City of Raleigh Community Greenhouse Gas Emissions Inventory Report

Calendar Year 2022

August 2024

Prepared for:

City of Raleigh

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Executive Summary

The City of Raleigh worked with hundreds of community stakeholders to create Raleigh's Community Climate Action Plan (CCAP) which was released and adopted by City Council in 2021. CCAP was developed with the help of experts, leaders, community organizations, and City staff. CCAP was one of the first in the country to focus on: reducing community-wide greenhouse gas (GHG) emissions, with the goal of an 80% reduction by 2050; addressing equity, environmental justice and community health; and building community resilience to the impacts of climate change. The City of Raleigh has conducted GHG inventories since 2007 which serves as its baseline year. This document outlines results of the calendar year 2022 (CY 22) community inventory, which provides an update on the last inventory conducted in fiscal year 2014.

What are Greenhouse Gases?

Greenhouse gases (GHGs) are gases that trap heat in the atmosphere, causing a greenhouse-like effect which impacts the global climate. The GHGs[1] contributing to climate change are:

- Carbon dioxide (CO_2),
- Methane (CH_4),
- Nitrous oxide (N_2O), and
- Fluorinated gases

Each gas's effect on climate change depends on three main factors:

1. Quantity of the gases are in the atmosphere,
2. Duration of time (residence time) they remain in the atmosphere, and
3. How strongly they impact global temperatures (global warming potential).[2]

Given that more than half of the world's population lives in cities, which consume approximately 70% of energy globally[3], cities should lead the way in the effort to reduce GHG emissions and limit the progression of climate change. The majority of Raleigh's community-wide GHG emissions come from community activities while less than 2% come from City of Raleigh municipal operations. With this in mind, much of Raleigh's community emissions come from the decisions we all make in our daily lives about how we get around, how we use energy and water in our buildings, and how we produce waste. It takes collective action from all of us to continue to make an impact on GHG emissions and climate change.

Purpose of a GHG Emissions Inventory

A GHG emissions inventory is an estimate of GHGs emitted to, or removed from, the atmosphere over a specific period of time (usually one year). Preparation of an emissions inventory helps an entity understand the source of the GHGs emitted and serves as a starting point for developing strategies that can effectively reduce GHG emissions. An emissions inventory can help with any or all of the following:

- Identifying the largest sources of emissions within a particular geographic region, department, or activity;
- Understanding emission trends;
- Quantifying the benefits of activities that reduce emissions;
- Establishing a basis for developing an action plan;
- Tracking progress in reducing emissions; and
- Setting goals and targets for future reductions.

[1] All seven GHGs that contribute to climate change covered by the Kyoto Protocol were included: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulfur hexafluoride (SF_6) and nitrogen trifluoride (NF3). However, activities within the City of Raleigh emit only CO_2, CH_4, N_2O and HFCs. There were no emissions of PFCs or SF_6 identified in the emissions analysis as these emissions are generally associated with the transmission and distribution of electricity from generation facilities and/or the manufacture of semi-conductors. Fugitive emissions of HFCs are associated with refrigerant usage.

[2] https://www3.epa.gov/climatechange/ghgemissions/gases.html

[3] Shttps://www.energy.gov/eere/understanding-energy-use-cities-infographic

Community Inventory Methodology

Raleigh's community GHG emissions inventories follow national and global best practices for inventory development. This ensures that Raleigh is aligning inventory practices with peer cities nationally and globally and can continue to accurately benchmark emissions over time. Raleigh's calendar year 2022 (CY 22) community GHG inventory was developed using the Global Protocol for Community-Scale Greenhouse Gas Inventories (GPC) and includes emissions released within the city's geographic boundaries and emissions released outside them as a result of community activities. The GPC defines the emissions sectors and sub-sectors that are required to be reported to produce a GPC-compliant inventory. Following this guidance, Raleigh's community inventory represents emissions from residential, commercial, institutional, and industrial activities within the following sectors:

- The transportation sector includes mobile emissions associated with two sub-sectors: on-road vehicle travel on community roadways and off-road equipment use (e.g., forklifts, lawnmowers).
- The buildings and energy sector includes emissions generated as a result of energy consumption in homes, offices, schools, stores, manufacturing facilities, and other buildings within the community.
- The waste sector includes emissions associated with solid waste disposal and wastewater treatment (separate from the energy-related wastewater treatment emissions included in the building and energy sector).

Some emissions sub-sectors were excluded due to lack of activity within the community.

2022 Community Inventory Results

In calendar year (CY 22), the City of Raleigh generated 4,904,734 metric tons of carbon dioxide equivalent (MTCO_2e). The transportation sector was the largest source of emissions, generating 52% of the community's total. Buildings and energy followed closely at 47%, with the smallest contribution from waste at 1%[4]. More specifically:

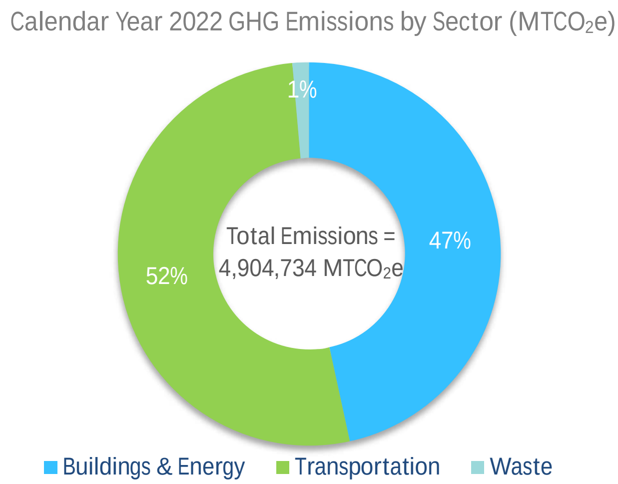
- The buildings and energy sector accounted for 47% of total emissions. Residential buildings contributed to approximately half of the total buildings and energy sector emissions, followed by commercial/institutional at 40%, and manufacturing and construction industries contributing the remaining 8% of emissions.
- The transportation sector accounted for over half (52%) of the community's emissions. The majority of the transportation emissions (93%) are from on-road sources while off-road vehicles and equipment are responsible for the remaining 7% of transportation emissions.

Raleigh's community activities generated 4,904,734 MTCO_2e in 2022.

Using the USEPA's GHG Equivalencies Calculator, this quantity is equivalent to emissions resulting from the energy used in a year by 635,000 average-sized US homes, and emissions which could be sequestered in a year by a forest 60 times larger than the City of Raleigh.

- The waste sector was the smallest contributor to the community's emissions footprint at approximately 1% of total emissions. Emissions associated with the waste sector are primarily from landfills (87%), particularly from landfilling of the community's solid waste in the South Wake County landfill. The remaining waste sector emissions (13%) are from solid waste biological treatment, incineration, and wastewater treatment.

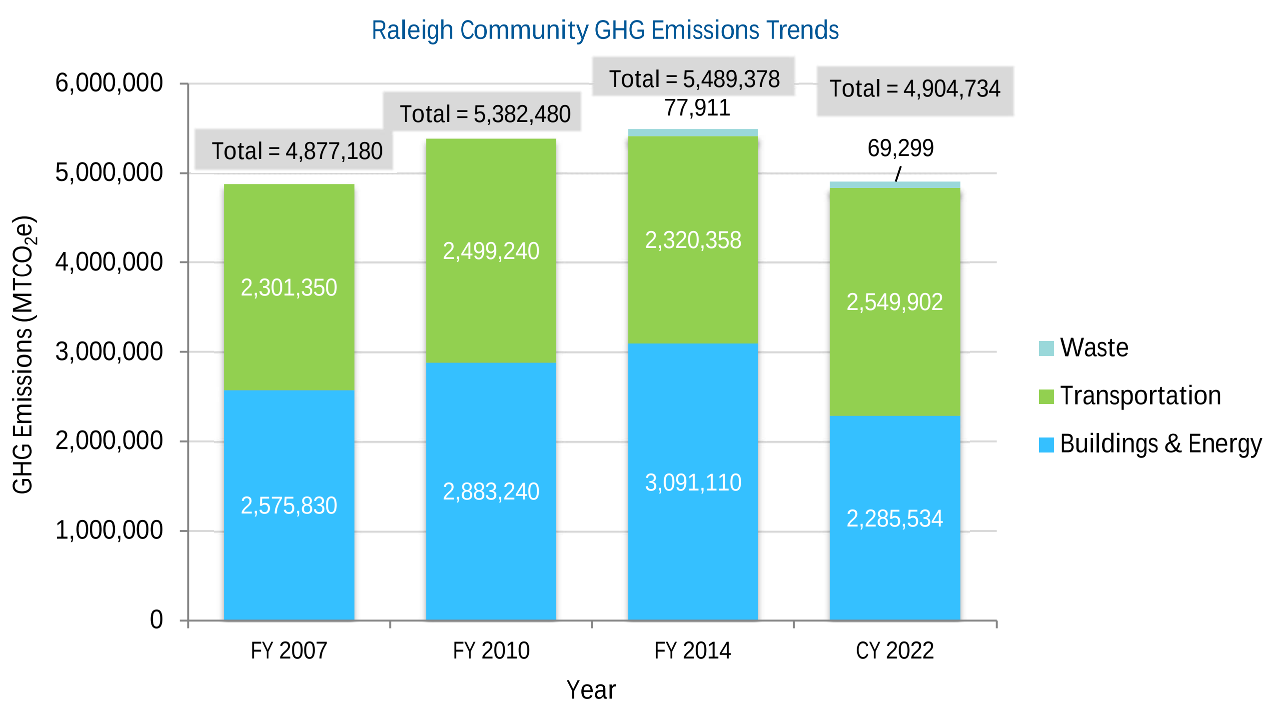
[4] GHG emissions are commonly expressed in metric tons of carbon dioxide equivalent (MTCO_2e) per year. CO_2e is the universal unit for comparing emissions of different GHGs to CO_2 based upon the varying global warming potentials (GWP) of each gas. GWPs were developed by the Intergovernmental Panel on Climate Change (IPCC)[4] and describe how much heat a GHG can trap in the atmosphere compared to CO_2, which has a GWP of 1. For example, CH_4 has a GWP of 25, which means that 1 MT of CH_4 will trap 25 times more heat than 1 MT of CO_2, making it a more potent GHG.



Raleigh's community emissions per capita (11.15 $MTCO_2e$ per capita) are in line with or better than comparable communities such as Charlotte, North Carolina, in addition to the state of North Carolina and the broader United States.

Trends and Drivers Over Time

Calendar year 2022 (CY 22) GHG emissions decreased 11% from the prior inventory conducted for fiscal year 2014 (FY 14). In previous inventories, results showed that the buildings and energy sector was the largest emissions contributor, followed closely by transportation. For 2022, however, that trend shifted, with the transportation sector contributing slightly more to the emissions profile than buildings and energy.



Waste emissions were not calculated for in the 2007 or 2010 inventories, but these represent a small portion of total community emissions (roughly 1% of the total). Since the first GHG inventory developed in 2007, emissions have increased 0.6%. Therefore, the City of Raleigh's 2022 emissions are roughly the same as they were in 2007. Emission changes from 2014 to 2022 are primarily a result of the following:

- Buildings and energy sector emissions decreased the most from 2014, by 26%. While electricity use increased by 1%, total electricity emissions decreased by 31%, contributing to most of the emissions decrease in the buildings and energy sector. Therefore, the decrease in electricity emissions is primarily due to the regional grid switching to electricity generation sources that produce lower GHG emissions. Given that population and employment increased significantly since FY 14, energy efficiency measures also played a role in reducing electricity use and related emissions.

- Transportation sector emissions increased by 10% when compared to 2014. This increase was primarily due to an increase in vehicle miles traveled (VMT).

- Waste sector emissions decreased by 11% even though total waste generated in the community increased. This is due to an improvement in the accuracy of the waste calculation methodology.[5]

Opportunities for GHG Reductions

While reductions in all sectors would contribute to an overall reduction in GHG emissions, focusing efforts on the transportation and building and energy sectors, which generate 99% of the Raleigh's total GHG emissions, will provide the highest impact.

The following table outlines high level opportunities for strategic GHG reductions by emissions sector. These strategies were also identified in the City of Raleigh's 2021 Community Climate Action Plan (CCAP) and in the subsequent 2023 CCAP Implementation Progress Report[6]. This shows that Raleigh's CCAP strategies and actions continue to align with the highest areas of GHG reduction impact.

Possible GHG Reduction Strategies by Sector

Sector	% Total Emissions	Possible GHG Reduction Strategy
Transportation	52%	1. Vehicle miles traveled (VMT) reduction (e.g., efficient and compact land use planning), especially for on-road vehicles 2. Zero emission vehicles and infrastructure (e.g., electric vehicles, zero-emissions buses), especially for on-road vehicles 3. Mode shift to active and public transit modes (e.g., improving bicycle, pedestrian, and bus infrastructure)
Buildings and Energy	47%	4. Building electrification (e.g., transitioning natural gas equipment to electric) 5. Building energy efficiency (e.g., reducing energy use per square foot, LEED-Certifications, ENERGY STAR buildings and equipment) 6. Allowing more inherently energy-efficient housing types such as apartments and townhouses that per unit use less than half the energy of a detached house. 7. Clean energy installations and purchasing (e.g., solar and geothermal installations)
Waste	1%	8. Waste reduction (e.g., reduced purchasing, increased reuse) 9. Waste diversion (e.g., recycling, composting)

Electricity is one of the largest contributors to Raleigh's community emissions, which ultimately comes from the portfolio of energy sources used by power suppliers to generate the electricity. The 2022 USEPA regional eGRID data shows that the Carolina/Virginia region shifted almost 4% of the fuel mix from fossil fuels to lower emissions energy sources compared to the energy mix in 2014. More substantial shifts from fossil fuels to renewable energy sources are expected to occur in the region and will play an important role in reducing electricity emissions. The City of Raleigh does not have direct control over electricity generation in the regional grid. However, as reflected in CCAP and the Implementation Reports, the City has been implementing several large renewable energy strategies

[5] The GPC allows cities to switch methodologies if there are more accurate or relevant data or methods available over time.

[6] https://cityofraleigh0drupal.blob.core.usgovcloudapi.net/drupal-prod/COR27/2023CCAPImplementationReport.pdf

across the region to increase the community's access to renewable energy, as well as supporting processes that further the transition to a cleaner energy mix.

1. Introduction

The City of Raleigh worked with hundreds of community stakeholders to create Raleigh's Community Climate Action Plan (CCAP) which was released and adopted by City Council in 2021. CCAP was developed with the help of experts, leaders, community organizations, and City staff. CCAP was one of the first in the country to focus on: reducing community-wide greenhouse gas (GHG) emissions, with the goal of an 80% reduction by 2050; addressing equity, environmental justice and community health; and building community resilience to the impacts of climate change. The City of Raleigh has conducted GHG inventories since 2007 which serves as its baseline year This document outlines results of the calendar year 2022 (CY 22) community inventory, which provides an update on the last inventory conducted in fiscal year 2014.

What are Greenhouse Gases?

Greenhouse gases (GHGs) are gases that trap heat in the atmosphere, causing a greenhouse-like effect which impacts the global climate. The GHGs contributing to climate change are[7]:

- Carbon dioxide (CO_2) is emitted from the burning fossil fuels (coal, natural gas, and oil) and also as a result of certain chemical reactions (e.g., manufacture of cement). Carbon dioxide is removed from the atmosphere (or "sequestered") when it is absorbed by plants as part of the biological carbon cycle.
- Methane (CH_4) is emitted during the production and transport of energy sources such as coal, natural gas, and oil. Methane emissions also result from livestock and other agricultural practices and by the decay of organic waste in landfills.
- Nitrous oxide (N_2O) is emitted during agricultural and industrial activities, as well as during combustion of fossil fuels.
- Fluorinated gases are manmade, powerful GHGs emitted from various industrial processes, and include:
  - Hydrofluorocarbons (HFCs),

[7] All seven GHGs that contribute to climate change covered by the Kyoto Protocol were included: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulfur hexafluoride (SF_6) and nitrogen trifluoride (NF3). However, activities within the City of Raleigh emit only CO_2, CH_4, N_2O and HFCs. There were no emissions of PFCs or SF_6 identified in the emissions analysis as these emissions are generally associated with the transmission and distribution of electricity from generation facilities and/or the manufacture of semi-conductors. Fugitive emissions of HFCs are associated with refrigerant usage.

- Perfluorocarbons (PFCs),
- Sulfur hexafluoride (SF_6), and
- Nitrogen trifluoride (NF_3).

Each gas's effect on climate change depends on three main factors:

1. Quantity of the gases are in the atmosphere,
2. Duration of time (residence time) they remain in the atmosphere, and
3. How strongly they impact global temperatures (global warming potential).[8]

Given that more than half of the world's population lives in cities, which consume approximately 70% of energy globally[9], cities can and should lead the way in the effort to reduce GHG emissions and limit the progression of climate change. The majority of Raleigh's community-wide GHG emissions come from community activities while less than 2% come from City of Raleigh municipal operations. With this in mind, much of Raleigh's community emissions come from the decisions we all make in our daily lives about how we get around, how we use energy and water in our buildings, and how we produce waste. It takes collective action from all of us to continue to make an impact on GHG emissions and climate change.

Purpose of a GHG Emissions Inventory

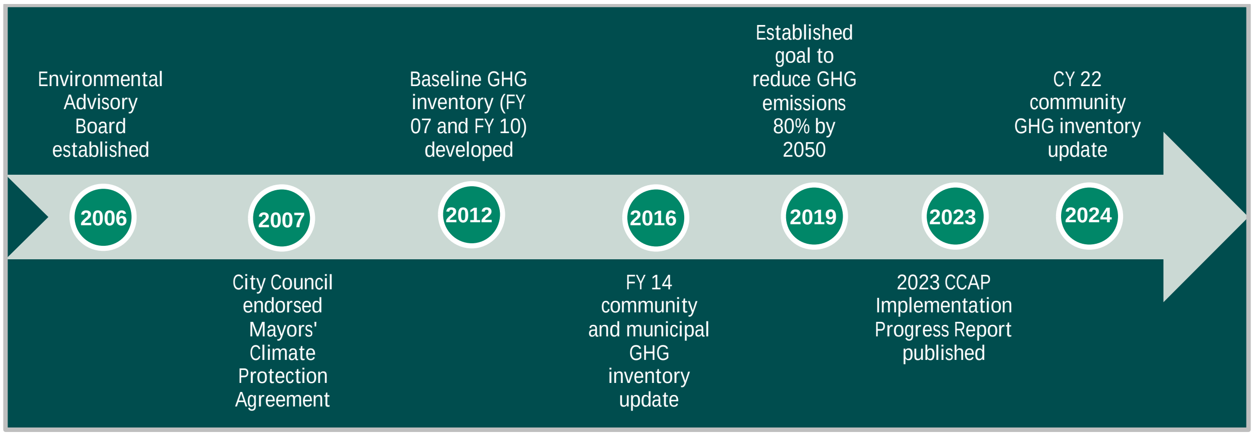
A GHG emissions inventory is an estimate of GHGs emitted to, or removed from, the atmosphere over a specific period of time (usually one year). Preparation of an emissions inventory helps an entity understand the source of the GHGs emitted and serves as a starting point for developing strategies that can effectively reduce GHG emissions. An emissions inventory can help with any or all of the following:

- Identifying the largest sources of emissions within a particular geographic region, department, or activity;
- Understanding emission trends;
- Quantifying the benefits of activities that reduce emissions;
- Establishing a basis for developing an action plan;
- Tracking progress in reducing emissions; and
- Setting goals and targets for future reductions.

City of Raleigh Sustainability

The City of Raleigh ("the City" or "Raleigh") recognizes the challenges that climate change presents and is committed to reducing greenhouse gas emissions. The City has a long history of taking action on climate change and GHG reduction. The following provides a few examples of actions taken over the past several decades. The Raleigh City Council established the Environmental Advisory Board in 2006 to help address the Council's commitment to environmental stewardship, and the following year endorsed the U.S. Mayors' Climate Protection Agreement in 2007. In 2012, the City of Raleigh developed a baseline GHG emissions inventory for selected community-wide activities for fiscal years (FY) 2007 and 2010. In 2016, the City developed an inventory for FY 14, covering both City operational and community emissions. In 2019, Raleigh's City Council established the goal of achieving an 80% reduction in GHG emissions by the year 2050. Raleigh's Community Climate Action Plan (CCAP)[10] set a course to reach that goal, and all City of Raleigh departments and Raleigh residents have a part to play. The 2023 CCAP Implementation Progress Report[11] documents implementation of projects and policy changes in each strategy area showing how the community's work has contributed to Raleigh's overall portfolio of climate action successes. These Implementation Reports and the associated data and performance metrics will help the City track community-wide progress on climate action.

[8] https://www3.epa.gov/climatechange/ghgemissions/gases.html
[9] Shttps://www.energy.gov/eere/understanding-energy-use-cities-infographic
[10] https://cityofraleigh0drupal.blob.core.usgovcloudapi.net/drupal-prod/COR27/RaleighCCAP.pdf
[11] https://cityofraleigh0drupal.blob.core.usgovcloudapi.net/drupal-prod/COR27/2023CCAPImplementationReport.pdf

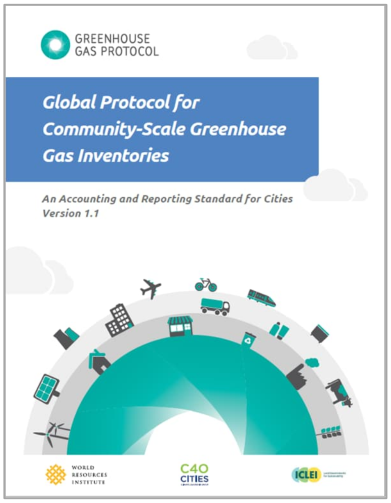

Environmental Advisory Board established
2006
2007
City Council endorsed Mayors' Climate Protection Agreement
Baseline GHG inventory (FY 07 and FY 10) developed
2012
2016
FY 14 community and municipal GHG inventory update
Established goal to reduce GHG emissions 80% by 2050
2019
2023
2023 CCAP Implementation Progress Report published
CY 22 community GHG inventory update
2024

Report Purpose and Organization

Raleigh developed a community-wide inventory for CY 22 to track progress towards the goal of 80% reduction in GHG emissions by 2050 and to inform the CCAP. The purpose of this report is to document the purpose, methodology, results, and trends of Raleigh's CY 22 community GHG inventory. The report is organized into the following sections:

1. Introduction
2. Methodology Overview
3. Analysis of Results, Trends, and Drivers
4. Comparing Raleigh's Community GHG Emissions to Peers
5. Opportunities for GHG Reductions

2. Methodology Overview



Raleigh's calendar year 2022 (CY 22) community GHG inventory was developed using the [Global Protocol for Community-Scale Greenhouse Gas Inventories (GPC)](). The GPC is a highly respected and widely accepted protocol for standardized GHG quantification at the community level. This section provides an overview of the emissions estimation methodology, including inventory boundary, emissions sources evaluated within the applicable sectors, and how emissions are calculated.

Appendix A includes the data sources, data collection process, emissions factors, underlying assumptions, and equations used to develop the CY 22 inventory.

Inventory Boundary

The first step in developing a GHG inventory is to define the boundary (i.e., the geographic area, gases, and emission sources) covered by a GHG inventory. The boundary for this inventory is the area within the City of Raleigh's jurisdiction within Wake County. The community occupies 144 square miles and is home to nearly 500,000 residents, as well as university and college campuses, and state and county government complexes.

Reporting Frameworks

GHG emission sources within a given boundary are described as direct or indirect, depending upon where the emissions generation occurs. The GPC requires cities to report emission under the Scope Framework and the City-Induced Framework. Both reporting frameworks are described below. At a high level, the community inventory represents emissions from residential, commercial, institutional, and industrial activities.

1. Scope Framework – involves the reporting of all GHG emissions resulting from activities occurring within a city's geographic boundary as either Scope 1, 2, or 3.

Scope 1 - Emissions generated directly by emission sources within the community boundary.

For the Raleigh community, this includes transportation fuel combustion, building and other stationary energy fuel combustion, and waste treatment (both solid waste and wastewater treated in the community).

Scope 2 - Indirect emissions from energy generation which is purchased and consumed by activities occurring within the community boundary.

For the Raleigh community, this is emissions from electricity use.

Scope 3 - All other indirect upstream and downstream emissions resulting from activities occurring within the community boundary.

For the Raleigh community, this includes emissions from electricity transmission and distribution losses and solid waste emission from the South Wake Landfill as this waste is generated in the community but treated outside of the community.

2. City-Induced Framework – outlines the specific Scope 1, 2, and 3 GHG emissions resulting from activities occurring within the geographic boundary of a city that should be measured and reported. Community GHG emissions in Raleigh were generated in three sectors: 1) transportation, 2) buildings and energy, and 3) waste. Transportation and buildings and energy make up the majority of GHG emissions in most cities, which is also true of Raleigh where they generate 99% of total community GHG emissions (see the Community GHG Inventory 2022 Results section for detailed inventory results).

The transportation sector represents mobile emissions and is associated with two sub-sectors: on-road vehicle use on community roadways and off-road equipment use (e.g., forklifts, lawnmowers).

The community's on-road transportation emissions come from vehicle trips that begin and/or end within the community's boundaries. Pass-through trips (for example, non-local drivers on the Interstate) are not included within the emissions inventory because they do not occur as a result of community activity (e.g., jobs, retail, or housing in Raleigh). The community's off-road emissions account for mobile sources associated with construction, lawns/gardens, industrial manufacturing, commercial retail, and railroads.

The buildings and energy sector includes emissions generated as a result of energy consumption in homes, offices, schools, stores, manufacturing facilities, and other buildings within the community. This sector is known as the "stationary energy" sector in the GPC as it accounts for the energy used inside stationary sources, such as buildings and facilities, and not mobile sources, such as vehicles.

Emissions result from the consumption of electricity from the local utility grid, as well as the direct combustion of natural gas, fuel oil, liquified petroleum gas (LPG), and landfill gas. This sector also includes energy-related emissions attributed to the community's share of wastewater treatment and potable water conveyance. The buildings and energy sector is organized into three sub-sectors: residential buildings, commercial and institutional buildings and manufacturing and construction industries.

The waste sector includes emissions associated with the treatment and disposal of the solid waste and wastewater that is generated in the community (separate from the energy-related wastewater treatment emissions included in the buildings and energy sector).

Solid waste emissions result from the different waste treatment methods, including landfilling at the South Wake County landfill[12]*, composting, and incineration. Waste hauling-related emissions are included in the transportation sector.*

Wastewater emissions include direct emissions from the wastewater treatment processes that were employed at the wastewater treatment plants (any emissions from the electricity used to treat the wastewater are included in the buildings and energy sector).

How Do Landfills Create GHG Emissions?

When placed in a landfill, organic waste (such as paper, food scraps, and yard trimmings) is initially decomposed by aerobic bacteria. After the oxygen has been depleted, the remaining waste is available for consumption by anaerobic bacteria, which break down organic matter into substances such as cellulose, amino acids, and sugars. These substances are further broken down through fermentation. These bacteria convert the fermentation products into CO_2 and CH_4 gases.

Applicable GHGs

Activities included within the City of Raleigh's GHG inventory emit CO_2, CH_4, N_2O, and HFCs. There are no emissions of PFCs or SF_6 identified in the emissions analysis as these emissions are generally associated with the transmission and distribution of electricity from generation facilities and/or the manufacture of semi-conductors. These activities do not occur in Raleigh, but other cities may account for emissions of PFCs and SF_6 due to industrial activities.

How are GHG Emissions Measured?

GHG emissions are commonly expressed in metric tons of carbon dioxide equivalent ($MTCO_2e$) per year. The metric ton is the standard international unit for measuring GHG emissions and is different than a U.S. short ton or "ton" (1 ton = 0.9072 metric tons). CO_2e is the universal unit for comparing emissions of different GHGs to CO_2 based upon the varying global warming potentials (GWP) of each gas. GWPs were developed by the Intergovernmental Panel on Climate Change (IPCC)[13] and describe how much heat a GHG can trap in the atmosphere compared to CO_2, which has a GWP of 1. GWPs are used to express the impact of each individual GHG in terms of the amount of CO_2 that would produce the same amount of warming. For example, CH_4 has a GWP of 25, which means that 1 MT of CH_4 will trap 25 times more heat than 1 MT of CO_2, making it a more potent GHG. Some gases used in industrial applications can have a GWP thousands of times larger than CO_2. Converting different GHGs into CO_2e ensure that that emissions inventories can be expressed through a single metric.

How are GHG Emissions Calculated?

To maintain consistency within each inventory and between the baseline and subsequent emission inventories, all GHG emissions have been quantified in units of $MTCO_2e$ per year. To calculate total CO_2e emissions per year, the mass of each GHG produced in a year is multiplied by its respective GWP and added together. In general, this calculation follows this general equation:

$$Activity\ Data \times Emission\ Factor \times Conversion\ Factors\ (if\ needed) \times\ GWP = MTCO_2e\ Emissions\ for\ the\ Activity$$

A detailed explanation of how emissions are calculated for the emission sources applicable to Raleigh is included in Appendix A.

[12] Wilders Grove Landfill and the East Wake Landfill are closed and no longer contribute to emissions per the methodology used.

[13] GWPs were sourced from the IPCC's 4th Assessment Report.

3. Analysis of Results, Trends, and Drivers

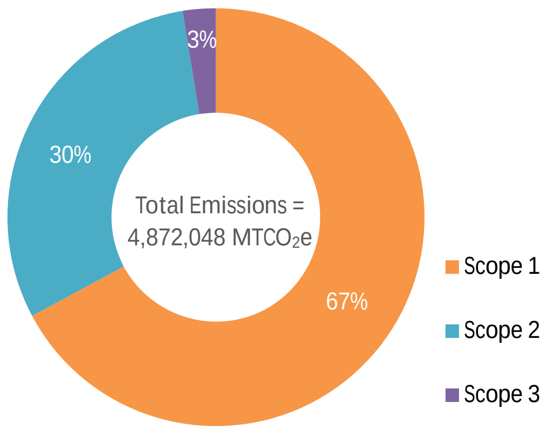
Community GHG Inventory 2022 Results

In calendar year 2022 (CY 2022), Scope 1 emissions constituted the largest portion of emissions at 67%, followed by Scope 2 at 30% and Scope 3 at 3%, as shown in Error! Reference source not found.. Scope 1 includes emissions from building and transportation fuel use and waste treatment within the community boundary, Scope 2 includes emissions from electricity use within the community boundary, and Scope 3 includes emissions from solid waste generated within the community boundary but disposed of outside the community boundary as well as transmission and distribution (T&D) losses from grid-supplied electricity consumption within the community boundary.

Raleigh's community activities generated 4,604,734 MTCO_2e in 2022.

Using the USEPA's GHG Equivalencies Calculator, this quantity is equivalent to emissions resulting from the energy used in a year by 635,000 average-sized US homes, and emissions which could be sequestered in a year by a forest 60 times larger than the City of Raleigh.

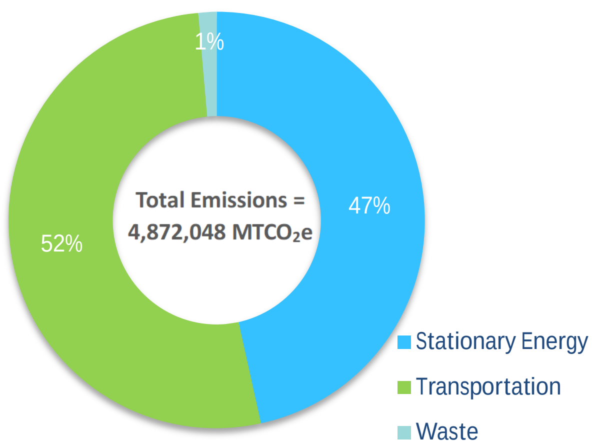
Figure 1. Calendar Year 2022 Community GHG Emissions by Scope (MTCO_2e)



Of all the emissions sectors, the transportation sector (Scope 1 emissions) was the largest source of emissions, generating 52% of the community's total. Buildings and energy (Scope 1 and Scope 2 emissions) followed closely at 47%. The smallest contribution (1%) was from waste (Scope 1 and Scope 3 emissions). This breakdown is shown in

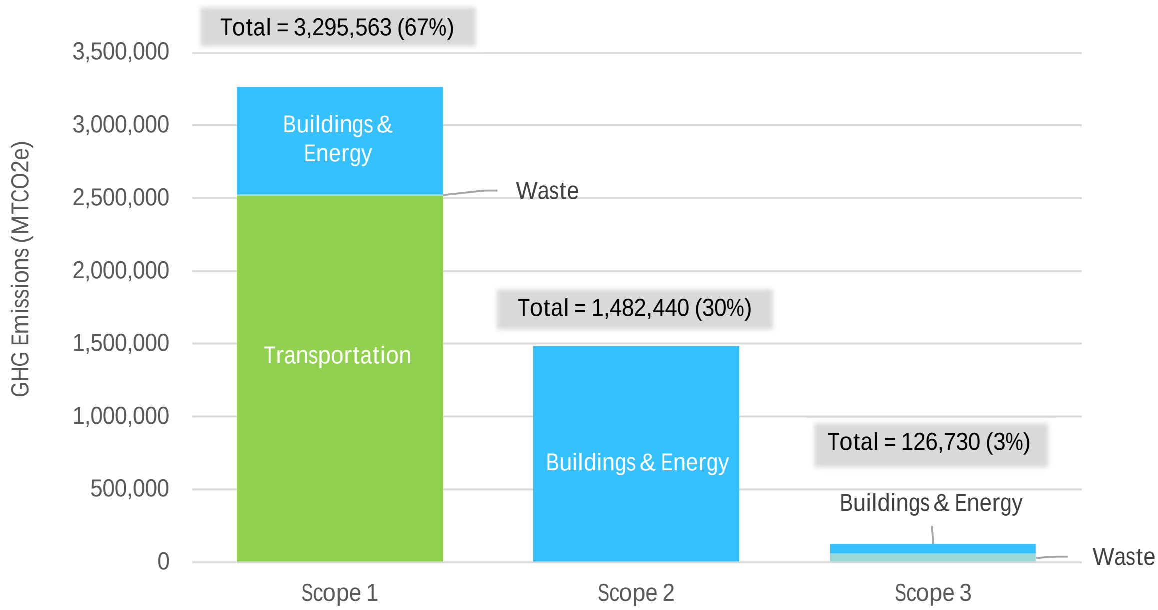
Figure 2.

Figure 2. Calendar Year 2022 GHG Emissions by Sector ($MTCO_2e$)



Considering the overlap of the two reporting frameworks, Figure 3 illustrates how the sector emissions intersect with Scope 1, 2, and 3 emissions. For Scope 1, transportation accounted for more than 75% of the emissions, with most of the remaining emissions from buildings and energy, and a minor amount from waste (<0.5%). Scope 2 emissions are 100% from buildings and energy, while Scope 3 is almost an even split between buildings and energy and waste.

Figure 3. Calendar Year 2022 GHG Emissions by Scope and Sector

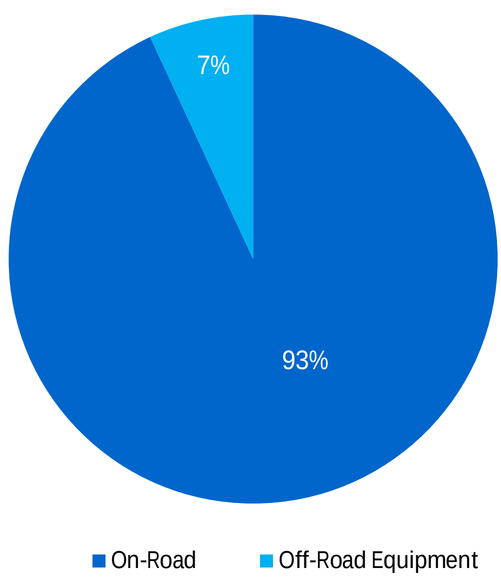


Transportation

The transportation sector accounted for over half (52%) of the community's emissions. The majority of the transportation emissions (93%) are from on-road sources, primarily automobiles, with a very small amount attributable to buses.

Off-road vehicles and equipment are responsible for the remaining 7% of transportation emissions, from sources such as construction, lawn and garden, commercial and industrial, and railroad equipment.

Figure 4. Calendar Year 2022 Transportation Emissions by Sub-Sector



Buildings and Energy

Emissions from the buildings and energy sector account for close to half of total community emissions at 47%. Commercial and institutional buildings and facilities contributed to approximately half of the total buildings and energy emissions (47%), followed by residential buildings and facilities at 40%, and the manufacturing industries and construction contributing the remaining 13% of emissions, as shown in Figure 5.

As illustrated in Figure 6, electricity and natural gas usage were the main drivers of emissions within each sub-sector. Electricity generated approximately two-thirds (68%) of buildings and energy emissions, with natural gas following at 31%. Less than 1% of buildings and energy emissions were from combustion of fuel oil and landfill gas.

Figure 5. Calendar Year 2022 Buildings and Energy Emissions by Sub-Sector

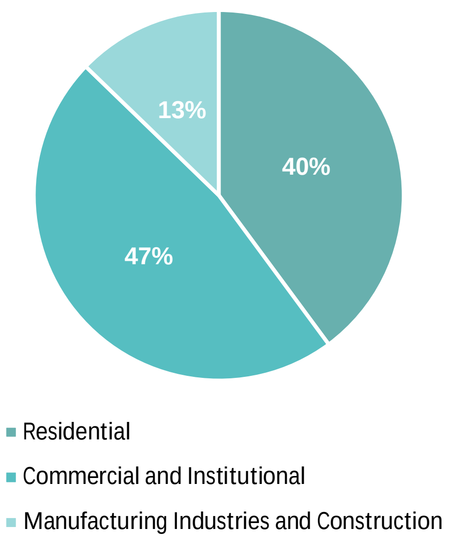
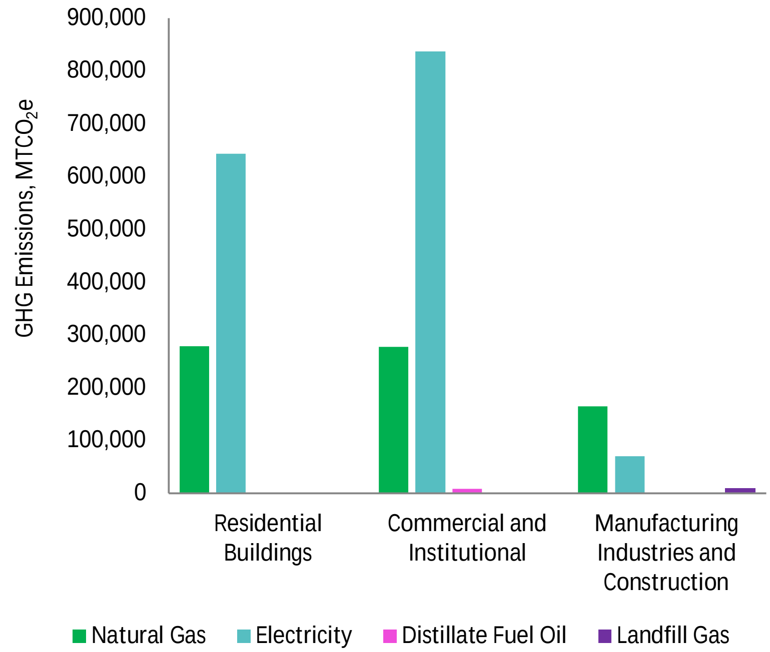


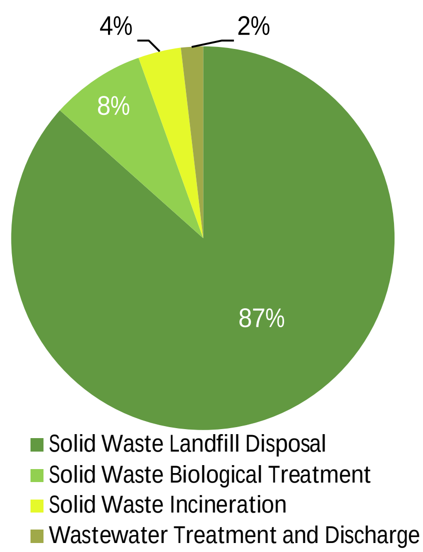
Figure 6. Calendar Year 2022 Buildings and Energy Emissions by Energy Type



Waste

The waste sector is the smallest contribution to the community's emissions footprint at approximately 1% of total emissions. Emissions associated with the waste sector are primarily from landfills (87%), particularly from landfilling of the community's solid waste in the South Wake County landfill. The remaining waste sector emissions (13%) are from solid waste biological treatment, incineration, and wastewater treatment.

Figure 7. Calendar Year 2022 Waste Emissions by Sub-Sector



Community GHG Trends and Drivers Over Time

11% decrease in emissions from 2014 to 2022

A summary of the CY 22 GHG emissions results compared to prior year inventories is in Table 1, showing an 11% decrease in emissions since the prior inventory conducted for 2014[14]. GHG emissions are reported in $MTCO_2e$.

Following the emissions accounting guidance in the GPC, electricity (Scope 2) emissions are calculated using two different methods: the location-based method and the market-based method. The location-based method reflects the average emissions intensity of the electricity grid on which energy consumption occurs. The market-based method reflects emissions from electricity that customers have purposefully chosen from a supplier, such as Duke Energy. The City of Raleigh previously only used the location-based method to calculate electricity emissions, as was best practice at the time. For CY 22, electricity emissions were calculated using both the location-based and market-based methods. Because the electricity Duke Energy provides to its customers is slightly cleaner than the regional grid average, the CY 22 market-based electricity emissions were slightly lower than the location-based emissions. When comparing total emissions, the market-based inventory is only 1% lower than the location-based inventory. Since market-based emissions were not calculated in prior year inventories, the emissions summary and historic inventory comparisons in this document reflect location-based emissions only.

Table 1. Community GHG Emissions Trends Over Time

Basis	FY 07	FY 10	FY 14	CY 22	% Change FY 14 to CY 22
Location-Based Total ($MTCO_2e$)	4,877,180	5,382,480	5,489,378	4,904,734	-11%
Market-Based Total ($MTCO_2e$)				4,853,939	

In previous inventories, results showed that the buildings and energy sector was the largest emissions contributor, followed closely by transportation (see Figure 8). For CY 22 however, that trend shifted, with the transportation sector contributing slightly more to the emissions profile than buildings and energy.

[14] Note that previous years' inventories were on a fiscal year basis, while 2022 is on a calendar year basis (January-December). The GPC states that the community inventory can follow the calendar or financial year, whichever is consistent with the time period most commonly used by the community. As most community emissions data is not provided on a fiscal year timeline, the City has decided to report on a calendar year basis for the CY 2022 and future GHG inventories.

Figure 8. Community GHG Emissions Trends, Location-Based Results

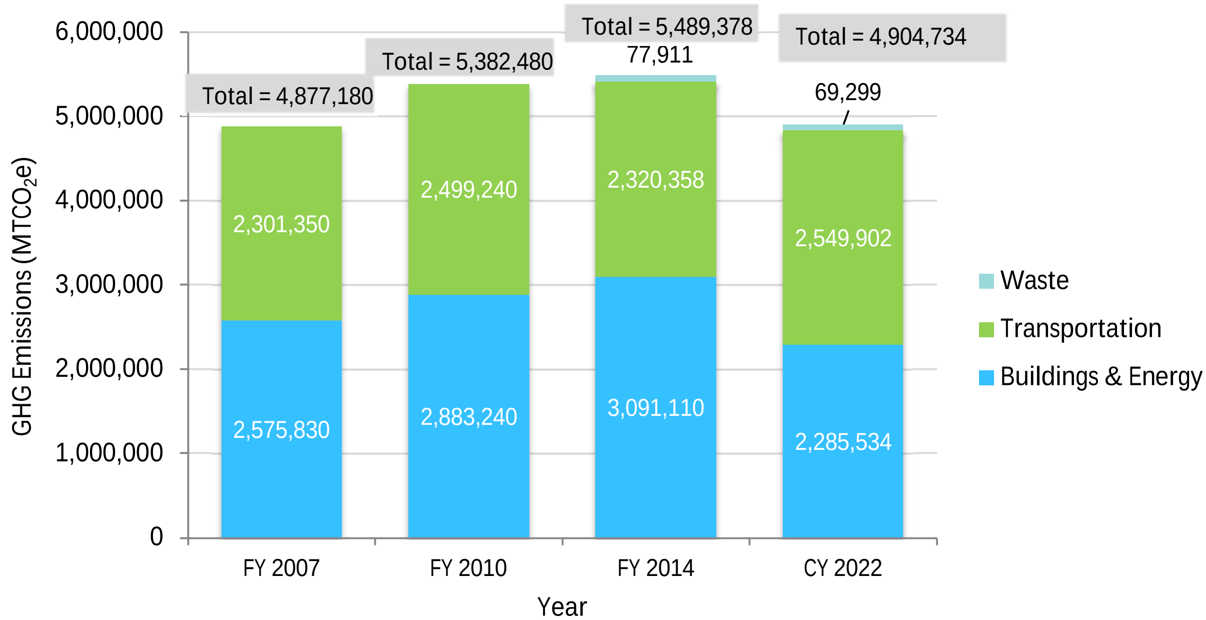


Table 2 shows a detailed comparison of the CY 22 inventory to the prior FY 14 inventory, demonstrating an overall 11% decrease in total community emissions. The FY 07 and FY 10 inventories are not included in the comparison review, as only sector level results, and not sub-sector, were available.

Table 2. Community GHG Emissions Comparison Fiscal Year 14 to Calendar Year 22

GPC Sector/Sub-Sector	FY 14 ($MTCO_2e$)	CY 22 ($MTCO_2e$)	% Change FY 14 to CY 22
Buildings and Energy	3,091,110	2,285,534	-26%
Residential Buildings	1,255,317	920,240	-27%
Natural Gas	322,663	277,688	-14%
Electricity (including T&D losses)*	932,654	642,552	-31%
Commercial and Institutional	1,578,469	1,121,711	-29%
Natural Gas	270,306	276,792	2%
Electricity (including T&D losses)*	1,300,508	836,457	-36%
Distillate Fuel Oil	7,628	8,461	11%
Liquified petroleum gas	27	0	-100%
Manufacturing and Construction	257,323	243,584	-5%
Natural Gas	139,457	164,057	18%
Electricity (including T&D losses)*	114,920	70,141	39%
Distillate Fuel Oil	2,163	77	-96%
Landfill Gas	783	9,309	1,088%
Transportation	2,320,358	2,549,902	10%
On-Road Transportation	2,114,273	2,373,270	12%
Off-Road	206,085	176,631	-14%
Waste	77,911	69,299	-11%
Solid Waste Landfill Disposal	65,986	60,020	-9%
Solid Waste Biological Treatment	7,912	5,528	-30%
Solid Waste Incineration	2,682	2,494	-7%
Wastewater Treatment and Discharge	1,330	1,257	-6%
Total	5,489,378	4,904,734	-11%

**Location-based electricity emissions are presented for comparative purposes.*

Contributions to the changes in emissions from 2014 to 2022 are a result of the following:

- Building and energy sector emissions decreased the most, by 26%.
  - While electricity use increased by 1% (Table 4), total electricity emissions decreased by 31% (Table 3), contributing to most of the emissions decrease in the buildings and energy sector (98%). Therefore, the decrease in electricity emissions is primarily due to the regional grid switching to electricity generation sources that produce lower GHG emissions. Given that population and employment increased significantly since FY 14, energy efficiency measures also played a role in reducing electricity use and related emissions.
  - Natural gas use decreased by 2% between FY 14 and CY 22. As the same emissions factor was used in both years, the lower natural gas usage directly contributed to the overall decrease in emissions. The decrease in natural gas emissions contributed 2% to overall buildings and energy sector emissions reductions.
  - As shown in Table 4, the decrease in commercial/institutional and manufacturing/construction electricity use versus the increase in residential electricity use could be partially attributed to a shift in the quantity of the population working at home as a result of the COVID pandemic and an increase in the number of residential units.

Table 3. Location-Based Electricity Emissions Trends (Excluding Transmission & Distribution Emissions)

Type	FY 14 $MTCO_2e$	CY 22 $MTCO_2e$	% Change
Commercial and Institutional	1,191,269	800,437	-33%
Manufacturing and Construction	105,267	67,121	-36%
Residential	854,313	614,882	-28%
Total	2,150,849	1,482,440	-31%

Table 4. Electricity Use Trends

Type	FY 14 kWh	CY 22 kWh	% Change
Commercial and Institutional	2,800,432,415	2,744,054,667	-2%
Manufacturing and Construction	247,461,066	230,103,639	-7%
Residential	2,008,318,133	2,107,935,394	5%
Total	5,056,211,614	5,082,093,699	1%

- Transportation sector emissions increased by 10%.
  - This increase was primarily attributable to both an increase in vehicle miles traveled (VMT) and a change in the transportation emissions calculation methodology, as methods for calculating both VMT and emissions factors have increased in accuracy since the development of the FY 14 GHG inventory. The GPC allows cities to switch methodologies if there are more accurate or relevant data or methods available over time. The methodology changes are described below:
    - For FY 14, VMT was derived from 2015 Triangle Regional Travel Demand (TDM) Model provided by the North Carolina Area Metropolitan Planning Organization (CAMPO). Emission factors used were from USEPA's Motor Vehicle Emission Simulator 2014 (MOVES2014a).
    - For CY 22, VMT was obtained from Google Environmental Insights Explorer (EIE), as recommended by ICLEI (one of the authors of the GPC). Google EIE provides localized VMT data based on continuous observation, which is a more reliable indicator of year-to-year change in on-road transport activity than regional models that are only updated every few years. MOVES4, an updated version of the MOVES model, was used to generate emission factors.

- 2018 is the earliest year Google EIE provided VMT data. Google EIE data shows that Raleigh VMT increased 4% from 2018 to 2022.

➢ Waste sector emissions decreased by 11%.

- Waste emissions decreased even though total waste generated in the community increased (in line with population increases). This decrease in emissions is due to an improvement in the accuracy of the waste calculation methodology, as both the data available and methodology guidance has improved since the development of the FY 14 inventory. The GPC allows cities to switch methodologies if there are more accurate or relevant data or methods available over time. The methodology changes are described below:
    - In FY 14, the first order of decay (FOD) model was used to calculate solid waste emissions, which accounts for waste emissions actually emitted that year, regardless of when the waste was disposed. This means that the FY 14 inventory shows residual emissions from the two closed landfills (Wilders Grove and North Wake) in addition to the open landfill (South Wake).
    - In CY 22, the methane commitment model was used, in which all current and future emissions from waste generated in the inventory year are accounted for in that year's emission inventory, regardless of when the emissions occur. This means that there are no additional emissions estimates once a landfill is closed, such that for CY 22, only emissions from the open landfill (i.e. the South Wake) are included in the inventory.
    - Calculation of biological treatment emissions from the Yard Waste Compost Center used the same methodology as the previous FY 14 inventory, but for CY 22, the data input into the calculation is the total waste delivered to the treatment site, instead of total mulch generated as was the calculation input for FY 14. Waste delivered better reflects emissions associated with CY 22 and aligns with the methane commitment method used to calculate landfill emissions.
    - All wastewater generated in the community is sent to the Neuse River Resource Recovery Facility (NRRRF). In CY 22, emissions from the treatment and discharge of wastewater decreased by 6% when compared to FY 14, but this can be attributed to the change in calculation methodology and not an actual emissions reduction. Wastewater treatment emissions calculations are dependent on the total population served. In FY 14, the total population served by the NRRRF was used to calculate emission, which also included the population outside of Raleigh (509,738 people), whereas in CY 22 only the City of Raleigh population was used (476,587 people). If the City of Raleigh population was used to calculate emissions in FY 14, then wastewater treatment emissions would have increased by 8% from FY 14 to CY 22.

GHG inventory calculation methodologies and activity data sources will continue to improve over time. The City of Raleigh will continue to track national and international best practices to ensure future GHG inventories are accurate and complete.

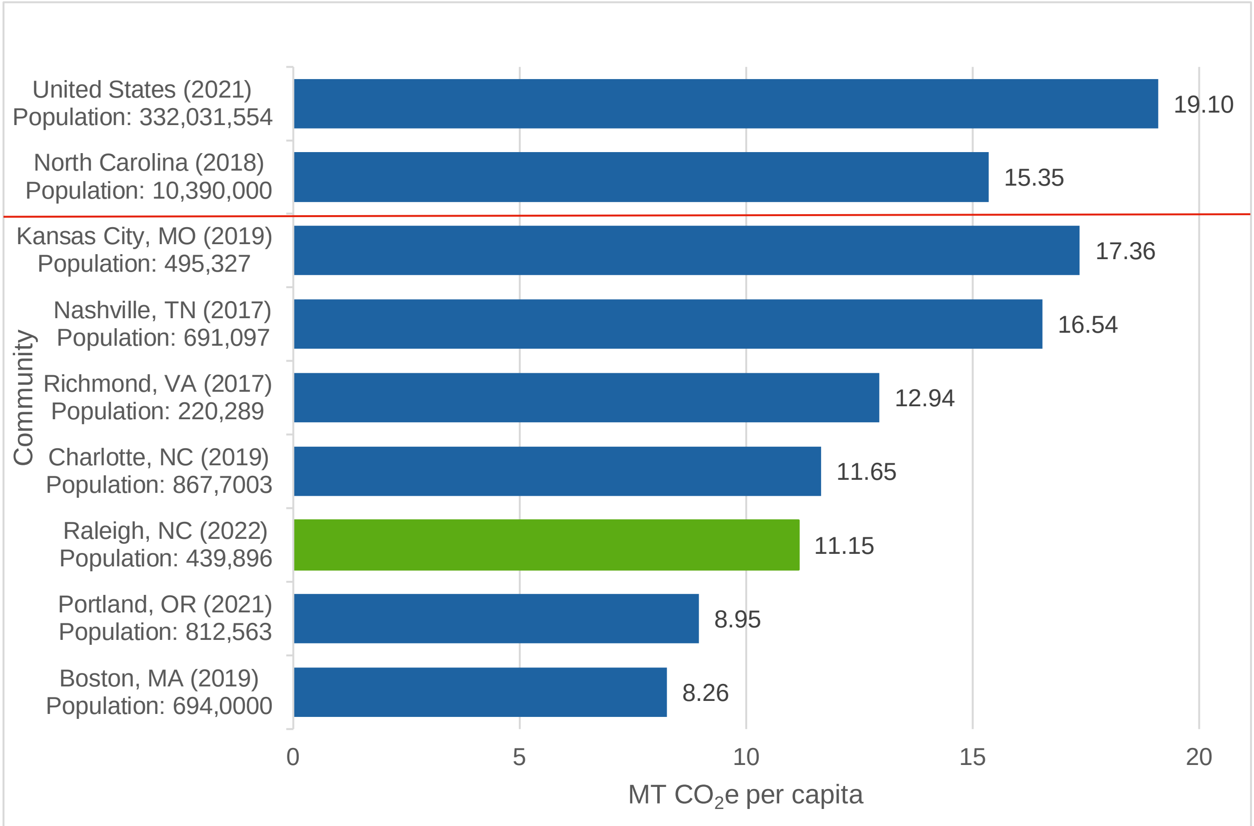
4. Comparing Raleigh's Community GHG Emissions to Peers

GHG inventory estimates can differ greatly between cities and communities due to the unique types of services available, such as significant transit operations or water and wastewater services, as well as cultural differences, such as more car dependent cultures versus those that are more inclined to prioritize mass transit options. GHG inventories may also vary in the selected operational boundary, timeframe, data sources, and specific methodology used. Even so, benchmarking GHG inventories against those of other similar cities and communities can provide helpful, high-level context for a city or community when analyzing emissions results.

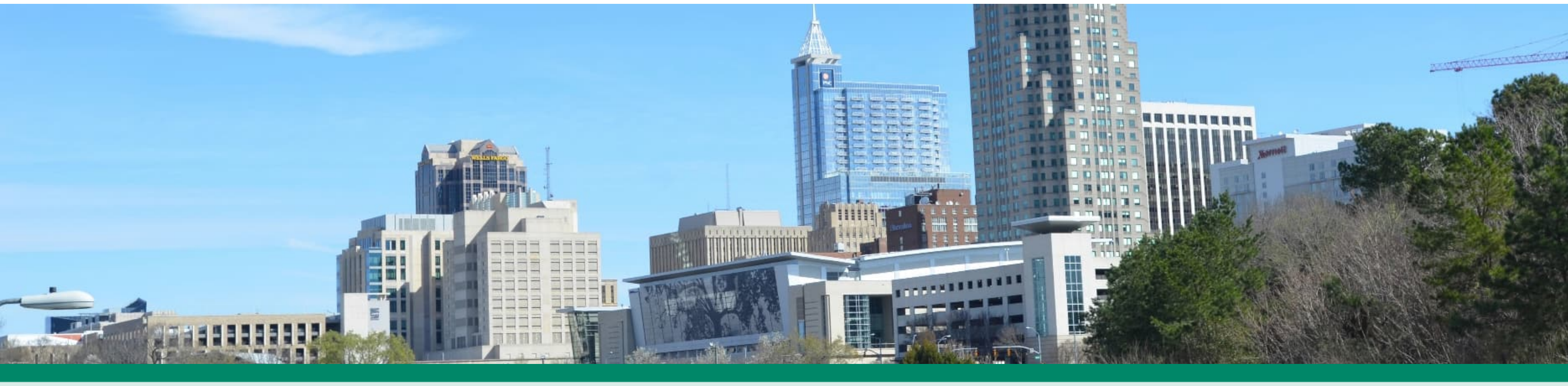
Figure 9 compares Raleigh's community emissions per capita to those of other comparable city communities, in addition to North Carolina and the broader United States. Note that Charlotte is the largest city in North Carolina, with a similar population to Portland, Oregon. These cities in Figure 9 were chosen to reflect a variety of cities with similar or larger populations, while also including cities like Portland and Boston, which both have larger populations and are more densely populated, resulting in lower total GHG emissions.

This comparison reflects that Raleigh is performing similarly or better as compared to other peer cities, the state of North Carolina, and the broader United States in terms of per capita emissions. Considering that Raleigh is one of the fastest growing cities in the country, the community should continue to focus on strategies that reduce GHG emissions as the City plans for continued growth. These strategies include those in Raleigh's Community Climate Action Plan (CCAP), such as reducing vehicle miles traveled, increasing public transportation options, increasing electric and clean fuel vehicles, and creating more densely populated walkable areas in Raleigh. Focusing on high impact strategies such as these will continue to help Raleigh reduce GHG emissions even as the community grows.

Figure 9. Community Emissions Benchmarking, $MTCO_2e$ per Capita



Note: Although Chapel Hill, NC and Durham, NC were included in the FY 14 report, they have been excluded from Figure 10 above as neither community has published an updated community-wide GHG Inventory since 2005, which is not comparable to the more recent data included in this report.



5. Opportunities for GHG Reductions

According to the results of the calendar year 2022 (CY 22) inventory, transportation contributed the highest percentage of GHG emissions (52%), followed by buildings and energy (47%) and waste (1%). Focusing efforts on strategies and actions in the transportation and buildings and energy sectors, which generate 99% of Raleigh's total GHG emissions, will provide the highest impact.

Table 5 below outlines high level opportunities for strategic GHG reductions by emissions sector. These strategies were also identified in the City of Raleigh's 2021 Community Climate Action Plan (CCAP) and the subsequent 2023 CCAP Implement Progress Report[15]. This shows that Raleigh's CCAP strategies and actions continue to align with the highest areas of GHG reduction impact.

Table 5. Possible GHG Reduction Strategies by Sector

Sector	% Total Emissions	Possible GHG Reduction Strategy
Transportation	52%	1. VMT reduction (e.g., efficient and compact land use planning), especially for on-road vehicles 2. Zero emission vehicles and infrastructure (e.g., electric vehicles, ZEV buses), especially for on-road vehicles 3. Mode shift to active and public transit modes (e.g., improving bicycle, pedestrian, and bus infrastructure)
Buildings and Energy	47%	4. Building electrification (e.g., transitioning natural gas equipment to electric) 5. Building energy efficiency (e.g., reducing energy use per square foot, LEED-Certifications, ENERGY STAR buildings and equipment) 6. Allowing more inherently energy-efficient housing types such as apartments and townhouses that per unit use less than half the energy of a detached house. 7. Clean energy installations and purchasing (e.g., solar and geothermal installations)
Waste	1%	8. Waste reduction (e.g., reduced purchasing, increased reuse) 9. Waste diversion (e.g., recycling, composting)

Electricity is one of the largest contributors to Raleigh's community-wide emissions, which ultimately comes from the portfolio of energy sources used by power suppliers to generate the electricity. The 2022 USEPA regional eGRID data shows that the Carolina/Virginia region shifted almost 4% of the fuel mix from fossil fuels to lower emissions energy sources compared to the energy mix in 2014. More substantial shifts from fossil fuels to renewable energy sources are expected to occur in the region and will play an important role in reducing electricity emissions. The

[15] https://cityofraleigh0drupal.blob.core.usgovcloudapi.net/drupal-prod/COR27/2023CCAPImplementationReport.pdf

City of Raleigh does not have direct control over electricity generation in the regional grid. However, as reflected in CCAP and the Implementation Reports, the City has been implementing several large renewable energy strategies across the region to increase the community's access to renewable energy, as well as supporting processes that further the transition to a cleaner energy mix.

Appendix A Community Inventory Calculation Detailed Methodology

Introduction

Raleigh's community inventory was prepared using the GHG Protocol's GPC standard methodology and guidance. This involves estimating emissions from specific activities occurring in the community and applying emission factors to the data associated with that activity. In general, this calculation follows this general equation:

$$\mathit{Activity\ Data} \times \mathit{Emission\ Factor} \times \mathit{Conversion\ Factors}\ (\mathit{if\ needed}) \times \mathit{GWP} = \mathit{GHG\ Emissions\ for\ the\ Activity}$$

Calculation Methodology by Sector

Transportation

Emissions from transportation were calculated for on-road and off-road sources in Raleigh using the following data and equations.

On-Road Transportation

Sub-Sector/Source	Activity Inputs and Source	Emission Factor Source	Assumptions
Automobiles	Vehicle Miles Travel (VMT/yr) obtained from Google EIE 2022 for Raleigh for each vehicle type	Emission factors (MTGHG / VMT) are derived from MOVES4 for each vehicle type and weighted by VMT for bus and non-bus vehicle types	Google EIE provides GPC-compliant VMT
Buses			

$$\text{MTCO}_2\text{e from VMT} = \left(\text{VMT} \times \frac{\text{MTCO}_2}{\text{VMT}} \times \text{GWP CO}_2\right) + \left(\text{VMT} \times \frac{\text{MTCH}_4}{\text{VMT}} \times \text{GWP CH}_4\right) + \left(\text{VMT} \times \frac{\text{MTN}_2\text{O}}{\text{VMT}} \times \text{GWP N}_2\text{O}\right)$$

Off-Road Transportation

Sub-Sector/Source	Activity Inputs and Source	Emission Factor Source	Assumptions
All off-road sources	N/A	Wake County emissions from MOVES4	Wake County emissions from MOVES4 are scaled to the City of Raleigh

Buildings and Energy

Emissions from electricity use and fuel combustion by buildings and other facilities were calculated using annual consumption and default emissions factors per energy/fuel type.

Electricity

Activity Inputs and Source	Emission Factor Source	Notes/Assumptions
Electricity usage (kWh/yr) provided by Duke Energy	Two factors for dual reporting: • Location-based: USEPA eGRID 2021 https://www.epa.gov/system/files/documents/2023-01/eGRID2021_summary_tables.pdf • Market-based: Duke Energy	Duke Energy provides electricity data by sub-sector: residential, commercial/industrial, and manufacturing. Government is included in commercial/industrial.

$$\text{MT CO}_2\text{e} = \left(\text{kWh} \times \frac{\text{EF MT CO}_2}{kWh} \times \text{GWP CO}_2\right) + \left(\text{kWh} \times \frac{\text{EF MT CH}_4}{kWh} \times \text{GWP CH}_4\right) + \left(\text{kWh} \times \frac{\text{EF MT N}_2\text{O}}{kWn} \times \text{GWP N}_2\text{O}\right)$$

Fuel Combustion – Natural Gas

Activity Inputs and Source	Emission Factor Source	Notes/Assumptions
Natural gas usage (therms/yr) provided by Dominion Energy	US EPA GHG Emission Factors Hub: https://www.epa.gov/climateleadership/ghg-emission-factors-hub	Dominion Energy provides natural gas data by sub-sector: residential, commercial/industrial, and manufacturing. Government is included in commercial/industrial.

$$1.\ MT\ CO_2 = therms \times \frac{29.3\ kWh}{therm} \times \frac{EF\ kg\ CO_2}{MMBtu} \times \frac{MT}{1{,}000\ kg} \times \frac{MMBtu}{293.3\ kWh} \times GWP\ CO_2$$

$$2.\ MT\ CH_4 = therms \times \frac{29.3\ kWh}{therm} \times \frac{EF\ g\ CH_4}{MMBtu} \times \frac{MT}{1{,}000{,}000\ g} \times \frac{MMBtu}{293.3\ kWh} \times GWP\ CH_4$$

$$3.\ MT\ N_2O = therms \times \frac{29.3\ kWh}{therm} \times \frac{EF\ g\ N_2O}{MMBtu} \times \frac{MT}{1{,}000{,}000\ g} \times \frac{MMBtu}{293.3\ kWh} \times GWP\ N_2O$$

$$4.\ MT\ CO_2e = (MT\ CO_2 \times GWP\ CO_2) + (MT\ CH_4 \times GWP\ CH_4) + (MT\ N_2O + GWP\ N_2O)$$

Fuel Combustion – Distillate No. 2 Fuel Oil

Activity Inputs and Source	Emission Factor Source	Notes/Assumptions
Fuel oil usage (gal/yr) provided by NC Department of Environment, Division of Air Quality	US EPA GHG Emission Factors Hub: https://www.epa.gov/climateleadership/ghg-emission-factors-hub	The only fuel oil used is diesel fuel

$$1.\ MT\ CO_2 = gallon \times \frac{40.5\ kWh}{gallon} \times \frac{EF\ kg\ CO_2}{MMBtu} \times \frac{MT}{1{,}000\ kg} \times \frac{MMBtu}{293.3\ kWh} \times GWP\ CO_2$$

$$2.\ MT\ CH_4 = gallon \times \frac{40.5\ kWh}{gallon} \times \frac{EF\ g\ CH_4}{MMBtu} \times \frac{MT}{1{,}000{,}000\ g} \times \frac{MMBtu}{293.3\ kWh} \times GWP\ CH_4$$

$$3.\ MT\ N_2O = gallon \times \frac{40.5\ kWh}{gallon} \times \frac{EF\ g\ N_2O}{MMBtu} \times \frac{MT}{1{,}000{,}000\ g} \times \frac{MMBtu}{293.3\ kWh} \times GWP\ N_2O$$

$$4.\ MT\ CO_2e = (MT\ CO_2 \times GWP\ CO_2) + (MT\ CH_4 \times GWP\ CH_4) + (MT\ N_2O + GWP\ N_2O)$$

Waste

Emissions from electricity use and fuel combustion by buildings and other facilities were calculated using annual consumption and default emissions factors per energy/fuel type.

Solid Waste Disposal

Sub-Sector/Source	Activity Inputs and Source	Emission Factor Source	Assumptions
Solid Wase Disposal	Solid waste disposal quantity from City of Raleigh Solid Waste Services and Wake County Solid Waste Division	Wake County Waste Characterization Study, 2019; Equation 8.1 DOC	Equation 8.3 Methane commitment estimate for solid waste sent to landfill; Equation 8.4 Methane generation potential Wake County Waste Characterization Study, 2019

Equation 8.3. Methane commitment estimate for solid waste sent to landfill
This equation is formatted to take individual waste streams into account. As such, it is applied to each waste composition then summed to get the total CH4 emissions.

$$\text{MT } CO_2e = MSW_x \times L_o \times (1 - f_{req}) \times (1 - OX) \times \text{GWP } CH_4$$

Where:	Value:
MSW_x = Mass of solid waste sent to landfill in inventory year, waste stream specific (MT)	User input
L_o = Methane generation potential	Calculated in Equation 8.4
f_{req} = Fraction of methane recovered at the landfill; estimated from County	0.7
OX = oxidation factor; default for managed landfill	0.10

Equation 8.4. Methane generation potential, L_o
This equation is formatted to take individual waste streams into account. As such, the DOC_f is different per waste type.

$$\text{Methane Generation Potential } L_o = MCF \times DOC \times DOC_f \times F \times 16/12$$

Where:	Value:
MCF = Methane capture rate; default value for managed landfill	1
DOC = degradable organic carbon; calculated	0.16626
DOC_f = Fraction of DOC that is ultimately degraded; default per waste composition	Per waste type (IPCC Guidelines Volume 5 Table 2.4, 2006)
F = Fraction by volume of CH_4 in LF gas fraction; default	0.5
16/12 = stoichiometric ratio b/w carbon and methane	1.333333333

Biological Treatment of Waste – Composting (Yard Waste)

Activity Inputs and Source	Emission Factor Source	Assumptions
Waste quantity composted (amount delivered to City Yard Waste Center) provided by City of Raleigh Solid Waste Services	IPCC 2006 Guidelines, Chapter 4, Table 4.1	IPCC 2006 Guidelines, Chapter 4, adaption of Equations 4.1 and 4.2

$$\text{MT } CO_2e = \text{Waste treated} \times \frac{907.18 \text{ kg}}{\text{ton}} \times [(EF\ CH_4 \text{ x GWP } CH_4) + (EF\ N_2O \text{ x GWP } N_2O)] \text{ x } \frac{MT}{1{,}000{,}000g}$$

Where:	Value:
Waste treated = Annual short tons of waste treated (wet basis)	User Input
EF CH_4 = CH_4 emission factor (wet weight basis) for composting (g CH_4/kg waste treated)	4
EF N_2O = N_2O emission factor (wet weight basis) for composting (g N2O/kg waste treated)	0.24

Waste Incineration

Activity Inputs and Source	Emission Factor Source	Assumptions
Waste quantity incinerated (private sector clinical waste) provided by Duke Energy for sources identified by NC Department of Environment Division of Air Quality (NCDAQ)	Default values from Table 8.4	Equation 8.6: Non-biogenic CO_2 emissions from the incineration of waste All waste is clinical waste (NCDAQ). Only CO_2 emissions are calculated for incineration, as default data is available for clinical waste. The only default data available for CH_4 or N_2O aligns with MSW.

$$MT\ CO_2 = m \times (Wf_i \times dm_i \times Cf_i \times FCF_i \times Of_i) \times (44/12)$$

Where:	Source:	Value:
m = Mass of waste incinerated in tonnes	User Input	User Input
Wf_i = Fraction of waste consisting of clinical waste	User Input	1
dm_i = Dry matter content in the type I matter	Default values from Table 8.4	NA
Cf_i = Fraction of carbon in the dry matter of type I matter		0.60
FCF_i = Fraction of fossil carbon in the total carbon component of type I matter		0.40
Of_i = Oxidation fraction or factor		1
i = Matter type of the Solid Waste incinerated		Clinical
44/12 = stoichiometric ratio b/w carbon and carbon dioxide		3.66667

Wastewater Process Effluent Emissions

Activity Inputs and Source	Emission Factor Source	Assumptions
Population served by WWTP (City of Raleigh population from US Census data[16]	Equation 10.7 from LGOP Version 1.1	Calculations are only for the Neuse River Resource Recovery Facility (NRRRF), as it is the only plant that services the Raleigh population.
Effluent treatment volume provided by City of Raleigh Staff for the NRRRF (used to calculate N load for Equation 10.9)	Equation 10.9 from LGOP Version 1.1	Total effluent from facility was multiplied by the percentage of the population treated by this facility from the City of Raleigh (77%) provided by the City.
Average total Nitrogen discharge (N Load) provided by City of Raleigh staff for the NRRRF (used to calculate N Load for Equation 10.9)	Equation 10.9 from LGOP Version 1.1	Since site specific N load data was available, Equation 10.9 was used instead of Equation 10.10 which only requires population data.

Equation 10.7. Process N_2O Emissions from WWTP with Nitrification/Denitrification

$$\text{MT } CO_2e = ((P_{total} \times F_{ind-com}) \times \text{EF nit/denit} \times \frac{\text{MT}}{1{,}000{,}000\text{ g}}) \text{ x GWP } N_2O$$

Where:	Value:
P_{total} = Total population served by the centralized WWTP adjusted for industrial discharge, if applicable [person]	User input
$F_{ind-com}$ = Factor for industrial and commercial co-discharge waste into the sewer system (not included in calculation as the wastewater discharged incudes city-wide residential water)	N/A
EF nit/denit = Emission factor for a WWTP with nitrification/denitrification [g N_20/person/year]	7.00

Equation 10.9. Process N_2O Emissions from Effluent Discharge (site-specific N Load data)

$$\text{MT } CO_2e = (\text{N Load x EF effluent x 365.25 x } \frac{\text{MT}}{1{,}000\text{ kg}} \times 44/28) \text{ x GWP } N_2O$$

Where:	Value:
N Load = Measured average total nitrogen discharged [kg N/day]	User input
EF effluent = Emission factor [kg N_20-N/kg sewage-N produced]	0.005
365.25 = Conversion factor [day/year]	365.25
44/28 = Molecular weight ratio of N_20 to N_2	1.57

[16] https://www.census.gov/quickfacts/fact/table/wakecountynorthcarolina,raleighcitynorthcarolina/PST045222