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2020 Community-Scale Greenhouse Gas Emissions Inventory

A comprehensive report prepared for

City of Phoenix

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sustainabilitysolutions.asu.edu

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Note: The data and calculations presented in this report may not be exact due to rounding errors within the GHG emissions template.

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Acronym List

AFFA	Agriculture, Forestry, and Fishing Activities
AFOLU	Agriculture, Forestry, and Land Use
APS	Arizona Public Service
AR	IPCC Assessment Report (Numbered 2 through 5)
ASU	Arizona State University
AZNM	Arizona and New Mexico eGRID Subregion
B20 Biodiesel	Contains up to 20% biodiesel
BEV	Battery Electric Vehicle
BPEV	Batter Plugin Electric Vehicle
CH_4	Methane
CNG	Compressed Natural Gas
CO_2	Carbon Dioxide
CO_2e	Carbon Dioxide Equivalent Emissions
E54	Fuel containing 54% ethanol
E85	Fuel containing 85% ethanol
eGRID	EPA's Emissions and General Resource Integrated Database
EIA	U.S. Energy Information Administration
EPA	U.S. Environmental Protection Agency
EV	Electric Vehicle
FCEV	Fuel Cell Electric Vehicle
FERC	Federal Energy Regulatory Commission
FTE	Full-time equivalent
GGE	Gasoline Gallon Equivalent
GHG	Greenhouse Gas
GPC	Global Protocol for Community-Scale GHG Emission Inventories
GWP	Global Warming Potential
ICLEI	International Council for Local Environmental Initiatives,
IE	Included Elsewhere
IPPU	Industrial Processes and Product Use
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
MPST	Mining, Processing, Storage, and Transport of Coal
MT	Metric Tons
MWh	megawatt-hour
NAU	Northern Arizona University
NE	Not Estimated
NERC	North American Electric Reliability Corporation
NO	Not Occurring
N_2O	Nitrous Oxide
ONGS	Oil and Natural Gas Systems
PNM	Public Service Company of New Mexico
SRP	Salt River Project
T&D	Transmission & Distribution
TRP	Trip Reduction Program
WECC	Western Electricity Coordinating Council
WWT	Wastewater Treatment
WWTP	Wastewater Treatment Plant

Executive Summary

The city of Phoenix (City) has completed a community-scale greenhouse gas (GHG) emissions inventory for calendar year 2020 using the Global Protocol for Community-Scale GHG Emission Inventories (GPC). The GPC 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. The City of Phoenix is a member of both the C40 Cities Climate Leadership Group and Global Covenant of Mayors for Climate and Energy.

The GPC categorizes direct and indirect GHG emissions into three sectors: Stationary Energy, Transportation and Waste. Direct GHG emissions occur within City boundaries, while indirect GHG emissions are induced by activity within the City boundary.

- The Stationary Energy Sector includes GHG emissions that occur from energy utilized in residential buildings, commercial buildings and facilities, manufacturing industries, agriculture, forestry and fishing energy use, and electricity transmission and distribution energy losses.
- The Transportation Sector includes GHG emissions from commercial and civil aviation, on-road transportation, non-road vehicle use, freight and light rail.
- The Waste Sector includes GHG emissions from solid waste disposal, the biological treatment of waste (composting), and wastewater treatment.

The 2020 community-scale GHG inventory is the fourth completed by the City following the 2012, 2016, and 2018 community-scale GHG inventories. While each of the community-scale GHG inventories completed by the City have followed the GPC, during each inventory process the previous year(s) GHG inventory have been recalculated to reflect updates to source data, data collection and processing methods, GHG global warming potentials, and GHG emissions estimation methods. Changes to GHG emissions totals for the 2012, 2016, and 2018 calendar years are reported along with the 2020 GHG emissions totals.

Key Findings

- In 2020, community-scale GHG emissions were 15,156,347 metric tons of carbon dioxide equivalents (MT CO_2e).
- 2020 community-scale GHG emissions were 14.0% lower than the 2012 levels of 17,622,666 MT CO_2e (Figure ES-1).
- Stationary Energy Sector GHG emissions totaled 7,406,849 MT CO_2e.
- Transportation Sector GHG emissions totaled 7,461,649 MT CO_2e.
- Waste Sector GHG emissions totaled 287,850 MT CO_2e.
- GHG emissions decreased 14% during a period when the City's population grew 12.1% and the metro area economy grew 41.6%.

[1] Greenhouse Gas Protocol. (n.d.). GHG Protocol for Cities | Greenhouse Gas Protocol. Retrieved from http://www.ghgprotocol.org/greenhouse-gas-protocol-accounting-reporting-standard-cities

- GHG emissions per capita fell 23.3% from the 2012 baseline of 11.75 MT CO_2e to 9.02 MT CO_2e in 2020.

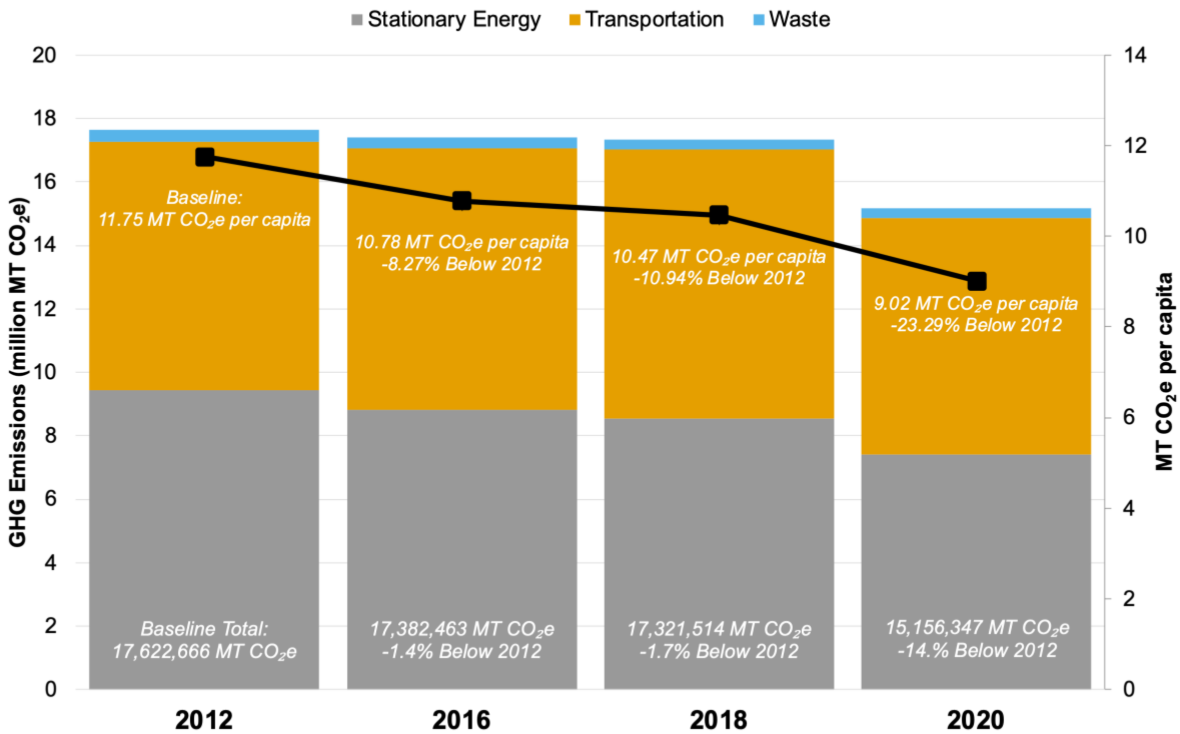


Figure ES-1. GHG emissions by emissions sector for 2012, 2016, 2018, and 2020.

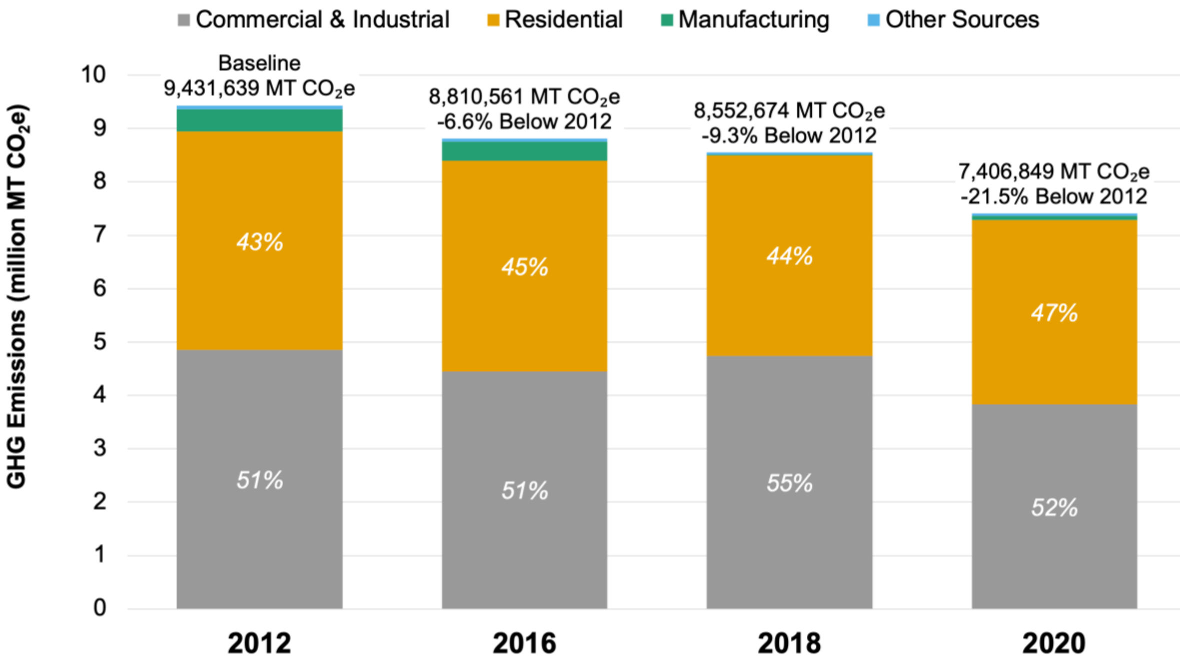
The distribution of GHG emissions between Stationary Energy, Transportation, and Waste Sectors for four community GHG inventories is detailed in Table ES-1.

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

Sector	2012	2016	2018	2020	% Change 2012 -2020
Stationary Energy	9,431,639	8,810,561	8,552,674	7,406,849	**-21.5%**
Transportation	7,823,097	8,255,732	8,464,774	7,461,649	**-4.6%**
Waste	367,931	316,170	304,066	287,850	**-21.8%**
Total	**17,622,666**	**17,382,463**	**17,321,514**	**15,156,347**	**-14.0%**

Stationary Energy

Stationary Energy is the second largest source of GHG emissions in Phoenix. These GHG emissions occur from energy utilized in residential buildings; commercial buildings and facilities; manufacturing industries; agriculture, forestry and fishing energy use; and electricity transmission and distribution energy losses.



Residential - Residential buildings; Commercial & Industrial - Commercial and institutional buildings and facilities;
Manufacturing - Manufacturing industries and construction; Other Sources - Agriculture, forestry, and fishing activities and Non-specified sources.
Manufacturing comprised 4% of Stationary Energy emissions in 2012 and 2016. Starting in 2018, Manufacturing and Other sources comprised <2% of Stationary Energy emissions.

Figure ES-2. Stationary Energy GHG emissions for 2012, 2016, 2018, and 2020.

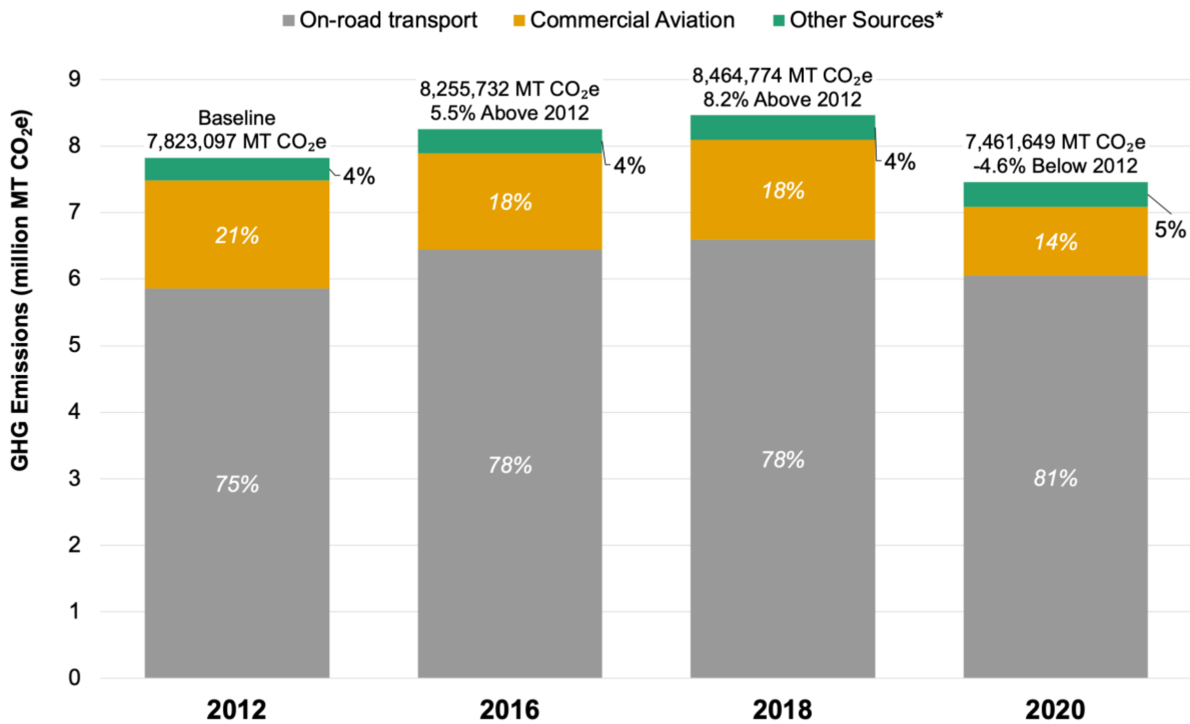
In 2020, Stationary Energy GHG emissions were 7,406,849 MT CO_2e; a 21.5% decrease below 2012 levels. Electricity-based GHG emissions decreased significantly mainly due to the retirement of the Navajo Generating Station, which decreased the carbon intensity of electricity consumed in Phoenix. Data to calculate Stationary Energy GHG emissions were obtained from Arizona Public Service (electricity), Salt River Project (electricity), Southwest Gas (natural gas), and the Energy Information Administration (electricity transmission and distribution loss). Figure ES-2 shows the distribution of GHG emissions between different sub-sectors in the Stationary Energy Sector and Table ES-2 details the GHG emissions by subsector.

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

Stationary Energy	2012	2016	2018	2020
Residential Buildings	4,093,323	3,939,273	3,752,152	3,457,002
Commercial & Institutional Buildings	4,853,598	4,454,805	4,745,669	3,831,741
Manufacturing Industries & Construction	415,704	364,647	8,303	72,459
Agriculture, Forestry & Fishing Activities	68,954	51,758	46,477	45,523
Non-Specified Sources	60	78	74	123
Total	9,431,639	8,810,561	8,552,674	7,406,849

Transportation

In 2020, the Transportation Sector was the largest source of GHG emissions in Phoenix. Transportation GHG emissions sources occur from commercial air travel, civil aviation, on-road transportation, non-road vehicle use, light rail, and freight rail. 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 through the consumption of electricity to charge electric vehicles. Transportation GHG emissions for 2020 were 7,461,649 MT CO_2e, a 4.6% decrease in GHG emissions from the 2012 level of 7,823,097 $MTCO_2e$ (Figure ES-3).



*Other Sources - The Other Sources category includes Off-road Transport, Railways, and Civil Aviation.

Figure ES-3.Transportation GHG emissions for 2012, 2016, and 2018.

Transportation emissions decreased in 2020 due to decreased commuting and travel, including air travel, caused in part by the COVID-19 pandemic, while at the same time there was a marked increase in heavy truck delivery services. Data were obtained from the City of Phoenix, Arizona Department of Transportation, the Weights and Measures Division of the Arizona Department of Agriculture, the Federal Aviation Administration, and the Energy Information Administration. Table ES-3 details GHG emissions among Transportation sub-sectors for the years 2012, 2016, 2018, and 2020.

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

Transportation	2012	2016	2018	2020
On-road transport	5,855,958	6,446,392	6,595,753	6,050,418
Railways	29,113	29,300	31,541	28,792
Commercial Aviation	1,626,397	1,448,210	1,494,963	1,039,280
Civil Aviation (Aviation Gasoline)	13,392	11,708	16,164	16,801
Off-road transport	298,237	320,122	326,353	326,353
Total	**7,823,097**	**8,255,732**	**8,464,774**	**7,461,649**

Waste

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, wastewater treated at the 91st Avenue and 23rd Avenue wastewater treatment plants in Phoenix, and the composting of waste generated in Phoenix. The total GHG emissions from the Waste Sector was 287,850 MT CO_2e in 2020 as compared to 367,931 MT CO_2e reported in 2012 (Table ES-4). Waste Sector GHG emission reductions were driven by multiple factors. First, while Solid Waste GHG emissions will 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. Second, the capture and reuse of flared methane biogas at the 91st Avenue Wastewater Treatment Plant led to a decrease in wastewater treatment GHG emissions despite Phoenix's population growing significantly between 2012 and 2020.

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

Waste	2012	2016	2018	2020
Solid Waste Disposal	353,689	302,773	285,742	273,395
Wastewater Treatment & Discharge	8,440	9,428	10,199	8,094
Biological Waste Treatment (Composting)	5,802	3,968	8,125	6,360
Total	**367,931**	**316,170**	**304,066**	**287,850**

Conclusion

In 2020, citywide GHG emissions in Phoenix were 15,133,075 metric tons CO_2e – 14.1% below the 2012 levels of 17,622,666 MT CO_2e. Stationary Energy GHG emissions decreased 2,051,816 MT CO_2e below 2012 levels due to decarbonization of the regional electricity grid. Transportation Sector GHG emissions decreased to 4.7% below 2012 levels possibly due to the travel and commuting impacts of the COVID-19 pandemic. Waste Sector GHG emissions decreased by 21.8% between 2012 and 2020, but are small compared to the Stationary Energy and Transportation sectors. While Solid Waste GHG emissions will occur from the ongoing disposal of solid waste, closed landfills within the City will produce less GHG emissions as the waste decays.

Despite falling below 2012 levels, the Transportation Sector was the largest source of GHG emissions in Phoenix in 2020. The largest source of Transportation Sector GHG emissions is gasoline and diesel use in private vehicles. The COVID-19 pandemic greatly affected transportation behavior, causing a decrease in gasoline consumption and an increase in diesel consumption between 2018 and 2020. The decrease in Transportation Sector GHG emissions in 2020 will likely be temporary and measures to reduce transportation-related GHG emissions will drive future community-scale GHG emissions. An increased adoption of battery electric vehicles (BEVs), fuel cell electric vehicles (FCEVs), plugin electric hybrid vehicles (PEHVs), or hydrogen vehicles can reduce transportation-related GHG emissions. Another is higher adoption rate of mass transit options.

Introduction

City of Phoenix community-scale GHG emissions were inventoried according to the Greenhouse Gas Protocol for Cities (GPC). The GPC has five GHG emissions sectors – Stationary Energy, Transportation, Waste, Industrial Processes and Product Use (IPPU), and Agriculture, Forestry, and Land Use (AFOLU). The city of Phoenix Community-scale GHG emissions inventory is a BASIC-level inventory. A BASIC-level community GHG emissions inventory includes: all scope 1 emissions from Stationary Energy sources (excluding energy production supplied to the grid, which shall be reported in the scope 1 total); all scope 1 emissions from Transportation sources; all scope 1 emissions from Waste sources (excluding emissions from imported waste, which shall be reported in the scope 1 total); all scope 2 emissions from Stationary Energy sources and transportation; scope 3 emissions from treatment of exported waste. IPPU and AFOLU are not required to be inventoried for BASIC-level reporting under the GPC.

In 2020, community-scale emissions totaled 15,160,180 MT CO_2e, 14.0% decrease below the baseline 2012 level of 17,622,666 MT CO_2e (Table 1). Appendix A contains a detailed breakdown of GPC sector and subsector GHG emissions for the 2012, 2016, 2018, and 2020 inventories. Stationary Energy and Transportation Sectors account for approximately 99% of community-scale GHG emissions. On-road motor gasoline combustion is the single largest source of GHG emissions, and comprises 71% Transportation emissions and 35% of total emissions. The next largest source of GHG emissions is commercial and industrial electricity consumption, which makes up 23% of total emissions. Moreover, the top three emitting sources – on-road motor gasoline consumption, commercial and industrial electricity consumption, and residential electricity consumption – are 78.6% of total emissions. Since GHG emissions from electricity consumption will likely decrease into the future due to the increased decarbonization of the regional electricity grid, GHG emissions from on-road motor gasoline consumption will likely remain the single largest source of GHG emissions for the City. Policies to reduce gasoline consumption across Phoenix are critical to meeting future GHG emissions targets and goals.

Table 1. Community- Level GHG Emissions by Sector for 2012, 2016, and 2018

Sector	GHG Emissions (MT CO_2e)				% Change 2012-20
	2012	2016	2018	2020	
Stationary Energy	9,431,639	8,810,561	8,552,674	7,406,849	**-21.5%**
Transportation	7,823,097	8,255,732	8,464,774	7,461,649	**-4.6%**
Waste	367,931	316,170	304,066	287,850	**-21.8%**
Total	**17,622,666**	**17,382,463**	**17,321,514**	**15,156,347**	**-14.0%**

The observed decreases in community-scale GHG emissions were driven by the regional electricity grid becoming less GHG-intensive. GHG emissions from electricity production fell by 2,024,790 MT CO_2e (21.5%) between 2012 and 2020. Transportation

Sector GHG emissions decreased by 357,614 MT CO_2e (4.6%). Waste GHG emissions, which are approximately 2% of community-scale GHG emissions, decreased by 80,081 MT CO_2e (21.8%) between 2012 and 2020. Per capita GHG emissions fell by 23.3% from 11.75 to 9.02 MT CO_2e per resident between 2012 and 2020 (Figure 1).

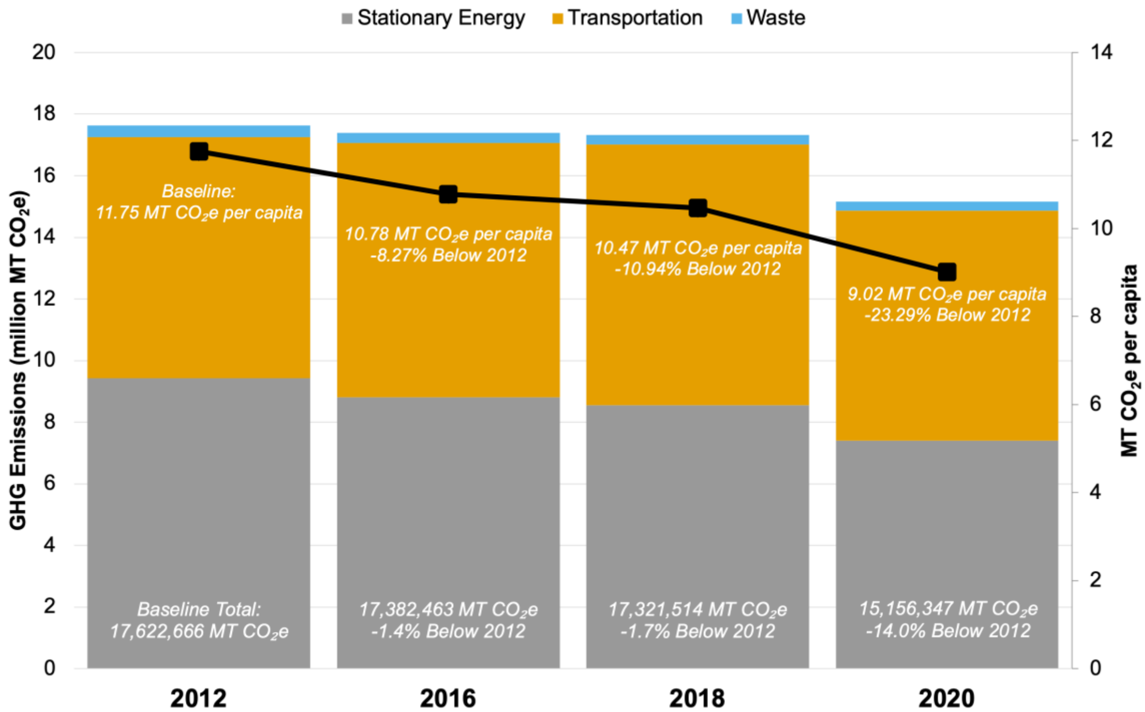


Figure 1. Total GHG Emissions and Per Capita GHG Emissions Since 2012

GHG emissions are assigned to scopes based on where the emitting activity occurs. Scope 1 GHG emissions occur directly within city boundaries from transportation activities, natural gas combustion, and waste disposal. Scope 2 GHG emissions are indirect GHG emissions through the purchase of grid-supplied energy, such as electricity and do not necessarily occur within city boundaries. Scope 3 GHG emissions are other indirect emissions from waste disposed of outside the city boundary. In 2020, 55% of GHG emissions occurred directly within the city boundary as Scope 1 emissions; 44% occurred indirectly as Scope 2 emissions through the purchase of electricity; and approximately 1% occurred indirectly as Scope 3 emissions from waste disposed of outside the city boundary (Table 2)

Table 2. 2018 Community-Level GHG Emissions by Sector and Scope

Sector	GHG Emissions (MT CO_2e)			
	Scope 1	Scope 2	Scope 3	Total
Stationary Energy	788,752	6,618,097	264,434	**7,406,849**
Transportation	7,448,545	13,104	548	**7,461,649**
Waste	139,649	0	148,200	**287,850**
Total	**8,376,946**	**6,631,201**	**148,200**	**15,156,347**

**Scope 3 Stationary Energy and Transportation GHG emissions do not count toward the BASIC-level GHG emissions total.*

In 2020, Stationary Energy activities – GHG emissions resulting from natural gas combustion and electricity consumption – accounted for approximately 48.8% of community-scale GHG emissions. Transportation activities comprise approximately 49.3%. Community-scale Transportation Sector GHG emissions have increased relative to Stationary Energy Sector GHG emissions since 2012. Gasoline combustion produced 71% of Transportation GHG Sector emissions within city boundaries. The two largest sources of GHG emissions produced 78.6% of total community-scale GHG emissions – electricity consumption (43.6%) and gasoline combustion (35.0%). Community-level GHG mitigation efforts should prioritize these two sources of GHG emissions to achieve material GHG emissions reductions.

Recent plant closures and announcements by Arizona Public Service[2] (APS), Salt River Project[3] (SRP) and the Public Service Company of New Mexico[4] (PNM) to retire and replace coal-fired power plants with generation sources that are less carbon intensive will result in significant reductions to community-scale GHG emissions. The single largest GHG emissions source in the regional electricity grid – the Navajo Generating Station operated by SRP – closed in 2019. In fact, the measure of the carbon intensity of the electricity grid – fell by 17.3% between 2018 and 2020.

Motor gasoline consumed for on-road transportation is the single largest GHG emitting activity in Phoenix. These emissions grew between 2012 and 2018, but fell back to 2012 levels in 2020 largely due to the COVID-19 pandemic. GHG emissions from gasoline consumption will likely rebound as activities return to pre-pandemic levels. Therefore, the viability and cost effectiveness of strategies to reduce GHG emissions from Transportation activities, specifically on-road motor gasoline consumption, will drive future community-scale GHG emissions and the ability to meet GHG emissions reductions goals.

[2] Arizona Public Service (2020). Stakeholder Perspectives. URL: https://www.aps.com/en/About/Our-Company/Clean-Energy/Stakeholder-Perspectives
[3] Salt River Project (2019). Navajo Generating Station Permanently Shuts Down. URL: https://media.srpnet.com/navajo-generating-station-permanently-shuts-down/
[4] PNM (2020). Our Commitment. URL: https://www.pnm.com/our-commitment

1. Stationary Energy Sector

Stationary Energy GHG emissions are predominantly Scope 2 emissions, which occur from electricity consumption (Figure 2). These emissions occur due to the combustion of natural gas (Scope 1) and the consumption of purchased electricity (Scope 2). Scope 2 Stationary Energy GHG emissions are the second largest of Phoenix's GHG emissions sources, comprising 48.9% of community-scale emissions in 2012; 46.1% in 2016; 44.9% in 2018; and 43.7% in 2020. However, because the carbon intensity of the regional electricity grid decreased significantly, electricity-related GHG emissions decreased 23% between 2012 and 2020 despite electricity consumption increasing 4.7%.

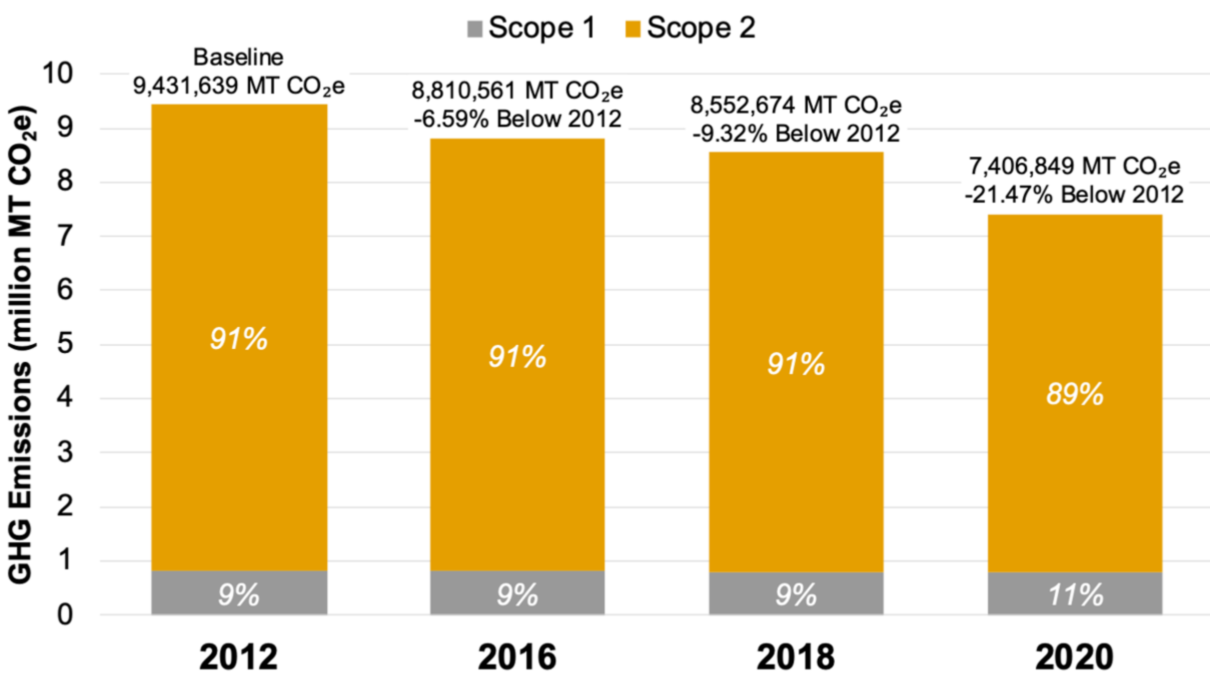


Figure 2. Stationary Energy GHG Emissions by Scope Since 2012

Electricity GHG emissions are calculated using electricity consumption data (activity data) and GHG emissions factors published by the EPA in the eGRID.[5] The Arizona-New Mexico (AZNM) subregion GHG emissions factor is used to calculate electricity GHG emissions. An eGRID subregion emissions factor is not utility-specific, and characterizes the typical GHG profile of electricity generation in that area in CO_2e emissions per MWh of net generation. The AZNM subregion includes power plants in Arizona, Western and Central New Mexico, Southern Nevada, and parts of

[5] The eGRID database inventories plant-level environmental attributes of electric power generation and its effect on air emissions for every power plant in the United States. Phoenix is in the Arizona and New Mexico (AZNM) subregion. The Emissions & Generation Resource Integrated Database (eGRID), developed by the EPA in collaboration with the Energy Information Administration (EIA), the North American Electric Reliability Corporation (NERC), and the Federal Energy Regulatory Commission (FERC), is a comprehensive source of data on the environmental characteristics of almost all electric power generated in the United States. Detailed information can be found at http://www.epa.gov/cleanenergy/energy-resources/egrid/index.html.

southwestern California. Since 2012, the AZNM subregion GHG emissions factor has decreased 26.6% due to increased natural gas and renewable electricity generation, and most importantly, a decrease in coal-fired electricity generation. The largest source of GHG emissions in the AZNM subregion, SRP's coal-fired Navajo Generating Station, closed in 2019.[6] Between 2018 and 2020, the AZNM subregion GHG emissions factor dropped 17.3%, contributing to a substantial decrease in Phoenix's GHG emissions. Two factors were largely responsible for the observed decrease in the AZNM subregion GHG emissions factor: (1) the closure of the Navajo Generating Station (NGS) coal-fired plant and (2) new generation brought online between 2018 and 2020 were mostly carbon-neutral electricity sources.[7,8] Looking to the future, SRP has a long-term goal of reducing the GHG-intensity of electricity production 65% below 2005 levels by 2035 and 90% by 2050[9]; APS has stated it will cease using coal to generate electricity by 2031[10] and has a carbon neutrality goal for 2050[11]; PNM plans to generate 100% carbon free electricity by 2040.[12] Utility plans to reduce the GHG-intensity of electricity generation will significantly reduce Phoenix's GHG emissions even further.

1.1 Scope 1 Stationary Energy

Scope 1 Stationary Energy GHG emissions occur, in part, from natural gas combustion within the city boundary. In 2020, citywide natural gas consumption was 2.9% greater than 2012 levels and 13.6% greater than 2018 levels (Table 3).

Table 3. Summary of Scope 1 Stationary Energy GHG Emissions

Scope 1 Activity Data (kilotherms)	**2012**	**2016**	**2018**	**2020**
Residential Buildings	58,796	58,946	53,241	60,479
Commercial & Industrial Buildings	63,802	69,036	83,367	65,688
Manufacturing Industries & Construction	16,289	13,850	1,562	13,632
Agriculture, Fishing, and Forestry Activities	12,982	9,737	8,744	8,564
Non-specified	11	15	14	23
Total	**151,881**	**151,584**	**146,927**	**148,386**

Scope 1 GHG Emissions (MT CO_2e)	**2012**	**2016**	**2018**	**2020**
Residential Buildings	312,298	313,330	283,007	321,480
Commercial & Industrial Buildings	338,887	366,966	443,139	349,167
Manufacturing Industries & Construction	86,522	73,622	8,303	72,459

[6] Salt River Project (2019). Navajo Generating Station Permanently Shuts Down. URL: https://media.srpnet.com/navajo-generating-station-permanently-shuts-down/
[7] Environmental Protection Agency (2020). eGRID2018 Unit, Generator, Plant, State, Balancing Authority Area, eGRID Subregion, NERC Region, U.S., and Grid Gross Loss (%) Data Files.
[8] Environmental Protection Agency (2022). eGRID2020 Unit, Generator, Plant, State, Balancing Authority Area, eGRID Subregion, NERC Region, U.S., and Grid Gross Loss (%) Data Files
[9] Salt River Project (2022). 2035 Sustainability Goals Delivering today, shaping tomorrow. URL: https://www.srpnet.com/environment/sustainability/2035-goals.aspx. Accessed 10 March 2022.
[10] Arizona Public Service (2020). Clean Energy. URL: https://www.aps.com/en/About/Our-Company/Clean-Energy
[11] Arizona Public Service (2020). Stakeholder Perspectives. URL: https://www.aps.com/en/About/Our-Company/Clean-Energy/Stakeholder-Perspectives
[12] PNM (2020). Our Commitment. URL: https://www.pnm.com/our-commitment

Agriculture, Fishing, and Forestry Activities	68,954	51,758	46,477	45,523
Non-specified	60	78	74	123
Total	**806,722**	**805,753**	**781,000**	**788,752**

Scope 1 Stationary Energy GHG emissions fell by 25,722 MT CO_2e below 2012 levels (Figure 3). Natural gas consumption at commercial and institutional buildings are the largest source of Scope 1 Stationary Energy GHG emissions. In 2012, Scope 1 Stationary Energy GHG emissions from commercial and institutional buildings and facilities subsector were only slightly higher than the residential buildings subsector, 42% and 39% respectively. In 2018, the commercial and institutional buildings and facilities subsector comprised 57% of Scope 1 Stationary Energy GHG emissions.

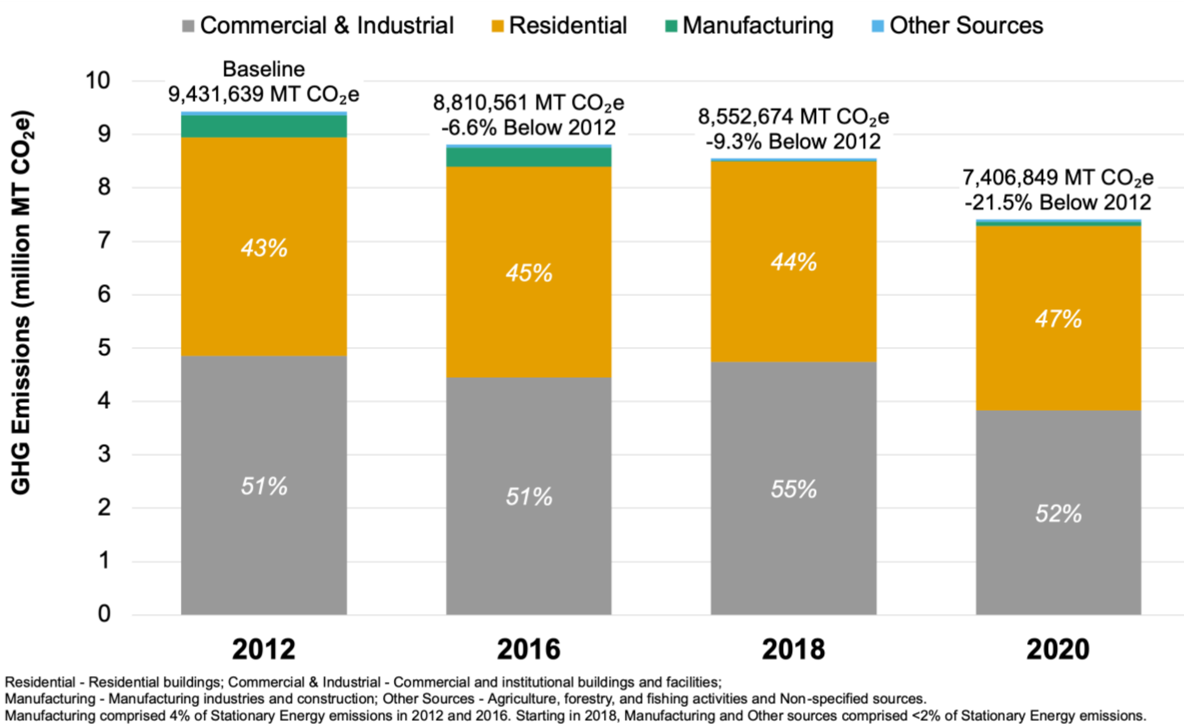


Figure 3. Scope 1 Stationary GHG Emissions Since 2012

1.2 Scope 2 Stationary Energy

Scope 2 Stationary Energy GHG emissions occur from the consumption of electricity purchased from APS and SRP within the city boundary. Between 2012 and 2020, electricity increased 4.7% (809,198 MWh) and between 2018 and 2020, electricity increased 2.9% (508,825 MWh) (Table 4). In 2020, Scope 2 Stationary Energy GHG emissions were 6,618,097 MT CO_2e, which was 23.3% below 2012 levels (Figure 4). Stationary Energy GHG emissions decreased due to the regional electricity grid becoming 35.4% less GHG-intensive between 2012 and 2020 from the retirement and replacement of coal-fired power plants with natural gas and renewable (wind and solar) electricity generation.[13] Additionally, between 2012 and 2020, commercial and industrial electricity consumption only grew 5.1% during a period in which GDP grew approximately 41.6%. The decreased growth in electricity consumption relative to economic growth could have occurred for numerous reasons, including energy efficiency retrofits, energy efficient new construction, and commercial solar adoption. Further work is recommended to explore the extent each of these factors contributed to the decreased growth in electricity consumption.

Table 4. Summary of Scope 2 Stationary Energy GHG Emissions

Scope 2 Activity Data (GWh)	**2012**	**2016**	**2018**	**2020**
Residential Buildings	7,202	7,620	7,444	8,132
Commercial & Industrial Buildings	8,599	8,579	9,220	9,046
Manufacturing Industries & Construction	627	612	IE	IE
Total	**16,428**	**16,815**	**16,671**	**17,199**

Scope 2 GHG Emissions (MT CO_2e)	**2012**	**2016**	**2018**	**2020**
Residential Buildings	3,781,025	3,625,943	3,469,145	3,135,523
Commercial & Industrial Buildings	4,514,711	4,087,840	4,302,529	3,482,574
Manufacturing Industries & Construction	329,182	291,025	IE	IE
Total	**8,624,917**	**8,004,808**	**7,771,674**	**6,618,097**

**In 2018, Manufacturing industries and construction were IE in Commercial and institutional buildings. Scope 2 Stationary Energy GHG emissions from Energy Industries; AFFA; and Non-Specified Sources were assumed to be included elsewhere (IE) and, therefore, not included in this table. Scope 2 Stationary Energy GHG emissions Fugitive Emissions from MPST; and Fugitive Emissions from ONGS were NE and, therefore, not included in this table*

[13] The Emissions & Generation Resource Integrated Database (eGRID), developed by the EPA in collaboration with the Energy Information Administration (EIA), the North American Electric Reliability Corporation (NERC), and the Federal Energy Regulatory Commission (FERC), is a comprehensive source of data on the environmental characteristics of almost all electric power generated in the United States. Detailed information can be found at http://www.epa.gov/cleanenergy/energy-resources/egrid/index.html. The 11.2% reduction in the GHG intensity of the regional electricity was calculated comparing the 2012 and 2018 emissions factor for the Arizona-New Mexico subregion.

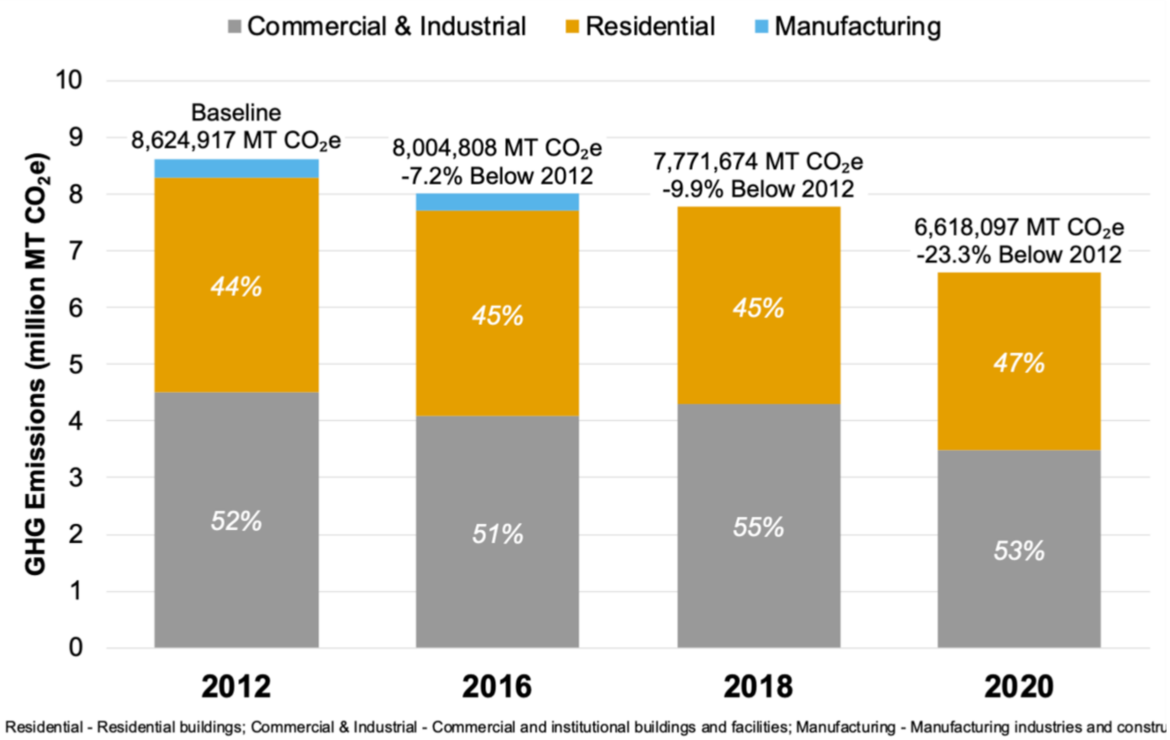


Figure 4. Scope 2 Stationary GHG Emissions Since 2012

1.3 Scope 3 Stationary Energy

Scope 3 Stationary Energy GHG emissions occur from transmission and distribution loss in the state's electricity grid and fluctuates from year-to-year (Table 5). Between 1990 and 2020, transmission and distribution (T&D) loss in the State of Arizona has averaged 4.5% $\pm$ 0.7% of electricity consumption and has ranged between 3.4% in 2015 up to 5.7% in 1996.[14] Scope 3 Stationary Energy GHG emissions are not within the scope of GPC BASIC-level reporting. Nonetheless, these GHG emissions are calculated to show the full extent of GHG emissions from electricity consumption.

Table 5. Summary of Scope 3 Stationary Energy GHG Emissions

Scope 3 Activity Data	2012	2016	2018	2020
Transmission & Distribution Loss (MWh)	613,573	631,792	666,138	685,863
Natural Gas Leakage (therms)	NE	NE	NE	NE
Total	**613,573**	**631,792**	**666,138**	**685,863**

Scope 3 GHG Emissions (MT CO_2e)	2012	2016	2018	2020
Transmission & Distribution Loss (MWh)	322,125	300,632	310,345	264,434
Natural Gas Leakage (therms)	NE	NE	NE	NE
Total	**322,125**	**300,632**	**310,345**	**264,434**

**NE – Not Estimated*

[14] U.S. Energy Information Administration, Form EIA-923, Power Plant Operations Report and predecessor forms. U.S. Energy Information Administration, Form EIA-860, Annual Electric Generator Report. U.S. Energy Information Administration, Form EIA-861, Annual Electric Power Industry Report. Form EIA-111, Quarterly Imports and Exports Report.

2. Transportation Sector

Transportation Sector GHG emissions have Scope 1, 2, and 3 components. Scope 1 Transportation Sector GHG emissions occur due to the combustion of fossil fuels – gasoline, diesel, CNG, LNG, LPG – and biofuel blends – B20 biodiesel and E85 ethanol. Scope 2 Transportation Sector GHG emissions occur from the consumption of electricity to charge plug-in electric vehicles and power electric light rail; and Scope 3 emissions occur from the T&D loss associated with Scope 2 transportation. In 2020, community-scale Transportation sector GHG emissions totaled 7,461,649 MT CO_2e and were 4.6% less than the 2012 levels of 7,823,097 MT CO_2e.

Motor gasoline is the largest source of community-scale Transportation Sector GHG emissions at 71.0% and 35% of all community-scale GHG emissions (Figure 5). Community-level gasoline consumption encompasses all gasoline end uses. While some end uses may not be for transportation purposes (e.g., gasoline lawnmowers), emissions from these end uses were assumed to be insignificant compared to gasoline consumption for motor vehicles.[15] GHG emissions from Jet Fuel A (13.9%) and on-road diesel fuel (8.8%) are the next largest sources of transportation GHG emissions. While Transportation Sector GHG emissions showed a decrease between 2012 and 2020, this may be a result of the COVID-19 pandemic. In previous inventories, GHG emissions from gasoline combustion has grown with population. As growth occurs, viable solutions to reduce gasoline consumption – from EVs and increased mass transit to creating walkable communities – are critical for meeting GHG emissions reductions goals.

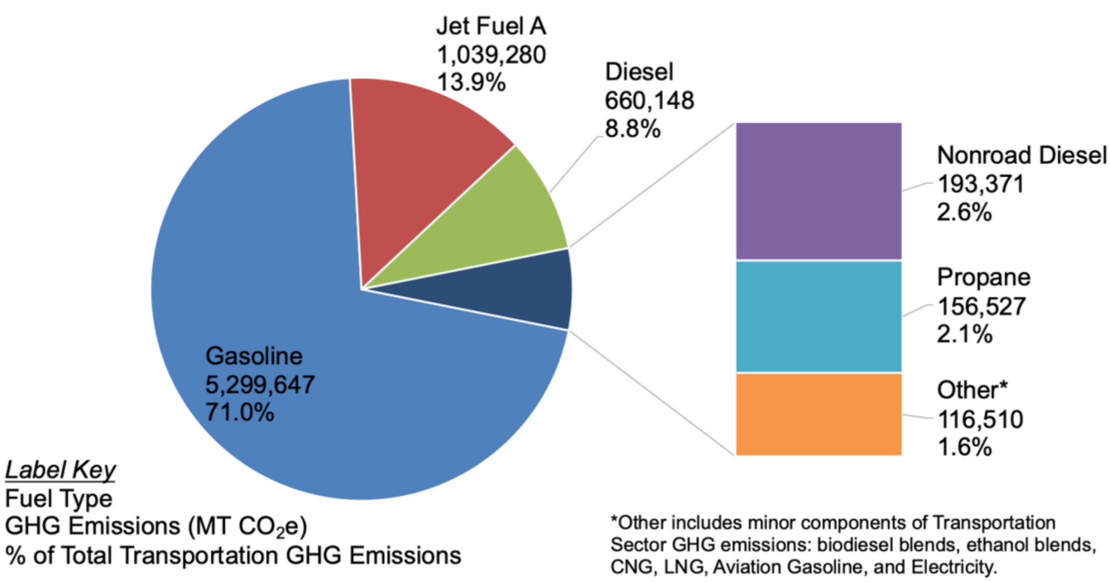


Figure 5. Summary of Transportation Sector GHG Emissions by Fuel Type

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[15] The U.S. Energy Information Administration estimates light-duty vehicles account for 92% of gasoline consumption in the United States. Source: U.S. Energy Information Administration, 2019. Use of Gasoline. URL: https://www.eia.gov/energyexplained/gasoline/use-of-gasoline.php

2.1 Scope 1 Transportation GHG Emissions

Scope 1 Transportation GHG emissions occur from the combustion of fossil fuels and biofuel blends in on-road motor vehicles, commercial and civil aircrafts, freight rail, and nonroad vehicles such as tractors and construction equipment (Table 6). Before 2020, on-road transport GHG emissions growth (12.7%) had largely followed population growth (12.7%). The second largest source of community-scale Transportation sector GHG emissions comes from Commercial Aviation, which is almost primarily from the Phoenix Sky Harbor International Airport. In 2020, Commercial Aviation GHG emissions were revised upwards for all inventory years due to revised source data from the EIA. Community-level GHG emissions from off-road transport, which is the third largest source of community-scale Transportation sector GHG emissions, result from construction equipment, agricultural equipment and mining equipment.

Table 6. Summary of Scope 1 Transportation GHG Emissions (MT CO_2e)

Scope 1 Sources	2012	2016	2018	2020
On-road transport	5,855,292	6,441,344	6,586,630	6,042,566
Railways*	23,545	23,545	23,545	23,545
Commercial Aviation	1,626,397	1,448,210	1,494,963	1,039,280
Civil Aviation	13,392	11,708	16,164	16,801
Nonroad transport	298,237	320,122	326,353	326,353
Total	**7,816,863**	**8,244,929**	**8,447,655**	**7,448,545**

*Freight rail GHG emissions have not been re-estimated since the 2012 community inventory due to constraints with source data.

Gasoline consumption is the major driver of Scope 1 Transportation GHG Emissions (Additionally, the further development and marketability and adoption of hydrogen vehicles will further reduce on-road GHG emissions and should explored as a strategy to displace fossil fuels.

Table 7). Between 2012 and 2020, fuel consumption increased across every fuel type except LNG and B20 biodiesel. The city of Phoenix vehicle fleet – e.g., buses and garbage and recycling trucks – is the primary consumer of LNG and B20 biodiesel. Additionally, the further development and marketability and adoption of hydrogen vehicles will further reduce on-road GHG emissions and should explored as a strategy to displace fossil fuels.

Table 7. Scope 1 Transportation Activity Data and GHG Emissions by Fuel

Scope 1 GHG Emissions (MT CO_2e)	2012	2016	2018	2020
Gasoline [1]	5,250,540	5,797,934	5,917,671	5,299,647
On-Road Diesel[1]	529,242	591,063	617,575	660,148
B20 Biodiesel[1]	24,785	22,062	24,732	35,199
E85 Ethanol[1]	379	207	410	441
E54 Ethanol [1]	0	441	0	0
CNG[1] – *therms*	22,595	18,293	33,391	27,484
LNG[1] – *GGE*	27,751	11,345	2,423	19,647
Jet Fuel A (Commercial Aviation)[2]	698,263	705,643	779,113	1,039,280
Aviation Gasoline (Civil Aviation)[2]	13,394	15,067	10,043	16,801
Railways**	23,545	23,545	23,545	23,545
Nonroad Diesel[3]	148,488	163,595	169,826	169,826
Nonroad LPG[3]	149,749	156,527	156,527	156,527

Total	6,888,732	7,505,722	7,735,257	7,448,545

*Activity Data are reported in gallons unless otherwise noted; NE – Not Estimated. Emissions estimated from EPA National Emissions Inventory; Italicized entries denote Activity Data estimated from EPA National Emissions Inventory; **Emissions estimated from the EPA National Emissions Inventory and not activity data; Transportation Sector: [1]On-Road Sector; [2]Aviation; [2]Off-Road.*

2.2 Scope 2 Transportation GHG Emissions

The 2020 levels of Scope 2 Transportation sector GHG emissions are 172% higher than 2012, but 1.1% lower 2018 levels (Table 8). The growth of Scope 2 Transportation sector GHG emissions is primarily from the increased adoption of plug-in electric vehicles. The estimated electricity consumption by EVs has increased 16-fold since 2012, but EVs are currently a small fraction of the on-road vehicle fleet. GHG emissions related to the Valley Metro light rail system increased 33% due to the expansion of the light rail system since 2012. GHG emissions from electric transport are a small percentage of overall transportation-related GHG emissions (~0.2%). As the regional electricity grid becomes less GHG-intensive over the coming decades, the use of electric personal transport – plugin EVs and plugin hybrid EVs – and electric mass transit – light rail and battery electric buses – will become GHG-saving alternatives to traditional gasoline-powered personal vehicles. Increasing electric-powered transit will require investment in electric mass transit, which is underway through T2050, battery technology improvements, installing a regional charging station network, and consumer-friendly market conditions.

Table 8. Summary of Scope 2 Transportation GHG Emissions

Scope 2 Activity Data (MWh)	2012	2016	2018	2020
On-road transport	1,269	10,608	19,576	20,368
Railways (Light Rail)	10,605	12,095	17,157	13,624
Total	**11,874**	**22,703**	**36,733**	**33,991**

Scope 2 GHG Emissions (MT CO_2e)	2012	2016	2018	2020
On-road transport	666	5,048	9,123	9,490
Railways (Light Rail)	5,568	5,755	7,996	7,447
Total	**6,234**	**10,803**	**17,119**	**16,937**

2.3 Scope 3 Transportation GHG Emissions

Scope 3 Transportation GHG emissions occur from transmission and distribution loss in the state's electricity grid (Table 9). Scope 3 Transportation GHG emissions are not within the scope of GPC BASIC-level reporting and presented for informational purposes. Refer to the ***Scope 3 Stationary Energy*** section for a more detailed discussion on T&D loss in the State of Arizona.

Table 9. Summary of Scope 3 Transportation GHG Emissions

Scope 3 Activity Data (MWh)	2012	2016	2018	2020
On-road transport	47	399	708	852
Railways (Light Rail)	396	454	620	570
Total	**443**	**853**	**1,328**	**1,422**

Scope 3 GHG Emissions (MT CO_2e)	2012	2016	2018	2020
On-road transport	25	190	330	397

Railways (Light Rail)	208	216	289	266
Total	**233**	**406**	**619**	**663**

3. Waste Sector

Waste Sector GHG emissions have both Scope 1 and Scope 3 components (Table 11). Unlike Scope 3 emissions in the Stationary Energy and Transportation sectors, Scope 3 Waste emissions are included within the GPC BASIC-level reporting. Overall, Waste Sector GHG emissions decreased 21.8% (80,081 MT CO2e) between 2012 and 2020.

Table 10. Summary of Waste Sector GHG Emissions

Waste Sector GHG Emissions (MT CO_2e)	2012	2016	2018	2020
Scope 1 Waste Emissions	250,130	156,167	150,118	139,649
Scope 3 Waste Emissions	117,800	160,003	153,948	148,200
Total	**367,931**	**316,170**	**304,066**	**287,850**

Scope 1 Waste Sector GHG emissions include emissions from municipal solid waste and wastewater generated and treated within the city boundary in addition to waste imported into the city and treated (Table 11). Scope 1 Waste Sector sources include the following facilities:

- The 23rd Avenue and 91st Avenue wastewater treatment plants.
- Emissions from composting– the biological treatment of waste –at the 27th Avenue Compost Facility. Prior to 2018, a different facility operated at the 27th Avenue Landfill.
- Closed landfills within in the city of Phoenix boundary. Over time, these emissions will decrease as the biological processes that generate methane decrease. The last city-owned landfill to accept waste within the City boundary closed in 2006 and the last privately-owned landfill to accept waste within the city boundary – the Waste Management Lone Cactus Landfill – closed in 2019.

Table 11. Summary of Scope 1 Waste GHG Emissions

Scope 1 Sources Activity Data (MT CH_4)	2012	2016	2018	2020
Disposal of Solid Waste Generated in the City	8,425	5,099	4,707	4,471
Biological Treatment of Waste Generated in the City	121	83	170	133
Wastewater Generated Inside the City	92	121	135	76
Total	**8,638**	**5,303**	**5,011**	**4,680**

Scope 1 Sources Activity Data (MT N_2O)	2012	2016	2018	2020
Biological Treatment of Waste Generated in the City	9	6	13	10
Wastewater Generated Inside the City	22	23	24	23
Total	**31**	**29**	**37**	**32**

Scope 1 GHG Emissions (MT CO_2e)	2012	2016	2018	2020
Disposal of Solid Waste Generated in the City	235,889	142,771	131,794	125,195
Biological Treatment of Waste Generated in the City	5,802	3,968	8,125	6,360
Wastewater Generated Inside the City	8,440	9,428	10,199	8,094
Total	**250,130**	**156,167**	**150,118**	**139,649**

Scope 3 Waste GHG emissions occur from the disposal of waste generated within the city but disposed outside the city (Table 12). As GHG emissions are expected to increase at the SR-85 landfill, methane capture and reuse programs may become a viable way to reduce waste-related emissions, and offset Scope 1 Stationary Energy GHG emissions from natural gas combustion. Organic waste diversion to the compost facility at 27th Avenue is a viable way to reduce future Waste Sector GHG emissions. Similarly, the capture of digester gas at the 91st Avenue Wastewater Treatment Plant (WWTP) for processing and sale as renewable natural gas (RNG) by Ameresco, Inc. will reduce Waste Sector GHG emissions from wastewater treatment.

Table 12. Summary of Scope 3 Waste GHG Emissions

Scope 3 Sources Activity Data (MT CH_4 Emissions)	2012	2016	2018	2020
Disposal of Solid Waste Generated in the City but Disposed Outside the City at SR-85	295	2,147	2,029	2,301
Disposal of Solid Waste Generated in the City but Disposed Outside the City by Private Haulers	3,912	3,567	3,469	2,992
Total	**4,207**	**5,714**	**5,498**	**5,293**

Scope 3 GHG Emissions (MT CO_2e)	2012	2016	2018	2020
Disposal of Solid Waste Generated in the City but Disposed Outside the City at SR-85	8,260	60,116	56,820	64,416
Disposal of Solid Waste Generated in the City but Disposed Outside the City by Private Haulers	109,540	99,887	97,128	83,784
Total	**117,800**	**160,003**	**153,948**	**148,200**

Appendix A. Detailed GHG Emissions Summary

Appendix A contains tables detailing City of Phoenix community-scale GHG emissions by each GPC sector and subsector.

Table A1. Year-to-Year Comparison of Stationary Energy GHG Emissions

GPC ref No.	Scope	GHG Emissions Source (By Sector and Sub-sector)	Greenhouse Gas Emissions (metric tons CO_2e)			
			2012	2016	2018	2020
I		**Stationary Energy**				
I.1		**Residential Buildings**				
I.1.1	1	Emissions from fuel combustion within the city boundary	312,298	313,330	283,007	321,480
I.1.2	2	Emissions from grid-supplied energy consumed within the city boundary	3,781,025	3,625,943	3,469,145	3,135,523
I.1.3	3	Emissions from transmission and distribution losses from grid-supplied energy consumption	141,216	136,245	138,614	125,284
I.2		**Commercial and institutional buildings and facilities**				
I.2.1	1	Emissions from fuel combustion within the city boundary	338,887	366,966	443,139	349,167
I.2.2	2	Emissions from grid-supplied energy consumed within the city boundary	4,514,711	4,087,840	4,302,529	3,482,574
I.2.3	3	Emissions from transmission and distribution losses from grid-supplied energy consumption	168,618	153,600	171,913	139,151
I.3		**Manufacturing industries and construction**				
I.1.1	1	Emissions from fuel combustion within the city boundary	86,522	73,622	8,303	72,459
I.1.2	2	Emissions from grid-supplied energy consumed within the city boundary	329,182	291,025	IE	IE
I.2.3	3	Emissions from transmission and distribution losses from grid-supplied energy consumption	12,294	10,935	IE	IE
I.4		**Energy Industries**				
I.4.1	1	Emissions from energy used in power plant auxiliary operations within the city boundary	NE	NE	NE	NE
I.4.2	2	Emissions from grid-supplied energy consumed in power plant auxiliary operations within the city boundary	NE	NE	NE	NE
I.4.3	3	Emissions from transmissions and distribution losses from grid-supplied energy consumption in power plant auxiliary operations	NE	NE	NE	NE
I.4.4	1	*Emissions from energy generation supplied to the grid*	986,289	1,200,633	1,391,552	1,659,111
I.5		**Agriculture, forestry and fishing activities**				
I.5.1	1	Emissions from fuel combustion within the city boundary	68,954	51,758	46,477	45,523
I.5.2	2	Emissions from grid-supplied energy consumed within the city boundary	IE	IE	IE	IE

GPC ref No.	Scope	GHG Emissions Source (By Sector and Sub-sector)	Greenhouse Gas Emissions (metric tons CO_2e)			
			2012	2016	2018	2020
I.5.3	3	Emissions from transmission and distribution losses from grid-supplied energy consumption	IE	IE	IE	—
I.6		**Non-specified sources**				
I.1.1	1	Emissions from fuel combustion within the city boundary	60	78	74	123
I.1.2	2	Emissions from grid-supplied energy consumed within the city boundary	IE	IE	IE	IE
I.1.3	3	Emissions from transmission and distribution losses from grid-supplied energy consumption	NO	NO	NO	NO
I.7		**Fugitive emissions from mining, processing, storage, and transportation of coal**				
I.7.1	1	Emissions from fugitive emissions within the city boundary	NO	NO	NO	NO
I.8		**Fugitive emissions from oil and natural gas systems**				
I.8.1	1	Emissions from fugitive emissions within the city boundary	NE	NE	NE	NE

Notation Key	Definition	Explanation
IE	Included Elsewhere	GHG emissions for this activity are estimated and presented in another category of the inventory. The category shall be noted in the explanation.
NE	Not Estimated	Emissions occur but have not been estimated or reported; justification for exclusion shall be noted in the explanation.
NO	Not Occurring	An activity or process does not occur or exist within the city.
C	Confidential	GHG emissions which could lead to the disclosure of confidential information and can therefore not be reported.

Color Key
Sources required for BASIC reporting
Sources required for BASIC+ reporting
Sources included in Other Scope 3
Sources required for territorial reporting
Non-applicable emissions

Scope	Definition
Scope 1	GHG emissions from sources within the city boundary.
Scope 2	GHG emissions occurring as a consequence of the use of grid-supplied electricity, heat, steam and/or cooling within the city boundary.
Scope 3	All other GHG emissions that occur outside the city boundary as a result of activities taking place within the city boundary.

Table A2. Year-to-Year Comparison of Transportation GHG Emissions

GPC ref No.	Scope	GHG Emissions Source (By Sector and Sub-sector)	Greenhouse Gas Emissions (metric tons CO_2e)			
			2012	2016	2018	2020
II		**Transportation**				
II.1		**On-road Transportation**				
II.1.1	1	Emissions from fuel combustion for on-road transportation occurring within the city boundary	5,855,292	6,441,344	6,586,630	6,042,566
II.1.2	2	Emissions from grid-supplied energy consumed within the city boundary for on-road transportation	666	5,048	9,123	7,852
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	25	190	330	329
II.2		**Railways**				
II.2.1	1	Emissions from fuel combustion for railway transportation occurring within the city boundary	23,545	23,545	23,545	23,545
II.2.2	2	Emissions from grid-supplied energy consumed within the city boundary for railways	5,568	5,755	7,996	5,253
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	208	216	289	220
II.3		**Waterborne navigation**				
II.3.1	1	Emissions from fuel combustion for waterborne navigation occurring within the city boundary	NO	NO	NO	NO
II.3.2	2	Emissions from grid-supplied energy consumed within the city boundary for waterborne navigation	NO	NO	NO	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	NO	NO	NO
II.4		**Aviation**				
II.4.1	1	Emissions from fuel combustion for aviation occurring within the city boundary	1,639,788	1,459,918	1,511,127	1,056,081
II.4.2	2	Emissions from grid-supplied energy consumed within the city boundary for aviation	NE	NE	NE	NE

GPC ref No.	Scope	GHG Emissions Source (By Sector and Sub-sector)	Greenhouse Gas Emissions (metric tons CO_2e)			
			2012	2016	2018	2020
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	NE	NE	NE
II.5		**Off-road transportation**				
II.5.1	1	Emissions from fuel combustion for off-road transportation occurring within the city boundary	298,237	320,122	326,353	326,353
II.5.2	2	Emissions from grid-supplied energy consumed within the city boundary for off-road transportation	IE	IE	IE	IE

Notation Key	Definition	Explanation
IE	Included Elsewhere	GHG emissions for this activity are estimated and presented in another category of the inventory. The category shall be noted in the explanation.
NE	Not Estimated	Emissions occur but have not been estimated or reported; justification for exclusion shall be noted in the explanation.
NO	Not Occurring	An activity or process does not occur or exist within the city.
C	Confidential	GHG emissions which could lead to the disclosure of confidential information and can therefore not be reported.

Color Key
Sources required for BASIC reporting
Sources required for BASIC+ reporting
Sources included in Other Scope 3
Sources required for territorial reporting
Non-applicable emissions

Scope	Definition
Scope 1	GHG emissions from sources within the city boundary.
Scope 2	GHG emissions occurring as a consequence of the use of grid-supplied electricity, heat, steam and/or cooling within the city boundary.
Scope 3	All other GHG emissions that occur outside the city boundary as a result of activities taking place within the city boundary.

Table A3. Year-to-Year Comparison of Waste GHG Emissions

GPC ref No.	Scope	GHG Emissions Source (By Sector and Sub-sector)	Greenhouse Gas Emissions (metric tons CO_2e)			
			2012	2016	2018	2020
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	131,794	131,794	131,794	125,195
III.1.2	3	Emissions from solid waste generated within the city boundary and disposed in landfills or open dumps outside the city boundary	117,800	160,003	153,948	148,200
III.1.3	1	*Emissions from waste generated outside the city boundary and disposed in landfills or open dumps within the city boundary*	NO	NO	NO	NO
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	5,802	3,968	8,125	6,360
III.2.2	3	Emissions from solid waste generated within the city boundary but treated biologically outside of the city boundary	NO	NO	NO	NO
III.2.3	1	*Emissions from waste generated outside the city boundary but treated biologically within the city boundary*	NO	NO	NO	NO
III.3		**Incineration and open burning**				
III.3.1	1	Emissions from solid waste generated treated within the city boundary	NO	NO	NO	NO
III.3.2	3	Emissions from solid waste generated within the city boundary but treated outside of the city boundary	NO	NO	NO	NO
III.3.3	1	*Emissions from waste generated outside the city boundary but treated within the city boundary*	NO	NO	NO	NO
III.4		**Wastewater treatment and discharge**				
III.4.1	1	Emissions from wastewater generated and treated within the city boundary	8,440	9,428	10,199	8,094
III.4.2	3	Emissions from wastewater generated within the city boundary but treated outside of the city boundary	NO	NO	NO	NO
III.4.3	1	*Emissions from wastewater generated outside the city boundary but treated within the city boundary*	NO	NO	IE	IE
IV		**Industrial Processes and Product Uses (IPPU)**				
IV.1	1	Emissions from industrial processes occurring within the city boundary	NE	NE	NE	NE
IV.2	1	Emissions from product use occurring within the city boundary	NE	NE	NE	NE
V		**Agriculture, Forestry, and Other Land Use (AFOLU)**				
V.1	1	Emissions from livestock within the city boundary	NE	NE	NE	NE

GPC ref No.	Scope	GHG Emissions Source (By Sector and Sub-sector)	Greenhouse Gas Emissions (metric tons CO_2e)			
			2012	2016	2018	2020
V.2	1	Emissions from land within the city boundary	NE	NE	NE	NE
V.3	1	Emissions from aggregate sources and non-CO_2 emissions sources on land within the city boundary	NE	NE	NE	NE
VI		**Other Scope 3**				
VI.1	3	Other Scope 3	3,001	483	564	800

Notation Key	Definition	Explanation
IE	Included Elsewhere	GHG emissions for this activity are estimated and presented in another category of the inventory. The category shall be noted in the explanation.
NE	Not Estimated	Emissions occur but have not been estimated or reported; justification for exclusion shall be noted in the explanation.
NO	Not Occurring	An activity or process does not occur or exist within the city.
C	Confidential	GHG emissions which could lead to the disclosure of confidential information and can therefore not be reported.

Color Key
Sources required for BASIC reporting
Sources required for BASIC+ reporting
Sources included in Other Scope 3
Sources required for territorial reporting
Non-applicable emissions

Scope	Definition
Scope 1	GHG emissions from sources within the city boundary.
Scope 2	GHG emissions occurring as a consequence of the use of grid-supplied electricity, heat, steam and/or cooling within the city boundary.
Scope 3	All other GHG emissions that occur outside the city boundary as a result of activities taking place within the city boundary.

Appendix B. DRAFT GHG Emissions from Agriculture, Forestry, and Land Use (AFOLU) and Food Systems

The 2020 community GHG emissions inventory represents the first attempt at cataloging GHG emissions for the AFOLU sector (Figure 1). AFOLU GHG emissions are required for BASIC+ GHG inventory reporting, but optional for the current BASIC-level GHG inventory reporting undertaken by the City of Phoenix and most cities. However, as AFOLU emissions will be required for future GHG C40 reporting, these initial efforts lay groundwork for comprehensive AFOLU emissions reporting for the 2022 community GHG emissions report and beyond.

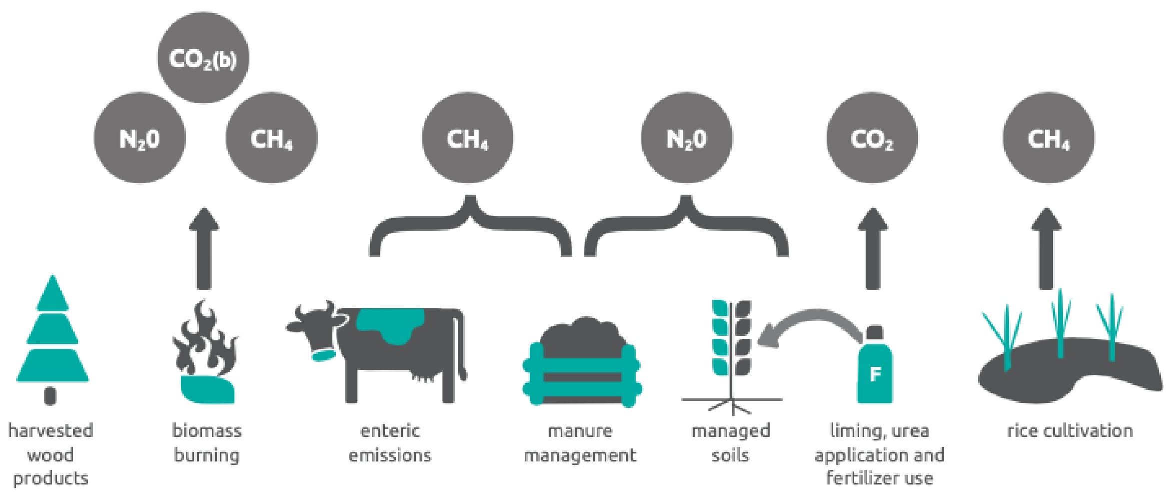

Figure B6. Sources of AFOLU GHG Emissions[16].

AFOLU emissions broadly fall into three categories: livestock; land; and aggregate sources and non-CO_2 emissions sources on land. As shown in Figure 1, some AFOLU emissions are relevant to the City of Phoenix and some are not. For example, changes in GHG emissions resulting from harvested wood products and rice cultivation are not relevant to the City of Phoenix. Biomass burning, through the combustion residential firewood; livestock emissions from enteric digestion and manure management; and CO_2 and non-CO_2 GHG emissions from agricultural soil management are relevant to the City of Phoenix. Additionally, changes in carbon stocks from land types and land use change are another highly relevant component of the City of Phoenix's AFOLU sector. This initial attempt at inventorying AFOLU GHG emissions will present estimation methods and results for livestock GHG emissions and a framework for calculating GHG

[16] Image Source: Greenhouse Gas Protocol. (n.d.). GHG Protocol for Cities | Greenhouse Gas Protocol. Retrieved from http://www.ghgprotocol.org/greenhouse-gas-protocol-accounting-reporting-standard-cities

emissions from land and land use change and aggregate sources and non-CO_2 emissions sources on land.

B.1 Livestock

Livestock GHG emissions fall into two categories: enteric fermentation and manure management. Livestock populations drive the estimation of these GHG emissions. Variations in livestock population estimation methods can create large ranges of potential GHG emissions. Summary city-level livestock GHG emissions reflect the uncertainty inherent to estimated livestock population levels. In 2020, total livestock GHG emissions occurring in the City of Phoenix were estimated to be 3,368 to 94,702 MT CO_2e. GHG Emissions from enteric fermentation were estimated to be 2,965 to 77,176 MT CO_2e and the emissions from manure management estimated to be 674 to 17,526 MT CO_2e.

Enteric fermentation by livestock – cattle, horses, sheep, swine, goats, American bison, and the non-horse equines (mules and asses) – results in the emissions of methane (CH_4). While numerous animals contribute to livestock-related GHG emissions, cattle are the primary source of livestock GHG emissions. In 2019 at the state-level, cattle were responsible for the emission of 82,378 MT CH_4 via enteric fermentation while all other livestock types emitted 2,935 MT CH_4[17]. Similarly, cattle, and moreover dairy cattle, were responsible for the vast majority of CH_4 emissions from manure management. In 2019 at the state-level, cattle were responsible for emitting 24,183 MT CH_4 of the state’s total 28,632 MT CH_4 resulting from livestock manure management[18]. Likewise, cattle were responsible for emitting 1,176 MT N_2O the state’s total 1,218 MT N_2O resulting from livestock manure management[19].

Estimates on the number of livestock head per livestock type – cattle, horses, sheep, swine, goats, American bison, and the non-horse equines (mules and asses) – are required to estimate livestock GHG emissions from the City of Phoenix. These data were obtained from the United States Department of Agriculture’s Census of Agriculture. However, the Census of Agriculture is published every 5-years for years ending in 2 and 7, and not published yearly[20]. For this, reason the 2017 Census of Agriculture was used to estimate livestock GHG emissions.

Census of Agriculture data on the number of livestock (head) are available at the state and county geographic scales, but not at the city geographic scale. However, data on the number and size of livestock operations are available at the zip code level. Using these constraints, a scaling factor was developed for each livestock category; the ratio of livestock operations in City of Phoenix zip codes to livestock operation in the county.

[17] U.S. EPA. 2022. Draft Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2020. Appendix 3, Part B. U.S. Environmental Protection Agency, EPA 430-P-22-001. https://www.epa.gov/ghgemissions/draft-inventory-us-greenhouse-gas-emissions-and-sinks-1990-2020.
[18] Ibid.
[19] Ibid.
[20] United States Department of Agriculture. National Agricultural Statistics Service - Census of Agriculture. URL: https://www.nass.usda.gov/AgCensus/.

This analysis found 151 cattle operations related with City of Phoenix zip codes and 610 cattle operations county-wide; 33 sheep operations related with City of Phoenix zip codes and 96 county-wide; and 20 swine operations associated with City of Phoenix zip codes and 104 hog operations county-wide[21]. It should be noted that these estimates provide an upper bound on livestock estimates for the City of Phoenix because they take into account the full zip code area, and zip codes located on the periphery of the city boundary, which are more likely to contain livestock operations, may contain a livestock operation though the livestock operation is not physically within the city boundary. Additionally, this analysis revealed numerous livestock operations associated with zip codes in the city center. Therefore, Census of Agriculture zip code level data may be associated with the physical address of the company owning the livestock operation, but not the physical location of the operation itself. Further, City of Phoenix code specifies which animals are allowed to be owned within the city boundary and city code currently forbids swine ownership within city limits except for certain types of pet pigs. Taking these factors into account, zip codes on the periphery of the city with livestock operations and city code, a more realistic upper bound estimated is 2-52 cattle operations, 0-19 sheep operations, and 0 swine operations. It should be noted that a satellite imagery evaluation of the Census of Agriculture data could only located two dairy facilities physically within the City of Phoenix boundary, while most were located adjacent to the city boundary in unincorporated county islands.

In the 2017 Census of Agriculture, Maricopa County had an estimated 210,980 cattle; 2,575 sheep and lamb; and 1,124 hogs and pigs[22]. Using the scaling factors described in the previous paragraph, the estimated City of Phoenix cattle population was 692-17,985 cattle; 0-510 sheep, and 0 swine. It should be noted that the horse population of the City of Phoenix was not estimated as these data were not available in the Census of Agriculture. Livestock emissions from enteric fermentation and manure management are calculated by multiplying livestock population by animal type by animal type emissions factors[23]. Animal type emissions factors were obtained and derived from the U.S. EPA's *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2020*[24]*.* Table B1 shows estimated GHG emissions from enteric termination.

Table B13. Estimated CH_4 Emissions from Enteric Fermentation in the City of Phoenix

Livestock	Head	CH_4 Emissions Factor (kg CH_4 per head per year)	CH_4 Emissions (MT CH_4)	CH_4 Emissions (MT CO_2e)
Cattle	692 – 17,985	153.00	106 – 2,752	2,965 – 77,048
Sheep and Lamb	0 – 510	9.00	0 – 459	0 – 128.43
Swine	0	1.50	0	0
Total	**–**	**–**	**106 – 3,211**	**2,965 – 77,176**

[21] USDA National Agricultural Statistics Service. (2017). NASS - Quick Stats. USDA National Agricultural Statistics Service. https://data.nal.usda.gov/dataset/nass-quick-stats. Accessed 2022-02-18.
[22] Ibid.
[23] Greenhouse Gas Protocol. (n.d.). GHG Protocol for Cities | Greenhouse Gas Protocol. Retrieved from http://www.ghgprotocol.org/greenhouse-gas-protocol-accounting-reporting-standard-cities
[24] EPA. 2022. Draft Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2020. Appendix 3, Part B. U.S. Environmental Protection Agency, EPA 430-P-22-001. https://www.epa.gov/ghgemissions/draft-inventory-us-greenhouse-gas-emissions-and-sinks-1990-2020.

Table B2 shows estimated GHG emissions from manure management, which is several times lower than the emissions from enteric fermentation.

Table B14. Estimated CH_4 Emissions from Manure Management in the City of Phoenix

Livestock	Head	CH_4 Emissions Factor (kg CH_4 per head per year)	CH_4 Emissions (MT CH_4)	CH_4 Emissions (MT CO_2e)
Cattle	692 – 17,985	23.82	16 – 428	462 – 11,995
Sheep and Lamb	0 – 510	0.21	0 – 0.11	0 – 3.00
Swine	0	416.73	0.00	0.00
Total	**–**	**–**	**16 – 428.11**	**462 – 11,998**

Table B3 shows estimated N_2O emissions from manure management. This is the smallest component of the GHG emissions emitted from the livestock sector.

Table B15. Estimated N_2O Emissions from Manure Management in the City of Phoenix

Livestock	Head	N_2O Emissions Factor (kg N_2O per head)	N_2O Emissions (MT N_2O)	N_2O Emissions (MT CO_2e)
Cattle	692-17,985	1.16	0.80-21	212-5,519
Sheep and Lamb	0-510	0.07	0-0.03	0-8.83
Swine	0	0.00	0.00	0.00
Total	**–**	**–**	**0.80 – 21.03**	**215 – 5,271**

Finally, Table B4 shows = total estimated GHG emissions by livestock type for both enteric fermentation and manure management.

Table B16. Estimated GHG Emissions from Manure Management in the City of Phoenix

Livestock	Head	CH_4 Emissions (MT CO_2e)	N_2O Emissions (MT CO_2e)	Total Emissions (MT CO_2e)
Cattle	692 – 17,985	3,426 – 89,043	212 – 5,519	3,368 – 94,562
Sheep and Lamb	0 – 510	0 – 131	0 – 9	0 – 140
Swine	0	0	0	0
Total	**–**	**3,426 - 89,174**	**212 – 5,528**	**3,368 - 94,702**

B.2 Land Use & Land Use Change

Land sector GHG emissions fall into two broad categories: GHG emissions from the changes in carbon stocks from land use and from changes in carbon stocks resulting from land use change. Changes in carbon stock from both land use and land use change requires in depth analysis on carbon stock by land use type in the City of Phoenix. This section contains a reproducible method for creating the land use and land use change data required for calculating the change in carbon stocks to calculate Land Use GHG emissions.

There are multiple comprehensive land cover databases that are open source and free to download. However, two provide a long history of comparable data for this analysis. First, the USDA Cropland Data Layer (CDL), which dates to 2008, is a satellite imagery data product that contains information on crop types under cultivation at 30-to-56-meter resolution for the continental United States[25]. The Cropland Data Layer provides high resolution of land cover type by crop, natural landcover, and type of urban settlement. Second, is the National Land Cover Database (NLCD) produced by the United States Geological Survey, provides land cover data on 16 land cover classes at a 30-meter resolution[26]. Since NLCD data date to 2001 and have a consistent resolution over time, these data were used to develop the method. However, CDL data could be used in the future to provide greater resolution for crop-specific carbon stock and soil management GHG emissions estimations.

A detailed summary of land use types by area, and changes between 2001 and 2019, within current City of Phoenix boundaries is shown below in Table B5. Definitions of these land use types can be found at the Multi-Resolution Land Characteristics Consortium website.[27]

Table B17. Estimated Land Use by Type in the City of Phoenix Between 2001 and 2019

Land Cover (sq mi.)	Year								
	2001	2004	2006	2008	2011	2013	2016	2019	Change 2001-19
Open Water	1.1	1.1	1.1	1.2	1.4	1.4	1.1	1.1	-0.1
Developed, Open Space	26.4	26.6	28.7	30.1	31.9	30.7	30.9	30.9	4.5
Developed, Low Intensity	69.1	70.6	75.7	80.3	81.3	81.2	81.3	81.1	12.0
Developed, Medium Intensity	128.5	130.4	137.6	144.0	145.7	147.4	148.9	151.8	23.3
Developed, High Intensity	46.5	47.9	50.7	53.3	54.1	55.4	56.2	58.3	11.8
Barren Land	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.0
Shrub, Scrub	224.3	222.5	211.8	199.3	194.6	193.3	191.5	186.6	-37.7
Grassland/Herbaceous	2.3	2.3	2.3	2.3	2.3	2.4	2.6	4.1	1.8

[25] USDA National Agricultural Statistics Service Cropland Data Layer. 2019. Published crop-specific data layer [Online]. Available at https://nassgeodata.gmu.edu/CropScape/ (accessed 14 February 2022; verified 18 February 2022). USDA-NASS, Washington, DC.
[26] Dewitz, J., and U.S. Geological Survey, 2021, National Land Cover Database (NLCD) 2019 Products (ver. 2.0, June 2021): U.S. Geological Survey data release, https://doi.org/10.5066/P9KZCM54
[27] Multi-Resolution Land Characteristics Consortium (n.d.). National Land Cover Database Class Legend and Description [Online]. Available at: https://www.mrlc.gov/data/legends/national-land-cover-database-class-legend-and-description (accessed 22 March 2022; verified 22 March 2022). MRLC, Washington D.C.

Pasture/Hay	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0
Cultivated Crops	30.9	27.7	21.2	18.6	17.9	17.4	16.8	15.3	-15.7
Woody Wetlands	1.0	1.0	0.8	0.8	0.8	0.8	0.8	0.8	-0.2
Emergent Herbaceous Wetlands	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0
Total	**530.5**	**530.5**	**530.5**	**530.5**	**530.5**	**530.5**	**530.5**	**530.5**	**0.0**

A simplified version of Table B5 is shown in Table B6. The Land Cover categories in Table B5 have been condensed to four major categories: open water, developed land, open space/desert, and cropland. Table B6 shows that the growth in developed area has come about from the conversion of cropland and open space/desert land covers.

Table B18. Simplified Table of Land Use by Type in the City of Phoenix Between 2001 and 2019

Land Cover (sq mi.)	Year								
	2001	**2004**	**2006**	**2008**	**2011**	**2013**	**2016**	**2019**	**Change 2001-19**
Open Water	1.1	1.1	1.1	1.2	1.4	1.4	1.1	1.1	-0.1
Developed Land	270.4	275.5	292.7	307.8	313.0	314.8	317.3	322.2	51.7
Open Space/Desert	227.9	226.1	215.3	202.8	198.1	196.8	195.3	191.9	-36.0
Cropland	31.0	27.8	21.3	18.7	18.0	17.5	16.8	15.3	-15.7
Total	**530.5**	**530.5**	**530.5**	**530.5**	**530.5**	**530.5**	**530.5**	**530.5**	**0.0**

As shown in Tables B5 and B6, the growth of developed areas in the City of Phoenix has resulted from the conversion of open space/desert and cropland. Calculating year-over-year changes in carbon stocks from land use and land use types has two major considerations. Land that remains in specified land use category and land that changes between land use categories. Per GPC and IPCC guidance, land use changes that occur within 20 years of the current inventory year need to be accounted for as land use changes, and land use changes that occur more than 20 years before the inventory year are not counted as land use changes. [28] For the 2022 inventory year, the NLCD will provide 20+ year of land cover data to accurately account for this cutoff. However, the fundamental challenge to calculating the change in carbon stocks from land use change within Phoenix boundaries is that established methods do not explicitly consider desert land use types. This first estimate was calculated assuming the grassland land use type.[29] Additional research studies are required to accurately tabulate the change in carbon stocks from land use changes in the City of Phoenix as it is a desert climate.

[28] Greenhouse Gas Protocol. (n.d.). GHG Protocol for Cities | Greenhouse Gas Protocol. Retrieved from http://www.ghgprotocol.org/greenhouse-gas-protocol-accounting-reporting-standard-cities
[29] U.S. EPA. 2022. Draft Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2020. Appendix 3, Part B. U.S. Environmental Protection Agency, EPA 430-P-22-001. https://www.epa.gov/ghgemissions/draft-inventory-us-greenhouse-gas-emissions-and-sinks-1990-2020.

B.3 Aggregate Sources And Non-CO_2 Emissions Sources On Land

GHG emission from aggregate sources and non-CO_2 emissions sources on land were not inventoried in 2022. However, estimates will be co-developed along with the development of Land Use and Land Use Change GHG emissions.

B.4 Food System GHG Emissions

The Food System GHG emissions inventory captures GHG emissions from the production, manufacturing, distribution, and consumption of food products at restaurants and retail establishments. It is a full life cycle GHG emissions inventory of the food consumption patterns of City of Phoenix residents. For 2020, food system GHG emissions were estimated to be approximately 5,591,820 MT CO_2e with a minimum/maximum range of 4,080,490 to 8,511,300 MT CO_2e. In 2020, overall food system GHG emissions for the City of Phoenix resident population, across the lifecycle of food from farm to table, are approximately 37% of total community-scale GHG emissions and may range from 27%-56% of total community-scale GHG emissions.

Numerous methodologies exist to conduct a food system GHG emissions inventory, including consumption-based emissions inventory methods and life cycle analysis (LCA) based methods. The food system GHG emissions estimate for the City of Phoenix uses published average per capita emissions numbers for the entire U.S. food supply chain[30]. Mohareb et al. (2018) conducted a meta-analysis of food system LCAs to establish, "representative carbon footprint values for a diversity of food commodities" for U.S. food consumption that includes "processing, packaging, transportation, distribution, retail, household preparation, and waste disposal[31]." Per capita GHG emissions factors are shown in Table B7.

Table B19. Per Capita Food System U.S. GHG Emissions Intensities for Food Supply Chain Steps[32]

Food System GHG Category	Average	Min	Max
Production & Primary Processing	**1935.8**	**1158**	**3366.1**
Nuts	*8.2*	*5.7*	*10.8*
Fresh Fruit	*33.2*	*13.7*	*68.5*
Added Sugar and Sweeteners	*39.5*	*39.5*	*39.5*
Processed Fruit	*40.4*	*32.8*	*54*
Fish and Seafood	*45.8*	*10*	*84.8*
Fresh Vegetables	*46.9*	*12.6*	*231.6*
Eggs	*47.4*	*20.4*	*100.7*
Processed Vegetables	*53.8*	*34.8*	*82.1*
Grain Products	*57.6*	*35.2*	*75.6*
Fluid Milk	*104.4*	*74.5*	*136.8*
Added Fats and Oils	*115.5*	*68.7*	*262*
Other Dairy Products	*246.6*	*202.7*	*301.6*
Meat	*1096.5*	*607.4*	*1918.1*

[30] Mohareb, E. A., Heller, M. C., & Guthrie, P. M. (2018). Cities' role in mitigating United States food system greenhouse gas emissions. Environmental science & technology, 52(10), 5545-5554.
[31] Ibid.
[32] Mohareb, E. A., Heller, M. C., & Guthrie, P. M. (2018). Cities' role in mitigating United States food system greenhouse gas emissions. Supporting Information. Environmental science & technology, 52(10), 5545-5554.

Secondary Processing	**109.03**	**109.03**	**109.03**
Packaging Materials	**114.12**	**77.97**	**131.22**
Distribution	**238.5**	**214.55**	**264.5**
Retail	**390.6**	**370.79**	**410.41**
Food Service	**179.39**	**179.39**	**179.39**
Grocery Trips	**49.41**	**8.05**	**292.96**
Household	**309.65**	**309.65**	**309.65**
Landfill - Food	**445.04**	**164.71**	**745.12**
Landfill - Sludge	**26.32**	**18.24**	**36.72**
Wastewater	**59.16**	**59.16**	**59.16**
Composting	**3.24**	**0.2**	**4.4**
Emissions	*4.75*	*0.4*	*9.51*
Fertilizer Offset from Composting	*-0.66*	*-0.08*	*-1.72*
Carbon Stored in Land Application	*-0.85*	*-0.12*	*-3.39*
Anaerobic Digesting	**-0.09**	**0.05**	**-0.25**
Emissions	*0.15*	*0.11*	*0.22*
Fertilizer Offset from Composting	*-0.14*	*-0.03*	*-0.28*
Carbon Stored in Land Application	*-0.07*	*-0.03*	*-0.12*
Offset from Electricity	*-0.03*	*0*	*-0.07*
Total Emissions (kg CO2e/cap)	**3860.17**	**2669.79**	**5908.41**

While Table B7 shows all GHG emissions factors developed by Mohareb et al. (2018), the City of Phoenix government operations and community GHG emissions inventories, contain GHG emissions totals from landfilling, composting, and wastewater. In order to avoid double counting within the system, the food system GHG emissions inventory only includes GHG emissions factors from production & primary processing to household use categories (farm-to-table), yield an average per capita emissions total of 3,326 kg CO_2e per capita, a minimum per capita emissions rate of 2,427 kg CO_2e per capita, and a maximum per capita emissions rate of 5,063 kg CO_2e per capita. However, it should be noted GHG emissions from local food production and processing will occur by default.

Given these emissions factors, the estimated food system GHG emissions is 5,591,820 MT CO2e with range of 4,080,490-8,511,300 MT CO_2e (Table B8). As these lifecycle inventory emissions factors are on a per capita basis, they scale with population.

Table B20. Estimated Farm-to-Table GHG Emissions of the City of Phoenix Food System

Inventory Boundary	2012	2016	2018	2020
Resident Population	1,499,274	1,612,199	1,654,675	1,680,992
Food System Minimum GHG Emissions (MT CO_2e)	3,639,383	3,913,500	4,016,608	4,080,490
Food System Average GHG Emissions (MT CO_2e)	4,987,335	5,362,980	5,504,276	5,591,820
Food System Maximum GHG Emissions (MT CO_2e)	7,591,214	8,162,983	8,378,050	8,511,300

A detailed breakdown of 2020 food system GHG emissions by component is shown in Table B9. As shown in numerous studies, meat production, processing, and consumption is the single largest contributor to the City Phoenix’s farm-to-table food system GHG emissions total.

Table B21. Estimated Farm-to-Table GHG Emissions of the City of Phoenix Food System

Food System GHG Category	Average	Min	Max
Production & Primary Processing	**3,254,064**	**1,946,589**	**5,658,387**
Nuts	13,784	9,582	18,155
Fresh Fruit	55,809	23,030	115,148
Added Sugar and Sweeteners	66,399	66,399	66,399
Processed Fruit	67,912	55,137	90,774
Fish and Seafood	76,989	16,810	142,548
Fresh Vegetables	78,839	21,180	389,318
Eggs	79,679	34,292	169,276
Processed Vegetables	90,437	58,499	138,009
Grain Products	96,825	59,171	127,083
Fluid Milk	175,496	125,234	229,960
Added Fats and Oils	194,155	115,484	440,420
Other Dairy Products	414,533	340,737	506,987
Meat	1,843,208	1,021,035	3,224,311
Secondary Processing	**183,279**	**183,279**	**183,279**
Packaging Materials	**191,835**	**131,067**	**220,580**
Distribution	**400,917**	**360,657**	**444,622**
Retail	**656,595**	**623,295**	**689,896**
Food Service	**301,553**	**301,553**	**301,553**
Grocery Trips	**83,058**	**13,532**	**492,463**
Household	**520,519**	**520,519**	**520,519**
Total Emissions (MT CO_2e)	**5,591,820**	**4,080,490**	**8,511,300**

Appendix C. Stationary Energy – Natural Gas Documentation

Appendix C describes the data collection and data processing for obtaining natural gas consumption data and calculating GHG emissions from natural gas combustion. Appendix C also describes any changes to data sources and methodologies in the 2018 community-scale GHG emissions inventory.

C.1 Natural Gas Data Collection

Stationary Energy GHG emissions from the combustion of natural gas occur at residential buildings, commercial and institutional buildings and facilities, manufacturing industries and construction, energy industries, agriculture, forestry, and fishing activities, non-specified sources, fugitive emissions from mining, processing, storage, and transport of coal, and fugitive emissions from oil and natural gas systems. Natural gas consumption data were obtained from the Southwest Gas Corporation (Southwest Gas), which is the only natural gas utility that services the city. Natural gas data were obtained for each GHG emissions inventory as the inventory was being compiled.

A similar data request process was followed for each of the GHG emissions inventory years. For 2012 and 2016, Southwest Gas provided consumption data at the zip code resolution for residential buildings, commercial and institutional buildings and facilities, manufacturing industries and construction, energy industries, agriculture, forestry, and fishing activities, and non-specified sources. For 2018 and 2020, Southwest Gas did not provide zip code level data. Southwest Gas provided total annual consumption data for residential buildings, commercial and institutional buildings and facilities, manufacturing industries and construction, energy industries; agriculture, forestry, and fishing activities, and non-specified sources.

C.2 Natural Gas Data Processing

For 2012 and 2016, zip code level data were scaled to the percentage of land area in a zip code that was within the city. Natural gas consumption data were scaled only for zip codes which contained a fraction of land within and outside the city boundary. Upon follow up evaluation of the natural gas data previously provided by Southwest Gas; it was found that this scaling of natural gas data by the percent area of a zip code with the City of Phoenix was not necessary. Previously, zip code level natural gas consumption was scaled by percent land area within the City boundary. However, a review of the previous 2012 and 2016 datasets found that if a zip code was associated with more than one Phoenix metropolitan area city the consumption was reported for each city associated with that zip code. To avoid under-reporting natural gas consumption, the zip code scaling factors which were used previously were no longer used. For this reason, 2012 and 2016 community-scale GHG emissions from natural gas combustion were revised upwards (See Section Appendix A.3).

Using the data provided by Southwest Gas, the following equation was used to calculate GHG emissions from Stationary Energy natural gas consumption.

$$GHG_{NG,i,j,y} = NG_{i,y} \times CF \times EF_{NG,j}$$

Where, $GHG_{NG,i,j,y}$ = The GHG emissions in metric tons from natural gas (NG) consumption from a Stationary Energy sector (*i*) for a GHG (*j*) for a GHG emissions inventory year (*y*).

$NG_{i,y}$ = Natural gas (NG) consumption from a Stationary Energy sector (*i*) for a GHG emissions inventory year (*y*) in therms.

CF = Conversion factor for converting data reported in therms to million British thermal units (mmBTU).

$EF_{NG,j}$ = The natural gas consumption GHG emissions factor for CO_2, CH_4, N_2O (*j*).

Finally, natural gas consumption GHG emissions were converted to metric tons of carbon dioxide equivalent (MT CO_2e) by multiplying $GHG_{NG,i,j,y}$ by global warming potential $GWP_{AR5,j}$ and summed across GHGs (*j*).

C.3 Changes between inventory years

As mentioned in Section Appendix B.1, the natural gas consumption data for 2012 and 2016 in the 2018 GHG emissions inventory were not scaled unlike the previous 2012 and 2016 GHG emissions inventories. A comparison between the scaled (previously reported) and unscaled natural gas consumption for 2012 and 2016 is shown below in Table C1.

Table C1. Changes to Natural Gas GHG Emissions Due to Updated Scaling Methods

Year	Scaled Natural Gas Use (kilotherms)	Scaled GHG Emissions (MT CO_2e)	Unscaled Natural Gas Use (kilotherms)	Unscaled GHG Emissions (MT CO_2e)	ΔGHG Emissions (MT CO_2e)	% Change
2012	122,983	650,267	151,881	806,722	156,455	24%
2016	128,256	678,147	151,584	805,753	127,606	19%

The result of using unscaled natural gas consumption data increases total Stationary Energy GHG emissions by approximately 2% over reported 2012 and 2016 levels.

Appendix D. Stationary Energy – Electricity Documentation

Appendix C describes the data collection and data processing for obtaining electricity consumption data and calculating GHG emissions from electricity consumption. This appendix also describes any changes to data sources and methodologies in the 2018 community-scale GHG emissions Inventory.

D.1 Electricity Data Collection

Stationary Energy GHG emissions from the consumption of purchased electricity can occur at residential buildings, commercial and institutional buildings and facilities, manufacturing industries and construction facilities, energy industry facilities, agriculture, forestry, and fishing activities, and non-specified sources.

Electricity consumption data for the Community GHG Emissions Inventory were obtained from Arizona Public Service (APS) and the Salt River Project (SRP). APS and SRP are the only electric utilities that provide electricity to consumers within the city boundary. Electricity data were obtained from APS and SRP for each GHG emissions inventory as the inventory was being compiled – i.e., 2012 data were collected while conducting the 2012 community-scale inventory, 2016 data were collected while conducting the 2016 community-scale inventory, and 2018 data were collected while conducting the 2018 community-scale inventory, and 2020 data were collected while conducting the 2020 community-scale inventory.

Both APS and SRP have electricity generation facilities located within the Phoenix metropolitan area, but only APS has an electricity generation facility within city boundaries – the APS West Phoenix Power Plant. The APS West Phoenix Power Plant is a 997 MW natural gas facility located in southwest Phoenix.[33] The APS West Phoenix Power Plant is included in the 2020 community-scale inventory as emissions from energy generation supplied to the grid (eGRID). Emissions from the APS West Phoenix Power Plant are included in this inventory as an information item (Appendix A, GPC ref. no I.4.4), and are not tabulated as part of the community-scale inventory per GPC guidelines. APS West Phoenix Power Plant emissions for 2012, 2016, 2018, and 2020 were obtained from the EPA Greenhouse Gas Reporting Program through the Facility Level Information on GreenHouse gases Tool (FLIGHT).[34]

A similar data request process was followed for each of the GHG emissions inventory years. For 2012 and 2020, APS provided consumption data at the zip code resolution for residential, commercial, and industrial consumers. However, for 2016 and 2018, APS only provided total consumption data for residential, commercial, and industrial

[33] Pinnacle West Capital Corporation (2019). 2018 Annual Report. URL: http://s22.q4cdn.com/464697698/files/doc_financials/annual/2018/Annual-Report_2018_Web.pdf
[34] U.S. Environmental Protection Agency (2019). EPA Greenhouse Gas Reporting Program through the Facility Level Information on GreenHouse gases Tool URL: https://ghgdata.epa.gov/ghgp/main.do

consumers for zip codes associated with the City of Phoenix. Unlike APS, SRP only provided total consumption for residential and commercial consumers within the City of Phoenix.

D.2 Electricity Data Processing

D.2.1 APS Electricity Data Processing

Using the data provided by APS, the following equation was used to calculate GHG emissions from Stationary Energy electricity consumption in 2012 and 2020.

$$GHG_{APS,i,j,scaled,y} = \sum_{z} EC_{APS,i,z,y} \times SF_{i,z,y} \times CF \times EF_{AZNM,j,y}$$

Where, $GHG_{APS,i,j,scaled,2012}$ = The scaled GHG emissions in metric tons from purchased electricity from APS for a Stationary Energy subsector (*i*) for a GHG (*j*) for inventory year (y) 2012 and 2020.

$EC_{APS,i,z,2012}$ = Purchased electricity from APS for a Stationary Energy subsector (*i*) in zip code (z) for inventory year (y) 2012 and 2020.

$SF_{i,z,y}$ = Scaling factor for zip code (*z*) for inventory year (y) 2012 and 2020.. The scaling factor the % of land area in *z* that is within the city boundary. $SF_{i,z,y}$ ranges from near 0 to 1.

CF = Conversion factor to convert kWh to MWh. If data were reported in the MWh, *CF = 1*. If data were reported in kWh than CF = 0.001.

$EF_{AZNM,j,y}$ = The eGRID[35] emissions factor for the AZNM subregion for GHG emissions factor for CO_2, CH_4, N_2O (*j*) for eGRID reporting year (*y)*.

Zip code level data from APS were not available for calendar years 2016 and 2018. Therefore, the 2012 data (SF_{2012}) were used to develop the scaling factors for 2016 and 2018:

$$SF_{APS,2012} = {\sum_{i,z} EC_{APS,i,z,2012} \times SF_{i,z,2012}} \Big/ {\sum_{i,z} EC_{APS,i,z,2012}}$$

Where, $SF_{APS,2012}$ = Is the overall scaling factor for APS data in calendar year 2012. It is the ratio of the total purchased electricity from APS within the city scaled by zip code specific scaling factors to the reported total unscaled purchased electricity from APS within the city.

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[35] The eGRID database inventories plant-level environmental attributes of electric power generation and its effect on air emissions for every power plant in the United States. Phoenix is in the Arizona and New Mexico (AZNM) subregion. The Emissions & Generation Resource Integrated Database (eGRID), developed by the EPA in collaboration with the Energy Information Administration (EIA), the North American Electric Reliability Corporation (NERC), and the Federal Energy Regulatory Commission (FERC), is a comprehensive source of data on the environmental characteristics of almost all electric power generated in the United States. Detailed information can be found at http://www.epa.gov/cleanenergy/energy-resources/egrid/index.html.

$EC_{APS,i,z,2012}$ = Purchased electricity from APS for a Stationary Energy subsector (*i*) in zip code (z) for an inventory year 2012.

$SF_{i,z,2012}$ = Scaling factor for zip code (*z*). The scaling factor the % of land area in *z* that is within the city boundary. $SF_{i,z,2012}$ ranges from near 0 to 1.

Therefore,

$$GHG_{APS,scaled,i,j,y} = \sum_z EC_{APS,i,z,y} \times SF_{APS,2012} \times EF_{AZNM,j,y}$$

.

Where, $GHG_{APS,scaled,i,j,y}$ = The scaled GHG emissions in metric tons from purchased electricity from APSY for a Stationary Energy subsector (*i*) for a GHG (*j*) for an inventory year 2016 or 2018 (*y*).

$SF_{APS,2012}$ = Is the overall scaling factor for APS data in calendar year 2012. It is the ratio of the total purchased electricity from APS within the city scaled by zip code specific scaling factors to the reported total unscaled purchased electricity from APS within the city.

$EF_{AZNM,j,y}$ = The eGRID emissions factor for the AZNM subregion for GHG emissions factor for CO_2, CH_4, N_2O (*j*) for eGRID reporting year (*y*).

Next, electricity consumption for the Lake Pleasant Water Treatment Plant (obtained from the City of Phoenix Government Operations GHG Emissions Inventory) was added to the APS electricity total to account its removal during the scaling process. Finally, GHG emissions from APS electricity consumption were converted to metric tons of carbon dioxide equivalent (MT CO_2e) by multiplying $GHG_{i,j}$ by the GHG-specific global warming potential found in the IPCC AR5 report ($GWP_{AR5,j}$).

D.2.2 SRP Data Processing

For each inventory, SRP provided total residential, commercial, and industrial electricity consumption for accounts within the city boundary. As this data consisted of account holders only within the city boundary, no scaling factor was applied to the data.

Using the data provided by SRP, the following equation was used to calculate GHG emissions from Stationary Energy natural gas consumption.

$$GHG_{SRPi,j,y} = EC_{SRP,i,y} \times CF \times EF_{AZNM,j,y}$$

Where, $GHG_{SRP,i,j,y}$ = The GHG emissions in metric tons from purchased electricity from SRP for a Stationary Energy subsector (*i*) for a GHG (*j*) for an inventory year (*y*).

$EC_{SRP,i,y}$ = Purchased electricity from SRP for a Stationary Energy subsector (*i*) for an inventory year (*y*).

CF = Conversion factor to convert kWh to MWh. If data were reported in the MWh, *CF = 1*. If data were reported in kWH than CF = 0.001.

$EF_{AZNM,j,y}$ = The eGRID emissions factor for the AZNM subregion for GHG emissions factor for CO_2, CH_4, N_2O (*j*) for eGRID reporting year (*y*)..

Finally, GHG emissions from SRP electricity consumption were converted to metric tons of carbon dioxide equivalent (MT CO_2e) by multiplying $GHG_{i,j,y}$ by the GHG-specific global warming potential found in the IPCC AR5 report ($GWP_{AR5,j}$).

D.2.3 Total GHG Emissions from Electricity Consumption

After the GHG emissions from electricity consumption (*EC*) in the SRP and APS service territories were calculated, the following equation was summed across inventory sectors (*i*) and GHGs (*j*) to calculate total GHG emissions from electricity consumption within city boundaries.

$$GHG_{EC,i,j,y} = GHG_{APS,i,j,y} + GHG_{SRP,i,j,y}$$

D.3 Transmission and Distribution Loss (T&D Loss)

GHG emissions from T&D loss were estimated using data obtained from the EIA on Arizona's supply and disposition of electricity from 1990 through 2020.[36] For each inventory year, T&D loss is calculated as the ratio between estimated electricity system losses and the difference between total electricity disposition minus direct use of electricity at power plants.

D.4 Changes between inventory years

For each of the inventory years – 2012, 2016, 2018, and 2020 – electricity consumption has been provided by APS and SRP. SRP data has been provided as an overall total electricity consumption for commercial and residential sectors within City boundaries. For the 2012 community-scale inventory, APS provided zip code level consumption data for commercial, industrial, and residential sectors for zip codes associated with the City. An analysis of this data showed that some of the zip codes with highest reported consumption only had minor portion of the zip code within the City. For example, in the 2012 data the zip code with the highest reported total consumption had less than 1% land area within City boundaries and the zip code with highest reported residential consumption had only 30% land area within City boundaries.

To account for this aspect of the data, a scaling factor was developed to scale reported electricity consumption to City electricity consumption using land area as indicator of electricity consumption. For 2012, a single scaling factor was used, which was a simple ratio of the total area of the City compared to the total area of all zip code for which data was provided. For the 2016 community-scale inventory, the same scaling factor methodology was used because the reported electricity consumption was within 0.5% of 2012 levels. For 2018 community-scale inventory, the scaling methodology was

[36] U.S. Energy Information Administration, Form EIA-923, Power Plant Operations Report and predecessor forms. U.S. Energy Information Administration, Form EIA-860, Annual Electric Generator Report. U.S. Energy Information Administration, Form EIA-861, Annual Electric Power Industry Report. Form EIA-111, Quarterly Imports and Exports Report.

updated for the 2012 data and then applied to 2016 and 2018 data. In the updated method, consumption for each zip code is scaled by the percent land area within the City; electricity consumption for some zip codes are scaled, others are not because those zip codes are entirely within City boundaries. Use of this scaling factor assumes that electricity consumption by customer-type within each zip code is constant through the reporting time period from 2012 to 2018. This assumption and scaling approach may need to be revisited in future community-scale GHG emissions inventories. After data from each zip code are scaled, they are summed to arrive at electricity consumption for the City. The result of this methodological change was to increase GHG emissions from electricity consumption in 2012 and 2016 (Table D1). The 2020 inventory was able to follow the approach of the 2012 inventory because zip-code level data were available.

Table D1. Changes to Scaling Methodologies for Electricity Data

Year	Old Scaling Method		New Scaling Method		ΔGHG Emissions (MT CO_2e)	% Change
	APS Electricity Consumption	GHG Emissions (MT CO_2e)	APS Electricity Consumption	GHG Emissions (MT CO_2e)		
2012 (kWh)*	6,429,328,231	3,102,482	9,873,891,733	4,764,661	1,662,179	54%
2016 (MWh)	5,677,762	2,413,206	9,875,762	4,197,472	1,784,266	74%

**kWh data were provided in 2012; MWh data were provided in 2016 and 2018.*

Appendix E. Transportation Sector Documentation

Transportation Sector GHG emissions are generated by a number of different sources and types of fuel. GHG emissions sources include on-road transport, railways, commercial aviation, civil aviation, and off-road transport. Fuel types consumed gasoline, diesel, B20 biodiesel, E85 ethanol, compressed natural gas (CNG), liquified natural gas (LNG), propane (LPG), aviation gasoline, and jet fuel A. Transportation sector GHG emissions also includes the consumption of purchased electricity to charge electric vehicles and to power electric light rail. Appendix D describes data sources and methods by fuel type.

E.1 Transportation Sector Data Processing

Transportation sector GHG emissions are calculated using a generalized formula.

$$GHG_{i,j,y} = FC_{i,y} \times CF \times EF_{i,j,y}$$

Where,	$GHG_{i,j,y}$ =	The GHG emissions in metric tons from a transportation fuel (*i*) for a GHG (*j*) for an inventory year (*y*).
	$EC_{SRP,i,y}$ =	Fuel consumption of a transportation fuel (*i*) for an inventory year (*y*).
	CF =	Conversion factor to convert fuel consumption data to the units of the emissions factor. A CF is only used when necessary and is equal to 1 when not necessary.
	$EF_{i,j,y}$ =	The GHG emissions factor in metric tons from a transportation fuel (*i*) for a GHG (*j*) for an inventory year (*y*).

Finally, GHG emissions from transportation fuel consumption were converted to metric tons of carbon dioxide equivalent (MT CO_2e) by multiplying $GHG_{i,j,y}$ by the GHG-specific global warming potential found in the IPCC AR5 report ($GWP_{AR5,j}$).

E.2 On-Road Transport

E.2.1 Gasoline and Diesel

Gasoline and diesel consumption for Maricopa County were obtained from the Arizona Department of Transportation (ADOT) via a public records request. Gasoline and diesel gallonage data are reported to the ADOT in order to obtain funds through the Highway User Revenue Fund (HURF). Historic HURF monthly distribution reports are available through ADOT. ADOT HURF reports contain county-level monthly gasoline and use oil (diesel) sales data.[37] As these data were for the entirety of Maricopa County, gasoline and diesel sales data were scaled using a ratio of City of Phoenix and Maricopa County populations. Per GPC guidance, population is an acceptable scaling factor for

[37] Arizona Department of Transportation. Archived Audits and Reports. *Highway User Revenue Fund (HURF).* URL: https://azdot.gov/node/5069.

population-dependent activity data. A future study would be needed to determine if and how driving behaviors differ by Phoenix metropolitan area city.

E.2.2 Alternative Fuel Vehicles – B20 Biodiesel, E85 Ethanol, CNG, LNG

The *City of Phoenix 2018 GHG Emissions Inventory of Local Government Operations* is the primary source of data for alternative fuel consumption and the resulting GHG emissions within the city boundary. It was assumed that local government operations were the largest consumer of these fuels for transportation within the city boundary and other alternative fuel uses were *de minimis*.

E.2.3 Electric Vehicles

GHG emissions from electric vehicles for 2012, 2016 and 2018 haven been added to the community-scale inventory. National data were used to estimate electric vehicle consumption as local data were not available for estimating these GHG emissions. National-level statistics for annual gasoline consumption and electricity use for mobile transportation were obtained from the EIA Annual Energy Outlook. The ratio between electric energy for transportation and the energy in gasoline usage in the U.S. was used as a proxy to estimate citywide residential electric vehicle usage. GHG emissions from electricity consumption from electric vehicles were calculated according to the method in Appendix C, Section C.2.2.

E.3 Railways

E.3.1 Valley Metro Light Rail

Valley Metro light rail electricity consumption data were obtained from two sources. The National Transit Database[38] used for inventory years 2012 and 2016. The National Transit Database is published by the U.S. Department of Transportation and contains various statistics about public transit systems across the United States, including fuel usage. Electricity usage by Valley Metro is reported to the National Transit Database as Valley Metro Rail, Inc. The National Transit Database had not been published for calendar year 2018 during the time in which the 2018 inventory was compiled. Therefore, 2018 electricity consumption by the Valley Metro light rail system was obtained via a public records request of Valley Metro.

For each inventory year, total Valley Metro electricity usage for rail operations were scaled based on ratio of the length of light rail track within the city compared to the overall length of Valley Metro light rail track. GHG emissions from electricity consumption from the Valley Metro light rail were calculated according to the method in Appendix C, Section C.2.2.

[38] U.S. Department of Transportation. The National Transit Database. URL: https://www.transit.dot.gov/ntd.

E.3.1 Freight Rail

The National Emissions Inventory (NEI)[39] published by U.S. EPA was used to gather data on GHG emissions from freight rail activity in Maricopa County. The 2011 NEI was used as a proxy for 2012, 2016, 2018, and 2020. Please refer to the 2016 community-scale GHG emissions inventory report for a summary of methods to estimate Freight Rail GHG emissions.

E.4 Aviation

E.4.1 Commercial Aviation

The Energy Information Administration (EIA) State Energy Data System (SEDS) was used to gather annual data on Jet Fuel A consumption in the State of Arizona. Next, airport operations data were obtained from the Federal Aviation Administration's (FAA) Operations Network (OPSNET) database for the State of Arizona, Phoenix Sky Harbor Airport, and the Phoenix Deer Valley. The FAA OPSNET data were used to calculate the proportion of commercial airport operations that occurred at the Phoenix Sky Harbor and Phoenix Deer Valley airports relative the State of Arizona. Once this annual scaling factors were calculated, they were multiplied by the annual state-level Jet Fuel A consumption to arrive at estimated Jet Fuel A consumption at the two Phoenix airports. This number was then divided by two to only account for takeoffs. It should be noted that EIA SEDS data are subject to revision from year-to-year.

E.4.2 Civil Aviation

The Energy Information Administration (EIA) State Energy Data System (SEDS) was used to gather annual data on Aviation Gasoline consumption in the State of Arizona. Next, airport operations data were obtained from the Federal Aviation Administration's (FAA) Operations Network (OPSNET) database for the State of Arizona, Phoenix Sky Harbor Airport, and the Phoenix Deer Valley. The FAA OPSNET data were used to calculate the proportion of non-commercial airport operations that occurred at the Phoenix Sky Harbor and Phoenix Deer Valley airports relative the State of Arizona. Once this annual scaling factors were calculated, they were multiplied by the annual state-level Aviation Gasoline consumption to arrive at estimated Aviation Gasoline consumption at the two Phoenix airports. This number was then divided by two to only account for takeoffs. It should be noted that EIA SEDS data are subject to revision from year-to-year.

E.5 Off-Road Transportation

E.5.1 Nonroad Diesel

Consumption data for nonroad diesel (dyed diesel) were obtained via a public records request of the Arizona Department of Transportation for dyed diesel sales in Maricopa County. Nonroad (dyed) diesel is only permitted for use in "vehicles and equipment

[39] U.S. Environmental Protection Agency. National Emissions Inventory (NEI). URL: https://www.epa.gov/air-emissions-inventories/national-emissions-inventory-nei.

used in agriculture (farming and ranching), mining and roadway construction"[40] and illegal for on-road transportation uses. Public records requests were submitted for two different points in time. The public records request for nonroad diesel consumption for calendar year 2016 was submitted in 2017 and data were obtained in 2017. These data had contained origin-destination flows of dyed diesel sales – from the terminal to point of sale – at the city level for Maricopa County. The second public records request for dyed diesel sales in Maricopa County for 2012 and 2018 (submitted as one public records request) yielded aggregate sales in Maricopa County for each calendar year requested. Therefore, the ratio of dyed diesel sales in Phoenix compared to Maricopa County was used as scaling factor for 2012 and 2018 data.

GHG emissions for dyed diesel were calculated using the following equation.

$$GHG_{NonRoadDiesel,Phoenix,j,y} = \begin{cases} DyedDiesel_{Gallons,Phoenix,y} \times EF_{diesel,j} & if\ y = 2016 \\ DyedDiesel_{Gallons,MaricopaCounty,y} \times SF_{Phoenix,2016} \times EF_{diesel,j} & if\ y = 2012, 2018 \end{cases}$$

Where,

$GHG_{NonRoadDiesel,Phoenix,j,y}$ =	the GHG emissions from red-dyed diesel sold within the city for a GHG (*j*) and an inventory year (*y*).
$DyedDiesel_{Gallons,Phoenix,y}$ =	The gallons of red-dyed diesel sold at pumps located within the city in an inventory year (*y*).
$EF_{diesel,j}$ =	The diesel emissions factor (*EF*) for a GHG (*j*).
$DyedDiesel_{Gallons,MaricopaCounty,y}$	The gallons of red-dyed diesel sold at pumps located within the Maricopa County in an inventory year (*y*).
$SF_{Phoenix,2016}$ =	The ratio between total red-dyed diesel gallons sold at pumps located in the city to the total red-dyed diesel gallons sold in pumps located in Maricopa County for year 2016.

For 2012 and 2016, the 2011 and 2014 US EPA National Emissions Inventory (NEI) were the sources of nonroad diesel GHG emissions, respectively. However, a follow up analysis showed that the amount of CO_2 emissions associated within nonroad diesel use reported in the NEI was equivalent to the volume diesel sold in both 2012 and 2016 in Maricopa County as reported by ADOT. Therefore, it was concluded there was double counting of diesel no. 2 sales for nonroad purposes included in the nonroad diesel GHG emissions in the 2012 and 2016 community-scale GHG emissions inventories (Table E1). To correct for this double-counting, red-dye diesel consumption data for the City (2016) and Maricopa County (2012, 2018) were obtained from ADOT. Red-dye diesel consumption was used as a proxy for nonroad diesel emissions because it is illegal for purchase for on-road transportation. ADOT provided city-specific data for Maricopa County for 2016 and county-level data for 2012 and 2018, so 2016 data was used to scale 2012 and 2018 county-level data to the city-level. Additionally, 2018 data was used as a proxy for 2020 data. With this updated method for estimating

[40] Arizona Department of Transportation (2019). Red-Dyed Diesel Fuel in Arizona. URL: https://azdot.gov/motor-vehicles/professional-services/fuel-tax-information/red-dyed-diesel-fuel-arizona.

non-road diesel consumption, on-road diesel GHG emissions may contain diesel purchased for nonroad purposes, but nonroad diesel GHG emissions only contains GHG emissions for nonroad purposes.

Table E1. Changes to Non-Road Diesel Consumption and GHG Emissions

Year	NEI Data Nonroad Diesel	ADOT Dyed Diesel Sales	ΔGHG Emissions ($MT\ CO_2e$)	% Change in GHG Emissions
	GHG Emissions ($MT\ CO_2e$)	GHG Emissions ($MT\ CO_2e$)		
2012	1,864,570	148,488	-1,716,082	-92%
2016	1,992,217	149,749	-1,842,468	-92%

E.5.2 Other Nonroad GHG Emissions

The NEI was used to gather data on GHG emissions from other nonroad fuel consumption in Maricopa County. The 2011 NEI was used as a proxy for 2012 and the 2014 NEI was used as a proxy for 2016, 2018, and 2020. Other nonroad fuel consumption data were scaled from Maricopa County to the city boundary. These data primarily cover the combustion of propane for nonroad uses.

Appendix F. Waste Sector Documentation

Waste Sector GHG emissions occur from numerous sources: solid waste, wastewater treatment, compost processing, and granulated activated carbon (GAC) hauling and regeneration. Much of these GHG emissions occur due to city's local government operations and as such a description of the methods to calculate these GHG emissions are found in the *City of Phoenix 2018 GHG Emissions Inventory of Local Government Operations*.

F.1 Solid Waste

Solid Waste GHG emissions occur at landfills owned and operated by the city within city boundary, a landfill owned and operated by the city outside city boundary, a privately-owned landfill within the city boundary, and privately-owned landfills outside the city boundary.

GHG emissions from landfills owned and operated by the city were obtained from the *City of Phoenix 2018 GHG Emissions Inventory of Local Government Operations*. Of the seven landfills owned and operated by the city, six are located within the city boundaries – these landfills are closed and no longer accept waste – and the only open landfill is located outside city boundaries. The names of these landfills, the data source, method of GHG emissions calculation, and GPC subsector are described in Table F1.

Table F1. Data and Method Documentation for City-Owned Landfills

Landfill	Activity Data	Source	Method	Active?	GPC Subsector
Skunk Creek	CH_4 Monitoring	City of Phoenix	ICLEI LGOP	No	Disposal of solid waste generated in the city
27th Avenue	CH_4 Monitoring	City of Phoenix	ICLEI LGOP	No	Disposal of solid waste generated in the city
Del Rio	CH_4 Monitoring	City of Phoenix	ICLEI LGOP	No	Disposal of solid waste generated in the city
Deer Valley	CH_4 Monitoring	City of Phoenix	ICLEI LGOP	No	Disposal of solid waste generated in the city
19th Avenue	CH_4 Monitoring	City of Phoenix	ICLEI LGOP	No	Disposal of solid waste generated in the city
Estes	EPA LandGEM Model	City of Phoenix	First Oder Decay	No	Disposal of solid waste generated in the city
SR-85	CH_4 Monitoring	City of Phoenix	ICLEI LGOP	Yes	Disposal of solid waste generated in the city but disposed outside the city

The City of Phoenix only collects municipal solid waste from single family residences within city boundaries. Residents in the city that live in multi-family housing in addition to commercial and industrial establishments are serviced by private haulers. There is one landfill within the city boundary – the Lone Cactus Landfill – owned by a private waste management company. GHG emissions from the Lone Cactus Landfill are reported by Waste Management, Inc. to the EPA Greenhouse Gas Reporting Program. Therefore, GHG emissions from the Lone Cactus Landfill were obtained from the EPA Facility-Level Information on Greenhouse Gas Emissions Tool (Table F2).

Table F2. Data Documentation for Privately-Owned Landfills

Landfill	Activity Data	Owner	Active?	GPC Subsector
Lone Cactus	EPA GHGRP	Waste Management	Yes	Disposal of solid waste generated in the city
Private Haulers	EPA GHGRP/Population	Multiple	Yes	Disposal of solid waste generated in the city but disposed outside the city

Since solid waste is also collected by private haulers and disposed of in privately-owned landfills outside of the city boundary, an additional estimation method was employed to estimate GHG emissions from the landfills attributable to solid waste generated within the City of Phoenix. First, a per capita GHG emissions from solid waste calculated for Maricopa County. To do this, all landfill emissions data reported to the EPA GHGRP within Maricopa County was pulled from EPA FLIGHT for 2012, 2016, and 2018 and converted to a per capita metric using population data obtained from the U.S. Census and City of Phoenix. Next, the number of residents living in multi-family housing in city was estimated using data obtained from the U.S. Census American Housing Survey. Finally, the population data were converted to GHG emissions using the per capita GHG emissions rate, as shown in the equation below.

$$GHG_{PrivateMSW,y} = \frac{\sum_l GHG_{SW,l,Maricopa,y}}{Pop_{Maricopa,y}} \times \left[\left(1 - \frac{\#\ Single\ Family\ Detached\ Housing}{All\ Dwellings}\right)_{PHX\ MSA,y} \times Pop_{Phoenix,y} \right]$$

Where,

$GHG_{PivateMSW,y}$ =	the GHG emissions from solid waste picked up by private haulers (PrivateHaulers) in an inventory year (*y*).
$\Sigma_l\ GHG_{SW,l,Maricopa,y}$ =	The total reported GHG emissions by all landfills in Maricopa County, Arizona.
$Pop_{Maricopa,y}$ =	The population of Maricopa County, Arizona in an inventory year (*y*).
# Single Family Detach Housing =	The number of single-family detached housing units in the Phoenix metropolitan area in an inventory year (*y*).
# All Dwellings =	The number of housing units in the Phoenix metropolitan area in an inventory year (*y*).
$Pop_{Phoenix,y}$ =	the population of Phoenix, Arizona in an inventory year (*y*).

F.2 Wastewater Treatment

GHG emissions from wastewater treatment were obtained from the *City of Phoenix 2018 GHG Emissions Inventory of Local Government Operations*. Please refer to the *City of Phoenix 2018 GHG Emissions Inventory of Local Government Operations* for details about monitoring data and method. A summary table is presented below (Table F3).

Table F3. Data Documentation for Wastewater Treatment Plants

Wastewater Treatment Plant	Service Area	GHG Emissions	Data Source	GHG Emissions Methodology	GPC Subsector
23rd Avenue	City of Phoenix	CH_4, N_2O	City of Phoenix CH_4 and effluent monitoring data	ICLEI LGOP	Wastewater generated in the city
91st Avenue	All or Portions of Glendale, Mesa, Phoenix, Scottsdale and Tempe	CH_4, N_2O	City of Phoenix CH_4 and effluent monitoring data	ICLEI LGOP	Wastewater generated in the city

F.3 Compost Processing

GHG emissions from compost processing were obtained from the *City of Phoenix 2018 GHG Emissions Inventory of Local Government Operations*. The city provided data on the total tons of green organic waste diverted to be processed as compost from FY 2005-2006 to FY 2018-19. Using these data, GHG emissions from composting were calculated according to the methodology employed by the EPA to estimate national-level emissions from composting in Section 7.3 of the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2017*.[41]

F.4 GAC Hauling and Regeneration

GHG emissions from GAC hauling and regeneration were obtained from the *City of Phoenix 2018 GHG Emissions Inventory of Local Government Operations*. The city provided data on the vehicle miles driven to the GAC recharging facility and the amount and type of energy used at the recharging facility. GHG emissions from GAC Hauling and Regeneration are included as Other Scope 3 GHG emissions.

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[41] U.S. EPA. Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2017. URL: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks-1990-2017