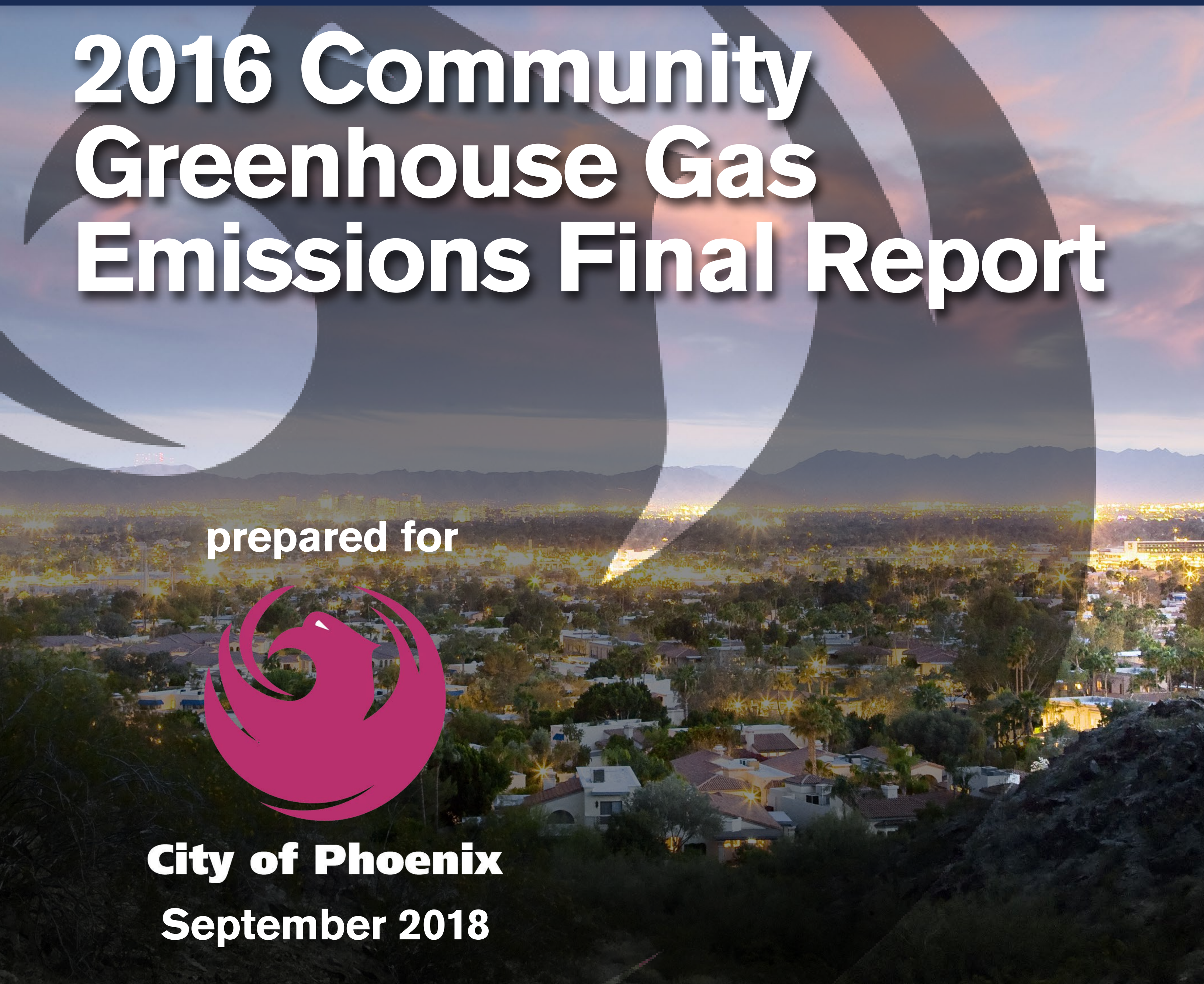
ASU Rob and Melani Walton Sustainability Solutions Initiatives
Arizona State University

2016 Community Greenhouse Gas Emissions Final Report



prepared for

City of Phoenix

September 2018

Global Sustainability Solutions Services

sustainabilitysolutions.asu.edu

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Acronyms

AFLOU	Agriculture, Forestry and Other Land Use
AZNM	Arizona and New Mexico eGRID Sub-region
APS	Arizona Public Service
AR5	5th Assessment Report of the IPCC Change
BT	Biological Treatment
BEVs	Battery Electric Vehicles
CAP	Climate Action Plan
CDP	Carbon Disclosure Project
CH_4	Methane
CIRIS	City Inventory Reporting and Information System (part of the GPC)
CNG	Compressed Natural Gas
CO_2	Carbon Dioxide
CO_2e	Carbon Dioxide Equivalent Emissions
e-GRID AZNM	EPA’s Emissions & General Resource Integrated DB for AZ/New Mexico
EIA	Energy Information Administration
EPA	Environmental Protection Agency
FAA	Federal Aviation Agency
FERC	Federal Energy Regulatory Commission
FTE	Full-time-equivalent
GAC	Granulated Activated Carbon

GHG	Greenhouse Gas
GPC	Global Protocol for Community-Scale Greenhouse Gas Emission Inventories
GWP	Global Warming Potential
ICLEI	International Council for Local Environmental Initiatives
IGCC	International Green Construction Codes
IPCC	Intergovernmental Panel on Climate Change
IPPU	Industrial Processes and Product Use
LEED	Leadership in Energy and Environmental Design
LGOP	Local Government Operations Protocol
LNG	Liquid Natural Gas
LPG	Liquefied Petroleum Gas
LTO	Landing and Take-off
MT	Metric Tons
NEI	National Emissions Inventory
N_2O	Nitrous Oxide
PEHV	Plug-in Electric Hybrid Vehicles
SRP	Salt River Project
SW	Solid Waste
T&D	Transmission & Distribution
TN	Total Nitrogen
TR	Transportation
TRP	Trip Reduction Program
UNFCCC	United Nations Framework Convention on Climate Change
WWTP	Wastewater Treatment Plant

Executive Summary

The City of Phoenix (Phoenix) has completed a community-scale greenhouse gas (GHG) emissions inventory for calendar year 2016, a follow up to its first community-scale GHG emissions inventory for calendar year 2012. The community-scale GHG emissions inventory was conducted according to the Global Protocol for Community-Scale Greenhouse Gas Emission Inventories (GPC Protocol).

The GPC Protocol is a worldwide standard for inventorying city-induced GHG emissions developed by the World Resources Institute, C40 Cities Climate Leadership Group, and ICLEI[1]. The GPC is also the standard supported by the Global Covenant of Mayors for Climate and Energy, of which Phoenix is a member. The GPC Protocol categorizes direct and indirect GHG emissions into three sectors: Stationary energy, Transportation and Waste. Direct GHG emissions occur within Phoenix boundaries, such as gasoline consumption or natural gas combustion, and indirect GHG emissions are induced by activity within the Phoenix boundary, such as electricity consumption.

- Stationary Energy Sector GHG emission sources include energy utilized in residential buildings; commercial buildings and facilities; manufacturing industries; agriculture, forestry and fishing energy use; and electricity transmission and distribution energy losses.
- Transportation Sector GHG emissions include emissions from commercial air travel, civil aviation, on-road transportation, non-road vehicle use, light rail, and freight rail.
- Waste Sector GHG emissions result from solid waste disposal, composting, and wastewater treatment.

The 2016 Community-Scale GHG Emission Inventory shows citywide emissions to be 15,684,329 metric tons of carbon dioxide equivalents (MT CO_2e), a 7.2% reduction in the overall GHG emissions compared to the 2012 levels of 16,897,600 MT CO_2e, and a positive change in the city's effort to mitigate climate change. The Transportation Sector is the largest source of GHG emissions in Phoenix and, in 2016, emitted 9,344,245 MT CO_2e. The Stationary Energy Sector is the second largest source of GHG emissions and emitted 5,958,302 MT CO_2e. The Waste Sector was the smallest source of GHG emissions for the City of Phoenix and emitted 381,783 MT CO_2e. These GHG emissions reductions occurred while the City of Phoenix population grew from 1,473,405 in 2012 to 1,615,017 in 2016.

[1] Wee Kean Fong, Mary Sotos, Michael Doust, and Seth Schultz. "An Accounting and Reporting Standard for Cities." Global Protocol for Community-Scale Greenhouse Gas Emission Inventories. No Publication Date. Accessed 2017. https://ghgprotocol.org/greenhouse-gas-protocol-accounting-reporting-standard-cities.

Methodology

The 2016 Community-Scale GHG Emission Inventory for the City of Phoenix was conducted using the Global Protocol for Community-Scale Greenhouse Gas Emission Inventories (GPC) methodology to inventory direct and indirect GHG emissions. The GPC Protocol provides a clear methodology for determining which emission sources to include or exclude in a GHG inventory; defining and categorizing GHG emission sources; and identifying how transboundary emissions are treated. In doing so, the GPC Protocol improves the quality and transparency of GHG inventories, increases the credibility of comparisons across geographies and timescales, and creates a meaningful benchmark to identify strategies for community-scale GHG emission mitigation.

Key Findings

The 2016 Community-Scale GHG Emission Inventory shows Phoenix-wide GHG emissions to be 15,684,329 MT CO_2e, a 7.2% reduction in the overall GHG emissions compared to the 2012 levels of 16,897,600 MT CO_2e. The distribution of GHG emissions among Stationary Energy, Transportation, and Waste Sectors for 2012 and 2016 is detailed in *Figure-ES 1* and shown in *Table-ES 1*.

Table-ES 1. Phoenix GHG emissions by Sector and Subsector (MT CO_2e)

Sector and Subsector	2012 Emissions	2016 Emissions	Change in Emissions	% Change
Stationary Energy				
Residential buildings	3,679,189	2,796,904	-882,285	-24%
Commercial & institutional buildings	3,936,896	2,925,368	-1,011,528	-26%
Manufacturing industries and construction	180,999	179,750	-1,249	-1%
Agriculture, forestry and fishing activities	4,273	56,188	51,916	1215%
Non-specified sources	75	92	16	22%
Stationary Energy Sector Total	**7,801,433**	**5,958,302**	**-1,843,131**	**-23.60%**
Transportation				
On-road transport	5,954,202	6,443,139	488,938	8.20%
Railways	30,309	29,455	-854	-2.80%
Commercial Aviation	698,263	705,643	7,380	1.10%
Civil Aviation (Aviation Gasoline)	13,394	15,067	1,673	12.50%
Off-road transport	2,009,524	2,150,940	141,416	7.00%
Transportation Sector Total	**8,705,692**	**9,344,245**	**638,553**	**7.30%**
Waste				
Solid waste disposal	365,749	356,623	-9,127	-2%
Wastewater treatment and discharge	10,066	10,840	775	8%
Biological treatment of waste (composting)	14,661	14,320	-341	-2%
Waste Sector Total	**390,476**	**381,783**	**-8,693**	**-2.20%**
GHG Emission Total	**16,897,600**	**15,684,329**	**-1,213,271**	**-7.20%**

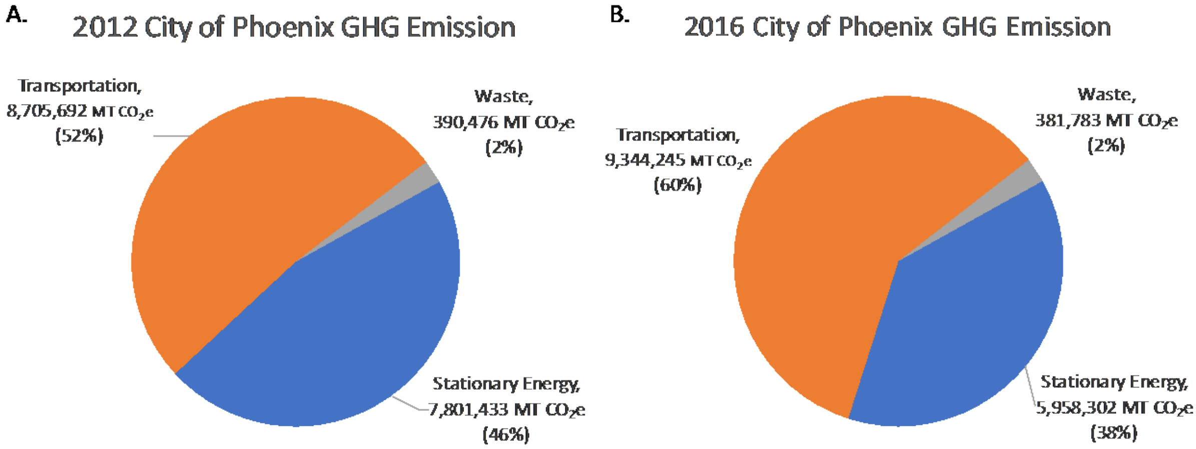

Figure-ES 1. (A) City of Phoenix GHG emissions by emission sector for 2012. (B) City of Phoenix GHG emissions by emission sector for 2016

Stationary Energy

The Stationary Energy Sector is the second largest source of GHG emissions in the City of Phoenix. Stationary Energy GHG emission results from the direct combustion of natural gas and indirectly from electricity consumption. Stationary energy GHG emission sources include energy utilized in residential buildings; commercial buildings and facilities; manufacturing industries; agriculture, forestry and fishing energy use; and electricity transmission and distribution energy losses. GHG emissions from natural gas leakages were not included for reporting in 2012 and 2016 due to a lack of data on leakage rates (*Figure-ES 2*).

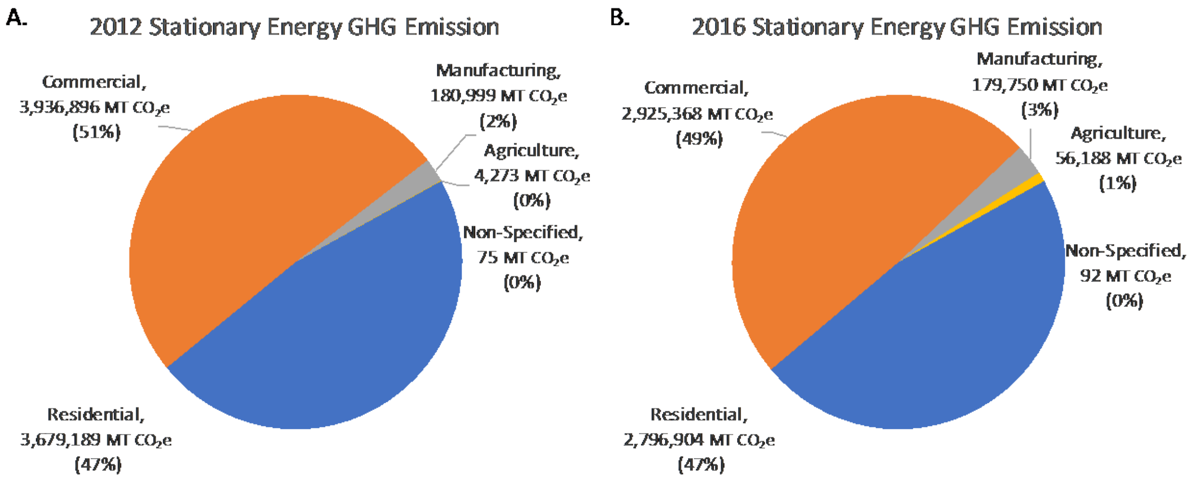

Figure-ES 2. (A) Stationary Energy GHG emissions by emission sector for 2012. (B) Stationary Energy GHG emissions by emission sector for 2016

Stationary Energy GHG emissions for 2016 were 5,958,302 MT CO_2e, which is a 23.6% decrease in emissions from 2012. The driving force behind the large reduction in Stationary Energy GHG emissions resulted from the continuing transition to greener sources of grid electricity generated and supplied by the two Phoenix electrical utility providers (*Table-ES 2*). The cleaner electricity decreased the carbon intensity (unit of

CO_2e per kWh) of what Phoenix consumes, as reflected in the EPA e-GRID GHG emission factor for the Arizona-New Mexico subregion. Data to calculate Stationary Energy GHG emissions were obtained from Arizona Public Service (electricity), the Salt River Project (electricity), Southwest Gas (natural gas), and the Energy Information Administration (electricity transmission and distribution loss).

Table-ES 2 details the GHG emissions by subsector and *Figure-ES 2* shows the distribution of GHG emissions among different sub-sectors in the Stationary Energy Sectory for 2012 and 2016.

Table-ES 2. Subsector Stationary Energy GHG Emissions (MT CO_2e)

Stationary Energy	2012 Emission	2016 Emission	Change in Emissions	% Change
Residential buildings	3,679,189	2,796,904	-882,285	-24%
Commercial & institutional buildings	3,936,896	2,925,368	-1,011,528	-26%
Manufacturing industries and construction	180,999	179,750	-1,249	-1%
Agriculture, forestry and fishing activities	4,273	56,188	51,916	1215%
Non-specified sources	75	92	16	22%
Stationary Energy Emission Total	**7,801,433**	**5,958,302**	**-1,843,131**	**-23.6%**

Transportation

Transportation Sector GHG emissions include emissions from commercial air travel, civil aviation, on-road transportation, non-road vehicle use, light rail, and freight rail (*Figure-ES 3*). Transportation GHG emissions result from the combustion of fossil fuels (gasoline, diesel, CNG, LNG, LPG, aviation gasoline, jet fuel A), blended alternative fuels (B20 biodiesel, E85 Ethanol, E54 Ethanol), or indirectly from the consumption of electricity to operate light rail and charge electric vehicles. The Transportation Sector is the largest source of GHG emissions in the City of Phoenix.

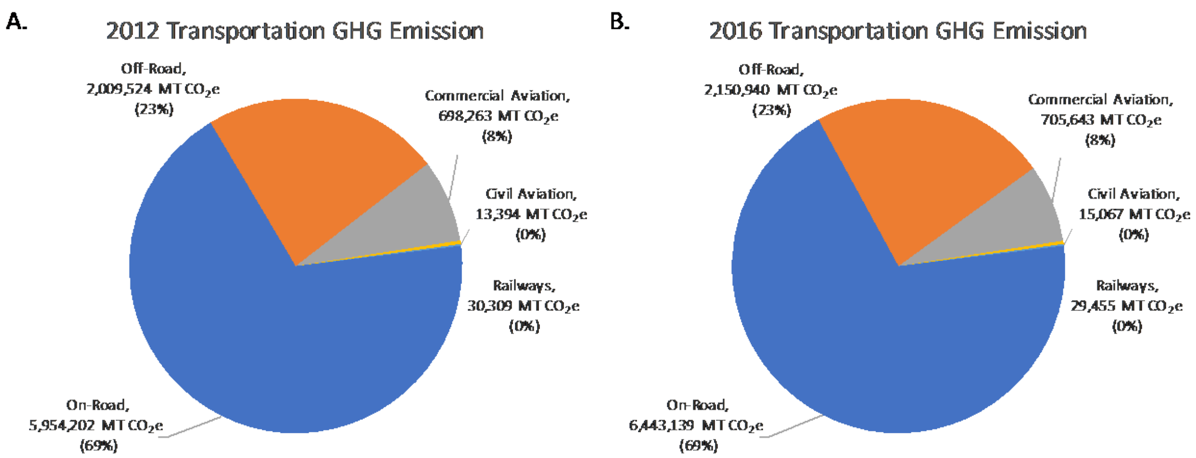

Figure-ES 3. (A) Transportation GHG emissions by emission sector for 2012. (B) Transportation GHG emissions by emission sector for 2016

Total Transportation Sector GHG emissions for 2016 was 9,344,245 MT CO_2e, which is a 7.3% increase in GHG emissions from the 2012 level of 8,705,692 MTCO_2e (*Table-ES 3*). Increased on-road and off-road transportation activity was responsible for the increased Transportation Sector GHG emissions. Data were obtained from the City of Phoenix, Arizona Department of Transportation, the Weights and Measures Division of the Arizona Department of Agriculture, the Valley of the Sun Clean Cities Coalition, the Federal Aviation Administration, and Southwest Gas.

Table-ES 3. Subsector Transportation GHG Emissions (MT CO_2e)

Transportation	2012 Emissions	2016 Emissions	Change in Emissions	% Change
On-road transport	5,954,202	6,443,139	488,938	8.20%
Railways	30,309	29,455	-854	-2.80%
Commercial Aviation	698,263	705,643	7,380	1.10%
Civil Aviation (Aviation Gasoline)	13,394	15,067	1,673	12.50%
Off-road transport	2,009,524	2,150,940	141,416	7.00%
Transportation Sector Total	**8,705,692**	**9,344,245**	**638,553**	**7.3%**

Waste

Waste Sector GHG emissions, are a comparatively small component of the total GHG emissions that occur in the City of Phoenix. The Waste Sector includes emissions from the current and historic disposal of solid waste generated and treated in Phoenix, the current disposal of solid waste generated in Phoenix that is disposed outside the city at the SR-85 Landfill, wastewater treated at the 91st Avenue and 23rd Avenue wastewater treatment plants in Phoenix, and the biological treatment (composting) of waste generated and treated in Phoenix; (*Figure-ES 4*).

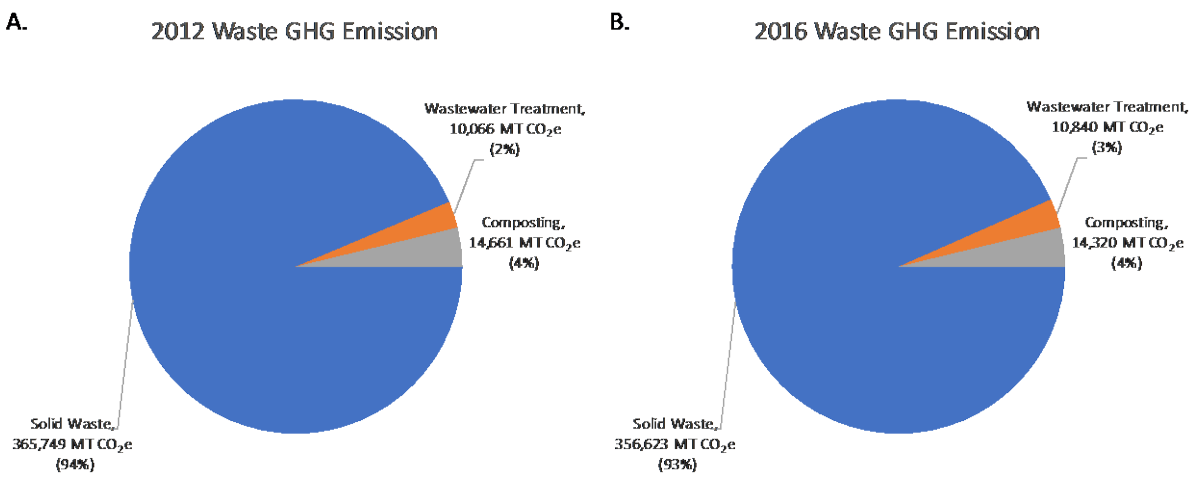

Figure-ES 4. (A) Waste Sector GHG emissions by emission sector for 2012. (B) Waste Sector GHG emissions by emission sector for 2016

Between 2012 and 2016 there has been a 2.2% decrease in Waste Sector GHG emissions. While GHG emissions from solid waste disposal and composting decreased by approximately 2%, similar to the Waste Sector overall, GHG emissions from wastewater treatment increased by 8%. The total GHG emissions from the Waste Sector were 390,476 MT CO_2e in 2012 as compared to 381,783 MT CO_2e reported for 2016. Waste Sector GHG emission reductions were driven by solid waste disposal, which is greater than 90% of the sector (*Table-ES 4*). While new Solid Waste GHG emissions occur from the ongoing disposal of solid waste, historic, closed landfills within the City of Phoenix would produce less GHG emissions over time, as the waste decays. Table ES 4 provides the breakdown of GHG emissions among different sub-sectors of the waste sector for the years 2012 and 2016.

Table-ES 4. Subsector Waste Sector GHG Emission (MT CO_2e)

Waste	2012 Emissions	2016 Emissions	Change in Emissions	% Change
Solid waste disposal	365,749	356,623	-9,127	-2%
Wastewater treatment and discharge	10,066	10,840	775	8%
Biological treatment of waste (composting)	14,661	14,320	-341	-2%
Waste Sector Total	**390,476**	**381,783**	**-8,693**	**-2.2%**

City Comparison[2]

While it is important for the City of Phoenix to understand its GHG emissions by completing a community GHG inventory, it is also important to understand GHG emissions relative to other large U.S. cities. The remainder of this report summarizes how city of Phoenix GHG emissions compare to a sample of other U.S. cities that have completed community GHG inventories – New York[3], Houston[4], Chicago[5], Las

[2] While city comparisons of emissions were made, no attempts were made to normalize the differences in inventory methodologies and the types of emissions calculated across all cities. After review of the available data, authors determined normalization could not be made consistently across all cities.

[3] Cathy Pasion, Mikael Amar, and Yun Zhou. "City of New York Inventory of New York City's Greenhouse Gas Emissions." April 2016. Cventure LLC, Mayor's Office of Sustainability, New York. Calendar year 2016. Accessed 2017.

[4] "Disclosure Insight Action." CDP Open Data Portal. January 21, 2018. Accessed April 21, 2017. https://data.cdp.net/Cities/2016-Citywide-GHG-Emissions/dfed-thx7/data.

[5] "CITY OF CHICAGO GREENHOUSE GAS INVENTORY REPORT." Global Protocol for Community-Scale Greenhouse Gas Emission Inventories. AECOM. December/January 2015. Accessed February 19, 2017. https://www.cityofchicago.org/content/dam/city/progs/env/GHG_Inventory/CityofChicago_2015_GHG_Emissions_Inventory_Report.pdf.

Vegas[6], Austin[7], Denver[8], Portland[9], Seattle[10], San Francisco[11], and New Orleans[12]. The comparisons allow one to understand what methodologies have been used across the US, how results differ among cities, and identify either where Phoenix is leader among major U.S. cities, or where Phoenix can improve GHG reporting. Different inventory types, inventory years, climate, population size, land size and inventory methods are important factors to be identified when making comparisons among cities.

Overall GHG Emissions

Figure-ES 5 shows the comparison of total GHG emissions of eleven US cities, including Phoenix.

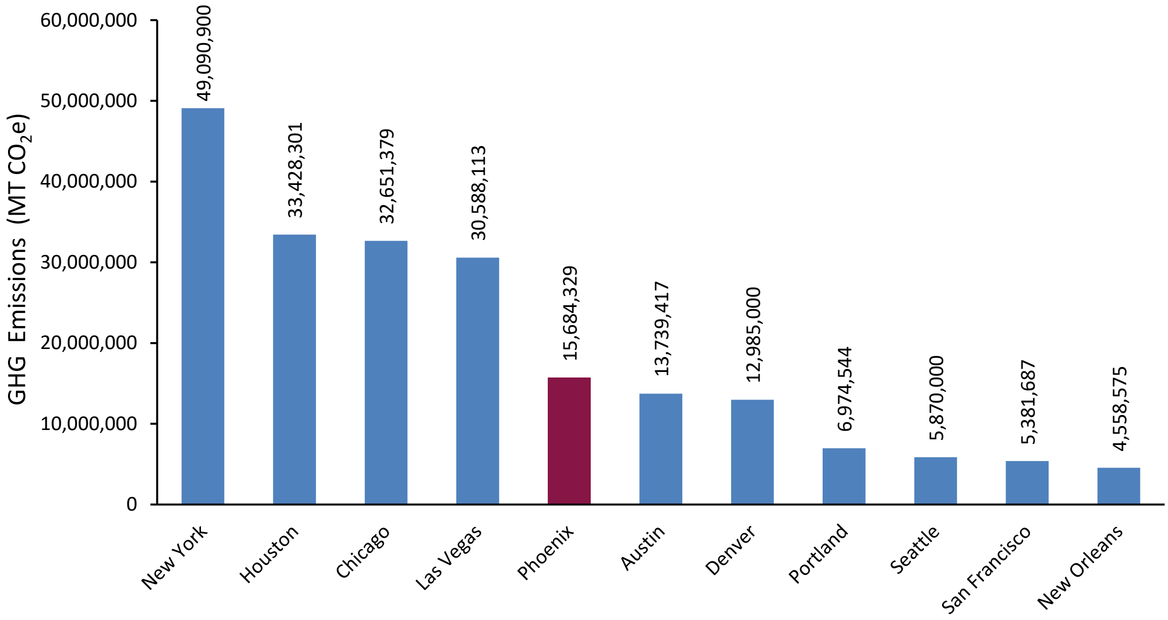

Figure-ES 5. Comparing Total GHG emissions from City of Phoenix to other major U.S. cities (MT CO_2e

[6] "City of Las Vegas Greenhouse Gas Inventory Report." Mayor's Office, Calendar Year 2014. Accessed January 25th 2017. https://www.lasvegasnevada.gov/cs/groups/public/documents/document/chjk/mdmx/~edisp/prd031750.pdf

[7] "City of Austin Greenhouse Gas Inventory Report." Calendar Year 2013, by Office of Sustainability 2013. Accessed January 2017. https://austintexas.gov/sites/default/files/files/2013_Community_Inventory.pdf

[8] "Denver Environmental Health." City and County of Denver Climate Action Plan 2015. Calendar Year 2014. Accessed January 2017. https://www.denvergov.org/content/dam/denvergov/Portals/771/documents/Climate/CAP%20-%20FINAL%20WEB.pdf.

[9] "Disclosure Insight Action." CDP Open Data Portal. Calendar Year 2018. Accessed January - April 21, 2017. https://data.cdp.net/Cities/2016-Citywide-GHG-Emissions/dfed-thx7/data

[10] P. Erickson, A. Down & D. Broekhoff. "Seattle Community Greenhouse Gas Emissions Inventory." Seattle, WA: Stockholm Environment Institute. Report prepared for the City of Seattle. Calendar Year 2014. Accessed July 2017. https://www.seattle.gov/Documents/Departments/OSE/ClimateDocs/2014GHG%20inventorySept2016.pdf

[11] "Disclosure Insight Action." CDP Open Data Portal. January 21, 2018. Accessed January - April 21, 2017. https://data.cdp.net/Cities/2016-Citywide-GHG-Emissions/dfed-thx7/data

[12] "Disclosure Insight Action." CDP Open Data Portal. January 21, 2018. Accessed January - April 21, 2017. https://data.cdp.net/Cities/2016-Citywide-GHG-Emissions/dfed-thx7/data

Per Capita GHG Emissions Comparison

Phoenix ranked fifth out of the eleven cities for lowest emissions per capita as shown in *Figure-ES 6* below.

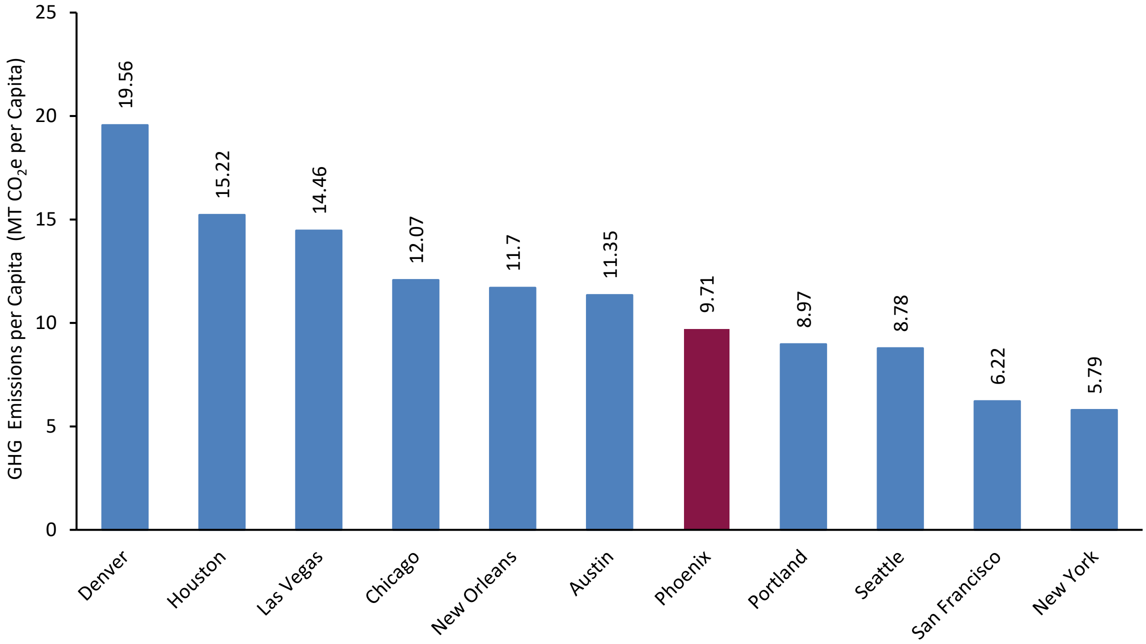

Figure-ES 6. A comparison of the per-capita GHG emissions from City of Phoenix to other major U.S. cities.

Stationary Energy

Phoenix had relatively low per capita stationary energy GHG emissions rates as shown in *Figure-ES 7*. Factors that influence this finding are, the local climate, and a reduction in Phoenix's regional e-GRID factor resulting from utilities moving to cleaner electricity generation.

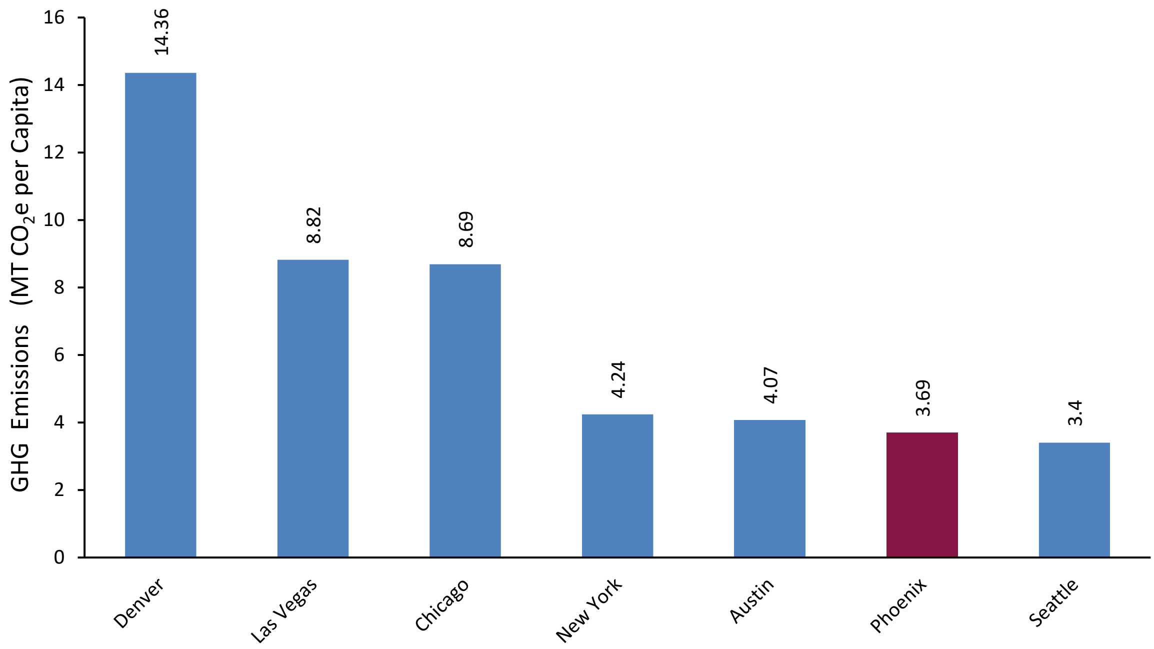

Figure-ES 7. Comparison of Phoenix's per-capita stationary energy GHG emissions to other U.S. cities

Transportation

Among the cities in the comparison, Phoenix had the highest per capita transportation GHG emissions rates. The transportation sector is also the largest source of emissions for the city. *Figure-ES 8* shows Transportation sector emissions per capita.

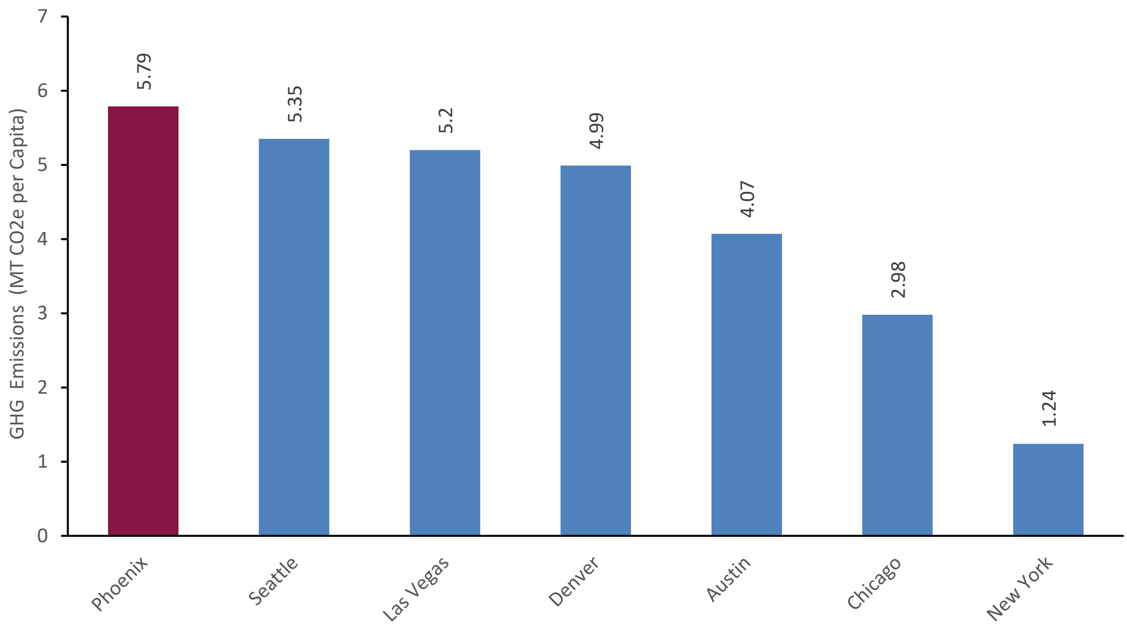

Figure-ES 8. A comparison of Phoenix's per-capita transportation GHG emissions to other U.S. cities

Waste

Overall, waste emissions were only a small percentage of emissions for all cities and are as shown in *Figure-ES 9*. Phoenix had one of the lowest waste emissions per capita GHG emission rates. This may be due to the efficient methane capture systems within the city's municipal landfills.

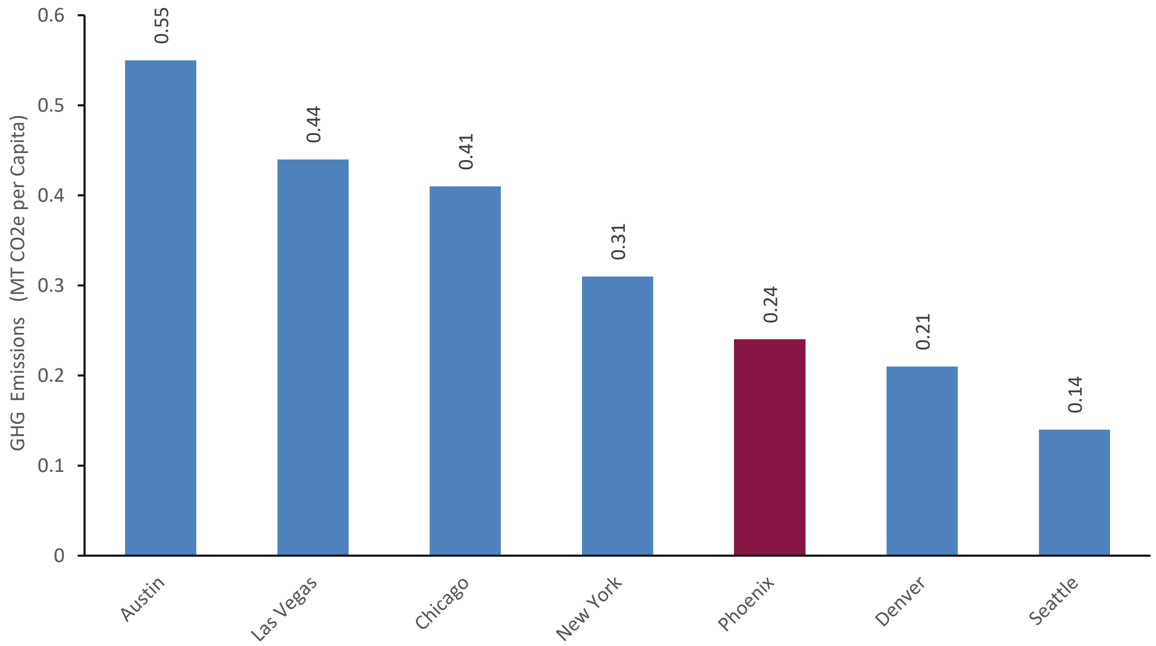

Figure-ES 9. A comparison of Phoenix's per-capita waste GHG emissions to other U.S. cities

Conclusion

In 2016, Phoenix citywide GHG emissions were 15,684,329 MT CO_2e – a 7.2% reduction compared to the 2012 level of 16,897,600 MT CO_2e. Phoenix's GHG emission reductions were driven by the Stationary Energy Sector, which saw a 22% decrease between 2012 and 2016, primarily due to a reduction in the regional EPA e-GRID GHG emission factor resulting from the continued transition to clean grid energy production by regional utilities. Waste Sector GHG emission decreased by 2.2% between 2012 and 2016. One possibility for the decrease may be because there is only one active City of Phoenix landfill and the closed landfills within the City of Phoenix produce less GHG emissions over time, as the waste decays.

The Transportation Sector, the largest source of GHG emissions in Phoenix, increased by 7% between 2012 and 2016. This increase occurred as the direct result of increased on-road transportation activity and the associated increase in gasoline consumption. Measures to reduce transportation GHG emissions would help Phoenix further reduce overall GHG emissions.

Gasoline-powered motor vehicles for on-road transportation are the largest source of transportation-related GHG emissions. An increased adoption of battery electric vehicles (BEVs) or plugin electric hybrid vehicles (PEHV) is one avenue to reduce transportation-related GHG emissions. Given current tailpipe emissions of gasoline-powered motor vehicles and current carbon intensity levels of the electric grid[13], replacing 1% of gasoline-powered motor vehicles for BEVs could result in an annual GHG emission reduction of 24,701 MT CO_2e. Therefore, there is potential for more than a 2,470,000 MT CO_2e reduction in GHG emissions from converting all existing gasoline-powered motor vehicles to BEVs, and this reduction will only increase as the regional electricity mix becomes cleaner and less carbon intensive (*Figure-ES 10*).

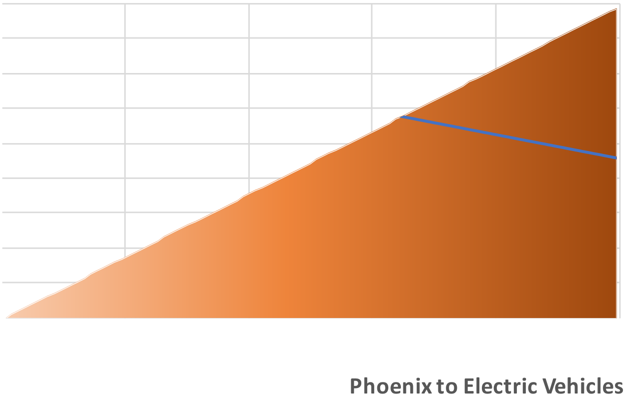

Figure-ES 10: The potential GHG emission reductions from the conversion of existing gasoline-powered motor vehicles to battery electric vehicles

[13] Sailsbury, Mike. "Air Quality and Economic Benefits of Electric Vehicles in Arizona." South West Energy Efficiency Project. September 21, 2015. Accessed July 21, 2017. http://www.swenergy.org/data/sites/1/media/documents/publications/documents/AZ EV AirQuality.EconAnalysis.9.26.13 .pdf.

1. Introduction

Our climate is changing rapidly with a variety of disruptive impacts, and that change appears to be accelerating. The worldwide rise in the combustion of fossil fuels generating increasing levels of greenhouse gas emissions has proven to be the main factor affecting climate change.

Climate change has impacted the City of Phoenix in many ways: Phoenix recorded its hottest year in 2017. The city's built development has also led to the creation of a local urban heat island effect which has limited the natural night-time cooling in the city's urban core.[14] Rising temperatures could also cause Phoenix to increase its need for water but reduce its supply.[15] The Colorado River basin, one of the primary sources of water for Phoenix, is at risk of long droughts in the decades to come.[15]

Cities have become the focus for climate change mitigation, both because cities are a major source of greenhouse gases and because of their ability to implement real solutions to climate change. It is imperative for Phoenix to assess the social, economic and environmental risks of climate change and use its ability to develop and implement solutions to tackle climate change issues. Phoenix, the fifth largest city in the United States, can serve as a platform to translate sustainability goals into achievable local policies and emerge as a national leader in both mitigating and adapting to climate change.

The City of Phoenix has completed a community-scale greenhouse gas (GHG) emissions inventory for calendar year 2016, a follow up to its first community-scale GHG emissions inventory for calendar year 2012. Both community-scale GHG emissions inventories were conducted using the Global Protocol for Community-Scale Greenhouse Gas Emission Inventories (GPC Protocol). The GPC Protocol is a worldwide standard for inventorying city-induced GHG emissions developed by the World Resources Institute, C40 Cities Climate Leadership Group, and ICLEI.[16] The GPC is also the standard supported by the Global Covenant of Mayors for Climate and Energy, of which Phoenix is a member.

The GPC Protocol categorizes direct and indirect GHG emissions into three sectors: Stationary energy, Transportation and Waste. Direct GHG emissions occur within Phoenix boundaries, such as gasoline consumption or natural gas combustion, and indirect GHG emissions are induced by activity within the Phoenix boundary, such as grid-supplied electricity consumption.

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[14] "A Hotter Climate May Catch up to Phoenix," Los Angeles Times, Distributed by Tribune Content Agency, LLC. March, 2017. https://phys.org/news/2017-03-hotter-climate-phoenix.html

[15] "What Climate Change Means For Arizona," United States Environmental Protection Agency, EPA 430-F-16-005, March - September 2016. https://19january2017snapshot.epa.gov/sites/production/files/2016-09/documents/climate-change-az.pdf

[16] "Greenhouse Gas Protocol. GHG Protocol for Cities." Switzerland, Geneva. World Resource Institute. Calendar Year 2017. Accessed January – September 2017. http://ghgprotocol.org/countries-and-cities

- Stationary Energy Sector GHG emission sources include energy utilized in residential buildings; commercial buildings and facilities; manufacturing industries; agriculture, forestry and fishing energy use; and electricity transmission and distribution energy losses.
- Transportation Sector GHG emissions include emissions from commercial air travel, civil aviation, on-road transportation, non-road vehicle use, light rail, and freight rail.
- Waste Sector GHG emissions result from solid waste disposal, composting, and wastewater treatment.
- Industrial Processes and Product Use and Agriculture, Forestry and Other Land Uses sectors were not reported due to data limitations and low relevance.

The 2016 Community-Scale GHG Emissions Inventory shows citywide emissions to be 15,684,329 metric tons of carbon dioxide equivalents (MT CO2e), a 7.2% reduction in overall GHG emissions compared to the 2012 levels of 16,897,600 MT CO2e, and a positive change in the city's effort to mitigate climate change. The Transportation Sector is the largest source of GHG emissions in Phoenix and, in 2016, contributed 9,344,245 MT CO2e. The Stationary Energy Sector is the second largest source of GHG emissions and emitted 5,958,302 MT CO2e. The Waste Sector was the smallest source of GHG emissions for the City of Phoenix and generated 381,783 MT CO2e. These GHG emissions reductions occurred while the City of Phoenix population grew from 1,473,405 in 2012 to 1,615,017 in 2016.

This report provides a detailed explanation of the methodology and findings of the City of Phoenix 2016 inventory of community-scale GHG emissions in the three major sectors of stationary energy, transportation and waste. This report explains the Global Protocol for Community-Scale Greenhouse Gas Emission Inventories (GPC) methodology, the specific Phoenix organizational boundaries, emissions scope definitions and scaling factors used in this inventory. A summary of the inventory results is broken down by reporting sector of stationary energy, transportation and waste and their respective subsectors. This report provides information regarding the changes in Phoenix's GHG emissions between the inventory years 2012 and 2016 and provides a city comparison of reported greenhouse gas emissions and major methodological differences between Phoenix and other U.S. cities.

2. Methodology

The City of Phoenix has adopted the Global Protocol for Community-Scale Greenhouse Gas Emission Inventories (GPC) methodology to report its GHG inventory for the year 2016. The GPC, created by the World Resources Institute (WRI), C40 Cities Climate Leadership Group (C40) and International Council for Local Environmental Initiatives (ICLEI), is considered to be the first widely endorsed global standard for citywide reporting of community-scale GHG emissions. The GPC overcomes issues such as determining the emission sources to be included in or excluded from the GHG inventory, defining and categorizing emissions sources and identifying how transboundary emissions are treated. It does so by offering a clear and robust framework for reporting emissions inventories, improving the quality and transparency of the inventory, increasing the credibility of comparisons across geographies and timescales and creating a meaningful benchmark to identify strategies for GHG mitigation.

2.1 Scope Classifications and Sectors

The GPC requires cities to report their emissions using the following two distinct but complementary approaches, namely the Scopes framework and the City-induced sectors framework. The scopes framework allows cities to comprehensively report all the GHG emissions by scope 1, 2 and 3; and the city-induced sector framework aggregates GHG emissions attributable to activities taking place within the geographic boundary of the city. The scopes classifications are defined as follows and are as shown in *Figure 1*.

- **Scope 1:** GHG emissions from sources located within the boundary of Phoenix.
- **Scope 2:** GHG emissions occurring as a result of using grid-supplied electricity, heat, and steam and/or cooling within the boundary of Phoenix.
- **Scope 3**: GHG emissions that occur outside the city boundary as a result of activities taking place within Phoenix.

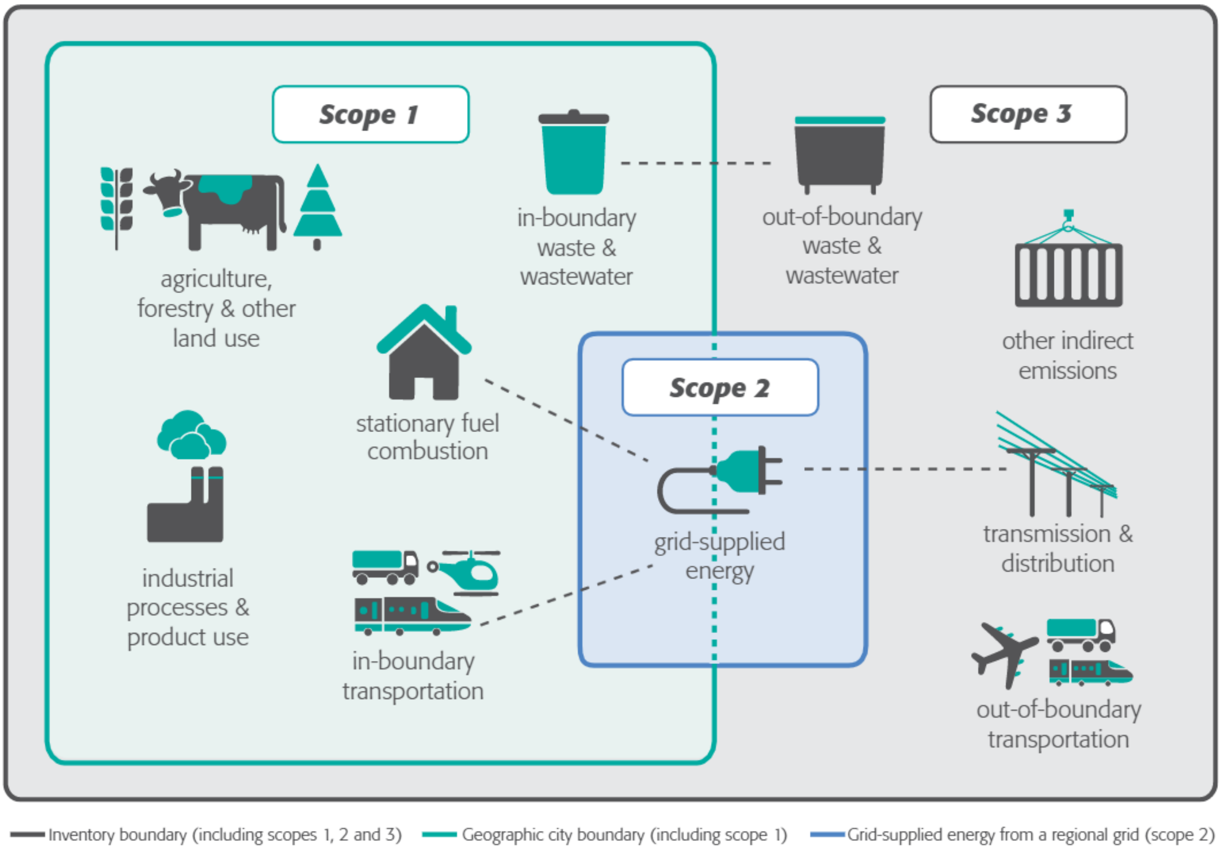


Figure 1. Sources and boundaries of city GHG emissions, adapted from GPC Protocol[17]

The GHG inventory is also categorized into six sectors which are defined by the GPC as follows:

- **Stationary Energy:** Energy consumption is one of the largest contributors to a city's GHG emissions. Included in this sector are emissions occurring as a result of combustion of fuels in residential, commercial and institutional buildings and facilities; manufacturing industries and construction. It also includes emissions from power plants which generate grid-supplied energy and fugitive emissions which occur while extracting, transforming and transporting primary fossil fuels.
- **Transportation:** The transportation sector emissions include those released from travelling by air, road, rail and water. These emissions occur as a direct combustion of fossil fuels or indirectly through the consumption of grid-supplied electricity.
- **Waste:** The waste sector emissions include emissions produced as a result of employing waste disposal and treatment methods such as aerobic or anaerobic decomposition and incineration. The methane recovered and consumed as

[17] Figure Adopted from p.11 of "Greenhouse Gas Protocol. Global Protocol for Community-Scale Greenhouse Gas Emission Inventories." Switzerland, Geneva. World Resource Institute. ICLEI. Calendar Year 2017. Accessed January – September 2017. http://ghgprotocol.org/countries-and-cities

energy from solid waste or wastewater treatment facilities is reported under Stationary energy as an energy source.

- **Industrial Processes and Product Use (IPPU):** IPPU emissions include emissions occurring as a result of processes which involve chemical or physical transformation of materials. It also includes emissions released upon using industrial products such as refrigerants, foams or aerosol cans. IPPU emissions were not inventoried in this report.
- **Agriculture, Forestry and Other Land Use (AFOLU):** The AFOLU sector includes emissions from livestock, land use and land use change (such as the transition of forest to cropland) and aggregate sources and non-CO2 emissions sources, such as fertilizer. AFOLU was not inventoried in this report.
- **Other (Non-specified sources):** Any other emissions occurring outside the geographic boundary as a result of activities taking place in the city.

2.2 Basic and Basic+

The city-induced sector framework of the GPC involves two levels of reporting GHG emissions attributable to activities taking place within the geographic boundary of a city, namely, BASIC and BASIC+. The two levels cover selected sectors and scope 1, 2 and 3 emission sources and illustrate different levels of completeness.

- **BASIC:** Scope 1 emissions from stationary energy, transportation and waste sectors, scope 2 emissions from stationary energy and transportation sectors and scope 3 emissions from the waste sector.
- **BASIC+:** All the BASIC source emissions plus scope 1 emissions from IPPU and AFOLU sectors and scope 3 emissions from stationary energy and transportation sectors. BASIC+ is a more comprehensive method of reporting GHG emissions as compared to the BASIC reporting.

Figure 2 shows the overlap of sectors, scopes and BASIC/BASIC+ reporting.

Sectors and sub-sectors	Scope 1	Scope 2	Scope 3
STATIONARY ENERGY			
Residential Buildings	✓	✓	✓
Commercial and institutional buildings and facilites	✓	✓	✓
Manufacturing industries and construction	✓	✓	✓
Energy industries	✓	✓	✓
Energy generation supplied to the grid	✓		
Agriculture, forestry, and fishing activities	✓	✓	✓
Non-specified sources	✓	✓	✓
Fugitive emissions from mining, processing, storage, and transportation of coal	✓		
Fugitive emission from oil and natural gas	✓		
TRANSPORTATION			
On-road	✓	✓	✓
Railways	✓	✓	✓
Waterborne navigation	✓	✓	✓
Aviation	✓	✓	✓
Off-road	✓	✓	
WASTE			
Disposal of solid waste generated in the city	✓		✓
Disposal of solid waste generated outside the city	✓		
Biological treatment of waste generated in the city	✓		✓
Biological treatment of waste generated outside the city	✓		
Incineration and open burning of waste generated in the city	✓		✓
Incineration and open burning of waste generated outside the city	✓		
Wastewater generated in the city	✓		✓
Wastewater generated outside the city	✓		
INDUSTIRAL PROCESSES AND PRODUCT USE (IPPU)			
Industrial processes	✓		
Product use	✓		
AGRICULTURE, FORESTRY AND OTHER LAND USE (AFOLU)			
Livestock	✓		
Land	✓		
Aggregate sources and non-CO_2 emission sources on land	✓		
OTHER SCOPE 3			
Other Scope 3			

✓ Sources Covered by the GPC
\+ Sources required for BASIC+ reporting
Sources included in Other Scope 3
Sources required for BASIC Reporting
Sources required for territorial total but not for BASIC/BASIC+report (*italics*)
Non-applicable emissions

Figure 2. Sources and Scopes covered by the GPC. Figured adapted from GPC.[18]

[18] Figure Adopted from p.13 of "Greenhouse Gas Protocol. Global Protocol for Community-Scale Greenhouse Gas Emission Inventories." Switzerland, Geneva. World Resource Institute. ICLEI. Calendar Year 2017. Accessed January – September 2017. http://ghgprotocol.org/countries-and-cities

2.3 2016 City Of Phoenix Methodology

The 2016 community GHG inventory includes the sources from the BASIC inventory based on relevance and available data. Some of the sources covered in BASIC inventories were not included in this report because of their irrelevance with respect to the City of Phoenix; Waterborne Navigation is one such source. *Table 1* shows the different sources comprising the BASIC inventory and those included for Phoenix.

Table 1. GPC Emissions by Source Sector and Sub-sector for Phoenix 2016 Community GHG Inventory.

GPC ref No.	Scope	GHG Emissions Source (By Sector and Sub-sector)	Notation Key
I		Stationary Energy	
I.1		**Residential Buildings**	
I.1.1	1	Emissions from fuel combustion within the city boundary	IN
I.1.2	2	Emissions from grid-supplied energy consumed within the city boundary	IN
I.1.3	3	Emissions from transmission and distribution losses from grid-supplied energy consumption	IN
I.2		**Commercial and institutional buildings and facilities**	
I.2.1	1	Emissions from fuel combustion within the city boundary	IN
I.2.2	2	Emissions from grid-supplied energy consumed within the city boundary	IN
I.2.3	3	Emissions from transmission and distribution losses from grid-supplied energy consumption	IN
I.3		**Manufacturing industries and construction**	
I.3.1	1	Emissions from fuel combustion within the city boundary	IN
I.3.2	2	Emissions from grid-supplied energy consumed within the city boundary	IN
I.3.3	3	Emissions from transmission and distribution losses from grid-supplied energy consumption	IN
I.4		**Energy Industries**	
I.4.1	1	Emissions from energy used in power plant auxiliary operations within the city boundary	IE
I.4.2	2	Emissions from grid-supplied energy consumed in power plant auxiliary operations within the city boundary	IN
I.4.3	3	Emissions from transmissions and distribution losses from grid-supplied energy consumption in power plant auxiliary operations	NE
I.4.4	1	*Emissions from energy generation supplied to the grid*	IN
I.5		**Agriculture, forestry and fishing activities**	
I.5.1	1	Emissions from fuel combustion within the city boundary	IN
I.5.2	2	Emissions from grid-supplied energy consumed within the city boundary	IE
I.5.3	3	Emissions from transmission and distribution losses from grid-supplied energy consumption	NE
I.6		**Non-specified sources**	
I.1.1	1	Emissions from fuel combustion within the city boundary	IN
I.1.2	2	Emissions from grid-supplied energy consumed within the city boundary	IE
I.1.3	3	Emissions from transmission and distribution losses from grid-supplied energy consumption	NE
I.7		**Fugitive emissions from mining, processing, storage, and transportation of coal**	
I.7.1	1	Emissions from fugitive emissions within the city boundary	NE

I.8		**Fugitive emissions from oil and natural gas systems**	
I.8.1	1	Emissions from fugitive emissions within the city boundary	NE
II		**Transportation**	
II.1		**On-road Transportation**	
II.1.1	1	Emissions from fuel combustion for on-road transportation occurring within the city boundary	IN
II.1.2	2	Emissions from grid-supplied energy consumed within the city boundary for on-road transportation	IE
II.1.3	3	Emissions from portion of transboundary journeys occurring outside the city boundary, and transmissions and distribution losses from grid-supplied energy consumption	IE
II.2		**Railways**	
II.2.1	1	Emissions from fuel combustion for railway transportation occurring within the city boundary	IN
II.2.2	2	Emissions from grid-supplied energy consumed within the city boundary for railways	IN
II.2.3	3	Emissions from portion of transboundary journeys occurring outside the city boundary, and transmissions and distribution losses from grid-supplied energy consumption	IN
II.3		**Waterborne navigation**	
II.3.1	1	Emissions from fuel combustion for waterborne navigation occurring within the city boundary	NO
II.3.2	2	Emissions from grid-supplied energy consumed within the city boundary for waterborne navigation	NO
II.3.3	3	Emissions from portion of transboundary journeys occurring outside the city boundary, and transmissions and distribution losses from grid-supplied energy consumption	NO
II.4		**Aviation**	
II.4.1	1	Emissions from fuel combustion for aviation occurring within the city boundary	IN
II.4.2	2	Emissions from grid-supplied energy consumed within the city boundary for aviation	NE
II.4.3	3	Emissions from portion of transboundary journeys occurring outside the city boundary, and transmissions and distribution losses from grid-supplied energy consumption	NE
II.5		**Off-road transportation**	
II.5.1	1	Emissions from fuel combustion for off-road transportation occurring within the city boundary	IN
II.5.2	2	Emissions from grid-supplied energy consumed within the city boundary for off-road transportation	NE
III		**Waste**	
III.1		**Solid waste disposal**	
III.1.1	1	Emissions from solid waste generated within the city boundary and disposed in landfills or open dumps within the city boundary	IN
III.1.2	3	Emissions from solid waste generated within the city boundary and disposed in landfills or open dumps outside the city boundary	IN
III.1.3	1	*Emissions from waste generated outside the city boundary and disposed in landfills or open dumps within the city boundary*	IN
III.2		**Biological treatment of waste**	
III.2.1	1	Emissions from solid waste generated within the city boundary that is treated biologically within the city boundary	IN

III.2.2	3	Emissions from solid waste generated within the city boundary but treated biologically outside of the city boundary	NO
III.2.3	1	*Emissions from waste generated outside the city boundary but treated biologically within the city boundary*	NE
III.3		**Incineration and open burning**	
III.3.1	1	Emissions from solid waste generated and treated within the city boundary	NO
III.3.2	3	Emissions from solid waste generated within the city boundary but treated outside of the city boundary	NO
III.3.3	1	*Emissions from waste generated outside the city boundary but treated within the city boundary*	NO
III.4		**Wastewater treatment and discharge**	
III.4.1	1	Emissions from wastewater generated and treated within the city boundary	IN
III.4.2	3	Emissions from wastewater generated within the city boundary but treated outside of the city boundary	IE
III.4.3	1	*Emissions from wastewater generated outside the city boundary but treated within the city boundary*	IE
IV		**Industrial Processes and Product Uses (IPPU)**	
IV.1	1	Emissions from industrial processes occurring within the city boundary	NE
IV.2	1	Emissions from product use occurring within the city boundary	NE
V		**Agriculture, Forestry, and Other Land Use (AFOLU)**	
V.1	1	Emissions from livestock within the city boundary	NE
V.2	1	Emissions from land within the city boundary	NE
V.3	1	Emissions from aggregate sources and non-CO_2 emissions sources on land within the city boundary	NE
VI		**Other Scope 3**	
VI.1	3	Other Scope 3	IN

Notation Key Definitions: IN - Included; IE – Included Elsewhere (Included another category but could not be separated); NE - Not Estimated; NO - Not Occurring.

2.3.1 Organizational Boundaries

Cities need to define an inventory boundary which identifies the geographic area, time span, gases, and emission sources covered by a GHG inventory. A geographic boundary which aligns itself with the administrative boundary of a local government, a ward or borough within a city, a combination of administrative divisions, a metropolitan area, or another geographically identifiable entity, can be used for the GHG inventory. Phoenix's GHG inventory defines the organizational boundary as the boundary of the city which is equivalent to a land area of 1,344.6 km^2. It is as shown in *Figure 3*. Although the GPC recommends inventories to include the seven greenhouse gases covered by the Kyoto Protocol, this inventory only contains CO_2, CH_4, and N_2O to remain consistent with previous City of Phoenix GHG emissions inventories.

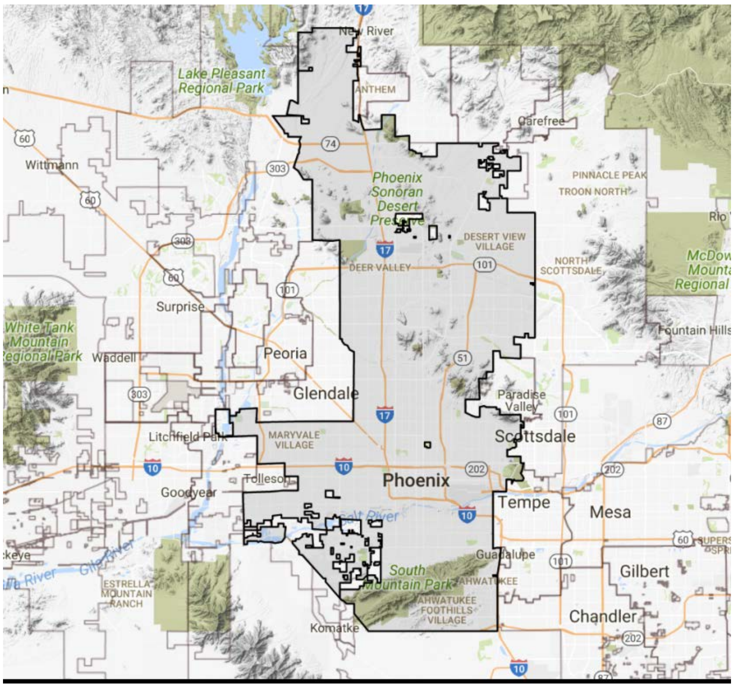


Figure 3. Map of Phoenix City Boundary. Adopted from MapTechnica.com

2.3.2 Scaling Factors

Scaling factors are used when the city-specific data for an inventory year are unavailable or incomplete. These instances of unavailability and incompleteness occur when the inventory data does not align with the geographical boundary of the city or the time period at which the assessment is being conducted. The scaling factor is therefore the ratio between the required inventory data and the best available data. *Table 2* shows the main scaling factors used by the City of Phoenix. Additional scaling factors by city zip codes can be found in Appendix B.

Table 2. Scaling Factors used by the City of Phoenix

Indicator	Unit	Year	Scaling Factor	Comparison Area	GPC Ref No.	Source
Light Rail	Miles	2016	0.68	Maricopa County	II.2.2, II.2.3	National Transportation Atlas Database
Population	People	2016	0.38	Maricopa County	II.1	US Census Bureau
Freight Rail	Miles	2015	0.11	Maricopa County	II.2.1	National Transportation Atlas Database
Zip Codes	km^2	2016	0.39	Zip Codes*	I.1, I.2, I.3, I.5, I.6	US Census & City of Phoenix
Multi-Family Housing	People	-	0.22	Maricopa County	III.1.2	American Housing Survey
Road Length	Miles	-	0.25	Maricopa County	II.1	US Census Bureau

*** For those zip codes that include areas both inside and outside city boundary.**

2.3.3 Estimating Tailpipe Emissions of CH_4 and N_2O

The methodology used to estimate tailpipe methane (CH_4) and nitrous oxide (N_2O) emissions involves using the Climate Registry's simple estimation method for tailpipe methane and nitrous oxide emissions through a fuels' carbon dioxide content that provides a comprehensive estimation of emissions across all fuel and vehicle types.

2.3.4 Landfill-Specific Characteristics for Solid Waste Landfills

The City of Phoenix has been reporting the emissions from landfills to the Greenhouse Gas Reporting Program (GHGRP) established by the EPA since 2010. The emissions data are made available to the public through the Facility Level Information of Greenhouse Gases Tool (FLIGHT), which is a nationwide database of large GHG sources. Under GHGRP, Phoenix reports the landfill emissions using the national average characteristics, which assumes landfill gas collection efficiency of 75% for closed landfills with intermediate soil cover, a collection efficiency of 67% for open landfills with daily cover and the percent of CH_4 that is oxidized near the surface of the landfill is assumed to be 10%. These assumptions vary greatly from the landfill-specific metrics used internally by the City of Phoenix, in which the collection efficiencies are estimated at each facility.

Phoenix municipal landfills are affected by local factors, such as the especially dry climate in Phoenix and the advanced technologies and data capture being implemented at specific landfills. For example, at the SR-85 Landfill there are horizontal as well as traditional vertical wells, surface monitoring, flare data capture and landfill cover maintenance. It was therefore appropriate to use site specific collection efficiency characteristics to estimate the GHG emissions of Phoenix-owned landfills for this report. Site specific data are detailed below in *Table 3* and *Table 4*.

Table 3. Landfill specific characteristics developed by City of Phoenix

Landfill	Destruction Efficiency	Collection Efficiency	Oxidation Rate
Skunk Creek Landfill	98%	85%	25%
27th Ave Landfill	98%	85%	25%
Del Rio Landfill	89%	50%	10%
Deer Valley Landfill	92%	75%	10%
19th Avenue Landfill	98%	85%	10%
Estes Landfill	0%	0%	0%
SR-85 Landfill	98%	90%	25%

Table 4 shows all the landfills included in this inventory; which scope they are assigned and the scaling factor applied to emissions from each landfill.

Table 4. The Landfills included in the Phoenix Community GHG Emissions Inventory, their Scope, Scaling Factor, and Justification

Landfill	Scope	Scaling factor	Justification
Skunk Creek Landfill	1	100%	Owned and operated by city of Phoenix and located within city boundaries.
27th Ave Landfill	1	100%	Owned and operated by city of Phoenix and located within city boundaries.
Del Rio Landfill	1	100%	Owned and operated by city of Phoenix and located within city boundaries.
Deer Valley Landfill	1	100%	Owned and operated by city of Phoenix and located within city boundaries.
19th Avenue Landfill	1	100%	Owned and operated by city of Phoenix and located within city boundaries.
Estes Landfill	1	100%	Owned and operated by city of Phoenix and located within city boundaries.
SR-85 Landfill	3	100%	Owned and operated by city of Phoenix, but outside of city boundaries.
Lone Cactus Landfill	1	100%	Construction debris disposed inside city boundaries. Owned and Operated by Maricopa County
Butterfield Station Landfill	1	22%	% is the multi-family residential population compared to the remainder of Maricopa County Population
Cave Creek Landfill	1	22%	% is the multi-family residential population compared to the remainder of Maricopa County Population
Northwest Regional Landfill	1	22%	% is the multi-family residential population compared to the remainder of Maricopa County Population

Southwest Regional Landfill	1	22%	% is the multi-family residential population compared to the remainder of Maricopa County Population

For the 2012 City of Phoenix Community GHG Emissions Inventory, GHG emissions from private landfills located outside of the City of Phoenix boundary that received waste from within the City of Phoenix were estimated using scaled GHG emissions data from the EPA Facility Level GHG Emissions Data tool. Total emissions from these landfills – the Butterfield Station Landfill, the Cave Creek MSW Landfill, the Northwest Regional Landfill, and the Southwest Regional Landfill -- were scaled using a 22% scaling factor to represent the fraction of waste in place in these landfills from sources within the City of Phoenix. This scaling factor was arrived at by estimating the fraction of Phoenix's population (multi-family housing unit residents*) not* serviced by City of Phoenix municipal collection relative to the remainder of the Phoenix metropolitan area population.

For the 2016 City of Phoenix Community GHG Emissions Inventory, GHG emissions from the Butterfield Station Landfill, Cave Creek Landfill, Northwest Regional Landfill, and Southwest Regional Landfill associated with City of Phoenix activities were estimated using a simplified population-based methodology, a small revision from the 2012 methodology. The methodology to estimate the 2016 emissions from those private landfills outside of the City of Phoenix boundary that received waste from sources within the City of Phoenix has three steps:

- First, estimate the population of Phoenix residents (multi-family housing unit residents) not serviced by City of Phoenix municipal solid waste pickup.
- Second, estimate waste generation using EPA per capita waste generation statistics.
- Third, use the City Inventory Reporting and Information System (CIRIS) population-based GHG emissions calculator to estimate solid waste emissions using the output of Step 2 and the default landfill characteristics – 75% collection efficiency with no energy recovery.

Additionally, to allow for comparability between the 2012 and 2016 City of Phoenix GHG emissions inventories, the 2012 City of Phoenix Community GHG emissions were updated using the simplified methodology to estimate GHG emissions from private landfills located outside of the City of Phoenix boundary that received waste from City of Phoenix. The population within Phoenix with waste not deposited in City of Phoenix municipal landfills was estimated as 338,883 people for 2012 and 362,392 people for 2016 using the American Housing Survey produced by the U.S. Census.

While the methodology was updated to estimate GHG emissions from private landfills located outside of the City of Phoenix boundary that received waste from the City of Phoenix, there were no updates to the method to estimate GHG emissions from landfills within the City of Phoenix not operated by the City of Phoenix. For both the 2012 and 2016 community GHG emissions inventories, GHG emissions from the Lone

Cactus Landfill were estimated using unscaled EPA Facility Level GHG Emissions Data.

2.3.5 Site Specific CH_4 Emissions from Wastewater Treatment

Data provided for the 2016 GHG inventory contained CH_4 production, flaring and on-site use data at both the 91st Avenue and 23rd Avenue WWTPs. Flaring emissions were then able to be separated into two emissions sources for the 91st Avenue and 23rd Avenue WWTP components.

2.3.6 N_2O Emissions from Wastewater Treatment

N_2O emissions are based on the total nitrogen (TN) content of the effluent and are estimated using either population-based methodologies or site-specific data. The 2016 inventory uses site-specific data to estimate the N_2O emissions from wastewater treatment. This is the same methodology employed by the City of Phoenix in past reports, thus enabling comparability between reports.

Table 5. The Wastewater Treatment Facilities, Their Scope, Scaling Factor, and Justification

Facility	Scope	Scaling Factor	Justification
91st Avenue	1	100%	Owned and operated by city of Phoenix and located within city boundaries.
23rd Avenue	1	100%	Owned and operated by city of Phoenix and located within city boundaries.

3. Results by Sector

3.1 Overview

The overall emissions for the City of Phoenix for the year 2016 totaled 15,684,329 MTCO2e. The three sectors used in the Phoenix Community GHG Inventory are 1) stationary energy, 2) transportation, and 3) waste. Each sector is distinct from one another and they together form the city's GHG emission sources. The sectors are shown below in *Table 6*, broken down by their respective Scopes. GHG emissions by sector and subsector are shown in *Table 7*. Scope 1 emissions account for approximately 65% of the total community GHG emissions, followed by Scope 2, which account for 32%, and Scope 3 with just 3% of the overall emissions, see *Figure 4*. Please note that energy generation supplied to the grid (I.4.4.) is reported but not tabulated as part of the total Scope 1, BASIC, or BASIC+ emissions to avoid double counting, as these emissions get accounted for in Stationary Energy Scope 2 emissions.

Table 6. Breakdown of the Phoenix Community CO2e emissions by sector and scope

GHG Emissions Source (By Sector)		Total GHGs (metric tons CO_2e)				
		Scope 1	Scope 2	Scope 3	BASIC	BASIC+
STATIONARY ENERGY	Energy use[1]	678,147	5,043,128	237,027	5,721,275	5,958,302
	Energy generation supplied to the grid[2]	854,168	-	-	-	-
TRANSPORTATION	Total[3]	9,338,335	5,645	265	9,343,979	9,344,245
WASTE	Waste generated in the city[4]	223,491	-	158,292	381,783	381,783
	Waste generated outside city[5]	-	-	-	-	-
IPPU	Total[6]	-	-	-	-	-
AFOLU	Total[7]	-	-	-	-	-
OTHER SCOPE 3	Total[8]	-	-	130	-	-
TOTAL		11,094,141	5,048,773	395,584	15,447,037	15,684,459

[1]All emissions except GPC Ref Number I.4.4 (See Table 1 for GPC ref numbers).
[2]GPC Ref Number I.4.4.
[3]All GPC Ref Number II emissions.
[4]GPC Ref Numbers .III.X.1 and III.X.2.
[5]GPC Ref Number III.X.3, which includes "Waste generated in the city".
[6]All GPC Ref Number IV emissions.
[7]All GPC Ref Number V emissions.
[8]All GPC Ref Number VI emissions.

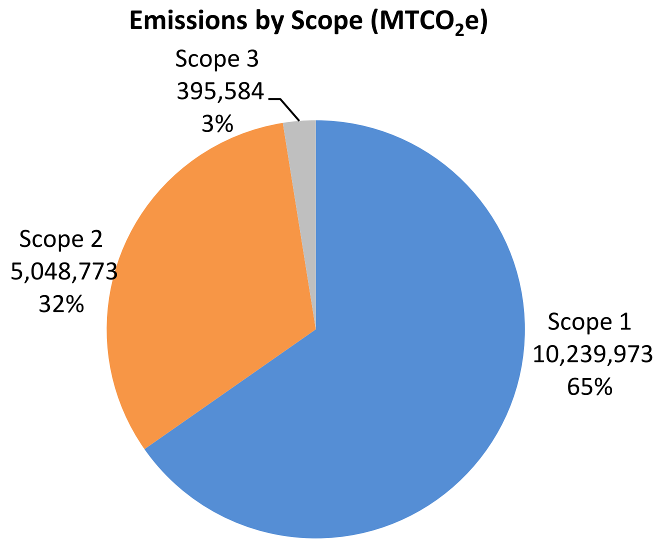


Figure 4. Total GHG Emissions in metric tons CO_2e by Reporting Scope

As broken down into the three major sectors shown in *Figure 5*, transportation accounts for approximately 60% of all emissions, stationary energy represents approximately 38% and waste makes up 2% of the total emissions.

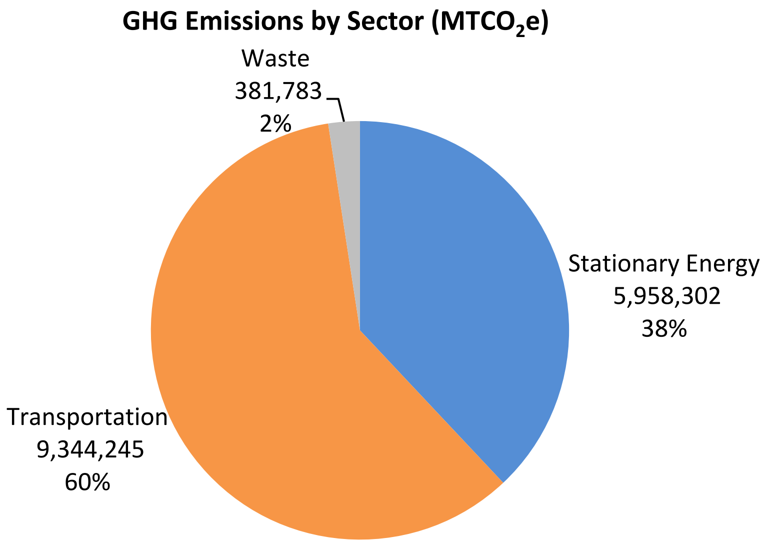


Figure 5. Total GHG Emissions in metric tons CO_2e by Reporting Sector

Table 7. Phoenix GHG emissions by Sector and Subsector (MT CO_2e)

Sector & Subsector	2016 Emission ($MTCO_2e$)
Stationary Energy	
Residential buildings	2,796,904
Commercial & institutional buildings	2,925,368
Manufacturing industries and construction	179,750
Agriculture, forestry and fishing activities	56,188
Non-specified sources	92
Stationary Energy Sector Total	**5,958,302**
Transportation	
On-road transport	6,443,139
Railways	29,455
Commercial Aviation	705,643
Civil Aviation (Aviation Gasoline)	15,067
Off-road transport	2,150,940
Transportation Sector Total	**9,344,245**
Waste	
Solid waste disposal	356,623
Wastewater treatment and discharge	10,840
Biological treatment of waste (composting)	14,320
Waste Sector Total	**381,783**
GHG Emission Total	**15,684,329**

3.2 Stationary Energy

3.2.1 Findings

Stationary energy sources are one of the largest contributors to a city's GHG emissions. Stationary energy includes energy utilized in residential buildings; commercial buildings and facilities; manufacturing industries; agriculture, forestry and fishing energy use; and transmission and distribution energy losses. Emissions from natural gas leakages are also included under stationary energy emissions. Fugitive emissions from mining, processing, storage and transportation of coal, oil and natural gas systems, which the GPC considers upstream stationary energy emissions, are not included in this report because data on these sources are not available, and Phoenix does not have significant sources in these categories.

Emissions from stationary energy sources can be classified into Scope 1, Scope 2 and Scope 3 emissions as follows: 1) fuel combustion and fugitive emissions in the city; 2) emissions from the consumption of grid-supplied electricity, steam, heating and cooling in the city; and 3) distribution losses from grid-supplied electricity, steam, heating and cooling consumed in the city. *Table 8* shows the breakdown of stationary energy emissions by each scope. Overall, Scope 2 emissions were the highest at 84.6%, followed by Scope 1 emission with 11.4%, and finally by Scope 3 emissions with 4%.

Table 8. Breakdown of stationary energy emissions by each scope

Scope	Emissions (MT CO_2e)	% of Total Emissions
Scope 1	678,147	11.4%
Scope 2	5,043,128	84.6%
Scope 3	237,027	4%
Total GHG Emissions	**5,958,302**	**100.0%**

Table 9 shows the emissions from different subsectors of the Stationary Energy sector for the year 2016. Residential buildings and Commercial and institutional buildings are the largest contributors to stationary energy sector GHG emissions.

Table 9. Breakdown of stationary energy emissions by subsector (MT CO_2e)

Subsector	2016 Emission(MTCO_2e)
Residential buildings	2,796,904
Commercial & institutional buildings	2,925,368
Manufacturing industries and construction	179,750
Agriculture, forestry and fishing activities	56,188
Non-specified sources	92
Stationary Energy Sector Total	**5,958,302**

Figure 6 and *Figure 7* show the breakdown of emissions by subsector of stationary energy for Scopes 1 and 2 respectively. *Figure 6* indicates Scope 1 emissions were primarily from residential buildings and commercial and institutional buildings. Scope 2 emissions were also mainly from commercial and residential buildings and are as shown in *Figure 7*. Emissions from manufacturing industries and construction were low compared to emissions from residential and commercial buildings yet were responsible for a significant portion of the Scope 1 emissions.

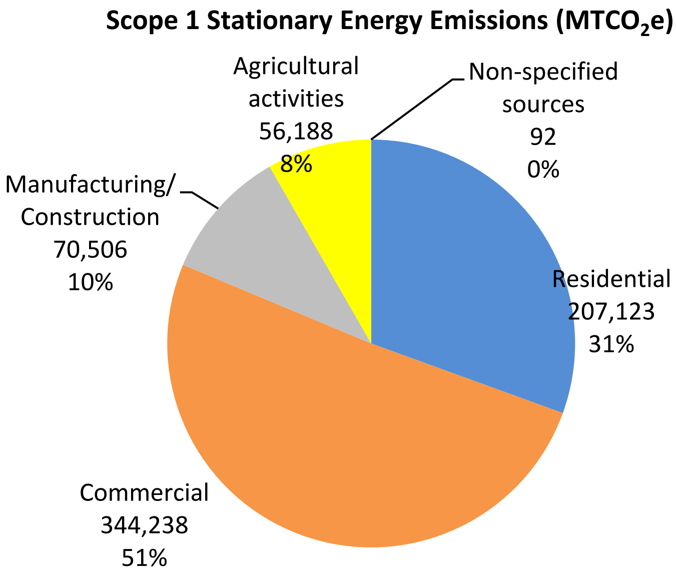


Figure 6. Total Scope 1 Stationary Energy GHG Emissions in metric tons CO_2e by Sub-Sector

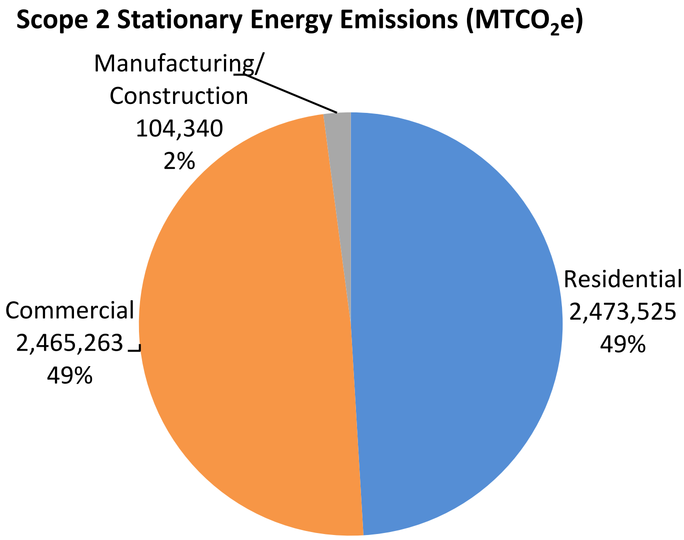


Figure 7. Total Scope 2 Stationary Energy GHG Emissions in metric tons CO_2e by Sub-Sector

Figure 8 shows the distribution of GHG emissions among different sub-sectors in the Stationary Energy Sectory for the year 2016 with commercial buildings and residential buildings having the largest emissions.

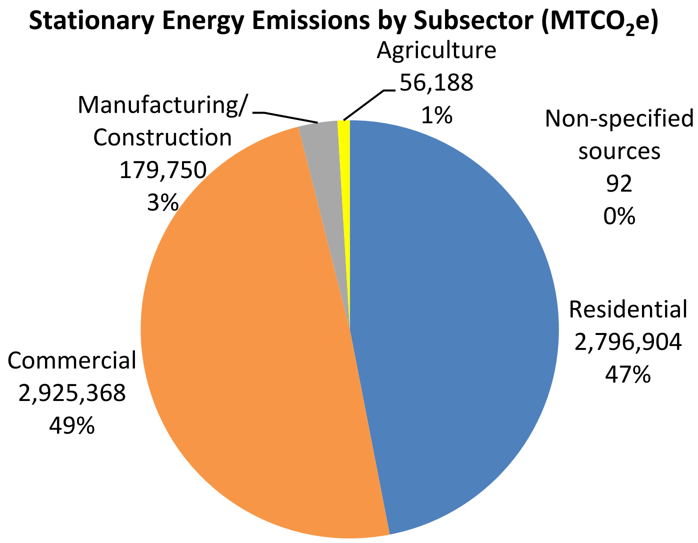


Figure 8. Breakdown of Stationary Energy Emissions by Subsector (MT CO_2e)

3.2.1.1 Stationary Energy Data Quality Assessment and Source

The activity data and emissions factors used for each sector were evaluated for data quality and quality assurance in compliance with the GPC. Since most of the data collected for GHG reporting were scaled based on either the areal boundary of Phoenix or its population, the scaling factors for these datasets had to be evaluated for data quality and quality assurance. Overall, confidence is high in the data quality for stationary energy and is summarized in *Table 10*. The activity data and the emission factors used to calculate stationary energy emissions were obtained from various sources and are detailed in *Table-AC 1*.

Table 10. Stationary Energy Data Quality Assessment

GHG Emission Source	Data Quality		
	Activity Data	Scaling Factor	Emissions Factor
Fuel combustion within the city (residential, commercial, and manufacturing industries)	High	Medium	High
Grid supplied energy consumed within the city	High	High	High
Grid-supplied energy consumed in power plant auxiliary operations within the city	High	Medium	High
Emissions from energy generation supplied to the grid	High	High	High
Fuel combustion within the city (agriculture, forestry, and fishing activities)	High	High	High

3.3 Transportation

3.3.1 Findings

Transportation Sector GHG emissions include emissions from commercial air travel, civil aviation, on-road transportation, non-road vehicle use, light rail, and freight rail. Transportation GHG emissions result from the combustion of fossil fuels (gasoline, diesel, CNG, LNG, LPG, aviation gasoline, jet fuel A), blended alternative fuels (B20 biodiesel, E85 Ethanol, E54 Ethanol), or indirectly from the consumption of electricity to charge electric vehicles. The Transportation Sector is the largest source of GHG emission in the City of Phoenix.

The emissions from on-road transport were determined using the fuel sales data for Maricopa County, which was then scaled based on population data for Phoenix compared to Maricopa County. Emissions from railways include both the freight rail emissions and light-rail emissions; the latter was determined by scaling electricity consumption by light-rail based on the miles of rail within Phoenix's boundary to the total miles of light rail. No emissions were reported for waterborne navigation since that mode of transport does not occur in Phoenix.

The emissions from civil and commercial aviation were determined by estimating the consumption of jet fuel using a top-down methodology from state-level EIA data for jet fuel consumption and were apportioned by Air Carrier landings and take-off (LTO) data from Federal Aviation Agency (FAA). The non-road transport emissions were obtained from 2014 EPA National Emissions Inventory (NEI) and were scaled using population data for 2016 compared to the 2014 population. It was also observed that non-road gasoline consumption was included in the fuel sales data; as a result, it was excluded from the non-road gasoline emissions obtained from the NEI.

For BASIC reporting, GHG emissions from the combustion of transportation fuels within the city contributed to Scope 1 emissions and emissions from electricity used for transportation within the city boundary constituted Scope 2. *Table 11* shows the emissions for transportation broken down by scope, with Scope 1 emissions being the largest, followed by Scope 2 and Scope 3 respectively, both of which were negligible compared to Scope 1 emissions.

Table 11. Transportation Emissions by Scope

Scope	Emissions (MT CO_2e)	% of Total Emissions
Scope 1	9,338,335	100%
Scope 2	5,645	0%
Scope 3	265	0%
Total GHG Emissions	**9,344,245**	**100.0%**

Table 12 shows emissions from different subsectors of the transportation sector for the year 2016. On-road transport and off-road transport are the largest contributors to the transportation sector emissions.

Table 12. Transportation Emissions by Sub-sectors (MT CO_2e)

Subsector	**2016 Emissions (MTCO_2e)**
On-road transport	6,443,139
Railways	29,455
Commercial Aviation	705,643
Civil Aviation (Aviation Gasoline)	15,067
Off-road transport	2,150,940
Transportation Sector Total	**9,344,245**

Figure 9 and *Figure 10* show the breakdown of emissions by subsector of transportation for Scopes 1 and 2 respectively. *Figure 9* shows that Scope 1 emissions were primarily from the combustion of fuels used for on-road transportation. Scope 2 emissions occurred as a result of electricity consumed by light rail operated within the boundary of Phoenix, and are shown in *Figure 10.*

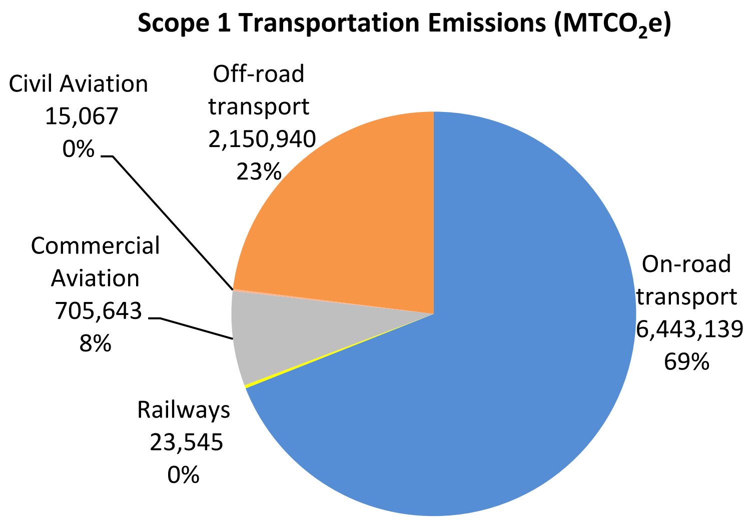


Figure 9. Total Scope 1 Transportation GHG Emissions in metric tons CO_2e by Sub-Sector

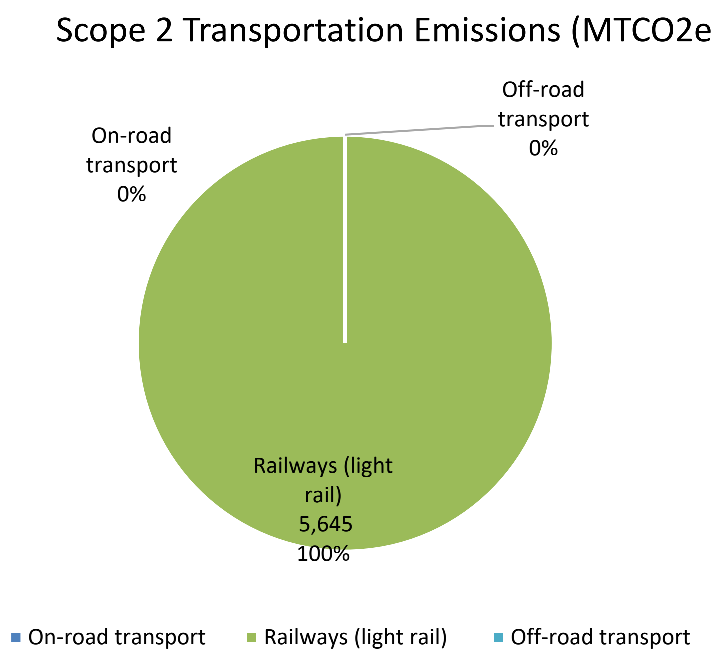


Figure 10. Total Scope 2 Transportation GHG Emissions in metric tons CO_2e by Sub-Sector

Figure 11 shows the distribution of GHG emissions among different sub-sectors in the Transportation sector for the year 2016, with on-road transportation as the largest contributor.

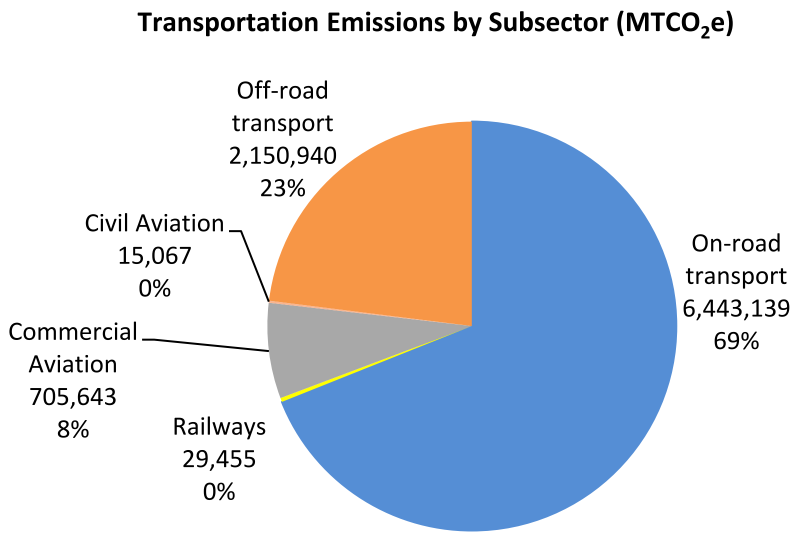


Figure 11. Breakdown of Transportation GHG Emissions in metric tons CO_2e by Sub-Sector

3.3.2 Transportation Data Quality Assessment and Source

The activity data and emissions factors used for each sector were evaluated for data quality and quality assurance in compliance with the GPC. Since most of the data collected for GHG reporting were scaled based on either the areal boundary of Phoenix or its population, the scaling factors for these datasets had to be evaluated for data quality and quality assurance. Collecting transportation data was more difficult than stationary energy and required using a combination of activity data and scaling factors. The emissions from the on-road transport sector were determined using the fuel sales data for Maricopa County, and non-road transport emissions were obtained from 2014 EPA National Emissions Inventory. These emissions were scaled based on population, thus resulting in high data confidence.

Emissions from railways include both the freight rail emissions and light-rail emissions; the latter were determined by scaling electricity consumption by light-rail based on the miles of rail within Phoenix's boundary to the total miles of light rail. The freight rail emissions listed for 2016 are the previously reported 2012 emissions; therefore, the confidence is low in calculating freight-rail emissions data.

The emissions from civil and commercial aviation were determined by estimating the consumption of jet fuel using a top-down methodology from state-level EIA data for jet fuel consumption and were apportioned by Air Carrier landings and take-off (LTO) data from Federal Aviation Agency (FAA). This led to high confidence in the aviation emissions data.

Overall, confidence varies between high and low in the data quality for transportation sector emissions and is summarized in *Table 13*. The transportation activity data and emission factors used to evaluate these emissions were obtained from various sources summarized in *Table-AC 2*.

Table 13. Transportation Data Quality Assessment

GHG Emission Source	Data Quality		
	Activity Data	Scaling Factor	Emissions Factor
Fuel combustion for on-road transportation occurring within the city	High	Medium	High
Fuel combustion for railway transportation occurring within the city	Low	Low	Low
Grid-supplied energy consumed within the city for railways	High	High	High
Fuel combustion for aviation occurring within the city	High	High	High
Fuel combustion for off-road transportation occurring within the city	High	Medium	High

3.4 Waste

3.4.1 Findings

Waste Sector GHG emissions are a comparatively small component of total community GHG emissions that occur in the City of Phoenix. The Waste Sector includes emissions from the current and historic disposal of solid waste generated and treated in Phoenix, the current disposal of solid waste generated in Phoenix that is disposed outside the city at the municipal SR-85 Landfill and private landfills, wastewater treated at the 91st Avenue and 23rd Avenue wastewater treatment plants in Phoenix, and the biological treatment (composting) of waste generated and treated in Phoenix. The emissions from landfills were calculated using the EPA method employed in national GHG inventories. Solid waste emissions from private haulers were estimated using Phoenix's population, national housing characteristics for Phoenix, and the solid waste GHG emissions calculator tool in the CIRIS workbook.

Disposal of solid waste generated and treated in the city, biological treatment of waste generated and treated in the city, \wastewater generated and treated in the city and wastewater generated outside of the city, but treated in the city, constituted Scope 1 emissions. Emissions from solid waste generated inside the city boundary but disposed outside the city contributed to Scope 3 emissions. *Table 14* shows the emissions for the Waste Sector broken down by scope, with Scope 1 emissions being the largest, followed by Scope 3.

Table 14. Waste Sector Emissions by Scope

Scope	Emissions (MT CO_2e)	% of Total Emissions
Scope 1	223,491	59%
Scope 2	-	-
Scope 3	158,421	41%
Total GHG Emissions	**381,912**	**100.0%**

Table 15 shows emissions from the different subsectors of the Waste Sector for the year 2016. Emissions from solid waste disposal are the largest contributors toward Waste Sector emissions.

Table 15. Waste Sector Emissions by Sub-sectors

Subsector	**2016 Emissions ($MTCO_2e$)**
Solid waste disposal	356,623
Wastewater treatment and discharge	10,840
Biological treatment of waste (composting)	14,320
*GAC Hauling, Recharge, Disposal**	*130*
Waste Sector Total	**381,783***
* *GAC Hauling, Recharge, Disposal emissions are not included in the Waste Sector Total because these emissions are classified as Other Scope 3 emissions and reported separate from GHG emissions sources that are included BASIC/BASIC+ totals. They were included as Wastewater Scope 3 emissions in Table 15.*	

Figure 12 and *Figure 13* show the breakdown of emissions by subsector of waste for Scopes 1 and 3 respectively. *Figure 12* shows that Scope 1 emissions were primarily from solid waste disposal in landfills within the boundary of Phoenix. Scope 3 emissions were mainly from solid waste emissions from private haulers, and are as shown in *Figure 13*.

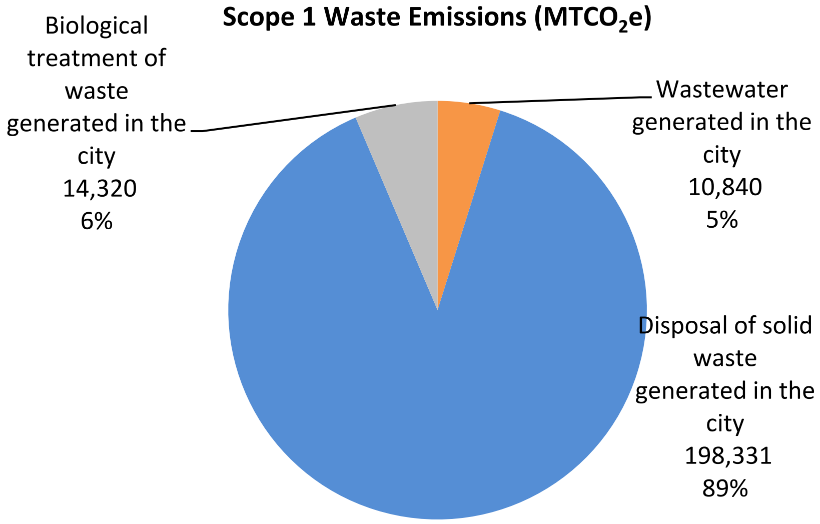


Figure 12. Total Scope 1 Waste GHG Emissions in metric tons CO_2e by Sub-Sector

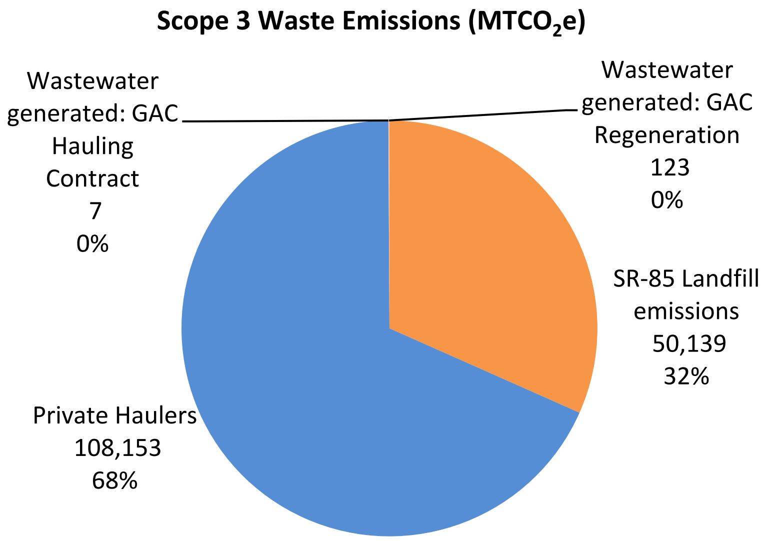


Figure 13. Total Scope 3 Waste GHG Emissions in metric tons CO_2e by Sub-Sector

Figure 14 shows the distribution of GHG emissions between different sub-sectors in the Waste Sector for the year 2016. Emissions from solid waste disposal were the largest contributors to waste sector emissions followed by emissions from composting and that from treatment of wastewater respectively.

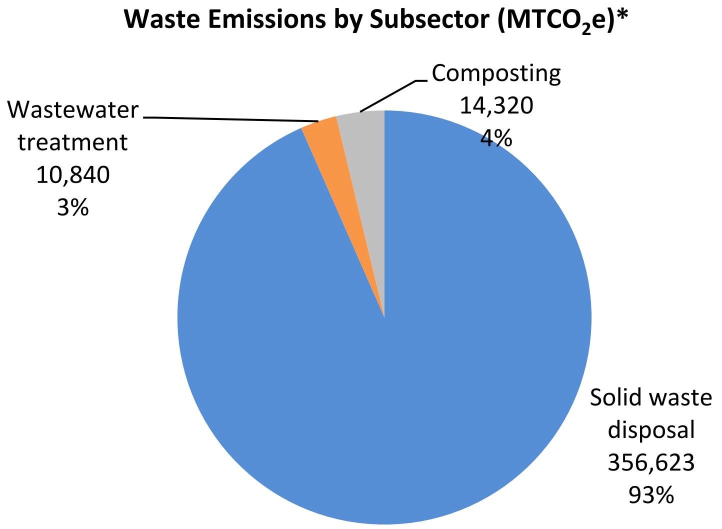


*Figure 14. Breakdown of Waste GHG Emissions in metric tons CO_2e by Sub-Sector. *GAC Hauling, Recharge, Disposal emissions are not included in the Waste Sector Total because these emissions are classified as Other Scope 3 emissions and reported separate from GHG emissions sources that are included BASIC/BASIC+ totals*

3.4.2 Waste Data Quality Assessment and Source

The activity data and emission factors used for each sector were evaluated for data quality and quality assurance in compliance with the GPC. Since most of the data collected for GHG reporting was scaled based on certain scaling techniques, the scaling factors for these datasets had to be evaluated for data quality and quality assurance. Overall, confidence in waste data was high and is as summarized in *Table 16*. Landfill emissions were obtained from the EPA FLIGHT Tool and were also calculated from available raw data.

Solid waste emissions from private haulers were estimated using the Phoenix population, national housing characteristics for Phoenix, and the solid waste GHG emissions calculator tool in the CIRIS workbook.

Table 16. Waste Data Quality Assessment

GHG Emission Source	Data Quality		
	Activity Data	Scaling Factor	Emissions Factor
Waste generated within the city boundary and disposed in landfills in the city	High	High	High
Waste generated within the city boundary and disposed in landfills outside the city	High	Medium	High
Waste generated outside the city but disposed within the city	High	High	High
Wastewater generated and treated within the city	High	High	High
Wastewater generated outside the city boundary but treated within the city	High	High	High

The activity data and emission factors used to calculate these emissions were obtained from various sources, which are as summarized in *Table-AC 3*

4. Comparison between 2012-2016 GHG Emissions

4.1 Overview

The 2016 Community-Scale GHG Emissions Inventory shows Phoenix-wide GHG emissions to be 15,684,329 MT CO_2e, a 7.2% reduction in the overall GHG emissions compared to the 2012 levels of 16,897,600 MT CO_2e. The distribution of GHG emissions among Stationary Energy, Transportation, and Waste Sectors for 2012 and 2016 is shown in *Figure 15* and detailed in *Table 17*.

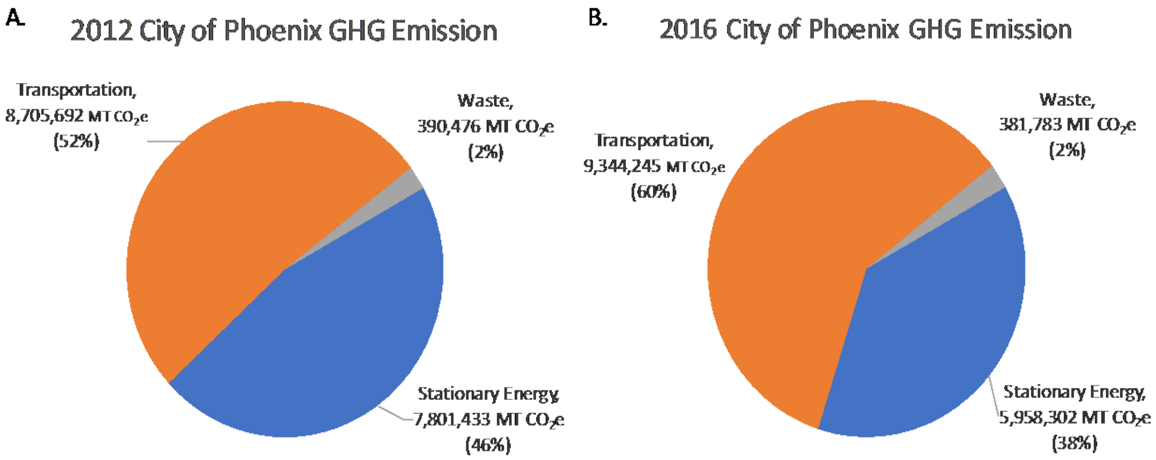


Figure 15. (A) City of Phoenix GHG emissions by emission sector for 2012. (B) City of Phoenix GHG emissions by emission sector for 2016.

Table 17. Phoenix GHG emissions by Sector and Subsector (MT CO_2e)

Sector and Subsector	2012 Emissions	2016 Emissions	Change in Emissions	% Change
Stationary Energy:				
Residential buildings	3,679,189	2,796,904	-882,285	-24%
Commercial & institutional buildings	3,936,896	2,925,368	-1,011,528	-26%
Manufacturing industries and construction	180,999	179,750	-1,249	-1%
Agriculture, forestry and fishing activities	4,273	56,188	51,916	1215%
Non-specified sources	75	92	16	22%
Stationary Energy Sector Total	**7,801,433**	**5,958,302**	**-1,843,131**	**-23.6%**

Transportation:				
On-road transport	5,954,202	6,443,139	488,938	8.2%
Railways	30,309	29,455	-854	-2.8%
Commercial Aviation	698,263	705,643	7,380	1.1%
Civil Aviation (Aviation Gasoline)	13,394	15,067	1,673	12.5%
Off-road transport	2,009,524	2,150,940	141,416	7.0%
Transportation Sector Total	**8,705,692**	**9,344,245**	**638,553**	**7.3%**
Waste:				
Solid waste disposal	365,749	356,623	-9,127	-2%
Wastewater treatment and discharge	10,066	10,840	775	8%
Biological treatment of waste (composting)	14,661	14,320	-341	-2%
Waste Sector Total	**390,476**	**381,783**	**-8,693**	**-2.2%**
GHG Emission Total	**16,897,600**	**15,684,329**	**-1,213,271**	**-7.2%**

4.2 Stationary Energy

Stationary Energy GHG emissions for 2016 were 5,958,302 MT CO_2e, which is a 23.6% decrease in emissions from 2012. The driving force behind the large reduction in Stationary Energy GHG emissions resulted from a regional increase in clean energy production, which decreased the carbon intensity of what Phoenix consumes, as reflected in the EPA eGRID GHG emission factor. Data to calculate Stationary Energy GHG emissions were obtained from Arizona Public Service (electricity), the Salt River Project (electricity), Southwest Gas (natural gas), and the Energy Information Administration (electricity transmission and distribution loss). *Table 18* details the GHG emissions by subsector and *Figure 16* shows the distribution of GHG emissions among different subsectors in the Stationary Energy Sector for 2012 and 2016.

Table 18. Stationary Energy GHG Emissions by Subsector (MT CO_2e)

Stationary Energy	**2012 Emissions**	**2016 Emissions**	**Change in Emissions**	**% Change**
Residential buildings	3,679,189	2,796,904	-882,285	-24%
Commercial & institutional buildings	3,936,896	2,925,368	-1,011,528	-26%
Manufacturing industries and construction	180,999	179,750	-1,249	-1%
Agriculture, forestry and fishing activities	4,273	56,188	51,916	1215%
Non-specified sources	75	92	16	22%
Stationary Energy Emissions Total	**7,801,433**	**5,958,302**	**-1,843,131**	**-23.6%**

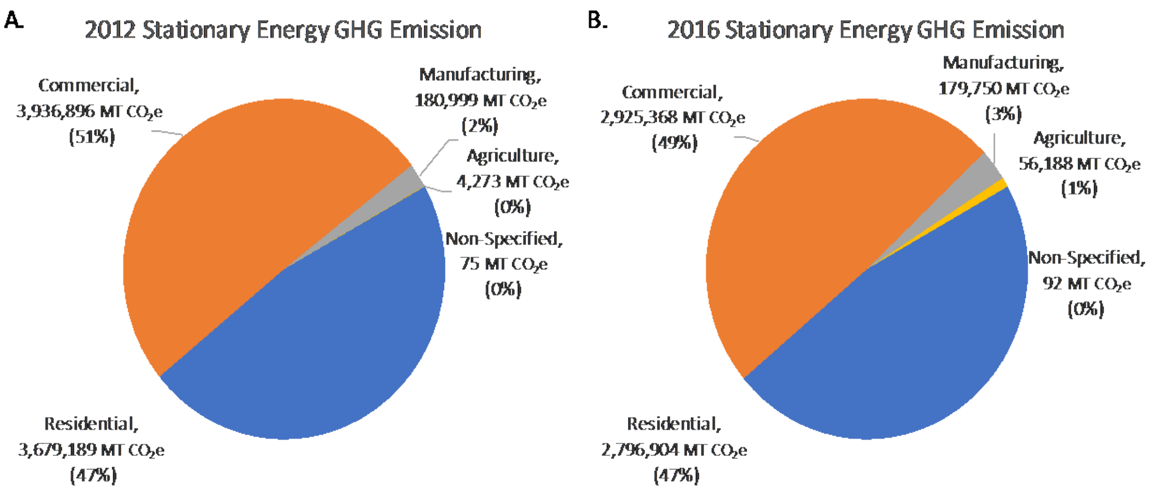


Figure 16. (A) Stationary Energy GHG emissions by emission subsector for 2012. (B) Stationary Energy GHG emissions by emission subsector for 2016

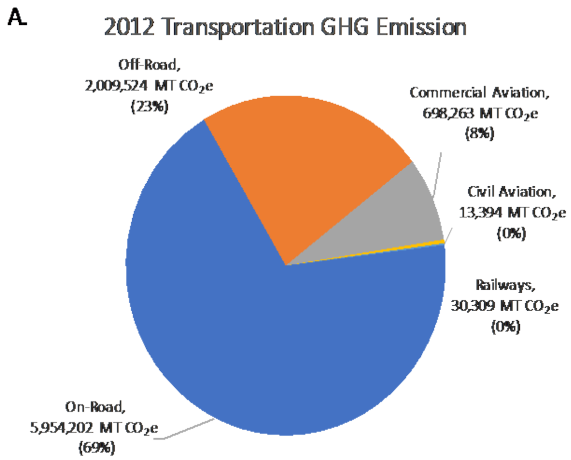
4.3 Transportation

Total Transportation Sector GHG emission for 2016 was 9,344,245 MT CO_2e, which is a 7.3% increase in GHG emission from the 2012 level of 8,705,692 MTCO_2e. Increased on-road and off-road transportation activity was responsible for the increased Transportation Sector GHG emissions. Data were obtained from the City of Phoenix, Arizona Department of Transportation, the Weights and Measures Division of the Arizona Department of Agriculture, the Valley of the Sun Clean Cities Coalition, the Federal Aviation Administration, and Southwest Gas.

Table 19 details the emissions by subsector and *Figure 17* shows the distribution of GHG emissions among different subsectors of transportation sources for the years 2012 and 2016.

Table 19. Transportation GHG Emissions by Subsector (MT CO_2e)

Transportation	2012 Emissions	2016 Emissions	Change in Emissions	% Change
On-road transport	5,954,202	6,443,139	488,938	8.2%
Railways	30,309	29,455	-854	-2.8%
Commercial Aviation	698,263	705,643	7,380	1.1%
Civil Aviation (Aviation Gasoline)	13,394	15,067	1,673	12.5%
Off-road transport	2,009,524	2,150,940	141,416	7.0%
Transportation Sector Total	**8,705,692**	**9,344,245**	**638,553**	**7.3%**



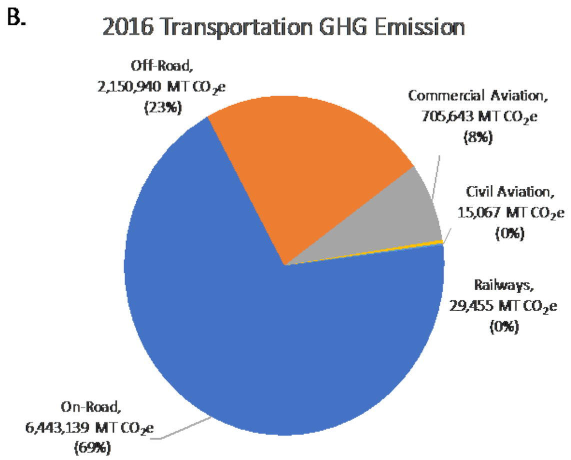


Figure 17. (A) Transportation GHG emissions by emission subsector for 2012. (B) Transportation GHG emissions by emission subsector for 2016

4.4 Waste

Between 2012 and 2016, there was a 2.2% decrease in Waste Sector GHG emissions. While GHG emissions from solid waste disposal and composting decreased by approximately 2%, similar to the Waste Sector overall, GHG emissions from wastewater treatment increased by 8%. The total GHG emissions from the Waste Sector were 381,783 MT CO_2e in 2016 as compared to 390,476 MT CO_2e reported in 2012. Waste Sector GHG emission reductions were driven by solid waste disposal, which is greater than 90% of the sector. While new Solid Waste GHG emissions occur from the ongoing disposal of solid waste, historic, closed landfills within the City of Phoenix are producing less GHG emissions over time, as the waste decays.

Table 20 details waste sector GHG emissions among the different subsectors for the years 2012 and 2016 *and Figure 18* shows the per cent breakdown of of those emissions.

Table 20. Subsector Waste Sector GHG Emission (MT CO_2e)

Waste	2012 Emission	2016 Emission	Change in Emission	% Change
Solid waste disposal	365,749	356,623	-9,127	-2%
Wastewater treatment and discharge	10,066	10,840	775	8%
Biological treatment of waste (composting)	14,661	14,320	-341	-2%
Waste Sector Total	**390,476**	**381,783**	**-8,693**	**-2.2%**

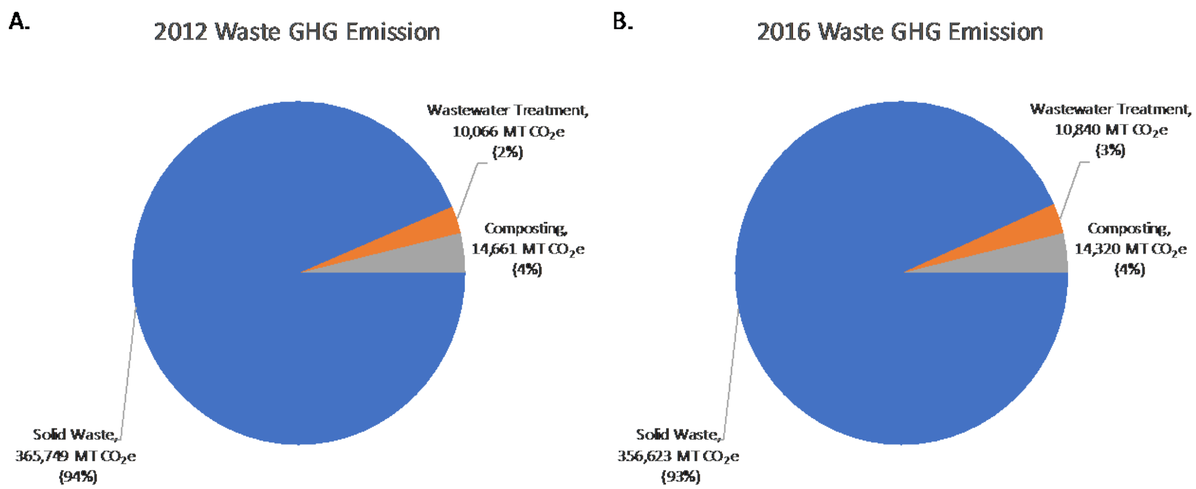


Figure 18. (A) 2012 Waste Sector GHG emissions by subsector. (B) 2016 Waste Sector GHG emissions by subsector.

5. City Comparison

While it is important for the City of Phoenix to understand its local impact by completing a community GHG inventory and looking internally, it is also important to understand the impact of these results in a regional and national context. A review of other U.S. cities that have completed community GHG inventories was conducted in order to understand what methodologies have been used across the U.S., how results differ among cities and then to identify either where Phoenix is leading the way or where there are areas of improvement for GHG reporting. Different inventory types, inventory years, climate, population size, land size and inventory methods are important factors to be considered when making comparisons among cities. It should be noted however, that even though differences exist across the compared cities, there was no attempt to normalize inventory results.

5.1 City Information

5.1.1 Seattle

The City of Seattle reported their community-scale GHG inventory for the year 2014 in August 2016. Seattle's 2030 climate goals, initiated by Seattle's Climate Action Plan, calls for a combined reduction (road transportation and building energy) of emissions by 64% from 2008 levels[19]. This inventory suggests that Seattle has reduced these emissions since 2008 by 6%. The reductions have resulted from lower passenger vehicle travel and more efficient cars, improvements in building energy performance, more residents living in multifamily (and less energy-intensive) dwellings, and warmer weather that led to lower heating demands in 2014 compared to 2008.

- Total reported GHG emissions: 5,870,000 MT CO_2e

[19] P. Erickson, A. Down & D. Broekhoff. "Seattle Community Greenhouse Gas Emissions Inventory." Seattle, WA: Stockholm Environment Institute. Report prepared for the City of Seattle. Calendar Year 2014. Accessed July 2017. https://www.seattle.gov/Documents/Departments/OSE/ClimateDocs/2014GHG%20inventorySept2016.pdf

- Stationary energy sector emissions: 2,275,000 MT CO_2e
- Transportation sector emissions: 3,576,000 MT CO_2e
- Waste sector emissions: 91,000 MT CO_2e
- GHG Offsets: -72,000 MT CO_2e
- Land area: 83.78 mi^2
- Population[20]: 668,342
- Emissions per capita (reported): 8.8
- Reporting methodology: ICLEI - US format

5.1.2 Chicago

The City of Chicago reported their GHG inventory for the year 2015 in August 2017, which indicated a reduction of 11% in total emissions since 2005. This resulted in an improvement in emission intensity from 13.0 MT CO_2e per capita in 2005 to 12.0 MT CO_2e per capita in 2015. There was also a stronger improvement in economic efficiency, leading to a change from 7.6 MT CO_2e / $100k of GDP to 5.1 MT CO_2e /$100k of GDP.[21] The city's CAP outlined its goal to reduce GHG emissions 80% below the 1990 levels by 2050, with an interim goal for the year 2020 of 25% below 1990 levels. The city's Mayor announced that Chicago will power all its public buildings with 100% renewable energy by 2025[22].

- Total reported GHG emissions: 32,651,379 MT CO_2e
- Stationary energy sector emissions: 23,500,082 MT CO_2e
- Transportation sector emissions: 8,048,463 MT CO_2e
- Waste sector emissions: 1,102,834 MT CO_2e
- Land area: 227.63 mi^2
- Population[23]: 2,704,958
- Emissions per capita (reported): 12
- Reporting method: GPC

5.1.3 New York

The inventory of New York City community-scale GHG emissions for the year 2014 was reported in April 2016. The city aims to reduce GHG emissions by 80 percent below 2005 levels by the year 2050, with an interim goal to achieve a 35 percent

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[20] Resident populations were acquired from the U.S Bureau of the Census Population Estimates Program. "United States Census Bureau." Population and Housing Estimates. Calendar Year 2016 - 2017. Accessed January – September 2017. www.census.gov/popest/

[21] "City of Chicago Greenhouse Gas Inventory Report." Global Protocol for Community-Scale Greenhouse Gas Emission Inventories. AECOM. December/January 2015. Accessed February 19, 2017. https://www.cityofchicago.org/content/dam/city/progs/env/GHG_Inventory/CityofChicago_2015_GHG_Emissions_Inventory_Report.pdf

[22] "Mayor Emanuel Announces City Buildings to be Powered by 100 Percent Renewable Energy by 2025." Press Release office of the Mayor, Mayor Rahm Emanuel. April 9, 2017. Accessed April, 2017. https://www.cityofchicago.org/city/en/depts/mayor/press_room/press_releases/2017/april/RenewableEnergy2025.html

[23] "United States Census Bureau." Population and Housing Estimates. Calendar Year 2016 - 2017. Accessed January – September 2017. https://www.census.gov/quickfacts/fact/table/chicagocityillinois/PST045216

reduction below 2005 levels in city government buildings by 2025[24]. The GHG emissions have been reduced by 12 percent since 2005, despite the significant increases in population, building area and economic activity. New York City's per capita GHG emissions in 2014 was equivalent to an average of 5.8 MT CO_2e emissions per capita. Cleaner and more efficient electricity generation has been the most significant driver behind the reduction of GHG emissions.

- Total reported GHG emissions: 49,090,900 MT CO_2e
- Stationary energy sector emissions: 35,920,000 MT CO_2e
- Transportation sector emissions: 10,510,000 MT CO_2e
- Waste sector emissions: 2,660,000 MT CO_2e
- Land area: 304.6 mi^2
- Population[25]: 8,472,000
- Emissions per capita (reported): 5.8
- Reporting method: GPC

5.1.4 Denver

The City of Denver established the Denver 2020 Climate Goal, which calls for an absolute reduction of GHG emissions to 1990 levels by 2020. This would require a 10 percent reduction of GHGs from 2005 levels. The City of Denver reported their community 2014 GHG inventory in 2015. Denver saw a slight decrease below 2013 emissions, primarily due to stationary energy emission reductions in the built environment. Although Denver is currently undergoing a construction boom, the grid electricity emission factor had fallen as a result of increased renewables and the transition away from coal to natural gas in grid power generation[26].

- Total reported GHG emissions: 12,985,000 MT CO_2e
- Stationary energy sector emissions: 9,535,200 MT CO_2e
- Transportation sector emissions: 3,311,000 MT CO_2e
- Waste sector emissions: 139,000 MT CO_2e
- Land area: 155 mi^2
- Population[27]: 663,963
- Emissions per capita (reported): 20

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[24] Cathy Pasion, Mikael Amar, and Yun Zhou. "City of New York Inventory of New York City's Greenhouse Gas Emissions." April 2016. Cventure LLC, Mayor's Office of Sustainability, New York. Calendar year 2016. Accessed 2017.

[25] "United States Census Bureau." Population and Housing Estimates. Calendar Year 2016 - 2017. Accessed January – September 2017. https://www.census.gov/quickfacts/fact/table/chicagocityillinois/PST045216

[26] "United States Census Bureau." Population and Housing Estimates. Calendar Year 2016 - 2017. Accessed January – September 2017. https://www.census.gov/quickfacts/fact/table/chicagocityillinois/PST045216

[27] "United States Census Bureau." Population and Housing Estimates. Calendar Year 2016 - 2017. Accessed January – September 2017. https://www.census.gov/quickfacts/fact/table/chicagocityillinois/PST045216

- Reporting method: Demand-Centered Hybrid Life-Cycle Method[28]

5.1.5 Austin

The City of Austin (Travis County) reported their GHG inventory for the year 2013 in August 2016. The Travis County GHG emissions decreased by approximately 2% between the years 2010 and 2013, despite a significant increase in the population. The city aims to achieve net-zero community-wide GHG emissions by 2050[29]. The reduction in emissions was driven by the use of renewable energy in electricity generation, energy efficiency and improved fuel efficiency of the citywide vehicle fleet.

- Total reported GHG emissions: 13,739,417 MT CO_2e
- Stationary energy sector emissions: 7,376,681 MT CO_2e
- Transportation sector emissions: 4,919,066 MT CO_2e
- Waste sector emissions: 660,632 MT CO_2e
- Land area: 1023 mi^2
- Population[30]: 1.21 million
- Emissions per capita (reported): 11.35
- Reporting method: ICLEI

5.1.6 Las Vegas / Clark County

The City of Las Vegas and Clark County reported their GHG inventory for the year 2014 in the year 2016. The city's GHG emissions inventory included emissions from five areas, residential, commercial, industrial, transportation and waste Emissions[31].

- Total reported GHG emissions: 30,588,113 MT CO_2e
- Stationary energy sector emissions: 18,654,205 MT CO_2e
- Transportation sector emissions: 11,002,925 MT CO_2e
- Waste sector emissions: 930,983 MT CO_2e
- Land area: 8,061mi^2
- Population[32]: 2,115,000
- Emissions per capita (reported): 14.4
- Reporting method: ICLEI-Five Milestone Method

[28] Ramaswami, A., Hillman, T., Janson, B., Reiner, M., & Thomas, G. "A Demand-Centered, Hybrid Life-Cycle Methodology for City-Scale Greenhouse Gas Inventories." January, 2018. Environmental Science & Technology, 42(17), 6455-6461. Accessed January, 2018.

[29] "City of Austin Greenhouse Gas Inventory Report." Calendar Year 2013, by Office of Sustainability 2013. Accessed January 2017. https://austintexas.gov/sites/default/files/files/2013_Community_Inventory.pdf

[30] "City of Las Vegas Greenhouse Gas Inventory Report." Mayor's Office, Calendar Year 2014. Accessed January 25th 2017. https://www.lasvegasnevada.gov/cs/groups/public/documents/document/chjk/mdmx/~edisp/prd031750.pdf

[31] "City of Las Vegas Greenhouse Gas Inventory Report." Mayor's Office, Calendar Year 2014. Accessed January 25th 2017. https://www.lasvegasnevada.gov/cs/groups/public/documents/document/chjk/mdmx/~edisp/prd031750.pdf

[32] "United States Census Bureau." Population and Housing Estimates. Calendar Year 2016 - 2017. Accessed January – September 2017. https://www.census.gov/quickfacts/fact/table/chicagocityillinois/PST045216

5.1.7 Other Comparable Cities[33]

Table 21 summarizes information required for drawing comparisons between the GHG emissions of other comparable cities.

Table 21. City Information

City	Inventory Year	Year Reported	Emissions (MT CO_2e)	Emissions per capita	Population	Land Area (sq. km)	Methodology
Portland	2014	2016	6,974,544	11.3	777,880	1116	ICLEI
New Orleans	2014	2016	4,558,575	11.7	389,617	468	GPC
Houston	2014	2016	33,428,301	15.2	2,195,914	1,625	ICLEI
San Francisco	2012	2016	5,381,687	6.22	864,816	121	GPC

5.2 City to City

5.2.1 Overall GHG Emissions

Figure 19 shows the comparison of total GHG emissions of eleven US cities, including Phoenix.

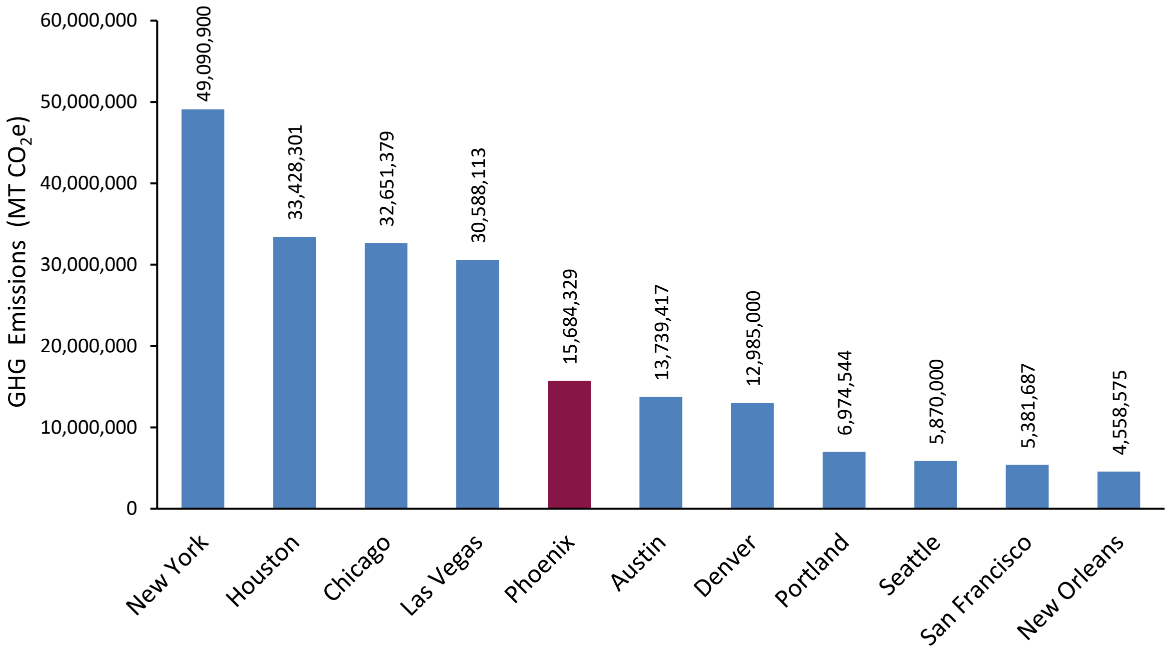

Figure 19. Total GHG Emissions in MT CO_2e

5.2.2 Per Capita Emissions Comparison

Per capita emissions were calculated for the cities and are shown in *Figure 20*. Phoenix ranked fifth out of the eleven cities for lowest emissions per capita.

[33] "Disclosure Insight Action." CDP Open Data Portal. January 21, 2018. Accessed January - April 21, 2017. https://data.cdp.net/Cities/2016-Citywide-GHG-Emissions/dfed-thx7/data

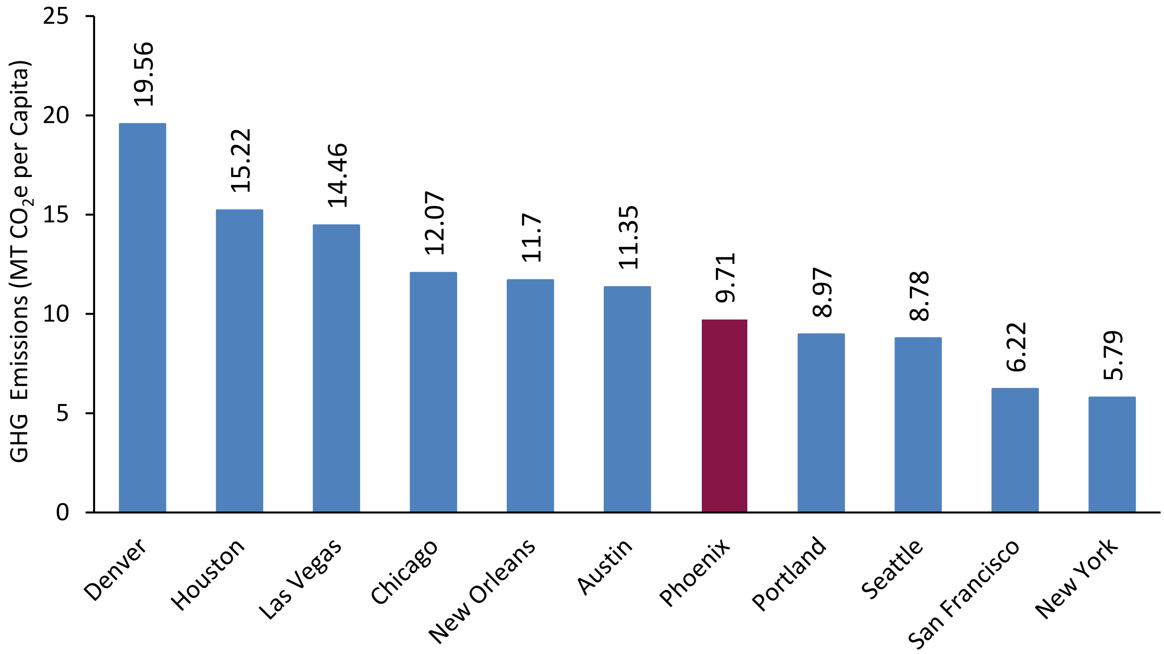

Figure 20. Total Per Capita GHG Emissions

5.2.3 Stationary Energy

Phoenix has relatively low stationary energy emissions per capita as shown in *Figure 21*. Stationary energy emissions per capita tend to be lower because Phoenix has relatively cleaner grid electricity and neither heating nor cooling is required during a significant portion of the year.

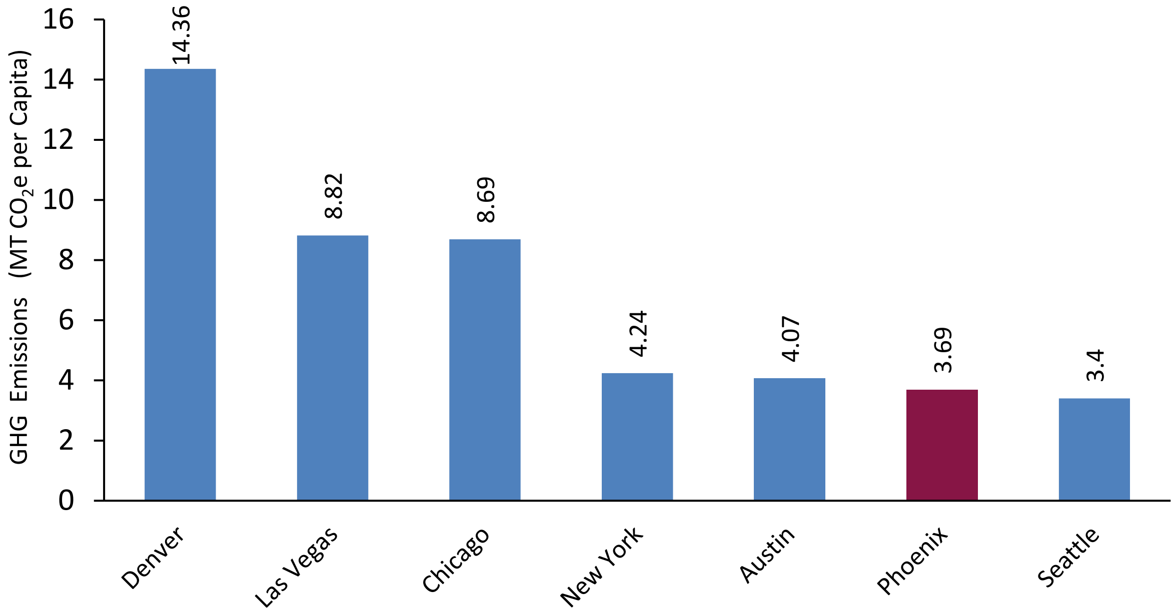

Figure 21. Stationary Energy Emissions Per Capita

5.2.4 Transportation

Phoenix ranked relatively high for the transportation sector per capita emissions, which is also the largest source of emissions for the city. *Figure 22* shows Transportation Sector emissions per capita.

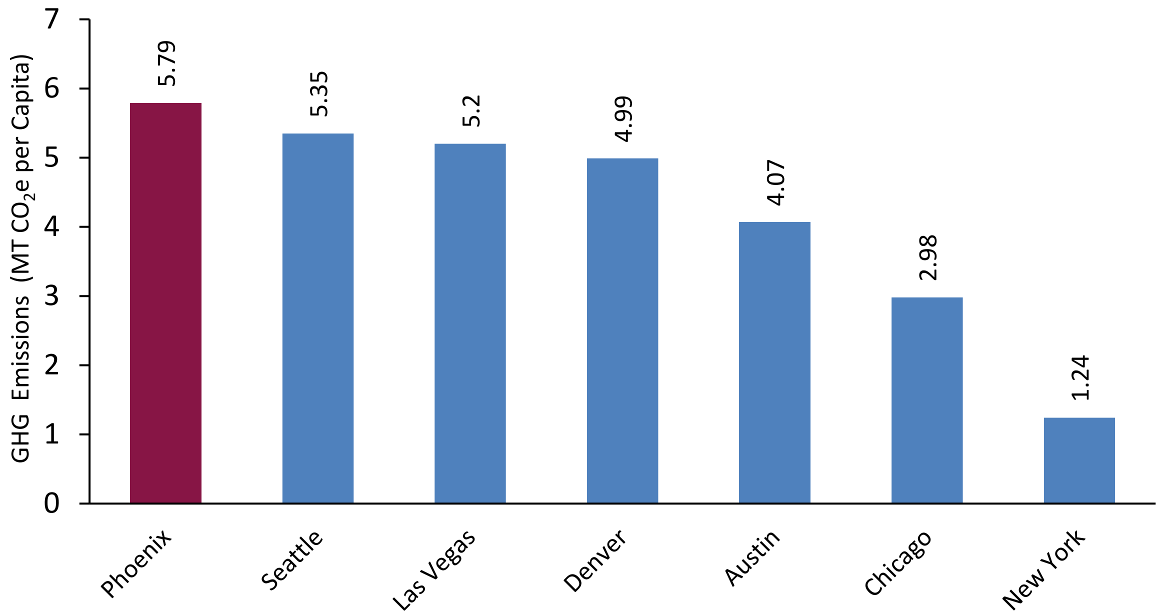

Figure 22. Transportation Emissions Per Capita

5.2.5 Waste

Overall, waste emissions were only a small percentage of emissions for all cities and per capita emissions by city are as shown in *Figure 23*. Phoenix had one of the lowest waste emissions per capita. This may be due to the efficient methane capture systems within Phoenix's municipal landfills.

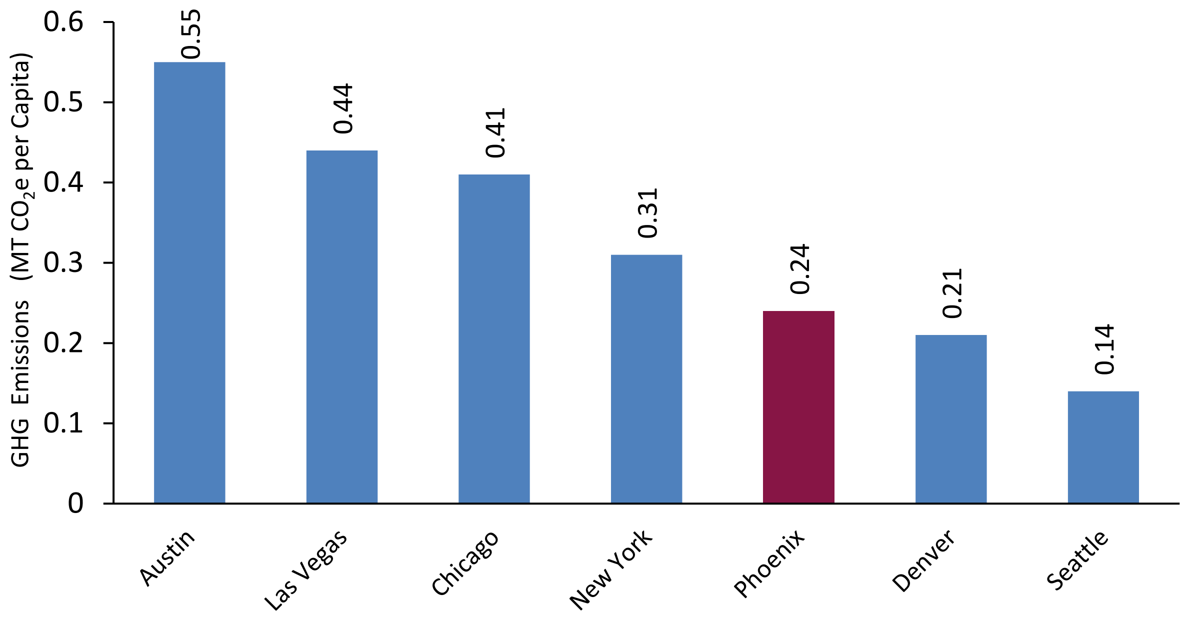

Figure 23. Waste Sector Emissions Per Capita

6. Conclusion

In 2016, Phoenix's citywide GHG emissions were 15,684,329 MT CO_2e – a 7.2% reduction compared to the 2012 level of 16,897,600 MT CO_2e. Phoenix's GHG emission reductions were driven by the Stationary Energy Sector, which saw a 22%

decrease between 2012 and 2016, due mostly to a reduction in the regional EPA e-GRID GHG emission factor, as the transition to regional clean grid electricity generation continues. Waste Sector GHG emissions decreased by 2.2% between 2012 and 2016. One possibility for the decrease may be that while new Solid Waste GHG emissions occur from the ongoing disposal of solid waste, closed landfills within the City of Phoenix produce less GHG emissions over time as the waste decays.

The Transportation Sector, the largest source of GHG emissions in Phoenix, increased by 7% between 2012 and 2016. This increase occurred as the direct result of increased on-road transportation activity and the associated increase in gasoline consumption. Measures to reduce transportation GHG emissions would help Phoenix further reduce overall GHG emissions.

Gasoline-powered motor vehicles used for on-road transportation is the largest single source of transportation-related GHG emissions. An increased adoption of battery electric vehicles (BEVs) or plugin electric hybrid vehicles (PEHV) is one avenue to reduce transportation-related GHG emissions. Given current tailpipe emissions of gasoline-powered motor vehicles and current carbon intensity levels of the electric grid[34], replacing 1% of gasoline-powered motor vehicles for BEVs could result in an annual GHG emission reduction of 24,701 MT CO_2e. Therefore, there is potential for more than a 2,470,000 MT CO_2e reduction in GHG emissions from converting all existing gasoline-powered motor vehicles to BEVs, and this reduction will only increase as the regional electricity mix becomes cleaner and less carbon intensive, see *Figure 24*.

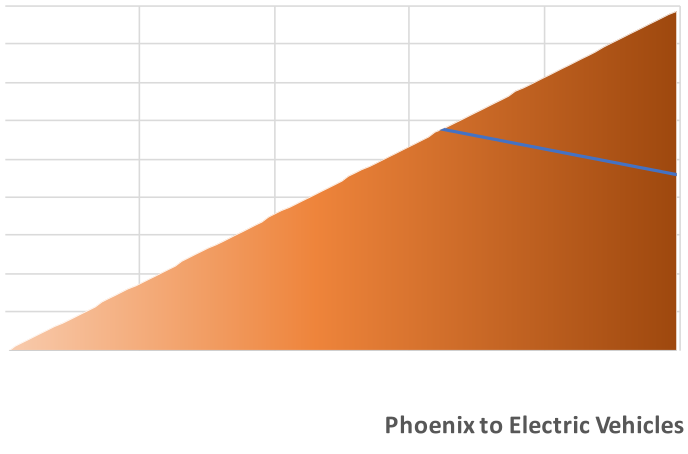

Figure 24. The potential GHG emission reductions from the conversion of existing gasoline-powered motor vehicles to battery electric vehicles.

[34] Sailsbury, Mike. "Air Quality and Economic Benefits of Electric Vehicles in Arizona." South West Energy Efficiency Project. September 21, 2015. Accessed July 21, 2017.http://www.swenergy.org/data/sites/1/media/documents/publications/documents/AZ EV AirQuality.EconAnalysis.9.26.13 .pdf

7. Appendix A - Global Warming Potentials

Table-AA 1. Greenhouse Gas Equivalents for the 2016 Community GHG Inventory

Greenhouse Gas	AR5 GWP Values[35]
Carbon Dioxide (CO_2)	1
Methane (CH_4)	28
Nitrous Oxide (N_2O)	265

[35] "Global Warming Potential Values." Greenhouse Gas Protocol. Original Authors: Myhre, G., D. Shindell, F.-M. Bréon, W. Collins, J. Fuglestvedt, J. Huang, D. Koch, J.-F. Lamarque, D. Lee, B. Mendoza, T. Nakajima, A. Robock, G. Stephens, T. Takemura and H. Zhang, 2013: Anthropogenic and Natural Radiative Forcing. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. http://www.ghgprotocol.org/sites/default/files/ghgp/Global-Warming-Potential-Values%20%28Feb%2016%202016%29_1.pdf

8. Appendix B - GHG Scaling Factors by Zip Code

Table AB 1. Scaling Factors of Zip Codes by Proportion of Land Area in Phoenix

Name	Zip Code	Phoenix Zip Area	Total Zip Area	Zip Scaling Factor
PHOENIX	85003	6,868,468	6,868,468	100.00%
PHOENIX	85004	7,993,824	7,993,824	100.00%
PHOENIX	85006	14,976,401	14,976,401	100.00%
PHOENIX	85007	17,021,758	17,021,758	100.00%
PHOENIX	85008	35,317,128	35,317,233	100.00%
PHOENIX	85009	54,119,790	54,147,577	99.95%
PHOENIX	85012	7,774,585	7,774,585	100.00%
PHOENIX	85013	14,675,528	14,675,528	100.00%
PHOENIX	85014	14,757,994	15,304,832	96.43%
PHOENIX	85015	18,127,766	18,127,766	100.00%
PHOENIX	85016	32,342,254	32,342,732	100.00%
PHOENIX	85017	18,764,639	18,764,639	100.00%
PHOENIX	85018	34,400,422	34,500,868	99.71%
PHOENIX	85019	14,764,498	14,764,498	100.00%
PHOENIX	85020	43,063,981	43,063,981	100.00%
PHOENIX	85021	26,831,848	26,831,848	100.00%
PHOENIX	85022	34,066,976	34,066,976	100.00%
PHOENIX	85023	28,875,890	28,875,891	100.00%
PHOENIX	85024	40,916,128	42,758,098	95.69%
PHOENIX	85027	45,075,189	45,075,189	100.00%
PHOENIX	85028	36,484,538	36,584,572	99.73%
PHOENIX	85029	31,890,936	31,890,936	100.00%
PHOENIX	85031	15,055,140	15,104,818	99.67%
PHOENIX	85032	47,382,223	47,382,223	100.00%
PHOENIX	85033	23,737,077	23,817,906	99.66%
PHOENIX	85034	42,491,084	42,680,033	99.56%
PHOENIX	85035	19,488,159	19,488,159	100.00%
PHOENIX	85037	31,013,155	32,590,972	95.16%
PHOENIX	85040	36,406,460	36,503,864	99.73%
PHOENIX	85041	59,716,058	66,109,894	90.33%
PHOENIX	85042	62,723,397	62,723,780	100.00%
PHOENIX	85043	64,010,077	75,449,903	84.84%
PHOENIX	85044	42,873,390	43,561,285	98.42%
PHOENIX	85045	28,356,417	28,470,837	99.60%
PHOENIX	85048	55,663,246	55,765,985	99.82%
PHOENIX	85050	53,523,579	53,523,579	100.00%

Name	Zip Code	Phoenix Zip Area	Total Zip Area	Zip Scaling Factor
PHOENIX	85051	23,770,828	23,770,828	100.00%
PHOENIX	85053	19,350,615	19,350,614	100.00%
PHOENIX	85054	58,740,380	59,136,650	99.33%
PHOENIX	85083	77,227,807	78,092,613	98.89%
PHOENIX	85085	153,958,401	166,001,483	92.75%
PHOENIX	85086	91,491,042	194,567,659	47.02%
PHOENIX	85087	90,913,962	912,749,070	9.96%
PHOENIX	85226	1,453,317	276,169,735	0.53%
PHOENIX	85251	2,293,806	27,154,270	8.45%
PHOENIX	85253	5,968,351	68,852,007	8.67%
PHOENIX	85254	44,443,764	51,044,229	87.07%
PHOENIX	85255	439,606	197,641,274	0.22%
PHOENIX	85257	37,439	26,772,267	0.14%
PHOENIX	85266	93	63,003,046	0.00%
PHOENIX	85281	2,568,699	51,373,282	5.00%
PHOENIX	85282	40,734	40,172,714	0.10%
PHOENIX	85283	25,448	33,180,382	0.08%
PHOENIX	85301	77,413	34,791,561	0.22%
PHOENIX	85302	49,518	21,770,138	0.23%
PHOENIX	85304	5,834,413	21,384,409	27.28%
PHOENIX	85305	281,437	23,535,992	1.20%
PHOENIX	85306	7,275,002	21,331,040	34.11%
PHOENIX	85307	3,517,141	36,283,984	9.69%
PHOENIX	85308	19,302,757	64,282,669	30.03%
PHOENIX	85310	28,635,742	36,544,467	78.36%
PHOENIX	85331	29,833,379	234,325,880	12.73%
PHOENIX	85339	68,491,006	405,349,961	16.90%
PHOENIX	85340	102,028	93,736,137	0.11%
PHOENIX	85353	34,670,859	81,482,127	42.55%
PHOENIX	85383	725,849	800,923,651	0.09%
PHOENIX	85392	952	35,992,598	0.00%

9. Appendix C – Data Sources

Table-AC 1. Stationary Energy Data Sources

Scope 1 – Subsector	Activity Data Source	Emission Factor Source
Residential Buildings	Southwest Gas Corporation via City of Phoenix	EPA
Commercial and institutional buildings and facilities	Southwest Gas Corporation via City of Phoenix	EPA
Manufacturing industries and construction	Southwest Gas Corporation via City of Phoenix	EPA
Energy Industries	Southwest Gas Corporation via City of Phoenix	EPA
Energy Supplied to the grid	Southwest Gas Corporation via City of Phoenix	EPA
Agriculture, forestry, and fishing activities	EPA Flight Tool Data – 2015	EPA
Non-specified sources	Southwest Gas Corporation via City of Phoenix	EPA
Scope 2 – Subsector	**Activity Data Source**	**Emission Factor Source**
Residential buildings – APS	APS via City of Phoenix	EPA
Residential buildings – SRP	SRP vis City of Phoenix	EPA
Commercial and institutional buildings and facilities – APS	APS via City of Phoenix	EPA
Commercial and institutional buildings and facilities – SRP	SRP vis City of Phoenix	EPA
Manufacturing industries and construction – APS	APS via City of Phoenix	EPA
Manufacturing industries and construction – SRP	SRP vis City of Phoenix	EPA
Scope 3 – Subsector	**Activity Data Source**	**Emission Factor Source**
Residential Buildings	U.S. Energy Information Administration	EPA
Commercial and institutional buildings and facilities	U.S. Energy Information Administration	EPA
Manufacturing industries and construction	U.S. Energy Information Administration	EPA

Table-AC 2. Transportation Sector Data Sources

Scope 1 – Subsector	Activity Data Source	Emission Factor Source
On-road Transport		
Gasoline	Department of Weights and Measures	EPA
Diesel	Department of Weights and Measures	EPA
Biodiesel (B20)	City of Phoenix/Clean Cities Coalition	EPA
E85	City of Phoenix/Clean Cities Coalition	EPA
E54	City of Phoenix/Clean Cities Coalition	EPA
CNG	Southwest Gas Corporation via City of Phoenix	EPA
LNG	Clean Cities Coalition	EPA
Propane	Clean Cities Coalition	EPA
Railways	Locomotive Emission Inventories for the United States from ERTAC Rail	EPA
Commercial Aviation	EIA, SEDS Data for 2015	EPA
Civil Aviation (AvGas)	EIA, SEDS Data for 2015	EPA
Off-road Transport	2014 National Emissions Inventory (NEI) Data	EPA
Scope 1 – Subsector	**Activity Data Source**	**Emission Factor Source**
Railways (Light rail)	Valley Metro, National Transit Database	EPA
Scope 1 – Subsector	**Activity Data Source**	**Emission Factor Source**
Railways (Light rail)	US Energy Information Administration	EPA
Scope 1 – Subsector	**Activity Data Source**	**Emission Factor Source**
On-road Transport		
Gasoline	Department of Weights and Measures	EPA
Diesel	Department of Weights and Measures	EPA
Biodiesel (B20)	City of Phoenix/Clean Cities Coalition	EPA
E85	City of Phoenix/Clean Cities Coalition	EPA

E54	City of Phoenix/Clean Cities Coalition	EPA
CNG	Southwest Gas Corporation via City of Phoenix	EPA
LNG	Clean Cities Coalition	EPA
Propane	Clean Cities Coalition	EPA
Railways	Locomotive Emission Inventories for the United States from ERTAC Rail	EPA
Commercial Aviation	EIA, SEDS Data for 2015	EPA
Commercial Aviation	EIA, SEDS Data for 2015	EPA
Civil Aviation (AvGas)	EIA, SEDS Data for 2015	EPA
Off-road Transport	2014 National Emissions Inventory (NEI) Data	EPA
Scope 1 – Subsector	**Activity Data Source**	**Emission Factor Source**
Railways (Light rail)	Valley Metro, National Transit Database	EPA
Scope 1 – Subsector	**Activity Data Source**	**Emission Factor Source**
Railways (Light rail)	US Energy Information Administration	EPA
Railways (Light rail)	Valley Metro, National Transit Database	EPA
Scope 1 – Subsector	**Activity Data Source**	**Emission Factor Source**
Railways (Light rail)	US Energy Information Administration	EPA

Table-AC 3. Waste Sector Data Sources

Scope 1 – Subsector	Activity Data Source	Emission Factor Source
Solid Waste Disposal		
Skunk Creek Landfill	City of Phoenix	EPA (2015 – GWP for Methane)
27th Avenue Landfill	City of Phoenix	EPA (2015 – GWP for Methane)
Del Rio Landfill	City of Phoenix	EPA (2015 – GWP for Methane)
Deer Valley Landfill	City of Phoenix	EPA (2015 – GWP for Methane)
19th Avenue Landfill	City of Phoenix	EPA (2015 – GWP for Methane)
Estes Landfill	City of Phoenix	EPA (2015 – GWP for Methane)
Lone Cactus Landfill	EPA Flight Tool Data	EPA (2015 – GWP for Methane)
Biological Treatment of Waste	City of Phoenix*	EPA
Wastewater Treatment and Discharge	City of Phoenix	EPA
Scope 3 – Subsector	**Activity Data Source**	**Emission Factor Source**
Solid Waste Disposal		
SR85 Landfill	City of Phoenix	EPA (2015 – GWP for Methane)
Private Haulers	CIRIS Landfill Emissions Model	EPA
*Biological Treatment of Waste (composting) data were obtained from the 2015 City of Phoenix GHG emissions inventory of local government operation.		

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Wee Kean Fong, Mary Sotos, Michael Doust, and Seth Schultz. "An Accounting and Reporting Standard for Cities." Global Protocol for Community-Scale Greenhouse Gas Emission Inventories. No Publication Date. Accessed 2017. https://ghgprotocol.org/greenhouse-gas-protocol-accounting-reporting-standard-cities.

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"Disclosure Insight Action." CDP Open Data Portal. January 21, 2018. Accessed April 21, 2017. https://data.cdp.net/Cities/2016-Citywide-GHG-Emissions/dfed-thx7/data.

"City of Chicago Greenhouse Gas Inventory Report." Global Protocol for Community-Scale Greenhouse Gas Emission Inventories. AECOM. December/January 2015. Accessed February 19, 2017. https://www.cityofchicago.org/content/dam/city/progs/env/GHG_Inventory/CityofChicago_2015_GHG_Emissions_Inventory_Report.pdf.

“City of Las Vegas Greenhouse Gas Inventory Report.” Mayor’s Office, Calendar Year 2014. Accessed January 25th 2017. https://www.lasvegasnevada.gov/cs/groups/public/documents/document/chjk/mdmx/~edisp/prd031750.pdf

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