	1995	2000	2005	2010	2015	2020	2025	2030	2035
T&D SF6	0.027	0.027	0.027	0.027	0.027	0.061	0.061	0.061	0.061	0.061
Coal	0.00	0.00	0.00	2.85	2.94	3.61	3.51	3.51	3.51	3.51
Fuel Oil	10.0	11.7	11.7	11.2	10.5	5.14	0.26	0.00	0.00	0.00
Distillate Oil	1.97	2.35	2.92	2.76	1.21	1.16	0.00	0.00	0.00	0.00
Natural Gas	0.00	0.00	1.01	1.29	1.5	3.4	6.8	6.9	6.9	6.9
MSW	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.25	0.25	0.25
Total	**12.0**	**14.1**	**15.6**	**18.1**	**16.1**	**13.4**	**10.7**	**10.4**	**10.5**	**10.5**

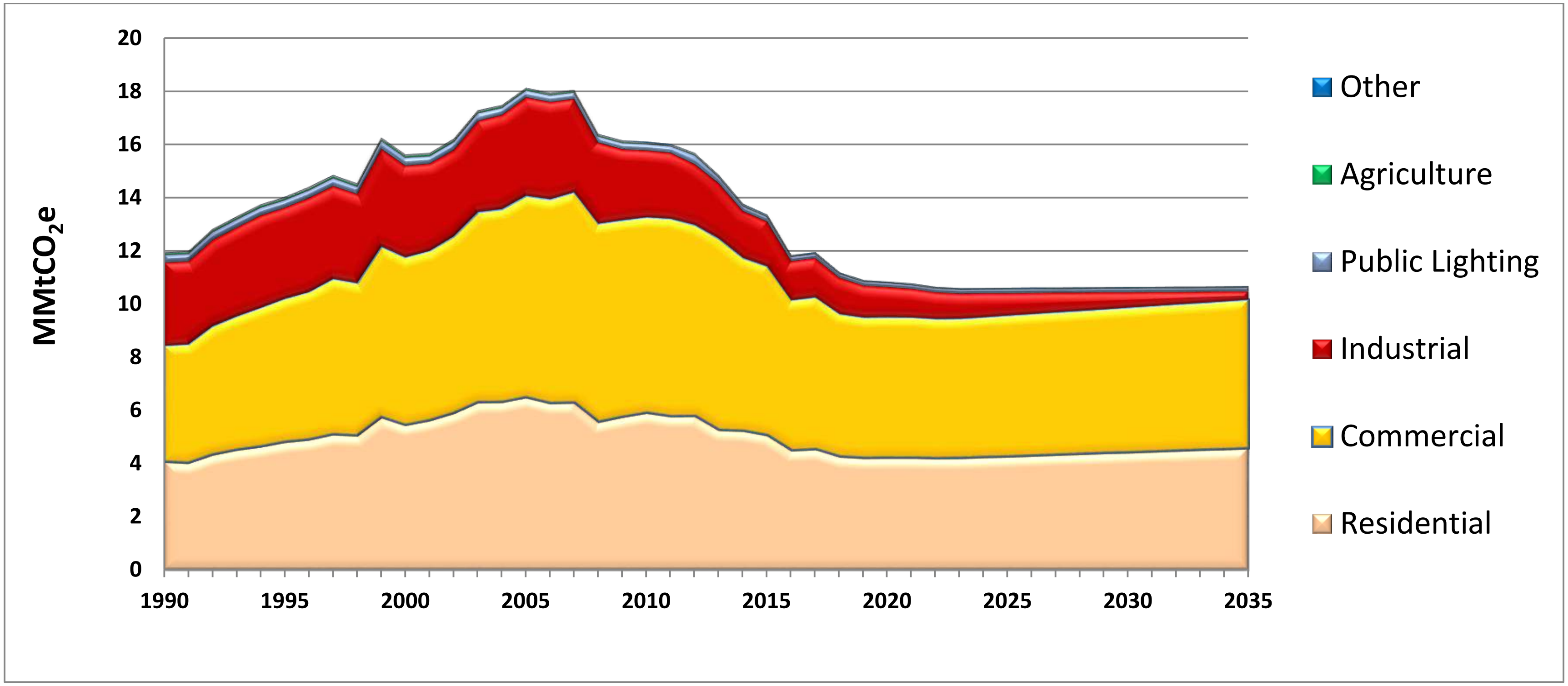
Figure A-6. Carbon Intensity of Electricity Supply



	1990	1995	2000	2005	2010	2015	2020	2025	2030	2035
tCO2e/MWh	0.920	0.898	0.841	0.871	0.847	0.731	0.582	0.566	0.564	0.562

Figure A-7 shows the electricity sector emissions allocated to end use sector. The chart closely follows Figure A-4 on electricity demand.

Figure A-7. Electricity Sector Emissions Allocated to End Use Sector



End Use Sector	1990	1995	2000	2005	2010	2015	2020	2025	2030	2035
Residential	4.1	4.8	5.5	6.5	5.9	5.1	4.2	4.3	4.4	4.6
Commercial	4.4	5.4	6.3	8	7	6	5	5	5	6
Industrial	3.1	3.4	3.4	3.7	2.5	1.7	1.1	0.9	0.6	0.32
Public Lighting	0.29	0.29	0.30	0.26	0.24	0.18	0.15	0.14	0.14	0.14
Agriculture	0.060	0.061	0.064	0.053	0.025	0.019	0.016	0.015	0.015	0.015
Other	0.032	0.033	0.034	0.028	0.049	0.047	0.037	0.036	0.036	0.036
Total ($MMtCO_2e$)	**11.9**	**14.0**	**15.6**	**18.1**	**16.1**	**13.4**	**10.8**	**10.6**	**10.6**	**10.7**

Key Uncertainties and Additional Research Needs

Key sources of uncertainty underlying the estimates above are as follows:

- For the inventory period, 1990-2013, the data used in this initial analysis are based on PR-specific data compiled by PREPA and standard GHG emission factors. The uncertainty associated with these reported values is considered to be low.
- For the forecast period, 2014-2035:
  - ✓ *Electricity Demand:* The forecast relies on the most recent PR near-term demand through 2018 and then uses trending of the previous 10-year period to forecast demand through 2035. Better long-term estimates could be derived using macro-economic indicators for Puerto Rico, particularly for the commercial and industrial sectors. It is also unclear what the assumptions are in the near-term forecast regarding energy efficiency improvements for end users.
  - ✓ *Generation Sources:* The planned Energy Answers, Inc. WTE facility has been incorporated into the forecast with an assumed start-up date in 2016. It is currently unclear whether the facility will be constructed and operated on this schedule. The heat rate for the facility uses a U.S. average for WTE plants and static assumptions about the heat content of MSW and the fraction of non-biogenic carbon combusted. The long-term forecast does not assume any increase in plant-level efficiency.
    The renewable portfolio standard (RPS) targets for PR include generating 20% of electricity from renewable resources by 2035. The current generation forecast includes about 7% of generation coming from renewable resources by 2035 (including hydro-electric and all WTE generation). Any additional penetration of renewables needed to achieve the targets has not been incorporated into the forecast.
  - ✓ *Other:* transmission & distribution losses and theft rates are kept constant through the forecast at 14%. The uncertainty associated with these assumed values is considered to be high.

Future work should include gathering data to estimate CO_2 emissions associated with the use of limestone and sodium carbonate at the AES facility. The facility also consumes propane for limestone drying and diesel fuel in auxiliary equipment. Methane emissions from coal storage and crushing activities should also be investigated.

Future work should also include gathering information to assess CH_4 emissions from natural gas storage and transmission at the EcoElectrica cogeneration facility and any associated natural gas transmission and distribution pipelines.

B. Residential, Commercial, Institutional & Industrial Fuel Combustion

Overview

Activities in the RCII sectors produce carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) emissions when fuels are combusted to provide space heating, water heating, process heating, cooking, and other energy end-uses. CO_2 accounts for over 99% of these emissions on a million metric tons (MMt) of CO_2-equivalent (CO_2e) basis. This sector also reflects emissions associated with industrial thermal energy consumption. Excluded from the RCII sector is fossil fuel combustion for the purposes of electricity generation and all end uses of electricity consumption (e.g., space cooling), which are covered in the Energy Supply chapter.

Data Sources

Environmental Quality Board
The Environmental Quality Board (EQB) provided fossil fuel usage from commercial and industrial users' operating equipment with a heat input rating equal or greater than 10 MMBtu. Fuels reported include various classes of fuel oils ranging from class number 1 to number 6, and reports covered the period 1992 to 2013. Additional fuel types include liquid petroleum gas (LPG), coal, and natural gas. The commercialization of natural gas started in 1999 to supply primary energy to a combined heat and power (CHP) plant. Note that GHG emissions from the CHP plant described in the RCI sector only account for useful thermal energy production that is supplied to other industrial users. Combustion emissions attributed to electricity generation are covered in the Energy Supply chapter.

Furthermore, standard industrial classification codes (SIC) were used to distinguish between industrial and commercial fuel consumption; note that virtually all the commercial fuel use was associated with hospitals and health centers under SIC code 80.

Energy Information Agency
The U.S. Energy Information Agency (EIA) publishes top-down estimates of energy consumption for the period 1990 to 2010[16]. Relevant data series, including distillate fuel oil, residual fuel oil, coal, LPG and natural gas consumption were used where appropriate to supplement the energy consumption picture provided by the EQB records.

Specifically, the EIA distillate fuel oil data set was used as proxy data to back cast the EQB's estimate of commercial/industrial fuel oil number 1 and number 2 consumption from 1992 to 1990. Similarly, EIA's residual fuel oil data set was used as proxy data to back cast EQB's estimate of commercial/industrial fuel oil number 5 and number 6 consumption. The EIA coal data set was used to back cast EQB estimates of coal consumption from 1992 to 1990.

[16] EIA 2014. U.S. Energy Information Agency (EIA). International Energy Statistics. Puerto Rico. http://www.eia.gov/cfapps/ipdbproject/iedindex3.cfm?tid=3&pid=49&aid=3&cid.

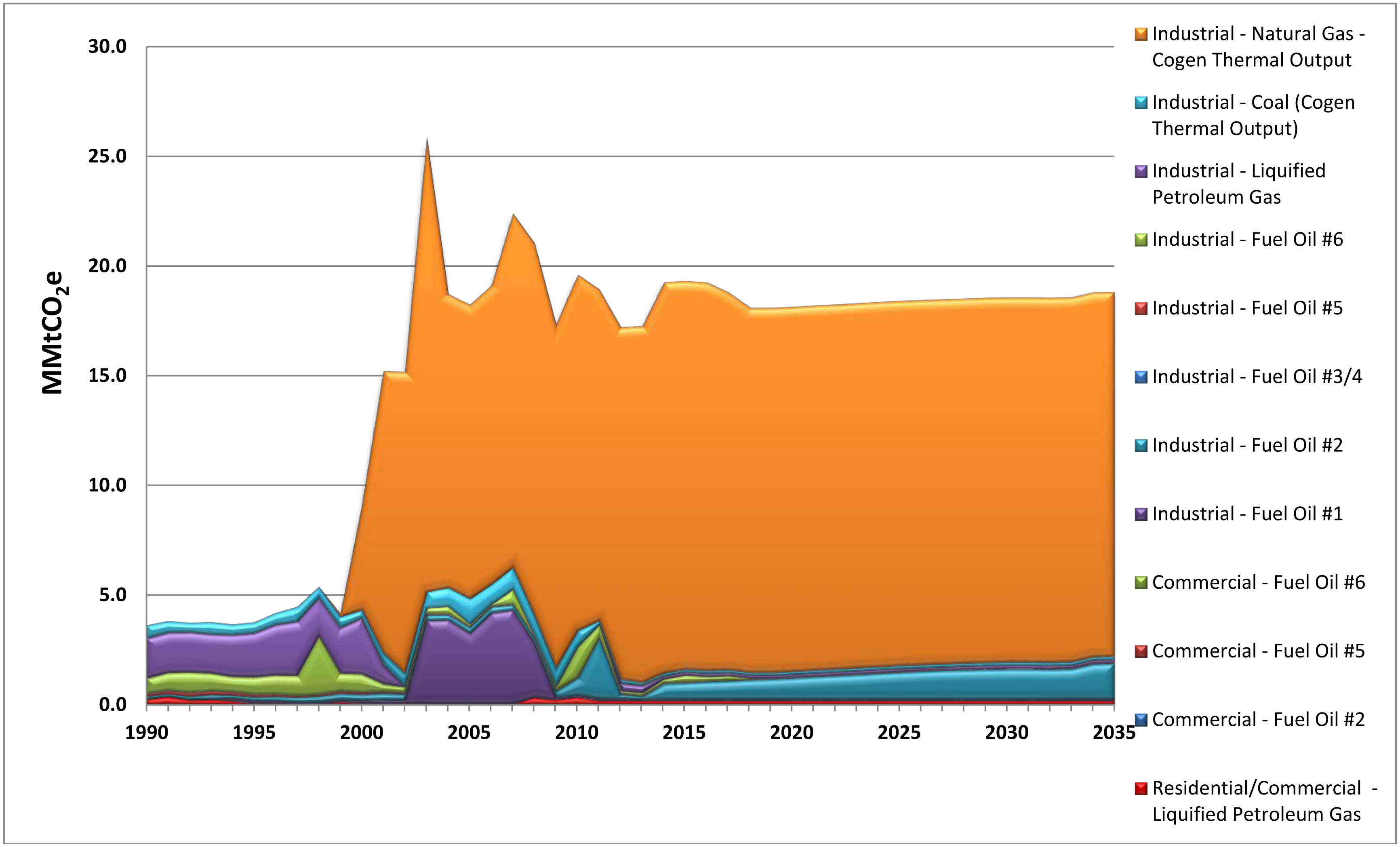
Although some LPG sales information was compiled during the inventory development process[17], the data set was not complete and did not reflect the totality of Puerto Rico's LPG consumption. For that reason, the top-down LPG consumption estimate from EIA was used. Historically, LPG was a common energy source for residential applications but has been phased out in more recent years by electrical appliances. However, LPG remains an important residential energy source in rural areas. In order to estimate LPG residential consumption, the EIA LPG data set was used as the reference for island-wide consumption from which EQB's commercial/industrial LPG consumption was subtracted.

Emissions and BAU Projections

In the 1990s, LPG dominated the commercial/industrial energy consumption landscape, followed by the consumption of distillate and residual fuel oils. In the early 2000's, natural gas entered the market and rapidly became dominant energy source. By 2013, once dominant energy sources such as fuel oil no. 6 and LPG became marginal sources of energy. In the case of coal, consumption declined in the early 2000s and has remained relatively flat across the temporal series. In the forecast scenario, natural gas and fuel oil no. 2 are projected to supply the majority of energy needs for residential, commercial, and industrial users combined. Figure B-1 presents GHG emissions for the entire RCI sector for the period 1990 to 2035.

[17] DACO 2014. Departamento de Asuntos del Consumidor. RE: Cumplimiento con OE-2013-018 (Oficina Estatal de Política Pública Energética). Email correspondence dated September 23, 2014.

Figure B-1. RCI Emissions by User and Fuel Type in $MMtCO_2e$, 1990-2035



Sector		**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**
Residential/Commercial - Liquefied Petroleum Gas	CO2e	0.22	0.03	0.04	0.00	0.32	0.17	0.17	0.17	0.17	0.17
Commercial - Fuel Oil #2	CO2e	0.01	0.00	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.01
Commercial - Fuel Oil #5	CO2e	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Commercial - Fuel Oil #6	CO2e	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Industrial - Fuel Oil #1	CO2e	0.04	0.13	0.13	3.22	0.11	0.07	0.07	0.07	0.07	0.08
Industrial - Fuel Oil #2	CO2e	0.12	0.19	0.29	0.29	0.80	0.77	0.98	1.24	1.38	1.63
Industrial - Fuel Oil #3/4	CO2e	0.00	0.00	0.02	0.00	0.01	0.00	0.01	0.01	0.01	0.01
Industrial - Fuel Oil #5	CO2e	0.12	0.11	0.07	0.03	0.01	0.02	0.02	0.02	0.02	0.02
Industrial - Fuel Oil #6	CO2e	0.69	0.80	0.83	0.11	1.39	0.32	0.00	0.00	0.00	0.00
Industrial - Liquefied Petroleum Gas	CO2e	1.82	1.99	2.54	0.00	0.00	0.14	0.14	0.14	0.14	0.14
Industrial - Coal (Cogen Thermal Output)	CO2e	0.59	0.50	0.36	1.16	0.72	0.12	0.12	0.13	0.13	0.14
Industrial - Natural Gas - Cogen Thermal Output	CO2e	0.00	0.00	4.80	13.39	16.21	17.70	16.62	16.62	16.62	16.62

Some notable outliers were observed in the historic fuel consumption data set. First, fuel oil no. 1 consumption peaked between 2003 and 2008. EQB records indicates large volumes (as high as 350 million gallons) of fuel oil no.1 were reported by a single plant (Shell Chemicals) in the Petroleum and Coal Products industry segment and then no consumption was reported from 2009 to the end of the historic temporal series in 2013[18]. For the purposes of this study, it is assumed that EQB records were reliable, and therefore, this peak in fuel no. 1 consumption was kept as part of the inventory.

However, it is recommended that EQB or the reporter corroborate this information. Second, a number of spikes were observed for fuel oil no. 6 in 1998, 2007, and 2008. These could be traced to consumption at a single distillery (Bacardi Corporation). It is assumed in this study these spikes reflect changes in market demand. Third, the fuel oil no. 2 spike in 2011 could be traced to a single plant in the Paper and Allied Products category. It is assumed this spike reflects changes in market demand.

Greenhouse Gas Inventory Methodology

Combustion of fossil fuels yields carbon dioxide, methane, and nitrous oxide. Emissions were calculated as a function of the volume or mass of fuel consumed, the energy content of the fuel on a gross calorific value (GCV) basis, and fuel specific emission factors. Default GCV and emissions factors compiled by The Climate Registry[19] were used in combination with aforementioned fuel consumption activity data. The methodology is expressed as follows.

$V_i \times GCV_i \times EF_{i,j} = GHG\ emissions$ (Equation 1)

Where

V_i = volume of mass of fuel “i” combusted.

GCV_i = gross calorific value of fuel “i”.

$EF_{i,j}$ = emission factor for fuel “i” combusted for specific to GHG “j”.

Greenhouse Gas Forecast Methodology – Business as Usual

In general, the forecast scenario followed official macroeconomic growth projections[20]. In some cases, forecasting was conducted using a simple linear regression of the historic data series whenever the historical values exhibited a large variance from year to year, which was the case for fuel oil no. 2 and fuel oil no. 6. Actually, industrial fuel oil no. 6 use is projected to reach zero consumption by the year 2018 based on a historical trend analysis while commercial fuel oil no. 6 consumption was discontinued in 1995. In the case of LPG, there was reason to believe that this fuel is losing market share to natural gas; therefore, a flat growth rate was applied. As for natural gas consumption, no growth is expected after 2010 when CHP plant stopped

[18] EQB 2014. Environmental Quality Board (EQB). Emisiones_gases 2005_2013.xlsx and Emisiones_gases 92_2004.xlsx. Microsoft Excel files provided on August 25, 2014.

[19] TCR 2013. The Climate Registry. General Reporting Protocol. 2013 Climate Registry Default Emission Factors. http://www.theclimateregistry.org/resources/protocols/general-.

[20] Planning Board. Puerto Rico Planning Board. Program of Economic and Social Development. Subprogram of Social Analysis, Models and Projections. Appendix B. Selected Macroeconomic Variables: Fiscal Years 2008-2018.

providing thermal energy to end user Chevron. The mean annual growth rates applied in the BAU forecast are shown in Table B-1.

Table B-1. Projected Mean Annual Growth Rates by User and Fuel Type

User - Fuel Type	2011-2015	2016-2020	2021-2025	2026-2030
Residential/Commercial - Liquefied Petroleum Gas	0.0%	0.0%	0.0%	0.0%
Commercial - Fuel Oil #2	4.3%	-2.8%	2.6%	1.0%
Commercial - Fuel Oil #5	-5.8%	0.6%	0.6%	0.6%
Commercial - Fuel Oil #6	NA	NA	NA	NA
Industrial - Fuel Oil #1	-9.6%	0.6%	0.6%	0.6%
Industrial - Fuel Oil #2	-22.6%	3.9%	3.6%	1.5%
Industrial - Fuel Oil #3/4	-2.5%	0.6%	0.6%	0.6%
Industrial - Fuel Oil #5	-4.8%	0.6%	0.6%	0.6%
Industrial - Fuel Oil #6	-11.0%	-100.0%	NA	NA
Industrial - Liquefied Petroleum Gas	NA	0.0%	0.0%	0.0%
Industrial - Coal (Cement Production)	-8.5%	0.8%	0.8%	0.8%
Industrial - Coal (Cogen Thermal Output)	NA	NA	NA	NA
Industrial - Natural Gas - Cogen Thermal Output	3.2%	-1.3%	0.0%	0.0%

NA = Not applicable because fuel consumption is projected to be zero.

Results

In 1990, LPG accounted for 57% of total RCI emissions and was used extensively by industrial users. Fuel oil no. 6 consumption and coal use accounted for 19% and 16%, respectively, and were used exclusively by industrial users.

By 2010, the LPG emissions share plummeted to 3%; in its place, natural gas consumption for thermal production became the single largest source of RCI emissions at 59%. Industrial coal and fuel oil no. 6 consumption continue to be important fuel sources, accounting for 19% and 11% of RCI greenhouse gas emissions.

The 2030 BAU scenario shows that the share of emission from natural gas use will increase to 64%, followed by industrial coal (20%) and industrial fuel oil no. 2 (12%). It is also projected that consumption of fuel oil no. 6 will be discontinued and the use of fuel oil no.1 will drop by 32% relative to 2010. Moreover, it is projected that commercial and industrial fuel oil no. 2 consumption will increase substantially compared to 2010 on based on the historical data trend. In absolute terms, total RCI emissions are expected to decrease 6% by 2030 relative to 2010. Finally, the results suggest that emissions peaked during the period of analysis in 2003 at 15.7 $MMtCO_2e$, primarily due to peak consumption of fuel oil no. 1.

Results are summarized in the tables below. Table B-2 presents the emission distribution for selected years by end user and fuel type. Table B-3 displays the energy consumption by end user and fuel type in units of energy with corresponding GHG emissions presented in Table B-4.

Table B-2. Emission Distribution by End User and Fuel Type, Selected Years

End User – Fuel Type	1990	2010	2030
Residential/Commercial - Liquefied Petroleum Gas	6%	2%	1%
Commercial - Fuel Oil #2	0%	0%	0%
Commercial - Fuel Oil #5	0%	0%	0%
Commercial - Fuel Oil #6	0%	0%	0%
Industrial - Fuel Oil #1	1%	1%	0%
Industrial - Fuel Oil #2	3%	4%	7%
Industrial - Fuel Oil #3/4	0%	0%	0%
Industrial - Fuel Oil #5	3%	0%	0%
Industrial - Fuel Oil #6	19%	7%	0%
Industrial - Liquefied Petroleum Gas	51%	0%	1%
Industrial - Coal (Cement Production)	16%	1%	1%
Industrial - Coal (Cogen Thermal Output)	0%	3%	0%
Industrial - Natural Gas - Cogen Thermal Output	0%	83%	90%

Table B-3. Activity Data by End User and Fuel Type in TJ, Selected Years

End User – Fuel Type	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**
Residential/Commercial - Liquefied Petroleum Gas	3,578	508	672	0	5,203	2,734	2,734	2,734	2,734	2,734
Commercial - Fuel Oil #2	73	13	127	95	36	110	98	101	108	100
Commercial - Fuel Oil #5	0	0	0	0	30	22	23	24	25	26
Commercial - Fuel Oil #6	127	116	0	0	0	0	0	0	0	0
Industrial - Coal - Cement Production	6,535	5,519	4,056	8,999	2,195	1,285	1,343	1,411	1,483	1,559
Industrial - Coal - Thermal Production	0	0	0	3,980	5,858	0	0	0	0	0
Industrial - Fuel Oil #1	512	1,920	1,886	46,300	1,558	938	973	1,013	1,054	1,097
Industrial - Fuel Oil #2	1,712	2,644	4,181	4,086	11,392	10,898	14,011	17,613	19,630	23,250
Industrial - Fuel Oil #3/4	0	0	322	0	74	71	74	77	80	83
Industrial - Fuel Oil #5	1,645	1,484	1,000	481	198	234	243	252	263	273
Industrial - Fuel Oil #6	9,976	11,513	11,966	1,588	20,127	4,636	0	0	0	0
Industrial - Liquefied Petroleum Gas	29,872	32,744	41,734	0	0	2,301	2,301	2,301	2,301	2,301
Industrial - Natural Gas - Cogen Thermal Output	0	0	95,324	266,264	322,277	351,870	330,311	330,311	330,311	330,311
Total	**54,029**	**56,462**	**161,270**	**331,792**	**368,948**	**375,099**	**352,110**	**355,836**	**357,989**	**361,733**

Table B-4. Emissions by End User and Fuel Type in $MMtCO_2e$, Selected Years

End User – Fuel Type	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**
Residential/Commercial - Liquefied Petroleum Gas	0.218	0.031	0.041	0.000	0.317	0.166	0.166	0.166	0.166	0.166
Commercial - Fuel Oil #2	0.005	0.001	0.009	0.007	0.003	0.008	0.007	0.007	0.008	0.007
Commercial - Fuel Oil #5	0.000	0.000	0.000	0.000	0.002	0.002	0.002	0.002	0.002	0.002
Commercial - Fuel Oil #6	0.009	0.008	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Industrial - Fuel Oil #1	0.036	0.134	0.131	3.220	0.108	0.065	0.068	0.070	0.073	0.076
Industrial - Fuel Oil #2	0.120	0.186	0.294	0.287	0.800	0.765	0.984	1.237	1.379	1.633
Industrial - Fuel Oil #3/4	0.000	0.000	0.023	0.000	0.005	0.005	0.005	0.005	0.006	0.006
Industrial - Fuel Oil #5	0.117	0.106	0.071	0.034	0.014	0.017	0.017	0.018	0.019	0.019
Industrial - Fuel Oil #6	0.691	0.798	0.829	0.110	1.394	0.321	0.000	0.000	0.000	0.000
Industrial - Liquefied Petroleum Gas	1.819	1.994	2.541	0.000	0.000	0.140	0.140	0.140	0.140	0.140
Industrial - Coal (Cement Production)	0.586	0.495	0.364	0.807	0.197	0.115	0.120	0.127	0.133	0.140
Industrial - Coal (Cogen Thermal Output)	0.000	0.000	0.000	0.357	0.525	0.000	0.000	0.000	0.000	0.000
Industrial - Natural Gas - Cogen Thermal Output	0.000	0.000	4.795	13.394	16.212	17.701	16.616	16.616	16.616	16.616
Grand Total	**3.60**	**3.75**	**9.10**	**18.22**	**19.58**	**19.31**	**18.13**	**18.39**	**18.54**	**18.81**

Key Uncertainties

The EQB data series does not capture fuel consumption from combustion equipment with a heat input rating less than 10 MMBtu. For the purpose of this study, GHG emissions from small stationary combustion equipment were not quantified and were considered *de minimis* relative to island wide emissions, except for LPG consumption, which were indeed capture by the implemented approach.

The historical data set shows a period of high fuel oil no. 1 consumption between 2003 and 2008 associated with activities of a single plant in Petroleum and Coal Products industry segment. It is recommended that EQB or the reporter corroborate this information and ascertain whether fuel oil no. 1 use will be discontinued indefinitely or demand for this fuel type will resume at comparable rates observed in the 2003-2008 time frame.

C. Industrial Processes and Product Use

Overview

Emissions in the industrial processes category span a wide range of activities, and reflect non-combustion sources of greenhouse gas (GHG) emissions from several industries as well as the consumption of industrial products that release GHG when used. The industrial processes and activities that were deemed to be likely sources of emissions on the basis of a risk analysis approach are listed below.

- Carbon Dioxide (CO_2) from cement production
- CO_2 emissions from glass production
- CO_2 emissions from lime production
- Hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs) from consumption of substitutes for ozone-depleting substances (ODS) used in cooling and refrigeration equipment
- HFCs, PFCs, and SF_6 from semiconductor manufacturing

Other industrial processes that are sources of GHG emissions but are likely to be absent in Puerto Rico or produce negligible amounts of GHG emissions include the following:

- CO_2 emissions from iron, steel or ammonia production
- CO_2 emissions from urea applications
- CO_2 from taconite production
- Nitrous oxide (N_2O) from nitric and adipic acid production
- PFCs from aluminum production
- SF_6 from magnesium production and processing
- HFCs from HCFC-22 production
- Consumption of carbonates such as limestone, dolomite, and soda ash

The Montreal Protocol on Substances That Deplete the Ozone Layer and its amendments control the phase out of ODS, namely chlorinated carbon such as CFCs and HCFCs. HFCs, and to a very limited extent PFCs, are serving as alternatives to ODS. Because ODS substitutes are not subject to an international phase out, it is good practice for national and sub-national GHG inventories to focus on estimating emissions from HFCs and PFCs.

Data Sources

Table C-1 summarizes the key data sources used in this chapter. The application of these data sources is discussed under the heading *Greenhouse Gas Inventory Methodology*.

Table C-1. Summary Description of Activity and Proxy Data Sources

Activity	Temporal Series	Description	Reference
Cement production	2010 - 2012	Process emissions reported under 40 CFR Part 98	EPA FLIGHT
	1990 - 2012	Cement production in 94 pound bags	JPa[21]
Glass production	1992 - 2008	Title V permit to operate, maximum glass production output	Owens[22]
Emissions from ODS substitute use	1990 - 2012	U.S. emissions from ODS substitute use	EPA 2012[23]
	1990 - 2010	Puerto Rico and U.S. population used as proxy data for emissions allocation	Census[24]
Electronics manufacturing emissions	1990 - 2012	U.S. emissions from electronics manufacturing population	EPA 2012
	1990-2013	U.S. manufacturing economic activity used as proxy data for emissions allocation	BEA[25]
	1990-2013	Puerto Rico manufacturing economic activity used as proxy data for emissions allocation	JPb[26]

Emissions and BAU Projections

Cement production is a major contributor (89.6%) to GHG emissions in the industrial sector in 1990. However, its share of emissions dropped with the rapid introduction of HFCs and PFCs in the early 1990's as ODS substitutes entered the market. Emissions from lime and glass production ceased in 1994 and 2008 respectively. By 2010, ODS substitutes account for 54.0% of industrial processes emissions and cement production for 39.9%, while the share of emissions electronics manufacturing was 4.8%. By 2035, it is projected that in the BAU scenario, ODS substitutes will dominate sector emissions at 78.0%

[21] JPa. Office of the Governor Planning Board (Junta de Planificación). Selected Statistics of the Construction Industry: 2000, 2005, 2013. http://www.jp.gobierno.pr/.

[22] Owens. Illinois Owen - Puerto Rico. Title V Permit. Owens Illinois English TV-1446-73-0397-0032.pdf. http://www2.pr.gov/agencias/jca/Documents/Forms/DispForm.aspx?ID=8770.

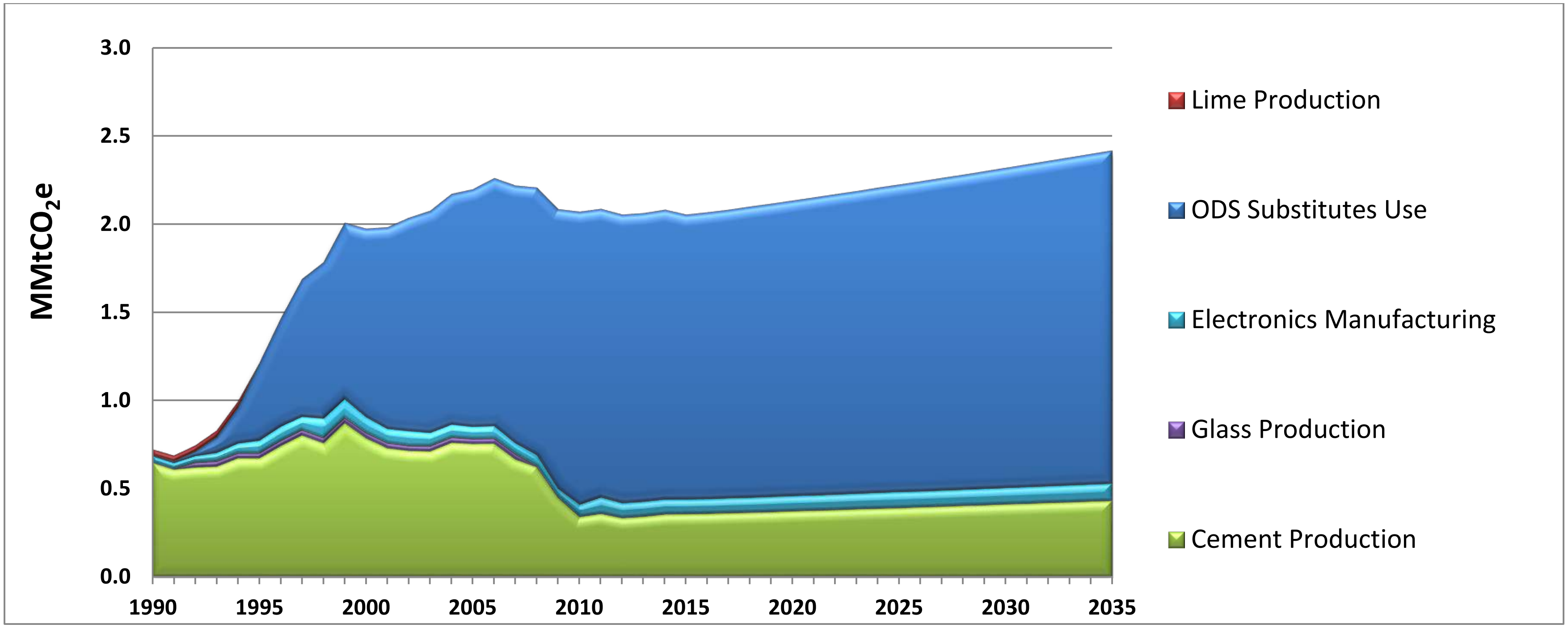
[23] EPA 2012. U.S. Environmental Protection Agency. Inventory of US Greenhouse Gas Emissions and Sinks, 1990-2012. http://www.epa.gov/climatechange/ghgemissions/usinventoryreport.html#overview.

[24] Census. U.S. Census. http://www.census.gov/population/international/data/idb/informationGateway.php; http://www.census.gov/popest/data/historical/index.html.

[25] BEA. US Bureau of Economic Analysis. Gross-Domestic-Product-(GDP)-by-Industry Data. http://www.bea.gov/industry/gdpbyind_data.htm.

[26] JPb. Office of the Governor Planning Board (Junta de Planificación). Income and Product: 2000, 2005, 2013. http://www.jp.gobierno.pr/.

Figure C-1. Industrial Processes and Product Use Emissions by Source, 1990-2035



Activity	1990	1995	2000	2005	2010	2015	2020	2025	2030	2035
Cement Production	0.65	0.67	0.79	0.75	0.34	0.36	0.37	0.39	0.41	0.43
Glass Production	0.00	0.03	0.03	0.03	0.00	0.00	0.00	0.00	0.00	0.00
Electronics Manufacturing	0.04	0.08	0.09	0.07	0.07	0.08	0.09	0.09	0.10	0.10
ODS Substitutes Use	0.00	0.44	1.06	1.34	1.66	1.61	1.67	1.74	1.81	1.88
Lime Production	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total (MMtCO₂e)	**0.72**	**1.21**	**1.97**	**2.20**	**2.07**	**2.05**	**2.13**	**2.22**	**2.32**	**2.41**

Greenhouse Gas Inventory Methodology

Cement Production
Cement plants are required to report to U.S. EPA fewer than 40 CFR Part 98 fuel combustion as well as process emissions associated with cement production. Combustion emissions at cement plants are covered under the RCI stationary combustion chapter while process emissions related to the release of CO_2 during the calcination process. Because emissions estimates under Part 98 are deemed high quality, this study used these values as reference for the years 2010 through 2012,[27] then back casted process emissions using historic cement production data published by the Planning Board as a surrogate.

Glass Production
Illinois Owens of Puerto Rico operated a glass production plant in Vega Alta until February 2008.[28] Glass production was inferred from the plant's Title V operating permit based on the maximum plant production output of 134,000 metric tons. The starting date of operations could be traced as far back as 1992 based on Rule 410, Regulation for The Control of Atmospheric Pollution records.[29]

Lime Production
Lime Production was reported in Puerto Rico's 1990-1994 GHG inventory;[30] however, it was not evident from available records maintained by EQB that a lime production plant operated on or after the year 1992 (EQB 2014). In order to maintain continuity with the previous GHG inventory, this study incorporates the 1990-1994 lime production emission estimates but did not extrapolate these emission estimates past those years.

Ozone Depleting Substances (ODS) Substitute Use
HFCs and PFCs are used as substitutes for ODS, most notably CFCs in compliance with the *Montreal Protocol* and the *Clean Air Act Amendments of 1990*.[31] CFCs are also potent greenhouse gases, with global warming potentials on the order of thousands of times that of CO_2 per unit of emissions. Even low amounts of HFC and PFC emissions from leaks and other releases associated with normal use of the products, can lead to high GHG emissions on a CO_2-equivalent basis. Emissions in Puerto Rico for the period 1990 to 2010 were estimated by scaling down U.S. ODS substitute emissions (US GHG 2012) proportionally to population (Census).

[27] EPA FLIGHT. U.S. Environmental Protection Agency. EPA Flight Database. Cement Plants in Puerto Rico, 2010-2012. http://ghgdata.epa.gov/ghgp/main.do.
[28] Nuevo Día. El Nuevo Día. Sin Comprador Owens Illinois. News release dated 1/29/2008. http://www.elnuevodia.com/Xstatic/endi/template/imprimir.aspx?id=353773&t=3.
[29] EQB 2014. Environmental Quality Board (EQB). Emisiones_gases 2005_2013.xlsx and Emisiones_gases 92_2004.xlsx. Microsoft Excel files provided on August 25, 2014.
[30] DNER 1996. Department of Natural and Environmental Resources. Energy Affairs Administration. Inventory of Puerto Rico Greenhouse Gas Emissions and Sinks 1990-1994. May 1996
[31] ODS substitutes are primarily associated with refrigeration and air conditioning, but also many other uses including as fire control agents, cleaning solvents, aerosols, foam blowing agents, and in sterilization applications. The applications, stocks, and emissions of ODS substitutes depend on technology characteristics in a range of equipment types. For the US national inventory, a detailed stock vintaging model was used to track ODS substitutes uses and emissions.

Electronics Manufacturing
The electronic manufacturing industry utilizes HFCs and to a lesser extent PFCs to remove flux residue that remains after soldering on printed circuit boards and other contamination-sensitive electronics application (EPA 2012). Emissions in Puerto Rico were estimated for the period 1990 to 2010 by scaling down U.S. electronics manufacturing emissions (US GHG 2012) in proportion to the ratio of economic activity of the industrial sector in Puerto Rico (JPb) relative to that of the US (BEA).

Greenhouse Gas Forecast Methodology – Business as Usual

The BAU scenario followed official macroeconomic growth projections (Planning Board). The macroeconomic indicator for construction activity was applied to cement emissions, while the gross product indicator was applied to ODS substitutes and electronics manufacturing activities. Table C-2 presents the mean annual growth rates applied in the BAU forecast for selected time intervals.

Table C-2. Projected Mean Annual Growth Rates by Activity

Activity	2011-2015	2016-2020	2021-2025	2026-2030	2031-2035
Cement Production	-0.1%	0.8%	0.8%	0.8%	0.8%
Glass Production	NA	NA	NA	NA	NA
Electronics Manufacturing	-2.2%	0.6%	0.6%	0.6%	0.6%
ODS Substitutes Use	-0.2%	0.6%	0.6%	0.6%	0.6%
Lime Production	NA	NA	NA	NA	NA

Results

Industrial emissions have increased in recent years at a regular pace. By 2010, industrial emissions increased by 186% relative to 1990, and are expected to increase by 17% in 2035 relative to 2010. Cement production emissions account for 89.6% of sector emissions in 1990 but this share of emissions has decreased to 16.4% by 2010 and maintain a similar share of sector emissions in 2035. Emissions from the use of ODS substitutes is responsible for the majority of industrial emissions after the year 2000. While lime and glass production occurred in Puerto Rico prior to 2008, their share of emissions was relatively small. Summary GHG emissions results are presented in Table C-3 and the relative distribution of emissions by industrial activity is shown in Table C-4.

Table C-3. Industrial Process Emissions by Source ($MMtCO_2e$), Selected Years

Activity	1990	1995	2000	2005	2010	2015	2020	2025	2030	2035
Cement Production	0.65	0.67	0.79	0.75	0.34	0.36	0.37	0.39	0.41	0.43
Glass Production	0.00	0.03	0.03	0.03	0.00	0.00	0.00	0.00	0.00	0.00
Electronics Manufacturing	0.04	0.08	0.09	0.07	0.07	0.08	0.09	0.09	0.10	0.10
ODS Substitutes Use	0.00	0.44	1.06	1.34	1.66	1.61	1.67	1.74	1.81	1.88
Lime Production	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	**0.72**	**1.21**	**1.97**	**2.20**	**2.07**	**2.05**	**2.13**	**2.22**	**2.32**	**2.41**

Table C-4. Percent of Total Emissions by Activity

Activity	1990	2000	2010	2030	2035
Cement Production	89.6%	39.9%	16.4%	17.8%	17.9%
Glass Production	0.0%	1.4%	0.0%	0.0%	0.0%
Electronics Manufacturing	5.2%	4.8%	3.4%	4.1%	4.1%
ODS Substitutes Use	0.6%	54.0%	80.1%	78.1%	78.0%
Lime Production	4.5%	0.0%	0.0%	0.0%	0.0%

Key Uncertainties

In the historical inventory, there is uncertainty as to the starting date of operations at the Illinois Owens glass production plant. Additionally, approach for estimating ODS substitutes and electronics manufacturing emissions does not yield high accuracy results, however, the proposed estimates are sufficient to signal that the use of HFCs and PFCs, including refrigerants and specialty solvents in printed circuit manufacturing, are important sources of GHG and warrant attention from stakeholders in government, industry, and consumers.

D. Transportation

Overview

The transportation sector is one of the largest sources of greenhouse gas (GHG) emissions in Puerto Rico. In 2005, carbon dioxide (CO_2) accounted for nearly 99% of transportation GHG emissions from fuel use. Most of the remaining GHG emissions from the transportation sector are due to nitrous oxide (N_2O) emissions from gasoline engines.

Data Sources

The primary data sources are outlined in Table D-1 below.

Emissions and BAU Projections

Transportation emissions were dominated by on road gasoline and diesel for the historical sector. These emissions are expected to decline during the forecast period, but still make up the majority of Puerto Rico emissions. The aviation and marine sectors account for the majority of remaining emissions in the historical period. Emissions from on road bioethanol combustion are forecast to increase during the forecast period, but still be significantly smaller than on road gasoline or diesel. Figure D-1 shows transportation emissions by sector for 1990-2035.

The emission decline for on road gasoline in the forecast BAU scenario is due the relatively flat VMT projection by the LRTP and energy efficiency improvements in the vehicle fleet driven by the CAFE standard combined with the retirement of old and inefficient vehicles. This forecast is based on historical estimates of fuel consumption, which has many fluctuations from year to year. This is most pronounced in the spike in diesel emissions in 2008, which does not match diesel fuel consumption in 2007 or 2009. These year to year fluctuations contribute to the overall uncertainty of the inventory.

Greenhouse Gas Inventory Methodology

Gasoline consumption for the historical period (1990-2010) come from the Department of Consumer Affairs, and is based on sales data. Diesel consumption comes from fuel tax revenue reported by the Department of Treasury of PR for 1997-2010. These fuel tax revenues were then converted into gallons based on the tax rate of 8 cents per gallon. Values were held constant at 1997 levels for 1990-1996.

The Department of Treasury of PR provided an estimate of revenue raised for 1997-2012 from jet and marine fuel. These values were converted to gallons using the tax rate of $0.08 / gallon. Values were held constant at 1997 levels for 1990-1996.

Table D-1. Key Data Sources and Methods for the Transportation Baseline

Vehicle Type and Pollutants	Data Sources
On road gasoline– CO_2, CH_4 and N_2O	**Inventory (1990 – 2010)** Departamento de Asuntos del Consumidor.[32] Published by Instituto de Estadísticas de Puerto Rico. Inventario de Estadísticas: Ventas de Gasolina en Puerto Rico. Accessed July 2014. Provides an estimate of gasoline gallons sold in Puerto Rico for 1990-2012. Vehicle categories: Departamento de Transportación y Obras Públicas.[33] **Reference Case Projections (2011 – 2035)** EPA MOVES model.
Onroad diesel– CO_2, CH_4 and N_2O	**Inventory (1990 – 2010)** Departamento de Hacienda.[34] Estadísticas y Recaudos: Arbitrios sobre Petróleo Crudo y Productos Derivados/Excise Tax on Crude Oil and Derived Products. Accessed July 2014. Provides an estimate of diesel revenue raised for 1997-2012. These values were converted to diesel gallons using the tax rate of $0.08 / gallon. **Reference Case Projections (2011 – 2035)** EPA MOVES model.
Non-highway fuel consumption (jet aircraft, boats,) – CO_2, CH_4 and N_2O	**Inventory (1990 – 2012)** Departamento de Hacienda. Estadísticas y Recaudos: Arbitrios sobre Petróleo Crudo y Productos Derivados/Excise Tax on Crude Oil and Derived Products. Accessed July 2014. Provides an estimate of revenue raised for 1997-2012 from jet and marine fuel. These values were converted to gallons using the tax rate of $0.08 / gallon. Values were held constant at 1997 levels for 1990-1996. **Reference Case Projections (2013 – 2035)** Maritime fuel consumption was grown into the future based on the 2002-2012 historical growth rates. Jet Fuel consumption was grown using the Federal Aviation Administration, Terminal Area Forecast (TAF)[35], based on the projected growth in Landing/Takeoff operations between 2012 and 2035.

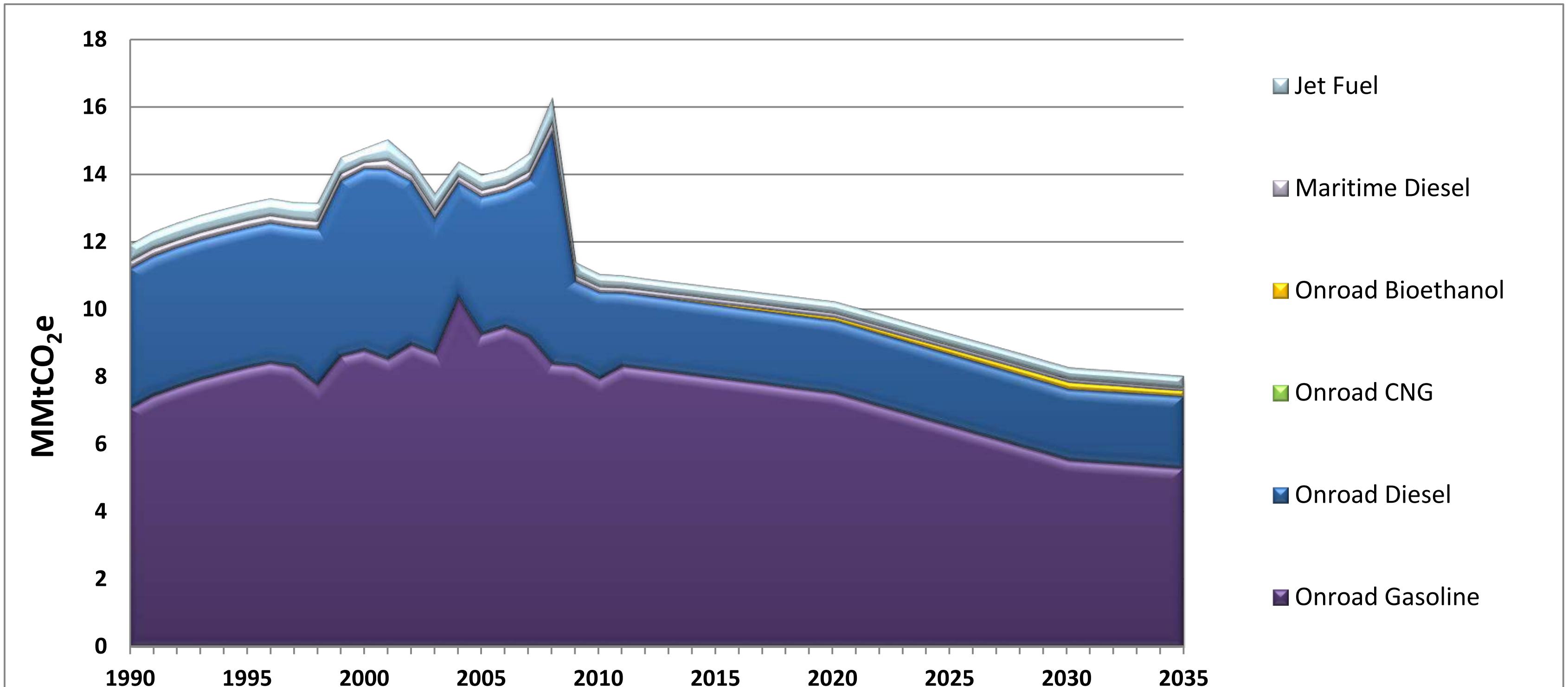
[32] Departamento de Asuntos del Consumidor. Published by Instituto de Estadísticas de Puerto Rico. Inventario de Estadísticas: Ventas de Gasolina en Puerto Rico. Accessed July 2014. Located online at: http://www.estadisticas.gobierno.pr/iepr/Estadisticas/InventariodeEstadisticas.aspx.

[33] Departamento de Transportación y Obras Públicas. Published by Instituto de Estadísticas de Puerto Rico. Inventario de Estadísticas: Registro de vehículos de motor por municipios y por categorías. Accessed July 2014. Located online at: http://www.estadisticas.gobierno.pr/iepr/Estadisticas/InventariodeEstadisticas.aspx

[34] Departamento de Hacienda. Estadísticas y Recaudos: Arbitrios sobre Petróleo Crudo y Productos Derivados/Excise Tax on Crude Oil and Derived Products. Accessed July 2014. http://www.hacienda.gobierno.pr/estadisticas/productos_derivados.html.

[35] Federal Aviation Administration, Terminal Area Forecast, 2014. Can be located online at: http://aspm.faa.gov/apowtaf/.

Figure D-1. Transportation Emissions by Sector and Fuel Type in $MMtCO_2e$, 1990-2035



Fuel Type	1990	1995	2000	2005	2010	2015	2020	2025	2030	2035
On road Gasoline	7.06	8.28	8.79	9.27	7.95	7.97	7.52	6.53	5.54	5.30
On road CNG	0.000	0.000	0.000	0.000	0.000	0.001	0.002	0.002	0.002	0.002
On road Diesel	4.14	4.14	5.38	4.07	2.56	2.17	2.15	2.13	2.11	2.13
On road Bioethanol	0.00	0.00	0.00	0.00	0.00	0.04	0.10	0.15	0.20	0.17
Water Transportation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maritime Diesel	0.22	0.22	0.18	0.19	0.16	0.13	0.12	0.10	0.09	0.08
Total (MMtCO2e)	**0.50**	**0.50**	**0.41**	**0.45**	**0.37**	**0.34**	**0.34**	**0.34**	**0.35**	**0.35**

In order to separate jet and marine fuel, CCS estimated the average CO_2 emissions from a single flight in the United States. This figure used the total CO_2 emissions from aircraft for 2008 from the US Greenhouse Gas Inventory and Sinks (175 million tons) and divided that by the total aircraft operations in the US in 2008 (110.7 million). This provided an estimate for average CO_2 emissions per flight of 1.58 tons.

This was then multiplied by the number of LTOs in PR in 2008 (~463,000) to provide a rough estimate of emissions in PR for that year. This was then divided by the TCR emissions factor for jet fuel to provide an estimate of total gallons of fuel consumed (75 million gallons). This number was divided by the fuel consumption from jet and marine fuel in 2008 (105 million gallons) to estimate the share of jet + marine fuel that comes from jet fuel. This allocation (71% jet fuel, 29% marine fuel) is held constant and applied to the Hacienda fuel estimate for all historical years.

All emissions for the historical period were calculated by multiplying the fuel quantities by the appropriate IPCC emissions factors for CO_2, CH_4 and N_2O. There were no historical data available on road CNG, LPG, biodiesel and bioethanol emissions for Puerto Rico, these emissions are assumed to be negligible.

Puerto Rico has no railroad infrastructure and therefore no rail emissions.

Greenhouse Gas Forecast Methodology – Business as Usual

Projections of daily VMT for Puerto Rico from 2010 to 2040 were obtained from Puerto Rico's Long Range Transportation Plan 2040. This projection was then converted to an average annual VMT growth rate and applied to the base year annual VMT for 2010 from the National Emission Inventory. Note that although the NEI is a 2011 inventory, the Federal Highway Administration data that provided VMT totals for Puerto Rico were actually 2010 data, so a year of growth was added to the NEI inventory VMT to estimate 2011 VMT.

The NEI data for Puerto Rico was used to estimate age distribution and vehicle type distribution, and these distribution values were held constant for the 2011-2040 forecast. Additional annual VMT estimates were made for 2020 and 2030. Using these annual VMT data as input, EPA's MOVES2014 model was used to estimate on road emissions and fuel consumption. Default data from the MOVES database for San Juan Municipio were modeled, along with total VMT for all of Puerto Rico included as input. Emissions for CO_2, CH_4, and N_2O were calculated, along with the corresponding fuel consumption. Emissions and fuel consumption were output by vehicle type and fuel type. Linear interpolation was used to estimate emissions for the years between 2011, 2020, 2030 and 2040.

There was no forecast information available for marine fuel consumption, so the historical growth rate for 2002-2012 was used for the 2013-2035 policy period. Growth in jet fuel consumption and emissions were estimated using data from the Federal Aviation Administration, Terminal Area Forecast (TAF) 2014. The TAF provides an estimate of Landing/Takeoff operations for the 2012-2035 period, and this was used to project emissions growth between 2012 and 2035. These growth rates are displayed in Table D-2 below.

Table D-2. Annual Growth Rates for Marine and Jet Fuel Consumption, 2012-2035

Marine Diesel	-2.78%
Jet Fuel	0.21%

Results

As can be seen in Table D-3 and D-4 below, on road gasoline and diesel consumption accounts for the largest share of transportation GHG emissions. Emissions from on road gasoline vehicles increased by about 13% from 1990 to 2010 to account for 72% of total transportation emissions in 2010. GHG emissions from on road diesel fuel consumption decreased by 39% from 1990 to 2010, and in 2010 accounted for 23% of GHG emissions from the transportation sector. Aircraft emissions made up 4% of Puerto Rico's transportation emissions in 2010, while marine emissions accounted for the remaining 1.5% of transportation emissions.

GHG emissions from all on road vehicles combined are projected to decrease by 27% between 2010 and 2035. This decline comes primarily from the result of efficiency improvements in the gasoline and diesel fleets. Marine emissions decrease 53% over the forecast period while emissions from aviation fuels are projected to remain relatively constant over the forecast period. See Tables D-3 and D-4 for more information.

Table D-3. Energy Consumption by Sector and Fuel Type, TJ

Fuel Type	1990	1995	2000	2005	2010	2015	2020	2025	2030	2035
On road Gasoline	99,235	116,358	123,562	130,285	111,779	109,604	103,912	90,229	76,545	75,872
On road Diesel	54,958	54,958	71,425	53,976	33,977	29,295	29,194	28,884	28,575	28,644
On road CNG	0	0	0	0	0	13	30	31	33	33
On road Bioethanol	0	0	0	0	0	628	1,414	2,091	2,769	2,680
Rail	0	0	0	0	0	0	0	0	0	0
Marine Diesel	2,783	2,783	2,271	2,491	2,059	1,711	1,487	1,291	1,122	975
Jet Fuel	6,933	6,933	5,657	6,204	5,128	4,668	4,719	4,769	4,821	4,872
Total	163,909	181,033	202,914	192,955	152,942	145,919	140,756	127,296	113,863	113,075

Table D-4. Transportation Emissions by Sector and Fuel Type, $MMtCO_2e$

Fuel Type	1990	1995	2000	2005	2010	2015	2020	2025	2030	2035
On road Gasoline	7.06	8.28	8.79	9.27	7.95	7.97	7.52	6.53	5.54	5.30
On road Diesel	4.14	4.14	5.38	4.07	2.56	2.17	2.15	2.13	2.11	2.13
Onroad CNG	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Onroad Bioethanol	0.00	0.00	0.00	0.00	0.00	0.04	0.10	0.15	0.20	0.17
Rail	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Marine Diesel	0.22	0.22	0.18	0.19	0.16	0.13	0.12	0.10	0.09	0.08
Jet Fuel	0.50	0.50	0.41	0.45	0.37	0.34	0.34	0.34	0.35	0.35
Total	**11.9**	**13.1**	**14.8**	**13.98**	**11.1**	**10.7**	**10.2**	**9.26**	**8.28**	**8.03**

Key Uncertainties

On road CNG, LPG, biodiesel and bioethanol emissions for Puerto Rico were assumed to be negligible due to a lack of data. These emissions are only captured in the MOVES forecast data for 2011-2040, but still make up only a tiny portion of total transportation emissions for the entire forecast period.

This forecast is based on historical estimates of fuel consumption, which has many fluctuations from year to year. This is most pronounced in the spike in diesel emissions in 2008, which does not match diesel fuel consumption in 2007 or 2009. These year to year fluctuations contribute to the overall uncertainty of the inventory. Nonetheless, historical fuel consumption estimates were used without adjustment.

The on road emissions forecast is based on the Long Range Transportation Plan 2040 estimate of VMT for Puerto Rico. VMT forecasts contain significant uncertainty, and if this forecast were not accurate, then the 2011-2040 emissions estimates would change.

E. Agriculture

Overview

This sector includes non-energy methane (CH_4) and nitrous oxide (N_2O) emissions from both livestock and crop production and emissions and sinks of carbon dioxide (CO_2) in agricultural soils and vegetation. The primary GHG sources and sinks from livestock production and crop production are further subdivided as follows:

- *Cropland soil:* this subsector covers N_2O emissions resulting from animal excretions directly on agricultural soils (e.g. pasture, paddock or range), synthetic and organic fertilizer application, and nitrogen fixation.
- *Cropland carbon:* this subsector covers carbon flux from woody perennial crops, such as orchards and woody plantation crops.
- *Livestock management – enteric fermentation:* CH_4 emissions from enteric fermentation are the result of normal digestive processes in ruminant and non-ruminant livestock. Microbes in the animal digestive system break down food and emit CH_4 as a by-product.
- *Livestock management – manure management:* CH_4 and N_2O emissions from the storage and treatment of livestock manure (e.g., in compost piles or anaerobic treatment lagoons) occur as a result of manure decomposition.

Data Sources

Most of the data for this assessment came from the following sources:

- USDA National Agricultural Statistics Service (NASS) Puerto Rico Census of Agriculture, 1998, 2002, 2007, and 2012; [36]
- Inventory of Puerto Rico Greenhouse Gas Emissions and Sinks 1990, 1994;[37] and
- United States Environmental Protection Agency's (US EPA) State Inventory Tool (SIT) software.

Emissions and BAU Projections

Emissions for 1990 through 2012 were estimated using the methods used in the United States Environmental Protection Agency's (US EPA) State Inventory Tool (SIT) software as provided in the Emission Inventory Improvement Program (EIIP) guidance document

[36] United States Department of Agriculture, National Agricultural Statistics Service, Puerto Rico Census of Agriculture, http://www.agcensus.usda.gov/Publications/2012/Full_Report/Census_by_State/Puerto_Rico/.
[37] Department of Natural and Environmental Resources, 1996. Energy Affairs Administration "Inventory of Puerto Rico Greenhouse Gas Emissions and Sinks: 1990, 1994".

for the sector.[38] In general, the SIT methodology applies emission factors developed for the US to activity data for the agriculture sector.

Greenhouse Gas Inventory Methodology

Cropland Soils. Sources addressed in this sub-sector are N_2O emissions that occur as a result of nitrogen (N) inputs to crop soils, including:

- Crop residues,
- Nitrogen fixing crops,
- Application of synthetic fertilizers, and
- Application of organic fertilizers: including manure and sewage sludge.

The primary activity data for estimating cropland soil emissions is crop production data. Crop production and lime application data for Puerto Rico was obtained from USDA NASS for 1993, 1998, 2002, 2007 and 2012. Synthetic fertilizer activity for 1990-1994 was obtained from the 1990-1994 Puerto Rico GHG Inventory. Intervening years were interpolated. For synthetic fertilizer application, the 1994 value was scaled to the years 1995-2012 based on crop production. The trend in this data was extended back to 1990.

The activity data for Puerto Rico was applied to emission factors developed from the default data from the SIT module. Default data factors taken from the SIT, include:

- Crop residue dry matter fraction,
- Fraction residue applied,
- Nitrogen content of residue,
- Typical animal mass, and
- Animal nitrogen excretion rate.

Cropland Carbon. These emissions address CO_2 flux from woody perennial crops. Acreage data for woody perennial crops was obtained from the USDA NASS Census of Agriculture for 1993, 1998, 2002, 2007, and 2012. Intervening years were interpolated. The acreage data for each year was applied to the IPCC emission factor for biomass accumulation rate in moist tropical regions (2.6 metric tons C/ha/year).[39]

Livestock Management. These emissions address CH_4 from enteric fermentation and manure management (prior to field application). The activity data for livestock production emissions are livestock populations. Livestock populations for Puerto Rico were obtained from several sources, including:

- 1990-1994 Puerto Rico GHG inventory (data for 1990 and 1994)

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[38] Emission Inventory Improvement Program, Volume VIII: Chapter 8. "Methods for Estimating Greenhouse Gas Emissions from Livestock Manure Management", August 2004; Chapter 10. "Methods for Estimating Greenhouse Gas Emissions from Agricultural Soil Management", August 2004.
[39] 2006 IPCC Guidelines, Volume 4, Chapter 5 "Cropland", http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html.

- USDA NASS (data for 1993, 1998, 2002, and 2007)
- Puerto Rico Department of Agriculture (data for 2007 and 2012)[40]

As with the crop production subsector, a set of emission factors were derived from default data in the EPA SIT Agriculture Module, including:

- Enteric fermentation methane emission factors
- Typical animal mass
- Manure volatile solids content
- Maximum potential manure methane emissions
- Methane conversion factors

Information on which manure management systems are used for each animal type was provided by the Puerto Rico Department of Agriculture; however, data on the percent contribution of each was not available. Therefore, an equal distribution was assumed for each of the manure management systems indicated for each animal type, as shown in Table E-1.

Table E-1. Manure Management Distribution

Livestock Type	Liquid Slurry	Solid Storage	Dry Lot	Pasture, Range, Paddock	Daily Spread
Dairy Cows	33%			33%	33%
Goats	25%		25%	25%	25%
Horses			50%		50%
Other Cattle	25%		25%	25%	25%
Poultry -broilers			100%		
Poultry -layers			100%		
Rabbits			100%		
Sheep			50%	50%	
Swine		100%			

Greenhouse Gas Forecast Methodology – Business as Usual

Historical data shows decreasing crop production and livestock populations over the past decade. These trends of were assumed to continue through 2020. Long-term trends in agriculture are uncertain; therefore, activity was held constant for 2020-2035.

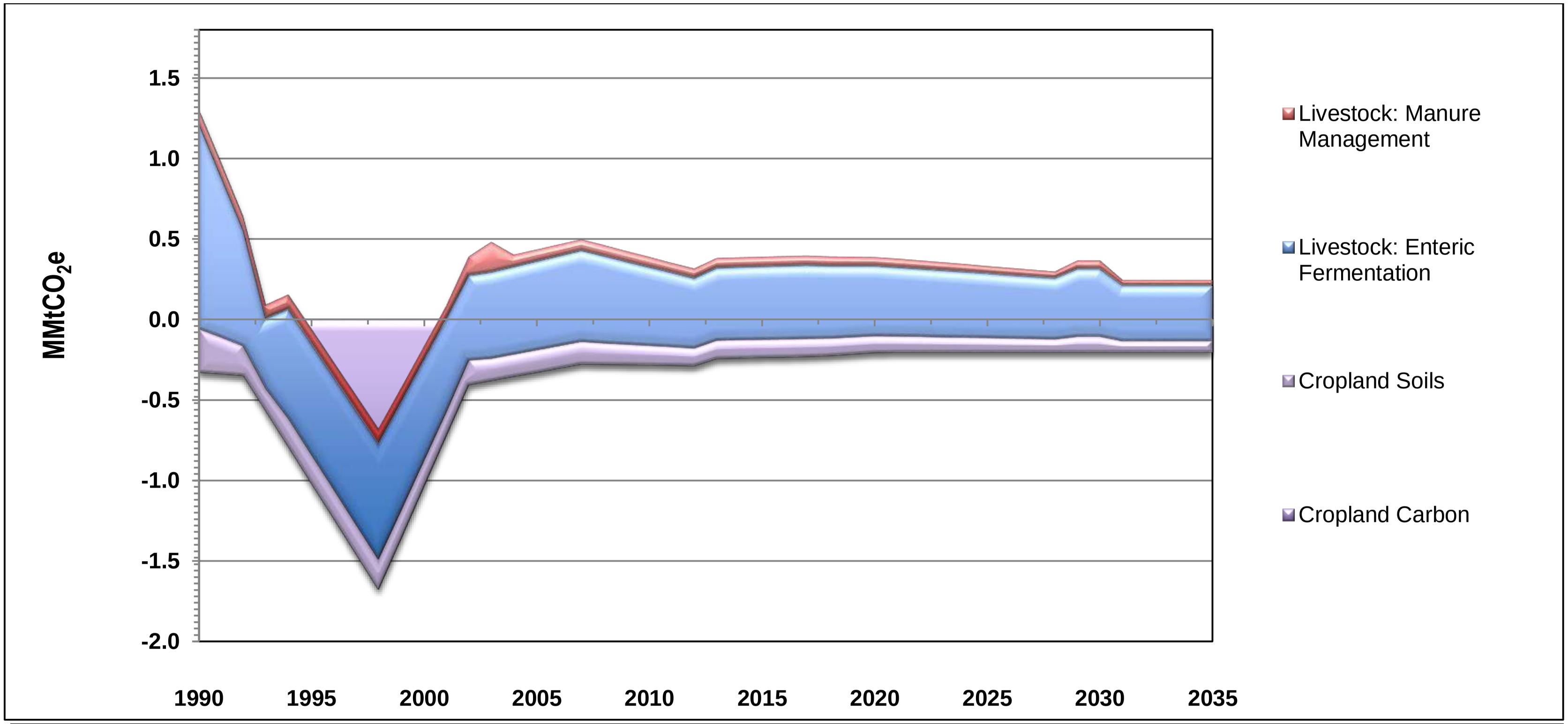
Results

Agriculture sources and sink estimates are shown in **Figure E-1**. Emissions are at highest in 1990 due to high livestock populations and crop production. Livestock populations then show a decreasing trend over the inventory period. Emissions become negative (net

[40] Puerto Rico Department of Agriculture: Data Request, August 2014.

sink) from 1995 to 2000 due to higher acreages of woody perennial crops, particularly coffee, which sequester carbon. After 2000, the sector shows decreasing emissions due to decreasing livestock populations and cropland areas.

Figure E-1. Agriculture Sector Emissions and Sinks



Emission Source	1990	2000	2005	2010	2015	2025	2035
Livestock: Enteric Fermentation	1.28	0.62	0.55	0.49	0.45	0.40	0.34
Livestock: Manure Management	0.09	0.08	0.07	0.06	0.06	0.04	0.03
Cropland Soils	0.28	0.17	0.14	0.13	0.12	0.10	0.08
Cropland Carbon	-0.33	-1.04	-0.33	-0.28	-0.24	-0.21	-0.21
Total MMtCO2e	**1.31**	**-0.17**	**0.43**	**0.39**	**0.39**	**0.33**	**0.24**

Key Uncertainties and Additional Research Needs

Several agricultural sources were not addresses in this inventory, because sources of activity data were not identified. These sources include:

- *Crop production, residue burning:* CH_4 and N_2O emissions are produced when crop residues are burned (CO_2 is emitted as well, however, since the source of carbon is biogenic, these emissions are not included in the inventory). The Puerto Rico Department of Agriculture provided data on burning for 2013; however the data only included small areas for rice and sugarcane. USDA crop production data does not show any production for rice, and the trend in sugarcane indicates a very small area for sugarcane in 2013 (assumed to be zero in the inventory). The emissions from these areas would small compared to the overall sector emissions and it would be difficult to scale this data to other inventory years. Therefore, these emissions were not included.
- *Urea application*: while the N_2O emissions from N application are addressed, the decomposition of urea also emits CO_2. These emissions could be estimated with some local information on the fraction of total synthetic N supplied by urea fertilizers.
- *Cultivation of histosols* (high organic soils, such as wetlands or peatlands): data on the area of histosols was not available.

Manure management estimates could be improved with more precise data on the distribution of management systems used in Puerto Rico, and information on how this distribution is changing over time. Estimates of carbon flux from woody perennial crops could be improved with carbon stock data or biomass accumulation rates specific to Puerto Rico crops.

F. Forestry and Other Land Use

Overview

This sector includes net CO_2 flux from both forested lands and urban forests (including parks, street trees, and trees on non-agricultural private land). Since vegetation and soils sequester carbon from the atmosphere, but also release carbon when decaying, the CO_2 flux in any given area could represent a net source or a net sink. The net CO_2 flux results from a net change in biomass (in soils or forest carbon) on lands that do not undergo land use or land cover change (e.g., early successional forests undergoing densification), or on lands that do undergo a change in land use/cover (e.g., conversion of forest land to another land use without forest cover).

Data Sources

The primary data sources for this sector include:

- Helmer et al. (2002)[41],
- Gould el al. (2008)[42], and
- Homer et al. (2007)[43].
- USFS Forest Inventory and Analysis (FIA) EVALIDator tool.[44]
- National Land Cover Database (NLCD) 2001 land cover and tree canopy GIS data layers for Puerto Rico[45],

Emissions and BAU Projections

Forestry emissions were estimated by carbon sequestration rates to forest areas. Forest areas were taken from land use data, cited above. For urban forests, the forest area is estimated by multiplying the total urban area, by the urban canopy percent.

Greenhouse Gas Inventory Methodology

Forests. Forest carbon flux was estimated by multiplying the forest area in each year for four forest types (Dry Forests, Moist Forests, Wet and Rain Forests, and Other) by the estimated sequestration rates for each forest type. Total forest areas for 1991, 2000, and

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[41] Helmer, et al. 2002. Mapping the Forest Type and Land Cover of Puerto Rico, a Component of the Caribbean Biodiversity Hotspot. Caribbean Journal of Science, Vol. 38, No. 3-4, pp 165-183 http://www.fs.fed.us/global/iitf/pubs/ja_iitf_2002_helmer001.pdf

[42] Gould, et al. 2008. The Puerto Rico Gap Analysis Project, Volume 1: Land cover, vertebrate Species distributions, and land stewardship. USDA Forest Service General Technical Report IITF-GTR-39. Río Piedras, Puerto Rico, 165p. http://www.fs.fed.us/global/iitf/pubs/iitf_gtr39.pdf

[43] Homer, et al. Completion of the 2001 National Land Cover Database for the Conterminous United States. Photogrammetric Engineering and Remote Sensing, Vol. 73, No. 4, pp 337-341. http://www.asprs.org/a/publications/pers/2007journal/april/highlight.pdf

[44] USFS Forest Inventory and Analysis (FIA), EVALIDator Version 1.6.0.01, accessed September, 2014.

[45] National Land Cover Database 2001 (NLCD2001), Puerto Rico Land cover (Version 1.0) and Puerto RicoTree Canopy (Version 1.0), http://www.mrlc.gov/nlcd01_data.php.

2001 were taken from the data sources stated above under Data Sources, with intervening years interpolated. Values for 1990, and 2001-2012 were estimated by scaling to forest area data from the United Nations Food and Agriculture Organization (FAO)[46]. The area for each forest type was then estimated by applying forest type area fractions calculated from FIA forest area, available for 2004 and 2009, to the total forest area.

Forest sequestration rates were estimated from FIA forest carbon data obtained from the FIA EVALIDator tool, referenced under Data Sources. Estimates of forest carbon density (metric tons carbon/acres of forest) by forest type and stand age (in 20-year increments) was obtained for Puerto Rico. The annual change in carbon density was then estimated by taking the difference between carbon densities for each 20-year age range and dividing by 20 years. The sequestration rates for each age range were then averaged to give an overall forest sequestration rate.

The FIA data for Puerto Rico only included carbon for aboveground and belowground carbon in live trees (at least 1 inch diameter); therefore, the same calculations were performed on FIA data from tropical hardwood forests in Florida for the remaining forest carbon pools (dead trees, soil, litter, understory). The sequestration rate estimated from Florida forest data was then added to the live tree sequestrations calculated for Puerto Rico to give a total forest carbon sequestration rate. Values for forest density, area fraction and sequestration rates estimated for Puerto Rico forests are shown in Table F-1. Forest Density, Area Fraction, and Sequestration Rates by Forest Type.

Table F-1. Forest Density, Area Fraction, and Sequestration Rates by Forest Type

Forest Type	2004 Forest Density (mt C/ha)	2004 Area Fraction	2009 Forest Density (mt C/ha)	2009 Area Fraction	Live Tree C Seq. (mt/ha/yr)	Other C Seq.[a] (mt/ha/yr)	Total Carbon Sequestration (mt/ha/yr)
Dry Forest	16.3	0.15	20.1	0.16	0.75	0.20	0.95
Moist Forest	41.1	0.48	50.9	0.48	1.98	0.20	2.17
Wet and Rain Forest	56.6	0.33	64.0	0.33	1.49	0.20	1.68
Other	38.2	0.04	27.8	0.03	-2.07	0.11	-1.96

[a] Includes understory, dead trees, litter, and soil. Based on tropical hardwood forests in Florida.

Urban Forests. Urban Forest area was estimated by applying an estimated urban forest canopy percentage to the total urban area. As with forest area, the total urban areas for 1991, 2000, and 2001 were taken from the data sources stated above under Data Sources, with intervening years interpolated. Urban areas for 1990 and 2001-2012 were estimated by continuing the 1991-2001 trend.

The urban forest canopy was estimated using 2001 NLCD land cover tree canopy GIS data layers. Because of the low resolution of the NLCD data, small clusters and

[46] Food and Agriculture Organization of the United Nations (FAO), FAOSTAT Land Use Database, http://faostat.fao.org/site/377/DesktopDefault.aspx?PageID=377#ancor, accessed September 2014.

individual trees are not captured. The tree canopy data for developed areas only reflected areas with greater than 30% canopy. Therefore, all developed land not captured by the NLCD tree canopy data was assumed to have 15% canopy. The resulting urban canopy estimate was 17.9%. Urban forest sequestration data was not available for Puerto Rico; therefore, an average of sequestration rates for the two most southern cities (Gainesville, FL and Atlanta, GA) in Nowak's 2013 urban forest study was used (1.68 metric tons C/ha/yr). [47]

Greenhouse Gas Forecast Methodology – Business as Usual

Historical land use data indicates that both forest and urban area has increased over the past two decades. The trends in these two land use areas were assumed to continue through 2020. Whether these trends will continue long-term is highly uncertain, so land use areas were held constant for 2020-2035.

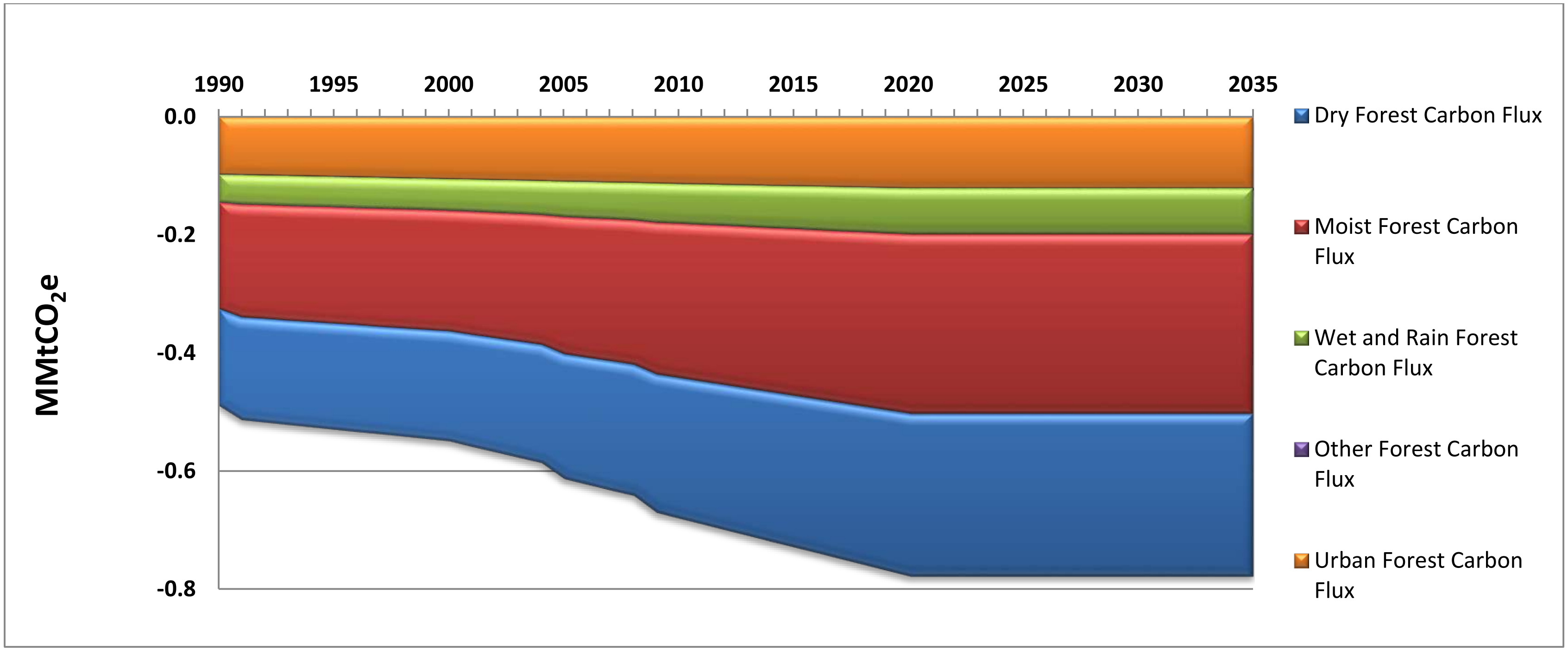
Data indicating trends in forest carbon density or urban tree canopy was not available; therefore, all other inputs were held constant over the forecast period.

Results

Forestry sector emissions and sinks are shown in Figure F-1. Forests and urban forests are both estimated to be carbon sinks over the inventory and forecast period, with forests contributing about 80% of the overall sequestration in 1990 and 84% in 2035. Land use trends show that forest areas have increased as some agricultural lands have returned to forest. Urban land area has also increased. This expansion of forests results in the increases in carbon sequestration shown in the inventory.

[47] Nowak, D., et al. "Carbon storage and sequestration by trees in urban and community areas of the United States". *Environmental Pollution* 178 (2013) 229-236. http://www.fs.fed.us/nrs/pubs/jrnl/2013/nrs_2013_nowak_001.pdf.

Figure F-1. Forestry Sector Emissions and Sinks



Source	1990	1995	2000	2005	2010	2015	2020	2025	2030	2035
Forest Carbon Flux	(0.39)	(0.43)	(0.44)	(0.50)	(0.56)	(0.61)	(0.65)	(0.65)	(0.65)	(0.65)
Urban Forest Carbon Flux	(0.10)	(0.10)	(0.11)	(0.11)	(0.12)	(0.12)	(0.12)	(0.12)	(0.12)	(0.12)
Total	(0.49)	(0.53)	(0.55)	(0.61)	(0.68)	(0.73)	(0.78)	(0.78)	(0.78)	(0.78)

Key Uncertainties and Additional Research Needs

Several forestry subsectors were not estimated for this inventory due to uncertainty or unavailability of data. These sources include:

- *Wetlands*: this land use is known to store large amounts of carbon (and to release large amounts of CO_2 when drained), net GHG emissions have always been highly uncertain due to methane emissions and the extent to which these counter-act carbon sequestration.
- *Forest fires:* burning forests release forest carbon, and also emit CH_4 and N_2O.
- *Settlement soils*: this subsector covers emissions of N_2O from non-agricultural fertilizer application.

The forestry inventory could be improved with better forest carbon data. The FIA inventory for Puerto Rico currently only includes data for live trees for 2004 and 2009. Forest data for additional forest carbon pools and for additional years provide a better indication of carbon sequestration and trends in forest density. Urban forest estimates would be greatly improved with a more precise measurement of urban canopy and data on urban tree carbon sequestration.

G. Waste Management

Overview

This appendix describes the data sources, key assumptions, and the methodology used to develop the GHG baseline for the Waste Management (WM) sector. The WM sector consists of two subsectors.

GHG emissions from waste the waste management sector include:

- Solid Waste Management (SW) – methane (CH_4) emissions from municipal SW landfills (LFs), accounting for CH_4 that is flared or captured for energy production (this includes both open and closed landfills) and Composting emissions - CH_4 and N_2O emissions from both composted vegetative waste and sludge;
- Wastewater Management (WW) – CO_2, CH_4, and N_2O from municipal wastewater (WW) treatment facilities, septic systems, latrines, and from the combustion of diesel fuel to manage sludge.

The WM sector is focused on determining the amount of CO_2, CH_4, and N_2O that are released from the above WM methods. The following topics are covered in this Appendix:

- *Data Sources:* This section provides a listing of data sources that were provided by Puerto Rico and data sources that are publicly available online for download and review.
- *Greenhouse Gas Inventory Methodology:* This section details the methodology and approach used to build the inventory for the WM sector.
- *Greenhouse Gas Forecast Methodology:* This section details the methodology and approach used to build the forecast for the WM sector.
- *Greenhouse Gas Inventory Results:* This section provides an overview of the key results of the Puerto Rico GHG inventory for the WM sector.
- *Key Uncertainties and Additional Research Needs:* This section outlines the key uncertainties that arose when building the I&F and identified key additional research needs that would strengthen future I&F work.

Data Sources

Solid Waste
The majority of data for the SW sector was obtained from Puerto Rico's executive agencies. Other data sources from US Environmental Protection Agencies' (EPA) GHG Reporting Program[48] and EPA's Landfill Methane Outreach Program (LMOP)

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[48] http://www.epa.gov/ghgreporting/

Database[49] were used to verify and supplement data provided by Puerto Rico. The data that Puerto Rico provided for SW includes:

- Total landfilled waste for 2003-2013
    - A weight base percentage of the type of waste landfilled
- Total amount of MSW recycled for 2009-2013
    - A 2003 waste profile detailing a percent each type of waste emplaced in the landfill
- Total amount of MSW composted broken out between total sludge (wet tonnes) and total vegetative material for 2010-2013[50]
- A database of all Puerto Rican landfills open and closed, the year the facility opened and closed/planned closure date, and if the landfill has flaring or landfill gas to energy (LFGTE) controls.[51]
- Other data sources include Puerto Rico's Dynamic Itinerary for Infrastructure Projects Public Policy Document[52], US EPA's GHG Reporting Program Database, EPA's LMOP Database[53], and the Intergovernmental Panel on Climate Change' (IPCC) Guidelines for National GHG Inventories, Volume 5 Waste[54].

Waste Water
All of the data from the wastewater sector was obtained from Puerto Rico' executive agencies, excluding GHG emission factors.

Puerto Rico Provided the below data for the WW sector:

- Amount of people serviced by Puerto Rico's centralized wastewater treatment facilities from 1990 to 2030, in increments of 10 to 2 years.
- Total amount of sludge waste and its management method for 1999-2013.
- Total gallons of diesel used to combust WW sludge for 2009-2013.
- Total amount of sludge used in agriculture application and deposited into landfills (both of these management method's GHG emissions are included in the Agriculture and solid waste sectors.)[55].

Greenhouse Gas Inventory Methodology

The WM sector inventory period covers 1990-2013. The methodology used to construct the WM sector inventory, including the SW and the WW subsectors, is consistent with methods developed by the IPCC and the USEPA.

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[49] http://www.epa.gov/lmop/projects-candidates/index.html#map-area
[50] E. Rivera, AAE, personal communication and data file to S. Roe, CCS, August 7, 2014
[51] M. Padilla, ADS, personal communication and data file to L. Bauer, CCS, August 25, 2014
[52] http://www.ads.pr.gov/files/2013/05/Dynamic_Itinerary.pdf
[53] http://www.epa.gov/lmop/projects-candidates/index.html#map-area
[54] http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol5.html
[55] L. Sierra, JCA, personal communication and data file to S. Roe, CCS, September 2, 2014

Solid Waste

For the SW sector the IPCC's solid waste model was used to calculate emissions from 1990 to 2013. The IPCC's Waste Model uses the First Order of Decay (FOD) equation[56]. During the inventory period in 2011 26% of total CH_4 is flared and in 2013 the percentage of waste that is flared increases to 50%. For all solid waste emplaced into a landfill 10% is removed from the total emissions due to oxidation in the soil[57]. Also, flaring is considered to remove 75% of all CH_4 released into the atmosphere[58].

Puerto Rico reported that the territory does not import or export waste[59]. Therefore this inventory is considered both consumption and direct-based profile of Puerto Rico's solid waste[60]. To build the inventory, a SWMP was developed to determine all of Puerto Rico's solid waste sources, amounts, and management methods. Table H-1 below outlines Puerto Rico's total amount of MSW deposited into landfills, composted, recycled, and combusted in the future planned Waste-to-Energy facility.

[56] http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_3_Ch3_SWDS.pdf.
[57] http://www.ipcc.ch/ipccreports/tar/wg3/index.php?idp=120.
[58] http://www.epa.gov/lmop/faq/lfg.html.
[59] M. Padilla, ADS, personal communication and data file to L. Bauer, CCS, September 12, 2014
[60] M. Padilla, ADS, personal communication and data file to L. Bauer, CCS, September 25, 2014

Table G-1. MSW Management Profile - BAU and Projected (Metric Tons)

	1990	1995	2000	2005	2010	2015	2020	2025	2030	2035
MSW Total	3,044,722	3,323,492	3,531,329	4,904,280	3,075,963	3,428,462	4,019,551	3,818,727	3,617,903	3,417,079
Population	3,522,037	3,709,032	3,810,605	3,821,362	3,722,133	3,598,357	3,519,901	3,476,473	3,414,456	3,329,725
MSW/capita	0.85	0.85	0.91	1.42	0.99	1.16	1.21	1.24	1.28	1.29
MSW Landfilled	3,032,186	3,193,174	3,280,620	4,531,743	2,515,892	2,780,766	2,438,437	2,096,108	1,753,779	1,411,451
WTE Combusted	0	0	0	0	0	0	791,913	791,913	791,913	791,913
MSW Diverted	12,535	130,319	250,709	372,537	560,071	647,696	789,200	930,705	1,072,210	1,213,715
MSW Recycled	12,535	130,319	248,102	365,885	543,388	601,452	719,235	837,019	954,802	1,072,585
MSW Composted	0	0	2,607	6,652	16,682	46,244	69,965	93,687	117,408	141,130

The above table H-1 is an excerpt of Puerto Rico's Solid Waste Management Profile (SWMP). From the data that Puerto Rico provided and other sources of data, a profile of all the waste management types and the total amount of MSW managed by that method, by year, were laid out in a spreadsheet. Puerto Rico provided data for the total amount of landfilled, recycled, composted, and future WTE-Combusted MSW. Data for each management method was incomplete for many of the 1990-2013 years. To complete the SWMP, two different back casting methodologies were used.

The first method used to fill data gaps was the use of Excel's TREND function. This function identifies a trend in the data and applies an assumed new value to the year in which there is a data gap. The trend function was used for composting and recycled MSW. The trend function was used for 1990-2008 for both recycled and composted waste. Puerto Rico provided actual data for years 2009-2012 for recycling and 2010-2013 for composting MSW. [61]

The second method for back casting was only used for landfilled MSW emplaced from 1990-2002. In the two previous I&Fs for Puerto Rico from 1990 and 1999, both reports assumed that Puerto Ricans produce 5.2 pounds of landfilled MSW per day or 1,898 pounds of landfilled MSW per year[62]. The total amount of waste per person was multiplied by the total Puerto Rican population then converted into metric tons of total waste produced by Puerto Rico. Each report also assumed that Puerto Rico's population was 3,530,000 for their report. The US Census Bureau does not have detailed data for Puerto Rico's total population from 1991-1999. It does have total population for 1990 and 1999. To calculate the population growth rate of 10.4% from 1990 to 1999, a linear trend was calculated so population grew at an equal percent each year till 1999. This also means that the back casted estimated landfilled MSW grew 10.4% from 1990 to 1999.

Waste Water

Puerto Rico provided all of the data for the WW subsector, excluding the emission factors outlined in the below table H-2.

Table G-2. Waste Water Emission Factors[63]

	CO_2	CH_4	N_20
Septic Systems	n/a	0.004383	n/a
None (Latrine)	n/a	0.004383	n/a
Centralized Aerobic Treatment Plant	n/a	n/a	0.000004
Diesel Combustion - Sludge[64]	74.1	0.003	0.0006

[61] E. Rivera, AAE, personal communication and data file to L. Bauer, CCS, August 7, 2014.
[62] The "Puerto Rico State Action Plan to Reduce Greenhouse gas Emissions and Inventory of Puerto Rico Greenhouse Gas Emissions and Sinks: 1990, 1994" provided by J. González, AAE, personal communication and data file to T. Peterson, CCS, April 28, 2014.
[63] http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol5.html.
[64] http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/2_Volume2/V2_2_Ch2_Stationary_Combustion.pdf.

To calculate the inventory for WW sector, a percentage based population calculation was used. There were two different types of population identified for this sector, those people in Puerto Rico that are serviced by the Puerto Rico Aqueducts and Sewer Authority (PRASA) centralized waste water treatment facilities and those that are not. Those people who are not serviced by PRASA are split into two subgroups half assumed to be using septic systems and the other half having no technology in place to manage waste water, none (latrine). By dividing each group or subgroup of Puerto Rico's population by the total population establishes a percent of the population broken out by WW management method. The percent of population is then multiplied by the overall total amount of WW produced each year and multiplied by its emission factor.

Again, to fill data gaps Excel's TREND function was used. The TREND function was used to calculate gallons of diesel fuel combusted from 1990-1997. Another method used to fill data gaps was establishing a growth/decline rate in between two sets of provided data and filling in the data gaps in between each year by creating a linear growth rate.

Waste Management and Greenhouse Gas Forecast Methodology

Solid Waste

The GHG forecast period is considered to be 2014-2035. The methodology for building a GHG forecast for solid waste is much like creating the inventory. Since the IPCC waste model uses the FOD equation, landfilled data must gathered and input into the model for years prior to the forecast period. The IPCC model strongly suggests that the user input data as far back as 1950. Back casted data all the way to 1955 was input into the IPCC model for forecasting. Table H-3 shows the data inputs for the IPCC model

Table G-3. IPCC Landfill Model Inputs for Puerto Rico

	1990	1995	2000	2005	2010	2015	2020	2025	2030	2035
IPCC Inputs - Uncontrolled										
Pop (/mil)	3.52	3.71	3.82	3.82	3.70	3.58	3.51	3.47	3.40	3.33
Total MSW	1,542,831	1,344,384	1,794,758	2,339,858	981,387	1,418,910	1,092,685	1,169,892	815,677	1,930,552
MSW/ cap kg	397.39	328.82	405.42	547.08	245.71	306.62	282.85	280.66	240.82	525.98
IPCC Inputs – Flared										
Pop/mil	3.53	-	3.81	3.82	3.72	3.60	3.52	3.48	3.41	3.33
Total WSW	1,306,847	-	1,381,200	1,709,883	1,428,003	1,371,311	1,249,469	1,224,380	1,309,012	-
MSW/ cap kg	336	191,214	329	406	348	346	322	320	348	-
Total MSW Flared	-	191,213,586	161,107	-	727,503	1,371,311	1,249,469	1,224,380	1,309,012	-
% of MSW Flared kg	0%	0%	0%	0%	51%	100%	100%	100%	100%	0%
IPCC Inputs – LFGTE										
Pop/mil	3.53	-	3.81	3.82	3.72	3.60	3.52	3.48	3.41	3.33
Total WSW	185,875	-	196,450	981,040	620,906	899,465	294,206	287,296	317,902	548,821
MSW/ cap kg	48	-	47	233	151	227	76	75	84	150
Total MSW captured	-	-	-	-	-	-	294,206	287,296	317,902	548,821
% of MSW LFGTE kg	0%	0%	0%	0%	0%	0%	100%	100%	100%	100%

The IPCC model also allows the user to input percent of landfilled waste types. Puerto Rico provided detailed types of waste emplaced in their landfills for 2003[65]. Since waste type data was only provided for 2003, it was assumed that the waste type percentages did not change. Table H-4 outlines the percentage of each waste type that was used in the IPCC model.

[65] E. Rivera, AAE, personal communication and data file to S. Roe, CCS, August 7, 2014

Table G-4. 2003 Waste Types Percentages Emplaced in Puerto Rican Landfills

IPCC Waste Types	Puerto Rico Percent by Weight
Food	13.1%
Garden	20.5%
Paper	20.675%
Wood	6.375%
Textiles	0%
Diapers (Nappies)	0%
Plastics, other inert	39.35%

The IPCC model gives the user total raw CH_4 emissions minus the 10% oxidation factor. To determine the amount of methane flared or captured in a landfill gas to energy (LFGTE) technology system, a total amount of MSW must be computed for uncontrolled, flared, and LFGTE landfills. Since Puerto Rico has 32 landfills[66] either open or recently closed, each landfill needs to be assigned as one of the three types: uncontrolled, flared, or LFGTE. Two sources of information were helpful in computing this.

The first data source was the Puerto Rico Dynamic Itinerary for Infrastructure Projects Public Policy Document[67]. This document outlined and forecasted the total amount of waste emplaced into each of the 32 landfills for the period of 2004-2030. Though the actual landfill emplacements were not used (Puerto Rico provided more accurate and current data for 2003-2013, which was a better basis for back and forecasting), the percent of waste emplaced into each landfill was calculated and used. Once the percentage of waste emplaced was determined, then the total waste emplaced into each landfill was calculated by multiplying the percentage of waste from the Dynamic Itinerary against the back and forecasted total landfilled emplacements.

The second source of data was from Puerto Rico. Currently Puerto Rico has no LFGTE technology but plans to bring this technology online at three of its landfills in the near future: Carolina, Toa Baja, and Fajardo.[68] Since Puerto Rico was not able to provide a firm start date for the LFGTE installation, an assumed 2016 start year for all three projects was used in the forecast.

The last source of emissions that were forecasted was from composting. Composting releases both CH_4 and N_2O[69]. Puerto Rico provided two different types of composting materials, sludge (wet tons from WW) and vegetative material. Both of these types of compost have different emission factors. Below, in table H-5, are the two emission factors used to calculate the total emissions from composting. For each year the total amount of sludge and the total amount of vegetative material was multiplied by their appropriate emission factor. Once each type of compost was multiplied by their CH_4 and

[66] http://www.epa.gov/region2/cepd/solidwaste_in_puerto_rico.html.
[67] http://www.ads.pr.gov/files/2013/05/Dynamic_Itinerary.pdf.
[68] M. Padilla, ADS, personal communication and data file to L. Bauer, CCS, September 24, 2014
[69] http://www.ipcc.ch/publications_and_data/ar4/wg3/en/ch10s10-3.html.

the N_2O emission factor, they were converted to tCO2e and added together to provide the total amount of tCO_2e.

Table G-5. Composting Emission Factors

Solid Waste Management Emission Factors:	Value	Units
CH_4 from composting of green waste	0.000789	tCH_4/t feedstock[70]
N_2O from composting of green waste	0.0000474	tN_2O/t feedstock[71]
CH_4 from composting of sludge	0.000004	tCH_4/t feedstock
N_2O from composting of sludge	0.0000003	tN_2O/t feedstock[72]

Waste Water

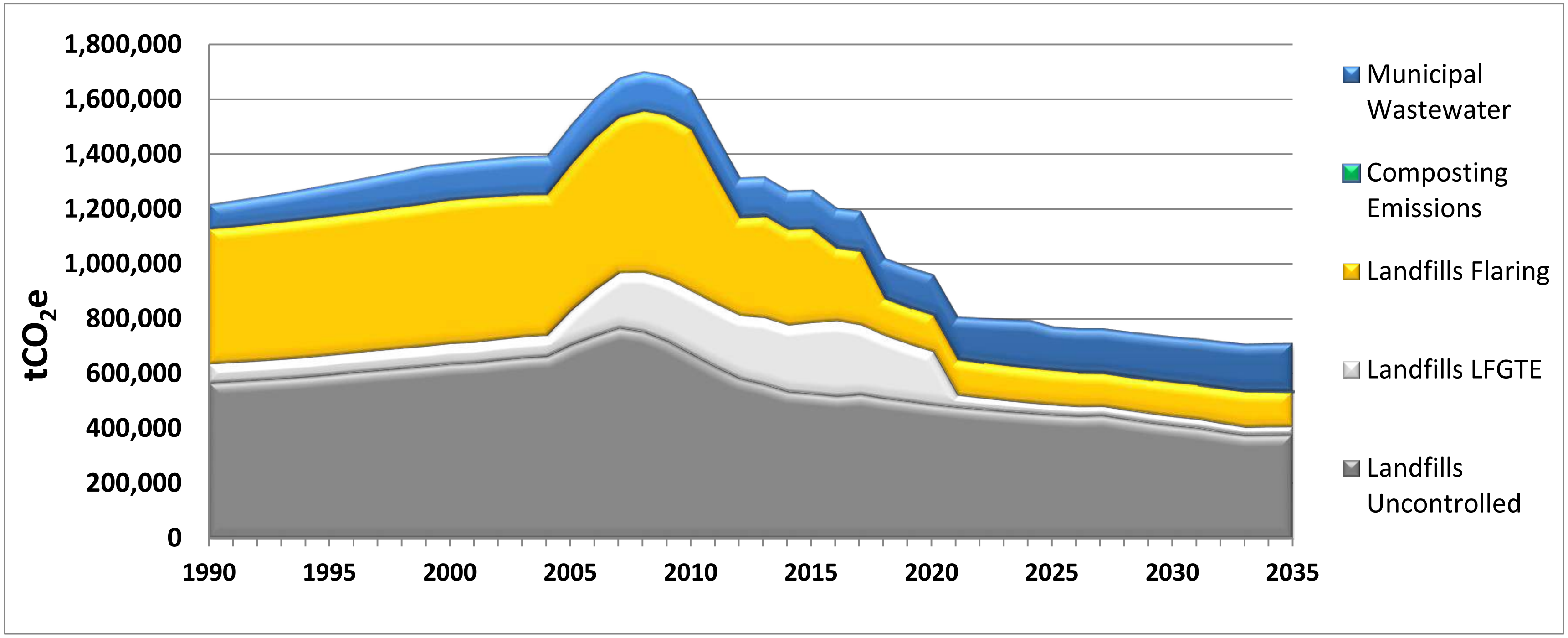
The same methodology for the WW inventory was applied to the forecast period 2014-2035. There were no technologies or expected changes assumed to occur within the forecasted period that would change the current increase rate of WW emissions.

GHG Results

Figure H-1 below shows the total back casted and forecasted emissions for SW and WW.

[70] http://www.epa.gov/ttnchie1/eiip/techreport/volume03/eiip_areasourcesnh3.pdf.
[71] http://cdm.unfccc.int/EB/021/eb21repan15.pdf.
[72] http://www.epa.gov/ttnchie1/efpac/ghg/GHG_Biogenic_Report_draft_Dec1410.pdf.

Figure G.1 Waste Management Sector GHG Emissions Summary



tCO2e	1990	1995	2000	2005	2010	2015	2020	2025	2030	2035
Landfills Uncontrolled	565,556	595,648	634,399	704,021	670,158	526,077	486,969	449,361	410,103	377,554
Landfills LFGTE	68,427	71,206	74,150	125,117	229,785	259,590	192,703	36,274	32,485	28,652
Landfills Flaring	492,988	506,465	524,426	532,952	591,417	342,462	132,733	125,677	125,052	128,159
Composting Emissions	0	0	82	208	218	466	596	726	856	986
Municipal Wastewater	90,446	116,577	134,846	144,756	144,798	142,403	149,220	160,056	167,483	177,877
Total	**1,217,418**	**1,289,897**	**1,367,903**	**1,507,054**	**1,636,376**	**1,270,999**	**962,222**	**772,095**	**735,980**	**713,229**

Landfill emplacement gases were the overall highest emitter of methane during the 45 year I&F period. Landfills also accounted for 88% of CO_2e emissions. Of the total amount of GHG emissions uncontrolled landfills were responsible for 47% of emissions. The second highest emission source at 31% was landfills with flaring controls installed, the third highest emission source was the WW sector at 12%. The Landfills with LFGTE technologies accounted for 10% of GHG emissions and composting accounted for less than 1% of emissions from the waste sector.

In 2010, the total amount of GHG emission from the waste sector was 1,444,798 tCO_2e. In 2013, the total amount of GHG emissions from the WW sector is expected to decrease to 177,877 tCO_2e. This is a 61% forecasted decrease of GHG emissions from 2010 to 2035. There are a few possible reasons as to why this decline is seen:

- Total projected population is declining according to the US Census Bureau, which would decrease the amount of people creating both SW and WW.
- Puerto Rico is constructing a Waste-to-Energy combustion facility that will come online in 2016. This plant is expected to take 791,913 tons of MSW out of the landfilled waste stream.
- Flaring technologies installed in landfills is recent and will continue to reduce the amount of methane that is released into the atmosphere, especially since methane is not emitted immediately after the MSW is emplaced. A few years must pass before the landfill will begin producing peak amounts of methane
- The last rational for the decline in GHG emissions is the installation of LFGTE technology, assumed to come online in 2016.

Key Uncertainties and Additional Research Needs

Key Sources of uncertainty underlying the estimates above are as follows:

- The data used to back cast from the previous climate action plan and I&F. This data presents many uncertainties. It assumes that the population does not change from 1990 to 1998 and that waste per capita consumption does not change in that period as well.
- Data gaps. Many data gaps had to be filled either because the data did not exist or the data was never received for input into the data profiles
- WW data needs to be firmer. According to the results of the data, the total amount of people serviced by PRASA declines, as the provided data trends indicate. The amount of people serviced by PRASA declines more quickly than the US Census Bureau projects. Therefore, the amount of people serviced by PRASA declines while the amount of people serviced by latrines and septic tanks increases.
- During the data gathering process, it was discovered that landfills are required to report total landfill emplacement on a voluntary basis. This leaves several data gaps and possible incorrect data.[73]

[73] M. Padilla, ADS, personal communication and data file to L. Bauer, CCS, August 22, 2014

H. Summary Figures and Tables

Table H.1 – Total Puerto Rico GHG Gas by Sector and Types of Gas

	CO_2	CH_4	N_2O	HFC	NF_3	PFC	SF_6	Total	% of Total
	42.6	**0.02**	**0.16**	**0.00**	**0.00**	**0.00**	**0.06**	**43**	**93.5%**
Fuel Combustion	**42.6**	**0.02**	**0.16**	**-**	**-**	**-**	**-**	**43**	**93.3%**
Electricity Generation	14.8	0.008	0.03	n/a	n/a	n/a	n/a	15	32.3%
Fossil Fuel Supply	n/q	n/q	n/q	n/a	n/a	n/a	n/a	-	0.0%
Transportation: Onroad	10	0.0076	0.10	n/a	n/a	n/a	n/a	10	22.6%
Transportation: Air, Marine & Rail	0.47	0.00031	0.0040	n/a	n/a	n/a	n/a	0.5	1.0%
Transportation: Pipeline, Handling, Storage	n/a	n/a	n/a	n/a	n/a	n/a	n/a	-	
Residential	0.16	0.000049	0.0032	n/a	n/a	n/a	n/a	0.2	0.4%
Commercial & Institutional	0.010	0.000002	0.000016	n/a	n/a	n/a	n/a	0.01	0.0%
Industrial	17	0.0067	0.017	n/a	n/a	n/a	n/a	17	37.0%
Non-Combustion	-	-	-	-	-	-	***0.061***	***0.06***	***0.1%***
Coal Mining & Dressing	n/a	n/a	n/a	n/a	n/a	n/a	n/a	-	0.0%
Oil & Gas Extraction/Processing/Transport	n/a	n/a	n/a	n/a	n/a	n/a	n/a	-	0.0%
Petroleum Refining	n/a	n/a	n/a	n/a	n/a	n/a	n/a	-	0.0%
Natural Gas T&D and Storage	n/a	0.00	n/a	n/a	n/a	n/a	n/a	-	0.0%
Electricity T&D	n/a	n/a	n/a	n/a	n/a	n/a	0.061	0.1	0.1%
	-0.61	**1.8**	**0.12**	**1.6**	**0.00**	**0.038**	**0.00**	**3**	**6.5%**
Industrial Processes & Products	***0.34***	***0.00***	***0.00***	***1.63***	***0.00***	***0.038***	***0.00***	***2***	***4.4%***
Cement Production	0.34	n/a	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	0.3	0.7%
Glass Manufacturing	0.00	n/a	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	-	0.0%
Lime & Soda Ash Production	0.00	n/a	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	-	0.0%
Carbonates Use	n/q	n/a	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	-	0.0%
Aluminum Production	n/a	n/a	*n/a*	*n/a*	*n/a*	n/a	*n/a*	-	0.0%
Magnesium Production	n/a	n/a	*n/a*	*n/a*	*n/a*	*n/a*	n/a	-	0.0%
Ammonia & Urea Production	n/a	n/a	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	-	0.0%
Adipic Acid Production	n/a	n/a	n/a	*n/a*	*n/a*	*n/a*	*n/a*	-	0.0%

Nitric Acid Production	n/a	n/a	n/a	*n/a*	*n/a*	*n/a*	*n/a*	-	0.0%
HCFC-22 Production	n/a	n/a	n/a	n/a	*n/a*	*n/a*	*n/a*	-	0.0%
Semiconductor Manufacturing	n/a	n/a	n/a	n/a	n/a	0.038	*n/a*	0.04	0.1%
Food & Beverage Production	n/a	n/a	n/a	n/a	*n/a*	*n/a*	*n/a*	-	0.0%
ODS Substitutes	n/a	n/a	n/a	1.63	*n/a*	*n/a*	*n/a*	1.6	3.6%
Agriculture, Forestry & Other Land Use	***(0.96)***	***0.51***	***0.12***	-	-	-	-	***(0.3)***	***-0.7%***
Agricultural Fuel Combustion	n/a	n/a	n/a	*n/a*	*n/a*	*n/a*	*n/a*	-	0.0%
Forestry Fuel Combustion	n/a	n/a	n/a	*n/a*	*n/a*	*n/a*	*n/a*	-	0.0%
Fisheries Fuel Combustion	n/a	n/a	n/a	*n/a*	*n/a*	*n/a*	*n/a*	-	0.0%
Perennial Tree Agriculture	-0.25	n/a	n/a	*n/a*	*n/a*	*n/a*	*n/a*	(0.2)	-0.5%
Livestock: Enteric Fermentation	n/a	0.45	n/a	*n/a*	*n/a*	*n/a*	*n/a*	0.4	1.0%
Livestock: Manure Management	n/a	0.06	n/a	*n/a*	*n/a*	*n/a*	*n/a*	0.06	0.1%
Rice Cultivation	n/a	n/a	n/a	*n/a*	*n/a*	*n/a*	*n/a*	-	0.0%
Crop Residue Burning	n/a	n/a	n/a	*n/a*	*n/a*	*n/a*	*n/a*	-	0.0%
Forest Wildfires	n/a	n/a	n/a	*n/a*	*n/a*	*n/a*	*n/a*	-	0.0%
Urea Application	n/a	n/a	n/a	*n/a*	*n/a*	*n/a*	*n/a*	-	0.0%
Urban Forest Carbon Flux	-0.12	n/a	n/a	*n/a*	*n/a*	*n/a*	*n/a*	(0.1)	-0.3%
Forest Carbon Flux	-0.59	n/a	n/a	*n/a*	*n/a*	*n/a*	*n/a*	(0.6)	-1.3%
Cropland Soils	n/a	n/a	0.12	*n/a*	*n/a*	*n/a*	*n/a*	0.1	0.3%
Settlement Soils	n/a	n/a	n/a	*n/a*	*n/a*	*n/a*	*n/a*	-	0.0%
Waste Management	***0.00027***	***1.3***	***0.0029***	-	-	-	-	***1***	***2.9%***
Waste Management Fuel Combustion	0.00027	0.0000002	0.0000007	*n/a*	*n/a*	*n/a*	*n/a*	0.0003	0.0%
Landfill Carbon Sequestration	n/a	n/a	n/a	*n/a*	*n/a*	*n/a*	*n/a*	-	0.0%
Landfills	n/a	1.18	n/a	*n/a*	*n/a*	*n/a*	*n/a*	1	2.6%
Solid Waste Combustion	n/a	n/a	n/a	*n/a*	*n/a*	*n/a*	*n/a*	-	0.0%
Solid Waste Biological Treatment	n/a	0.00025	0.00022	*n/a*	*n/a*	*n/a*	*n/a*	0.0005	0.0%
Municipal Wastewater Treatment	n/a	0.14	0.0026	*n/a*	*n/a*	*n/a*	*n/a*	0.1	0.3%
Industrial Wastewater Treatment	n/a	n/a	n/a	*n/a*	*n/a*	*n/a*	*n/a*	-	0.0%
Totals	**42.0**	**1.8**	**0.28**	**1.63**	**-**	**0.038**	**0.061**	**45.8**	**100%**

Table H.2 - EXAMPLES OF US STATE GHG EMISSIONS TARGETS

State	Economy-wide		Sector-based			
			Energy Supply and Demand (ESD)	**Transportation and Land use (TLU)**	**Residential, Commercial and Industrial (RCI)**	**Agriculture, Forestry and Waste (AFW)**
	Target reduction	Target year	Reduction Potential as Percentage of 2020 All-sector Baseline Emissions	Reduction Potential as Percentage of 2020 All-sector Baseline Emissions	Reduction Potential as Percentage of 2020 All-sector Baseline Emissions	Reduction Potential as Percentage of 2020 All-sector Baseline Emissions
Alaska	20% below 1990	2020				
	80%below 1990	2050				
Arizona	2000 level	2020	11.10%	9.51%	17.42%	3.67%
	50% below 2000	2040				
Arkansas	20% below 2000	2020				
	50% below 2000	2035				
California	1990 level	2020	2.64%	10.33%	6.37%	2.75%
	80% below 1990	2050				
Colorado	20% below 2005	2020	7.93%	2.70%	13.96%	7.81%
	80% below 2005	2050				
Connecticut	10% below 1990	2020	2.16%	9.96%	9.39%	2.31%
	75% below 1990	Long term				
Florida	2000 level	2017	23.55%	4.87%		18.35%
	1990 level	2025				
	80% below 1990	2050				
Hawaii	1990 level	2020				
Illinois	1990 level	2020				
	60% below 1990	2050				
Iowa	11 or 22% below 2005	2020				

	50 or 90% below 2005	2059				
Kentucky	20% below 1990	2030				
Maine	10% below 1990	2020	10.05%	9.43%	6.07%	7.99%
	75% below 1990	Long term				
Maryland	25% below 2006	2020	19.21%	5.02%	16.98%	6.93%
	90% below 2006	2050				
Massachusetts	25% below 1990	2020				
	80% below 1990	2050				
Michigan	20% below 2005	2020				
	80% below 2005	2050				
Minnesota	15% below 2005	2015	8.24%	1.98%	11.67%	21.96%
	30% below 2005	2025				
	80% below 2005	2050				
Montana	1990	2020	12.27%	2.44%	10.01%	9.72%
	80% below 1990	2050				
New Hampshire	1990	2010				
	10% below 1990	2020				
	75-85% below 2001	Long term				
New Jersey	1990	2020				
	80% below 2006	2050				
New Mexico	10% below 2000	2020	17.15%	7.97%	8.01%	5.42%
	75% below 2000	2050				
New York	10% below 1990	2020		6.70%	1.31%	
North Carolina	1990	2020	15.31%	6.38%	15.49%	11.51%
Oregon	10% below 1990	2020				
	75% below 1990	2050				
Pennsylvania	30% below 2000	2020				

Rhode Island	10% below 1990	2020	4.04%	12.96%	13.52%	5.41%
South Carolina	5% below 1990	2020	11.01%	4.94%	24.64%	15.21%
Vermont	50% below 1990	2028	22.18%	7.10%	22.53%	33.79%
	75% below 1990	2050				
Virginia	30% below BAU	2025				
Washington	1990	2020	4.50%	5.67%	11.45%	13.98%
	25% below 1990	2035				
	50% below 1990	2050				
Wisconsin	22% below 2005	2022				
	75% below 2005	2050				

Table H.5 - EXAMPLES OF CENTRAL AND SOUTH AMERICA COUNTRIES ECONOMY-WIDE GHG TARGETS AND PLEDGES			
Country	**Target Reduction**	**Target year**	**SOURCE**
Brazil	36.1-38.9% below BAU	2020	Pledge under the UNFCCC. 2009 National Law
Chile	20% below BAU (projected emissions from 2007 levels)	2020	Pledge under the UNFCCC. National climate change strategy under discussion
Costa Rica	Carbon Neutral	2021	Pledge under the UNFCCC. 2008 National Climate Change Strategy
Mexico	30% below BAU	2020	Pledge under the UNFCCC
	50% below 2000	2050	National Climate Change Strategy, June 2013
EXAMPLES OF CARIBBEAN COUNTRIES ECONOMY-WIDE GHG TARGETS AND PLEDGES			
Antigua and Barbuda	25% below 1990	2020	Pledge under the UNFCCC