Greenhouse Gas Emissions Inventory for the City of Baltimore, 2018-2020

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Executive Summary

Key takeaway points:

- Total GHG emissions from Baltimore City decreased by (100-year GWP):
  - 12.3% from 2007 to 2017
  - 7.6% from 2007 to 2018
  - 12.0% from 2007 to 2019
  - 23.2% from 2007 to 2020

- As of 2020, citywide GHG emissions are dominated by the *Stationary Energy* sector (64%), with additional emissions from the *Transportation* sector (22%) and the *Waste* sector (14%).
  - Within the *Stationary Energy* Sector, only 34% of emissions were for residential energy, while 66% of emissions were for industrial and commercial energy use.
  - Within the *Stationary Energy* Sector, 54% of GHG emissions resulted from electricity generation that occurred outside of the city, while 46% of GHG emissions resulted from natural gas use (combustion and fugitive gas leaks) within the city.

- GHG emissions from electricity generation for Baltimore City decreased by 32% from 2007 to 2020, largely driven by a shift from coal-power plants to natural gas-power plants.
  - Growth in the overall share of renewables contributing to the regional electricity grid has been slow, increasing from 1% in 2007 to only 5.5% in 2021.
  - Electricity produced via fossil fuel combustion has remained the dominant source of electricity for Baltimore – over 60% as of 2021, and only down ~3% since 2007.

- The COVID-19 pandemic made a sizable impact on GHG emissions from Baltimore City. The largest impacts were on transportation; total traffic volume decreased by 17% between 2017 and 2020. Other sectors also showed declines in emissions. Electricity usage dropped 5% and natural gas consumption 12% between 2019 and 2020. Overall, Baltimore City's GHG emissions dropped by 12% between 2019 and 2020.

Figure 1. Citywide GHG emissions totals for 2007 and 2017–2020

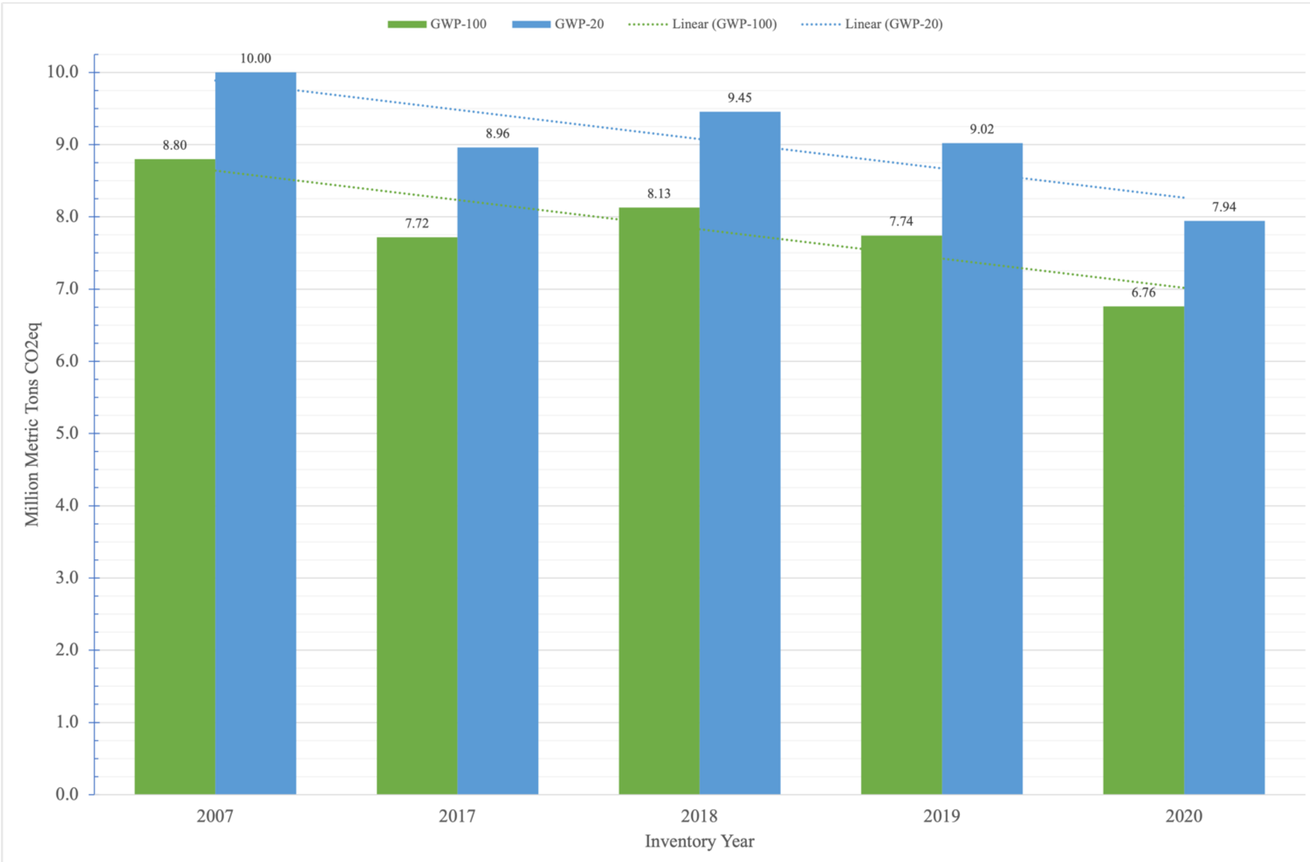


Table 1. Summary of Baltimore City's annual GHG emissions totals, per capita emissions, and net GHG emissions reductions since 2007

Year	100-year GWP			20-year GWP		
	Tons CO_2eq	% change since 2007	Tons CO_2eq per capita	Tons CO_2eq	% change since 2007	Tons CO_2eq per capita
2007	8,797,260	0.0	13.74	9,999,626	0.0	15.62
…	…	…	…	…	…	…
2017	7,716,606	–12.3	12.63	8,960,614	–10.4	14.67
2018	8,127,425	–7.6	13.47	9,452,925	–5.5	15.67
2019	7,740,773	–12.0	13.02	9,019,163	–9.8	15.17
2020	6,759,180	–23.2	11.59	7,942,461	–20.6	13.62

Table of Contents

Table of Figures

Table of Tables

Introduction

a) Context

The Baltimore Office of Sustainability was created by the Baltimore City Council in 2007, and the Office of Sustainability released the first *Baltimore Sustainability Plan* in 2009. This Sustainability Plan was designed as a comprehensive environmental roadmap for Baltimore City and outlined the city's first official commitment to greenhouse gas (GHG) emissions reductions. The city's first *Climate Action Plan*, released in 2012, expanded upon the GHG emissions reductions goals outlined in the *Baltimore Sustainability Plan*, and set an initial target of 15% GHG emissions reductions by 2020 (relative to a 2010 baseline). The Office of Sustainability updated the *Baltimore Sustainability Plan* in 2019, which committed Baltimore to GHG emissions reduction targets similar to those set by the 2015 Paris Climate Agreement – 25% GHG emissions reductions by 2020, and 30% by 2025 (relative to a 2007 baseline).

In 2020, the Baltimore Office of Sustainability teamed up with researchers from Johns Hopkins University to update Baltimore's GHG emissions inventory for 2017, and to reassess GHG emissions for the 2007 baseline year using analogous methodology. The goal of the 2017 GHG inventory was to benchmark progress that the City of Baltimore had made toward GHG emissions reductions since 2007, and to assess whether the city is on pace to meet its GHG emissions reductions targets. The overall takeaway from the 2017 GHG emissions inventory is that while Baltimore has made substantial progress in decreasing citywide GHG emissions, the city is not quite on pace to reach its emissions reductions goals for 2020 and 2025. With a goal of 25% GHG emissions reductions by 2020, Baltimore had only achieved emissions reductions of ~13% from the 2007 baseline as of 2017, signaling a need for the city to accelerate future emissions reductions in order to achieve upcoming targets.

More recently, the Baltimore Office of Sustainability started the process of updating the city's *Climate Action Plan*. In January 2022, Baltimore Mayor Brandon M. Scott and the Baltimore Office of Sustainability announced that the updated *Climate Action Plan* will set ambitious new targets for citywide GHG emissions reductions: a 30% reduction in GHG emissions by 2025, a 60% reduction in GHG emissions by 2030, and full carbon neutrality – or a 100% reduction in net GHG emissions – by 2045 (each relative to a 2007 baseline). This report serves as a progress report on GHG emissions reductions through 2020, in order to assess whether Baltimore achieved its target of 25% emissions reductions from 2007 to 2020. When data availability permits, we include analyses of year-to-year changes in GHG emissions sources in an effort to highlight sources with the highest and lowest potential for future citywide GHG emissions reductions.

b) Geographic Boundary and Timespan

We report GHG emissions occurring as a result of activities within Baltimore City geographic boundary for the 2018, 2019, and 2020 calendar years (Jan. 1 to Dec. 31). We also provide an update to the 2007 and 2017 emissions inventories using analogous data sets and methodologies, in order to avoid biases and mismatched data sources when comparing different inventory years. These adjustments have a minor effect (<10%) on the citywide GHG emissions totals but enable a more streamlined process for updating future inventories and comparing emissions totals across years where data sources may be inconsistent, or not yet available for recent years.

c) Greenhouse Gas Emissions Reporting Framework

We follow the *Global Protocol for Community-Scale Greenhouse Gas Emission Inventories* (GPC) – developed by the World Resources Institute, C40 Cities Climate Leadership Group, and ICLEI – Local Governments for Sustainability – for accounting and reporting Baltimore's city-wide greenhouse gas emissions [1]. The GPC provides an accounting and reporting standard for tracking city-scale greenhouse gas emissions across six main sectors: (1) Stationary Energy, (2) Transportation, (3) Waste, (4) Industrial Processes and Product Use (IPPU), (5) Agriculture, Forestry, and Other Land Use (AFOLU), and (6) Other Scope 3. Each of these main sectors are broken down further into subsectors, summarized in **Table 2**.

Table 2. Sectors and subsectors used by the GPC to classify city-wide GHG emissions

Sector	Subsector
1. Stationary Energy	1. Residential buildings 2. Commercial and institutional buildings and facilities 3. Manufacturing industries and construction 4. Energy industries 5. Agriculture, forestry, and fishing activities 6. Non-specified sources 7. Fugitive emissions from coal operations 8. Fugitive emissions from oil and natural gas systems
2. Transportation	1. On-road 2. Railways 3. Waterborne navigation 4. Aviation 5. Off-road
3. Waste	1. Solid waste disposal 2. Biological treatment of waste 3. Incineration and open burning 4. Wastewater treatment and discharge
4. IPPU	1. Industrial processes 2. Product use
5. AFOLU	1. Livestock 2. Land 3. Aggregate sources and non-CO_2 emission sources on land
6. Other Scope 3	1. Other

Across these six sectors, emissions are further classified by scope to differentiate between GHG emissions occurring within Baltimore City (Scope 1) and emissions occurring outside of the city boundary (Scope 2 and Scope 3). The definitions of each of the three scopes are given in **Table 3**.

Table 3. GPC definitions of Scope 1, Scope 2, and Scope 3 emissions

Scope	Definition
Scope 1	Greenhouse gas emissions from sources located within Baltimore City
Scope 2	Greenhouse gas emissions occurring as a consequence of the use of grid-supplied electricity, heat, steam and/or cooling within Baltimore City
Scope 3	All other greenhouse gas emissions that occur outside Baltimore City as a result of activities taking place within Baltimore City

This GHG emissions inventory satisfies the BASIC level reporting under the GPC, which includes Scope 1 and Scope 2 emissions from Stationary Energy and Transportation, as well as generated waste emissions within the City boundary. In particular, the GPC requires GHG emissions from the following sources to be included in the city-induced BASIC level reporting [1]:

- All Scope 1 emissions from *Stationary Energy* sources
- All Scope 1 emissions from *Transportation* sources
- All Scope 1 emissions from *Waste* sources
- All Scope 2 emissions from *Stationary Energy* sources and transportation
- Scope 3 emissions from treatment of exported waste

Notably, we report Scope 2 emissions from transportation (e.g., electricity consumption for electric vehicle charging) in the stationary energy sector, since it would be difficult to disaggregate the city's electricity consumption by end use. Additionally, due to the presence of two large municipal solid waste treatment facilities within the city limits (the Wheelabrator Baltimore incinerator and the Quarantine Road Landfill), we assume that most waste generated within Baltimore is not exported outside the city limits, and so Scope 3 waste emissions are assumed to be negligible.

In general, we follow the GHG emissions reporting framework for each source in Baltimore City as detailed in the *City of Baltimore 2017 Greenhouse Gas Emissions Inventory Report* (Gaeta et al. 2020) [2]. For most emissions sources in the current 2018-2020 inventory, one could look at the 2017 report for additional details on how emissions estimates are calculated. However, the current inventory report deviates from the 2017 methodology in two main ways. First, GHG emissions from Wheelabrator Baltimore are included in Sector 3.3 (Waste – Incineration and Open Burning) in this report, despite being omitted from overall GHG emissions totals in the 2017 report. Our reasoning for this update is that as a whole, Wheelabrator Baltimore is more accurately characterized as a waste treatment facility than as an electricity generating facility.

Although the Wheelabrator incinerator does produce some electricity for the regional grid, it is a very small amount of electricity relative to the size of the grid, equivalent to only ~5% of Baltimore City's total electricity demand [2]. In fact, all municipal solid waste incinerators on the regional grid together supply only ~0.5% of the grid's total electricity demand, and the contribution from Wheelabrator Baltimore is only a fraction of that. Thus, we argue that it would be misleading to omit GHG emissions from the Wheelabrator incinerator in Baltimore City's GHG emissions totals on the merit that it is an electricity source for the regional grid. One could correct the electricity grid CO_2 emissions factor to remove the contribution of the Wheelabrator incinerator, but it makes such a small contribution to the grid that with rounding, the CO_2 emissions factor would effectively be unchanged.

Secondly, we do not explicitly include GHG emissions from large commercial, institutional, and industrial point sources in this analysis, although emissions from these facilities are implicitly included in the total industrial/commercial stationary energy emissions. In the 2017 report, we used point source GHG emissions data from the U.S. Environmental Protection Agency (EPA) National Emissions Inventory (NEI) to specify facility-level GHG emissions within Baltimore City [3], [4]. We then adjusted the industrial/commercial stationary energy emissions totals to avoid double counting the point sources. However, since the EPA NEI is only released every three years and hasn't been made publicly available for 2020, we take a simpler approach for including GHG emissions from point sources in 2018-2020 by simply including them as part of the citywide industrial/commercial natural gas emissions, rather than disaggregating the point sources into their respective subsectors. When aggregating emissions totals by sector, the stationary energy emissions totals would not be affected by this change, since it effectively amounts to moving emissions from one subsector to another within the same sector. However, for context, we include a table summarizing some of the larger GHG emissions point sources and their relative contribution to the city's overall emissions in the Appendix (**Table 24**).

There are several other notable sources of GHG emissions that are not included in this GHG emissions inventory. In particular, GHG emissions resulting from activities occurring in the Helen Delich Bentley Port of Baltimore are not included in this report, since most of the activities in the shipping port are outside of the jurisdiction of Baltimore City. Other Scope 3 emissions are also not considered in this report, including transportation and aviation emissions caused by Baltimore residents outside of the city (including flights taken out of Baltimore/Washington International (BWI) airport), emissions related to agricultural production for Baltimore residents, and emissions caused by production and shipping of goods from outside of Baltimore. Indeed, few municipal GHG inventories include Scope 3 emissions, due in part to the tremendous breadth of emissions included in this category and the detailed accounting that would be required to quantify these emissions. (See Scope 3 emissions in Maryland's GHG emissions inventory [5], GHG emissions goals for BWI airport [6], and recent efforts to reduce GHG emissions from the Port of Baltimore [7] for more information).

d) Greenhouse Gases and Global Warming Potentials

In this report, we analyze emissions of the three major greenhouse gases: carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). In order to compare the climate warming impact of the different GHGs over different time scales, we use the common metric of global warming potential (GWP). GWPs indicate the heat-trapping effect of a non-CO_2 GHG relative to CO_2, over a particular time interval (commonly 100 years or 20 years). The two key factors that determine the GWP of a GHG are the potency (i.e., radiative efficiency, or how effectively the GHG absorbs and traps heat) and the atmospheric lifetime (i.e., how long the GHG persists in the atmosphere after being emitted).

For example, each ton of CH_4 emitted to the atmosphere traps far more heat than each ton of CO_2: ~28 times as much over a 100-year period, or ~84 times as much over a 20-year period [8]. The GWP of CH_4 is larger over shorter intervals because the gas has an atmospheric lifetime of only ~10-12 years, whereas the atmospheric lifetime of CO_2 is several thousands of years. Thus, when considering emissions of equal masses of CO_2 and CH_4 emitted at the same time, the cumulative heat-trapping effect of CH_4 relative to CO_2 is very large over the first couple decades, but the cumulative heat-trapping effect of the CO_2 begins to dominate after the shorter-lived CH_4 is removed from the atmosphere (typically via oxidation by hydroxyl radicals). GWPs are a useful way to quantitatively relate the relative, cumulative heat-trapping effect of emissions of different GHGs, with the caveat that the warming effect is different over different time intervals.

We use GWP values from the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5) throughout this report. Notably, GWP values for CH_4 and N_2O have varied slightly in each of the past three IPCC reports – AR6 (2021), AR5 (2013), and AR4 (2007). We list the GWP values for CO_2, CH_4, and N_2O from these reports in **Table 4** for reference [8]–[10].

Table 4. Global warming potentials of CO_2, CH4, and N_2O

Greenhouse Gas	GHG	IPCC AR6		IPCC AR5		IPCC AR4	
		20-year GWP	100-year GWP	20-year GWP	100-year GWP	20-year GWP	100-year GWP
Carbon Dioxide	CO_2	1	1	**1**	**1**	1	1
Methane (fossil origin)	CH_4	82.5	29.8	**84**	**28**	72	25
Methane (non-fossil)	CH_4	80.8	27.2				
Nitrous Oxide	N_2O	273	273	**264**	**265**	289	298

One innovation that is somewhat unique to Baltimore City's GHG emissions inventory is that we report emissions using both 100-year and 20-year GWPs. While the 100-year GWP is the most commonly used metric for reporting aggregated GHG emissions of multiple GHGs, the 20-year GWP may be useful when considering the short-term climate warming impact of CH_4 emissions.

Notably, the IPCC AR5, on the topic of interpreting and using GWPs, states, "The choice of time horizon has a strong effect on the GWP values — and thus also on the calculated contributions of CO_2 equivalent emissions by component, sector, or nation. There is no scientific argument for selecting 100 years compared with other choices. The choice of time horizon is a value judgement because it depends on the relative weight assigned to effects at different times [8]."

However, GHG emissions are typically reported using 100-year GWP values, a standard that was adopted by the United Nations Framework Convention on Climate Change (UNFCCC) in the 1990's. For the sake of consistency between GHG emissions inventories reported by other cities, states, and nations, we recommend using the 100-year GWP CO_2eq emissions totals in this report for most purposes. However, the 20-year GWP CO_2eq emissions totals may provide additional insight into whether CO_2 emissions reductions were achieved at the expense of increased CH_4 emissions (which have a stronger short-term climate warming impact, and thus a larger 20-year GWP).

e) Findings from recent atmospheric CO_2 studies in the Baltimore/DC area

The emissions numbers in this report generally parallel those in a recent academic study of CO_2 emissions from the Baltimore-Washington metropolitan area during the COVID pandemic. Yadav et al. (2021) used a network of atmospheric CO_2 sensors located at TV and other telecommunications towers to calculate changes in CO_2 emissions from the Baltimore-DC area during March and April 2020 [11]. They reported that CO_2 emissions dropped by 25% (±14%) in March 2020 relative to the average of March 2018 and 2019. However, they attributed the bulk of this decrease to warmer weather in March 2020 relative to previous years. They further found that emissions dropped 33% (±11%) in April 2020 (relative to April 2018 and 2019) and attribute most of this decrease to a 23% decline in traffic during this time. Note that the atmospheric CO_2 observations used in that study do not support more detailed emissions estimates than an aggregate total for the entire Baltimore-DC metropolitan area. In addition, the estimates in that study only encompass Scope 1 emissions, not Scope 2.

Sector 1: Stationary Energy

a) Electricity

Key points:

- Electricity emissions decreased by 32% between 2007 and 2020.
- This change is largely due to a decrease in coal and an increase in natural gas in Baltimore's electricity supply.
- By contrast, renewable energy still constitutes a small share of Baltimore's energy supply (5% in 2020).
- Baltimore's electricity consumption has changed little since 2007. However, per capita electricity consumption has increased by just over 10% since 2007.

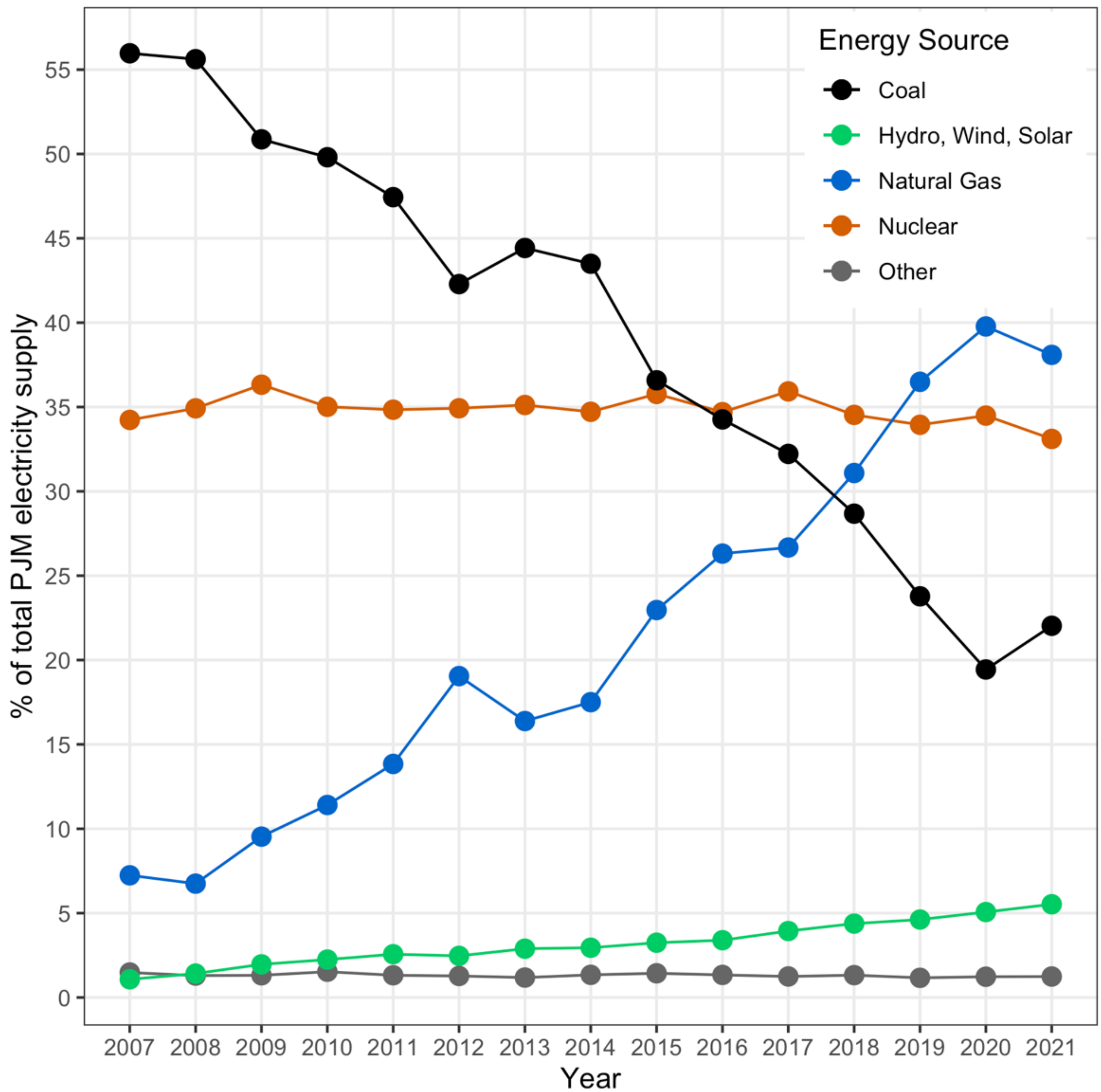
To analyze GHG emissions resulting from the consumption of electricity in Baltimore City, we follow the methodology described in the 2017 Baltimore Greenhouse Gas Emissions Report (Gaeta et al. 2020) [2]. Specifically, we use electricity consumption and supply data from Baltimore Gas & Electric Company (henceforth BG&E) and PJM Interconnection LLC (henceforth PJM). BG&E, a subsidiary of Exelon Corporation, supplies and delivers electricity to residential, commercial, industrial, and institutional buildings across Baltimore City. Electricity consumed by Baltimore residents is supplied to BG&E via the regional electricity grid operator, PJM, which supplies electricity to utility companies throughout all or most of Maryland, Washington DC, Delaware, New Jersey, Pennsylvania, West Virginia, Virginia, and parts of North Carolina, Kentucky, Tennessee, Ohio, Indiana, Michigan, and Illinois.

There are over 1,000 electricity generation sources that supply electricity to the PJM grid, each with varying CO_2 emissions factors (EF) that depend on the type of energy source utilized to generate electricity (e.g., coal, natural gas, nuclear, solar, hydro, wind) and the technologies deployed by the electricity producers. **Figure 2** shows the year-to-year changes in the mix of energy sources used to supply electricity to the PJM grid by fuel type.

Currently, renewable energy makes up only a small share of Baltimore's electricity supply. There are three types of renewable energy sources contributing to the PJM electricity grid: wind, hydro, and solar power. Growth in the overall share of renewables contributing to the PJM grid has been slow, increasing from 1% in 2007 to only 5.5% in 2021. Electricity produced via the combustion of fossil fuels such as coal and natural gas, on the other hand, has remained the dominant source of electricity supplied to the PJM grid – over 60% as of 2021, and only down ~3% since 2007.

The overall mix of energy sources, paired with the electricity consumption rate in Baltimore, determines the GHG emissions resulting from electricity consumption in Baltimore City. Annual electricity consumption data for Baltimore City was shared by BG&E with the Baltimore Office of Sustainability (John Quinn, BG&E, personal communication) [12]. The overall grid fuel mix and corresponding CO_2 emissions factors are verified and reported annually by PJM [13].

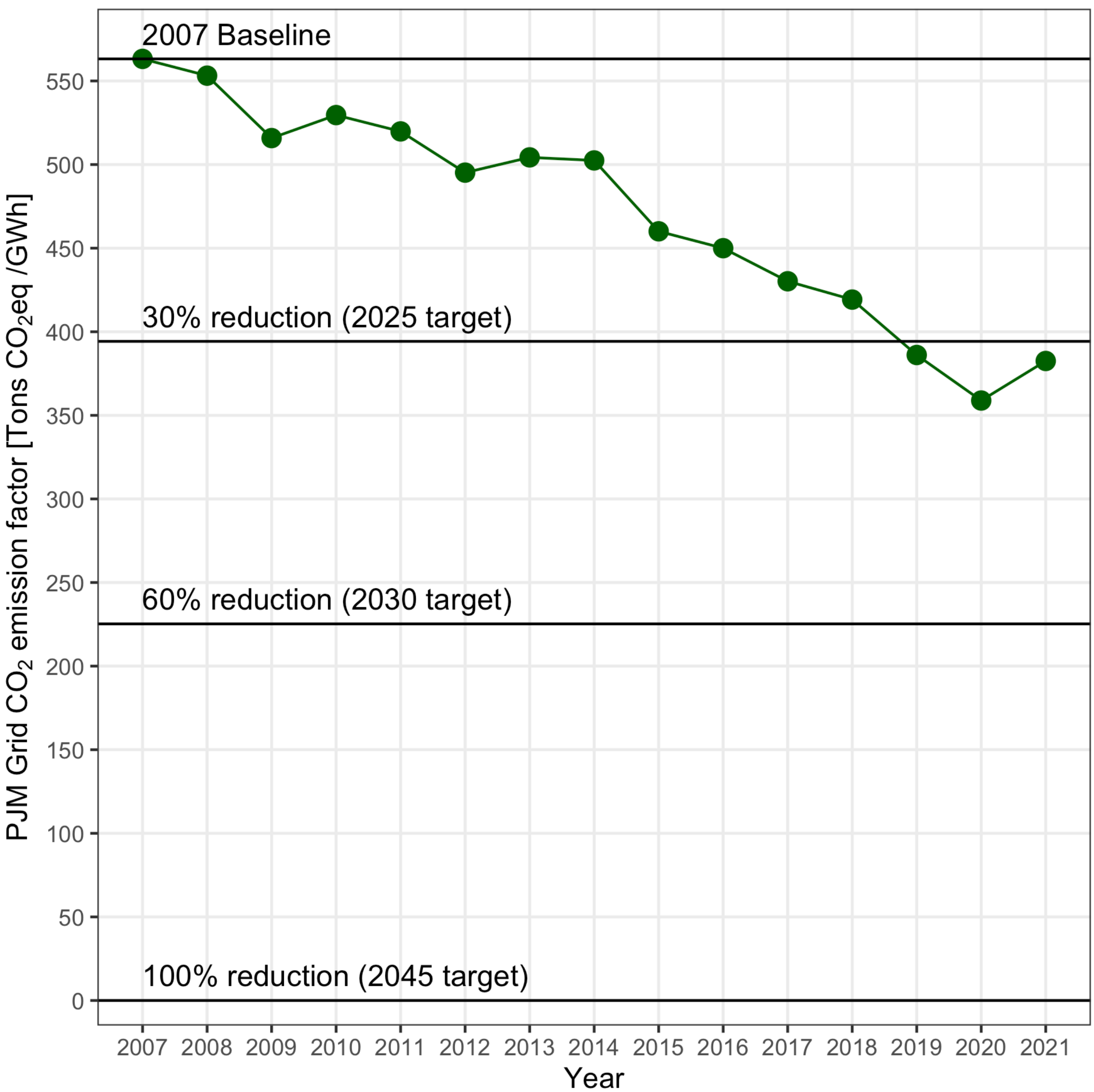
Figure 2. Time trends in the share of electricity generation by energy source (2007-2021)



In spite of the small and slowly increasing contribution of renewable energy, there has been a relatively steady decline in the CO_2 emissions factor for electricity from the PJM grid, shown visually in **Figure 3** and numerically in **Table 6**. This reduction in the CO_2 emissions factor has been largely driven by a simultaneously increasing share of natural gas power (7.2% in 2007 to 38.1% in 2021) and a decreasing share of coal power (56.0% in 2007 to 22.0% in 2021) supplied to the grid, as shown in **Figure 2**.

Replacing coal-powered electricity with natural gas-powered electricity leads to an effective reduction in the overall grid emission factor because the CO_2 emission factor for coal is 2-3 times larger than the CO_2 emission factor for natural gas (**Table 5**). In other words, each GWh of electricity produced via coal-fired power plants emits 2-3 times as much CO_2 as the each GWh of electricity produced via natural gas-fired power plants. The recent shift from coal to natural gas has resulted in a decrease in the overall CO_2 emissions factor for the PJM grid, shown in **Figure 3**.

Figure 3. Time series of the CO_2 emission factor for the PJM electricity grid (2007-2020)



However, there are limitations to GHG emissions reductions that can be achieved by switching from coal-powered electricity to natural gas-powered electricity. Natural gas power plants still have a CO_2 emissions factor of ~400 tons of CO_2 per GWh of electricity produced. Meanwhile, the overall PJM grid emission factor recently dropped below 400 tons CO_2/GWh (approximately equivalent to the 2025 goal of a 30% reduction in GHG emissions). This fact suggests that future GHG emissions reductions that rely on an increasing share of natural gas-powered electricity may start to plateau, especially if the overall share of coal-powered electricity (which has a very high CO_2 emissions factor of >1,000 tons CO_2/GWh) supplied to the PJM grid continues to decrease. Renewable energy sources, as well as nuclear power (which typically is not considered renewable energy), all have an effective CO_2 emissions factor of 0 tons of CO_2 per GWh of electricity produced (**Table 5**). An expansion of these "carbon neutral" electricity sources on the PJM grid, on the other hand, is certain to decrease Scope 2 GHG emissions from electricity consumption in Baltimore.

Table 5. PJM electricity grid fuel mix for 2018, 2019, 2020, and 2021

Fuel Type	Fuel Sub-type	CO_2eq EF [tons/GWh]	2018 % of total	2019 % of total	2020 % of total	2021 % of total
Gas	Natural Gas	398.3	31.0873	36.4926	39.7758	38.0912
Nuclear	Nuclear	0	34.5326	33.946	34.490	33.1093
Coal	Bituminous and Anthracite	984.5	23.7409	20.4267	17.7757	19.5672
Wind	Wind	0	2.6268	2.9402	3.2958	3.3566
Hydro	Conventional	0	1.4965	1.3452	1.2913	1.2768
Coal	Sub-Bituminous	1,100.2	3.6007	2.4742	0.954	1.7305
Coal	Waste/Other	1,314.2	1.3368	0.8773	0.7102	0.7352
Solid Waste	Municipal Solid Waste	930.4	0.5109	0.5045	0.5233	0.5189
Solar	Photovoltaic	0	0.2555	0.333	0.4777	0.8913
Gas	Captured Landfill Gas	43.8	0.2795	0.2639	0.2442	0.2099
Oil	Petroleum Coke	1,363.7	0.1314	0.0823	0.1325	0.1181
Wood	Wood Waste Solids	1,200.1	0.1761	0.1472	0.1215	0.1529
Gas	Other	284.5	0.0406	0.0411	0.0658	0.0841
Gas	Captured Coal Mine Gas	514.4	0.0236	0.0416	0.0568	0.0483
Fuel Cell	Non-Renewable	0	0.0273	0.0263	0.0284	0.0269
Wood	Black Liquor	73.0	0.0425	0.026	0.0235	0.0146
Oil	Distillate Fuel Oil	825.8	0.044	0.0094	0.0192	0.0545
Oil	Residual Fuel Oil	933.1	0.0349	0.0097	0.0074	0.0058
Biomass	Other Biomass Gases	22.7	0.0008	0.0006	0.0002	0.0
Solid Waste	Tire Derived Fuel	1,278.3	0.003	0.0011	0.0	0.0
Gas	Propane	1,383.5	0.0001	0.0001	0.0	0.0002
Other	Other	933.1	0.0082	0.011	0.0067	0.0077
Total			100.0	100.0	100.0	100.0

CO_2eq EF (emissions factor) for each fuel in this table are reported by PJM for the 2021 year but can vary slightly from year to year. Renewable energy sources are highlighted in green.

A more detailed summary of the mix of energy sources utilized by PJM is summarized in **Table 5**, including the CO_2 emissions factors corresponding to each fuel type [7]. CO_2 emissions factors for Baltimore's electricity use are verified and reported by PJM Interconnection. The overall use-weighted (by % of total electricity supplied to PJM) CO_2 emissions factors are given in **Table 6**. The corresponding CH_4 and N_2O emissions factors are calculated using emissions factors for each fuel from the U.S. EPA and the U.S. Energy Information Administration (EIA) [2], [13]–[15]. Emissions factors in **Table 6** are given in units of metric tons per Gigawatt-hour (GWh) (2018-2020, annual means). The % change in CO_2eq emission factor (EF) is calculated relative to the 2007 baseline year using 100-year GWPs.

Table 6. Greenhouse gas emissions factors for the PJM Interconnection electricity grid

Year	CO_2 EF [tons/GWh]	CH_4 EF [tons/GWh]	N_2O EF [tons/GWh]	% change in CO_2eq EF
2007	563.2082	0.058074	0.0084493	+0.0
2008	553.1746	0.057289	0.0083401	–1.78
2009	515.8349	0.052286	0.0075953	–8.42
2010	529.5975	0.052682	0.0076487	–5.99
2011	519.8299	0.050566	0.0073170	–7.74
2012	495.1801	0.045783	0.0065944	–12.14
2013	504.3036	0.047918	0.0069227	–10.51
2014	502.4768	0.047237	0.0068370	–10.84
2015	460.0731	0.040403	0.0058249	–18.40
2016	449.9843	0.037946	0.0054513	–20.21
2017	430.1990	0.035635	0.0051140	–23.72
2018	419.2355	0.032712	0.0046692	–25.69
2019	386.0949	0.027372	0.0038629	–31.60
2020	358.8581	0.023265	0.0032486	–36.45
2021	382.5167	0.026142	0.0036759	–32.25

Figure 4. Total citywide electricity consumption from BG&E for 2018-2020

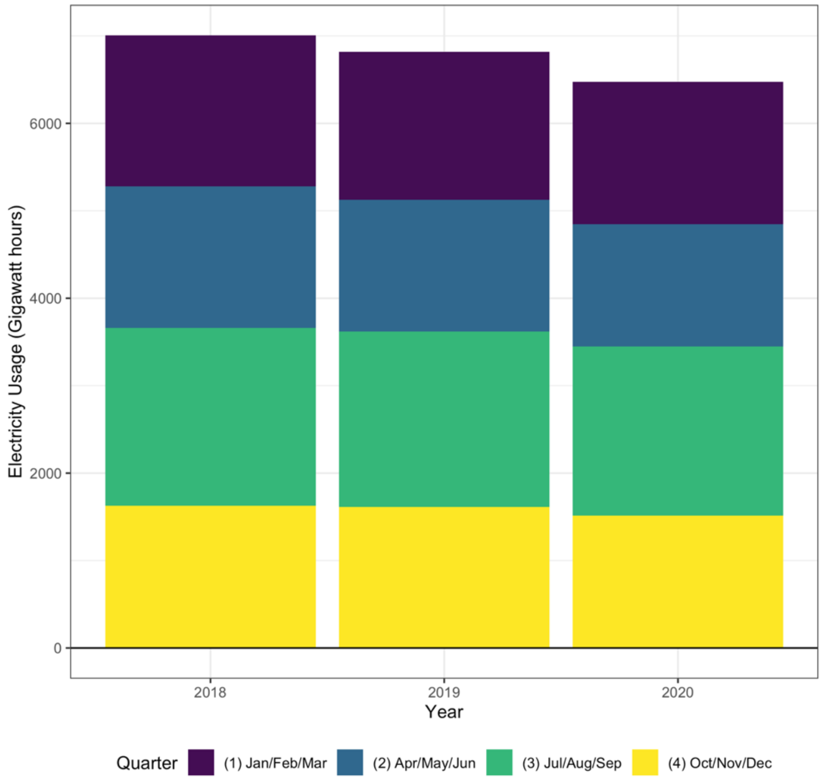


Figure 5. Citywide electricity consumption from BG&E by quarter for 2018-2020

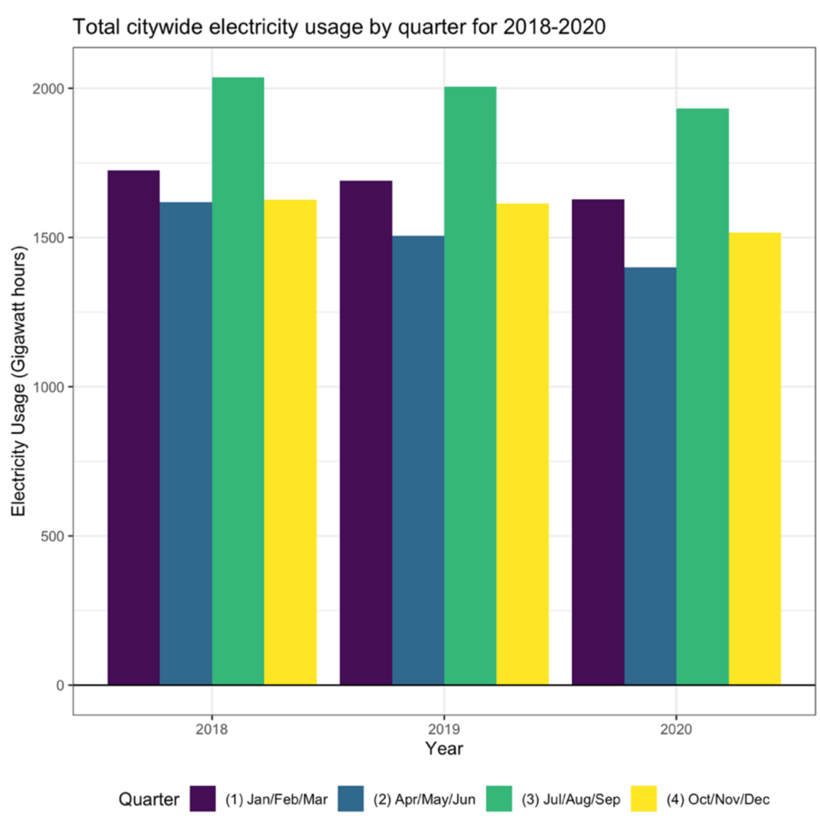


Figure 6. Quarterly electricity consumption for the residential sector

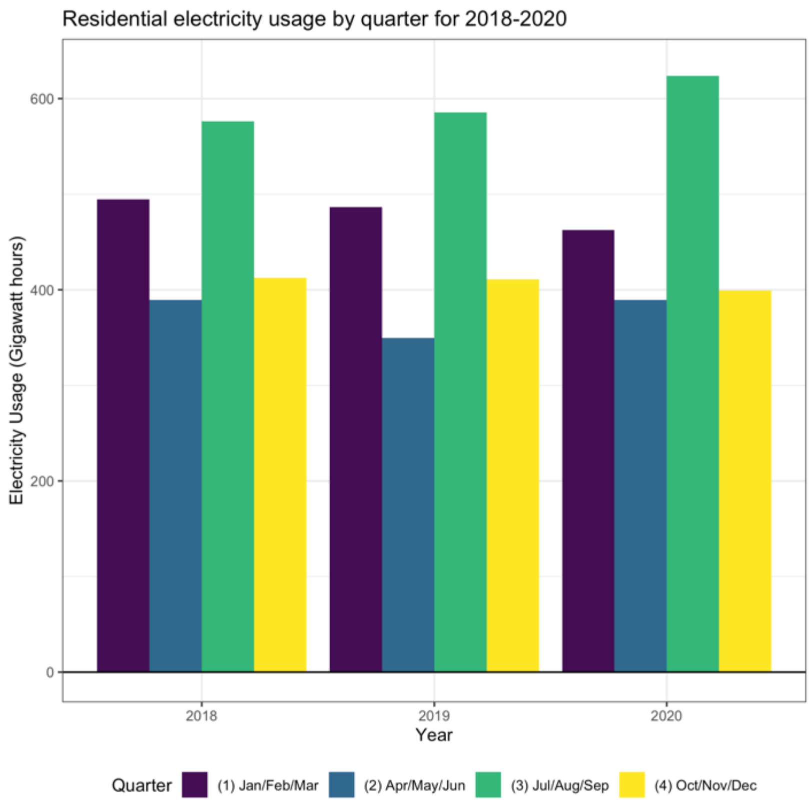


Figure 7. Quarterly electricity consumption for the industrial/commercial sector

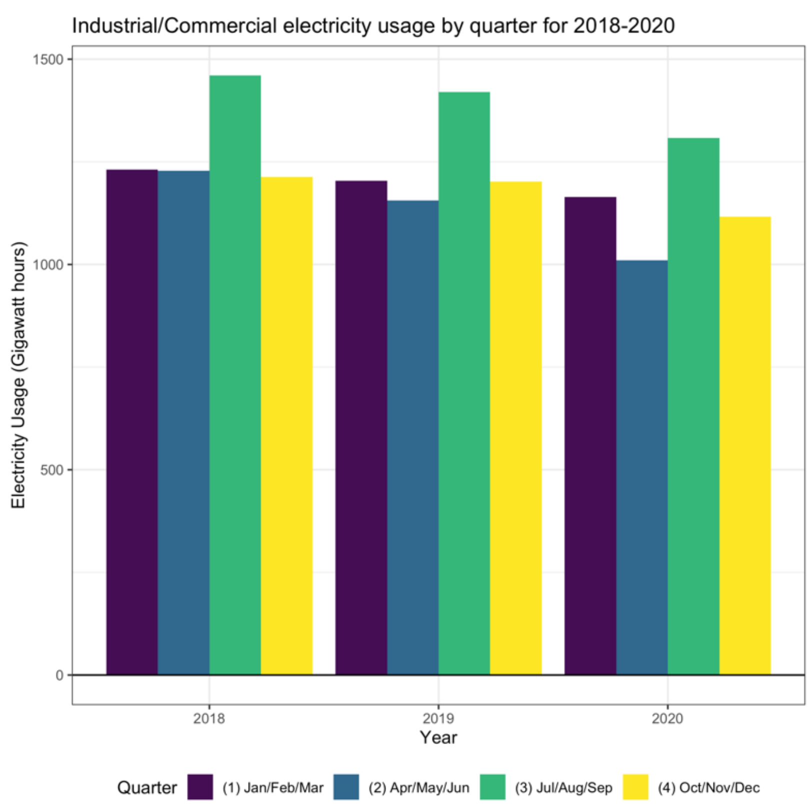


Table 7 lists Baltimore's annual citywide electricity consumption (including both residential and commercial/industrial sectors) in kilowatt-hours (kWh) using data from BG&E, as well as the corresponding CO_2 emission factor for the PJM grid and the resulting (Scope 2) CO_2 emissions. We also list the percent change (relative to 2007) in electricity consumption, the electricity grid EF, and the resulting total Scope 2 CO_2 emissions in **Table 7**.

Table 7. Citywide electricity consumption from BG&E and corresponding CO_2 emissions

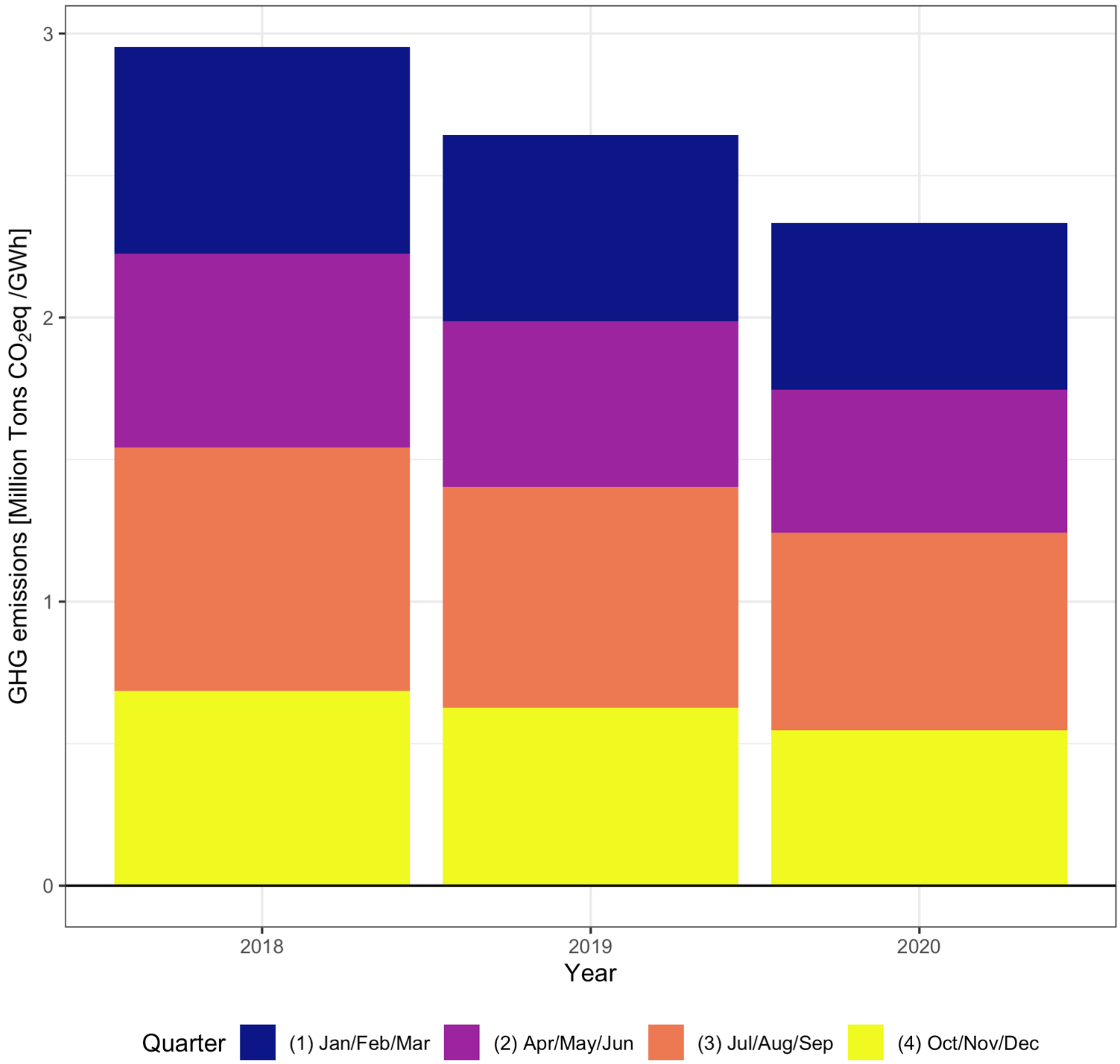
Year	Electricity usage [kWh]	% change in usage	% change per capita	CO_2 EF [tons/ GWh]	% change in CO_2eq EF	Total CO_2 emissions [tons CO_2]	% change in CO_2 emissions
2007	6,655,652,628	+0.0	+0.00	563.2082	+0.0	3,748,518	0.0
2008	6,402,608,501	–3.80	–3.46	553.1746	–1.78	3,541,760	–5.5
2009	6,207,325,779	–6.74	–6.15	515.8349	–8.42	3,201,955	–14.6
2010	6,343,476,859	–4.69	–1.74	529.5975	–5.99	3,359,489	–10.4
2011	6,249,993,397	–6.09	–3.12	519.8299	–7.74	3,248,933	–13.3
2012	6,343,535,240	–4.69	–2.07	495.1801	–12.14	3,141,192	–16.2
2013	6,904,029,704	+3.73	+6.66	504.3036	–10.51	3,481,727	–7.1
2014	6,443,053,471	–3.19	–0.66	502.4768	–10.84	3,237,485	–13.6
2015	6,484,248,110	–2.58	+0.13	460.0731	–18.40	2,983,228	–20.4
2016	6,449,472,805	–3.10	+0.61	449.9843	–20.21	2,902,162	–22.6
2017	6,436,897,620	–3.29	+1.35	430.1990	–23.72	2,769,147	–26.1
2018	7,005,318,377	+5.25	+11.69	419.2355	–25.69	2,936,878	–21.7
2019	6,815,082,460	+2.40	+10.24	386.0949	–31.60	2,631,269	–29.8
2020	6,474,129,020	–2.73	+6.78	358.8581	–36.45	2,323,294	–38.0
2021	6,636,180,056*	*	*	382.5167	–32.25	2,538,450*	–32.3*

* Electricity usage for 2021 is estimated as the mean of the previous 5 years.

Changes in overall electricity usage have been relatively small since 2007, indicating that changes in energy sources, not in usage, are driving the overall decline in Baltimore's electricity emissions. Specifically, usage increased by 2.4% between 2007 and 2019, in spite of a decline in the City's population during that time interval. By contrast, usage decreased by 2.73% in 2020 relative to 2007 levels, likely in part due to the COVID-19 pandemic.

Though total electricity consumption has not changed, per capita consumption has [16], [17]; Baltimore's per capita electricity consumption increased by 6.78% between 2007 and 2020 and by 10.72% between 2007 and 2021. However, this citywide per capita trend may be misleading, since 66% of Baltimore's electricity consumption is by industrial and commercial customers (**Figure 7**), and only 34% is by residential customers (**Figure 6**). Hence, trends in electricity consumption may not be very sensitive to changes in city population. Rather, these trends may be more reflective of changes in commercial or industrial activities within the city.

Figure 8. Citywide GHG emissions due to electricity consumption from BG&E, by quarter from 2018-2020



b) Natural Gas

Key points:

- Natural gas consumption and associated emissions increased by 19.6% between 2007 and 2019 and by 5.0% between 2007 and 2020.
- Per capita natural gas consumption increased 28.8% between 2007 and 2019 and 15.3% between 2007 and 2020. This increase is larger than reductions in home heating oil usage during the same time periods.
- Fugitive methane emissions from natural gas infrastructure are difficult to pinpoint due to uncertainty in the overall natural gas leak rate.
- BG&E is gradually replacing old cast/wrought iron gas pipes with new, plastic pipes that are presumably less leaky.

We analyze greenhouse gas emissions resulting from natural gas use within Baltimore City (Scope 1) in this section, including emissions resulting from both combustion of natural gas (which releases predominantly CO_2) and fugitive leaks of natural gas (which releases predominantly CH_4). In general, we follow the methodology described in the 2017 Baltimore GHG emissions report here [2].

We use emissions factors from the EPA/EIA to estimate GHG emissions from natural gas combustion, listed in **Table 8** [14], [15]. Annual and quarterly citywide natural gas consumption data was provided by BG&E (John Quinn, BG&E, personal communication) [12]. **Figure 9** and **Figure 10** show annual and quarterly natural gas consumption rates for the entire City of Baltimore, while **Figure 11** and **Figure 12** show the relative quarterly natural gas consumption for the residential and industrial/commercial sectors separately. Note that these four figures only include delivered and combusted natural gas, and do not include fugitive CH_4 emissions from natural gas leaks.

To estimate fugitive CH_4 emissions resulting from natural gas leaks occurring within Baltimore City, we follow the methodology described in Gaeta et al. (2020), which uses a constant 2.0% citywide natural gas leak rate scaled by annual natural gas consumption data from BG&E [2]. For context, the choice of a 2% leak rate was guided by findings from a variety of atmospheric measurement-based constraints on CH_4 emissions rates in the Baltimore/DC area and elsewhere in the northeast U.S., specified to one significant digit [18]–[29]. Annual citywide natural gas consumption values (in therms) are given in **Table 9**, as well as the corresponding fugitive CH_4 emissions, given in metric tons CH_4 and CO_2eq (100-year GWP and 20-year GWP).

Figure 9. Total citywide natural gas consumption from BG&E for 2018-2020

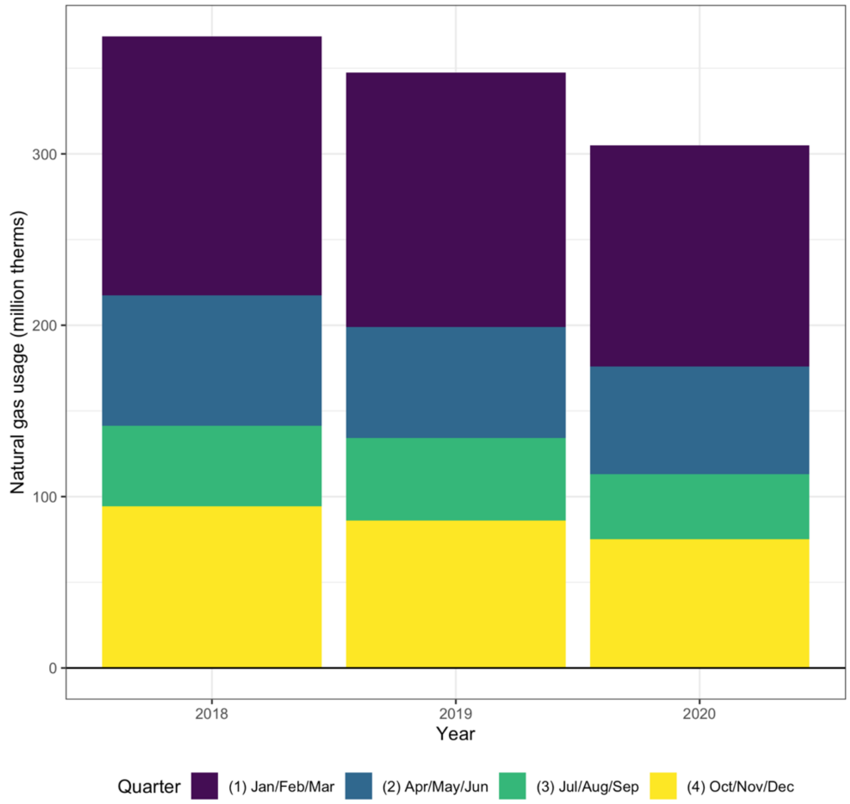


Figure 10. Total citywide natural gas consumption from BG&E by quarter for 2018-2020

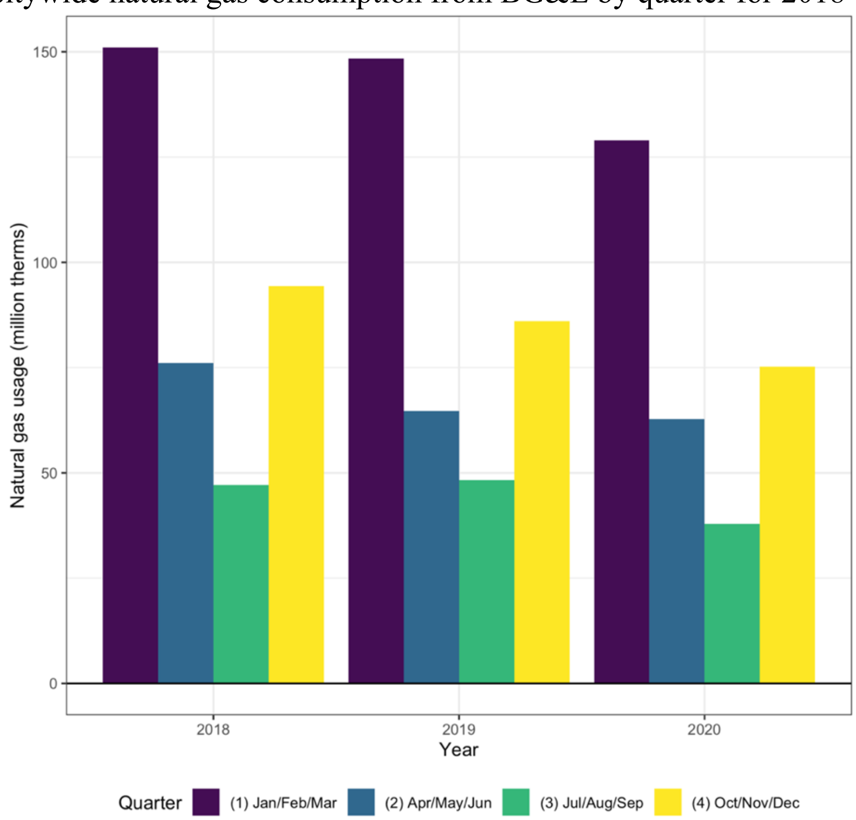


Figure 11. Residential natural gas consumption by quarter

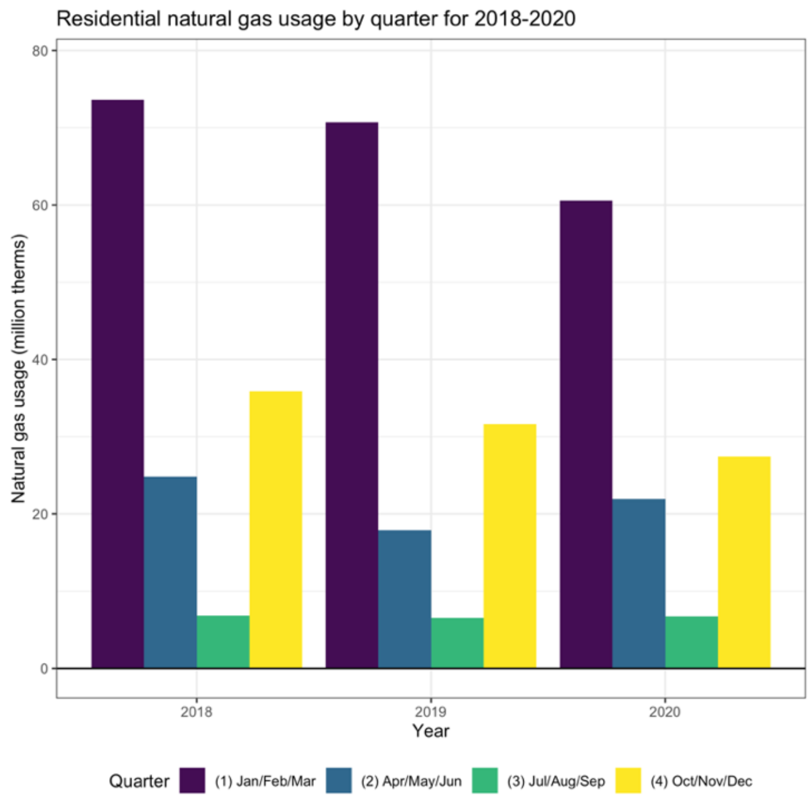


Figure 12. Industrial/commercial natural gas consumption by quarter

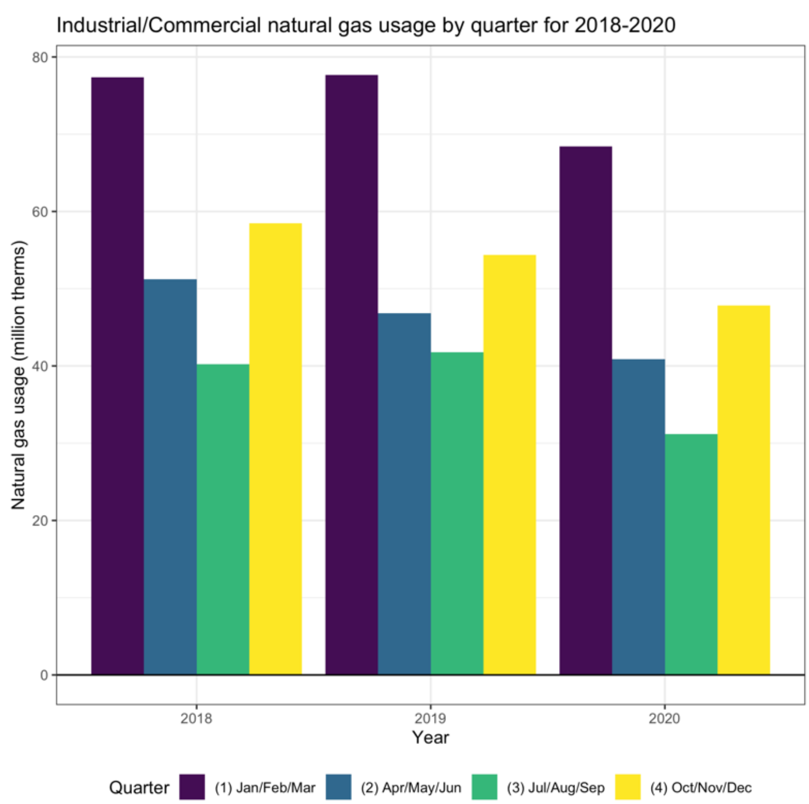


Table 8. Emissions factors for natural gas combustion from the EPA/EIA

CO_2 EF [tons/therm]	CH_4 EF [tons/therm]	N_2O EF [tons/therm]	Effective CH_4 leak %
0.005307	$1x10^{-7}$	$1x10^{-8}$	2.0%

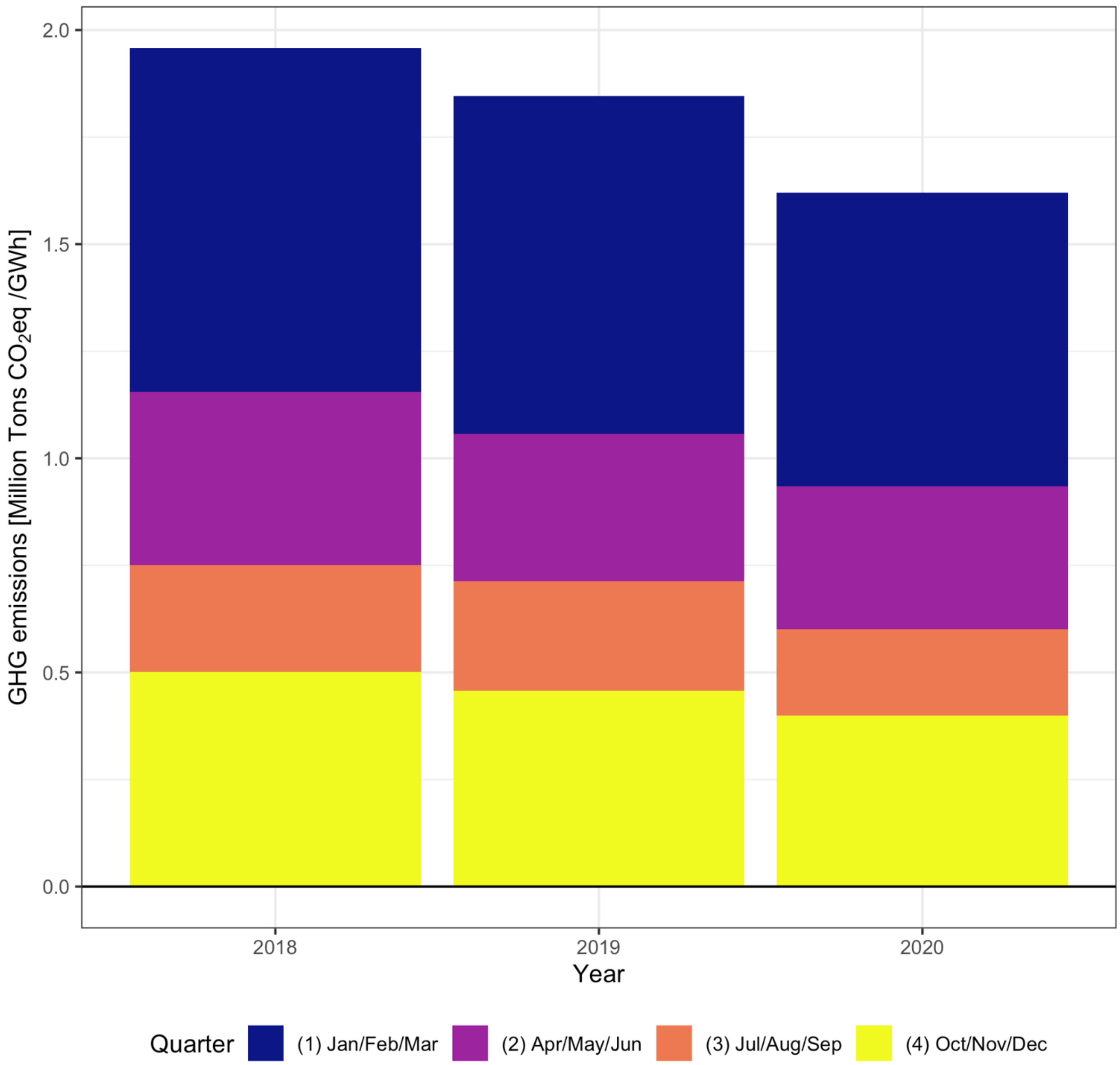
Table 9. Citywide natural gas consumption and corresponding fugitive CH_4 emissions

Year	Consumption [therms]	% change in consumption	% change per capita	Fugitive CH_4 (2% leak rate)	CO_2eq GWP-100	CO_2eq GWP-20
2007	290,353,510	+0.0	+0.00	10,848.8	303,767	911,300
2008	279,794,506	–3.64	–3.30	10,454.3	292,720	878,160
2009	294,279,925	+1.35	+1.99	10,995.5	307,875	923,624
2010	321,891,751	+10.86	+14.29	12,027.2	336,762	1,010,286
2011	320,777,347	+10.48	+13.98	11,985.6	335,596	1,006,788
2012	287,966,020	–0.82	+1.90	10,759.6	301,269	903,807
2013	350,221,880	+20.62	+24.02	13,085.7	366,401	1,099,203
2014	365,172,589	+25.77	+29.06	13,644.4	382,042	1,146,127
2015	348,699,995	+20.09	+23.43	13,028.9	364,809	1,094,426
2016	337,726,260	+16.32	+20.77	12,618.9	353,328	1,059,984
2017	329,123,908	+13.35	+18.79	12,297.4	344,328	1,032,985
2018	368,478,538	+26.91	+34.67	13,767.9	385,501	1,156,503
2019	347,366,375	+19.64	+28.80	12,979.1	363,413	1,090,240
2020	304,886,285	+5.01	+15.27	11,391.8	318,971	956,913

Percent change in natural gas consumption in **Table 9** is calculated relative to the 2007 baseline year. Fugitive CH_4 emissions and corresponding CO_2eq values are estimated using a constant 2% leak rate, following Gaeta et al. (2020) [2].

Figure 13 shows the total annual (and colored quarterly) GHG emissions resulting from natural gas combustion across Baltimore City, including both residential and industrial/commercial sectors. Note, this figure only includes emissions from natural gas combustion, and does not include fugitive emissions of CH_4.

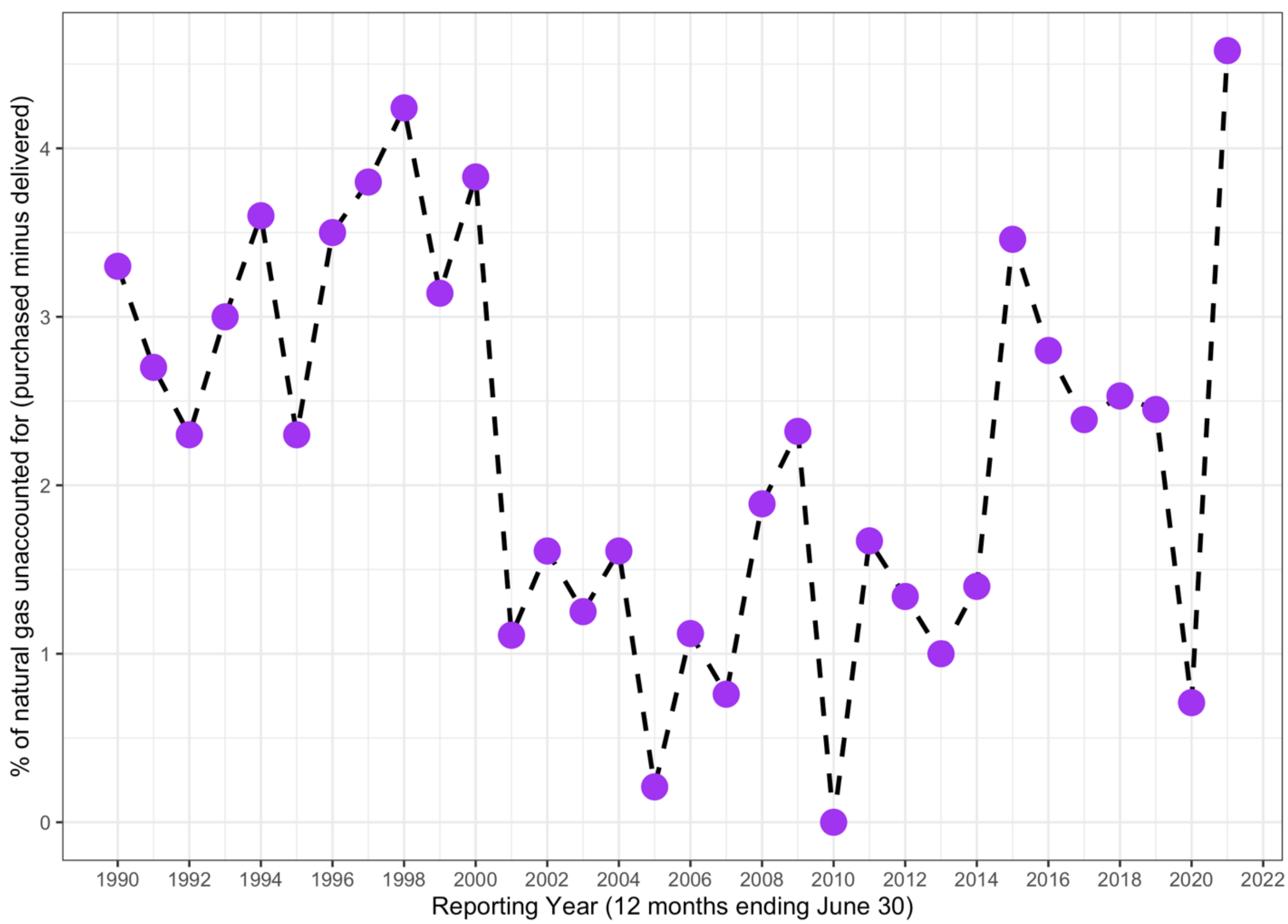
Figure 13. Citywide GHG emissions from utility natural gas combustion by quarter



Alternatively, instead of using a constant 2.0% CH_4 leak rate from utility natural gas consumption, we can estimate the annual fraction of fugitive CH_4 lost from natural gas use using data from the U.S. Department of Transportation Pipeline and Hazardous Materials Safety Administration (PHMSA) [30]. PHMSA reports the annual percentage of lost and unaccounted for (LAUF) natural gas within BG&E's distribution system. Notably, this approach using reported LAUF numbers may not be the most reliable predictor of fugitive natural gas emissions since LAUF natural gas includes leaks as well as accounting errors, flow meter measurement errors, and stolen gas. Thus, reports of natural gas LAUF are may not always be a direct indicator of fugitive natural gas emissions alone, and so there is a significant degree of uncertainty in the following LAUF-based estimates of fugitive CH_4 emissions.

Still, we can estimate the fugitive emissions of natural gas CH_4 directly from the reported LAUF percentages using the fugitive natural gas emissions factor of 1.831×10^{-3} tons CH_4/therm from the EIA. Estimates of fugitive CH_4 emissions using reported LAUF numbers from BG&E are summarized in **Table 10** and shown graphically in **Figure 14** [2], [14], [15]. Emissions of fugitive CH_4 and the corresponding CO_2eq values are given in metric tons/year.

Figure 14. U.S. DOT PHMSA reports of LAUF natural gas fractions for BG&E



However, the year-to-year variability in the CO_2eq emissions estimates derived from reported LAUF data makes it difficult to interpret trends in fugitive CH_4 emissions over time. Furthermore, there are concerns regarding the accuracy of the reported LAUF percentages; for instance, BG&E reports that 0.0% of their natural gas supply was unaccounted for in the 2010 year. A citywide 0.0% fugitive CH_4 loss rate is highly improbable and likely reflects errors in natural gas pipeline flow rate measurements. Although we do not include the fugitive CH_4 emissions estimates in **Table 10** in the overall GHG inventory totals, we still include these data in this report to provide additional insight into fugitive CH_4 emissions in Baltimore, and to highlight the recent large increase in BG&E's reported natural gas LAUF, which jumped to nearly 5% in 2021.

If the reported natural gas LAUF in 2021 is predominantly fugitive emissions, this would imply that there were strikingly high fugitive CH_4 emissions in 2021; the climate warming impact of these fugitive emissions would be approximately 792,000 tons CO_2eq over a 100-year interval or 2,377,000 tons CO_2eq over a 20-year interval – nearly 1/3rd of the City's overall 20-year GWP CO_2eq emissions.

Table 10. Fugitive emissions from natural gas leaks, estimated using LAUF reports from BG&E

Year	Natural gas use [therms]	LAUF [%]	Fugitive CH_4 [tons]	CO_2eq (GWP-100)	CO_2eq (GWP-20)
2007	290,353,510	0.76	4,040.1	113,123	339,368
2008	279,794,506	1.89	9,681.7	271,088	813,264
2009	294,279,925	2.32	12,499.7	349,992	1,049,976
2010	321,891,751	0.0*	0.0*	0.0*	0.0*
2011	320,777,347	1.67	9,807.8	274,618	823,855
2012	287,966,020	1.34	7,064.8	197,813	593,440
2013	350,221,880	1.00	6,412.0	179,536	538,609
2014	365,172,589	1.40	9,360.0	262,081	786,243
2015	348,699,995	3.46	22,089.2	618,497	1,855,490
2016	337,726,260	2.80	17,313.1	484,766	1,454,298
2017	329,123,908	2.39	14,401.5	403,243	1,209,728
2018	368,478,538	2.53	17,068.1	477,906	1,433,717
2019	347,366,375	2.45	15,581.4	436,278	1,308,834
2020	304,886,285	0.71	3,963.2	110,970	332,910
2021	Not yet available	4.58	28,301.6**	792,446**	2,377,337**

* BG&E reports a LAUF natural gas percentage of 0.0 in 2010.

**2021 fugitive emissions are estimated using the average citywide natural gas use over the previous 5-years.

Figure 15. Timeline of BG&E's natural gas pipeline construction

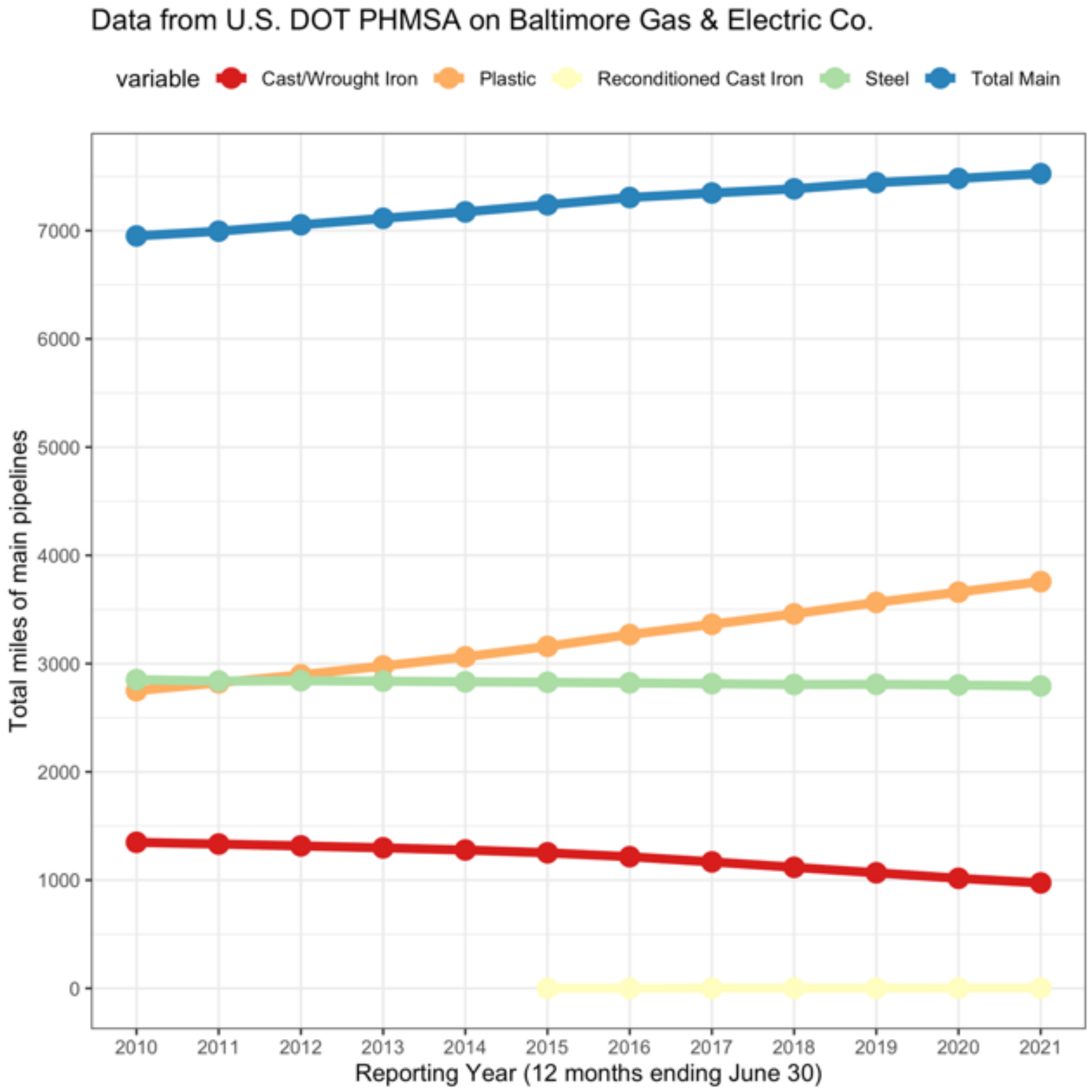


Figure 15 shows the year-to-year changes in the type of materials used in the BG&E natural gas distribution system. More specifically, it shows that the total miles of natural gas pipeline in BGE's distribution system have increased by 8.2% from 2010 to 2021. However, BG&E has been slowly replacing older, more leak-prone cast/wrought iron pipes with newer, presumably more leak-resistant plastic pipes. As of 2021, there are still ~975 miles of iron natural gas pipeline in BG&E's natural gas distribution system, though it is unclear how much of an impact those pipes have on BG&E's fugitive natural gas loss.

c) Home Heating Oil (HHO)

A small but non-negligible fraction of Baltimore residents have homes that are heated by home heating oil (typically petroleum, or No. 2 heating oil), rather than natural gas [31]. Overall, the estimated fraction of residential households in Baltimore that utilize home heating oil instead of utility natural gas to heat their homes and water-heaters has been steadily declining, down to ~4% as of 2020.

To estimate GHG emissions from these households, we follow the approach for estimating home heating oil emissions introduced in Gaeta et al. (2020), which uses household data from the U.S. Census Bureau American Community Survey (ACS) to estimate the fraction of homes in Baltimore that utilize home heating oil [2], [32]. We then scale the reported BG&E natural gas consumption for the residential sector (in therms) by the ratio of the fraction of residential homes utilizing home heating oil relative to the fraction of homes utilizing utility natural gas to estimate the total residential consumption of home heating oil (in therms). We then apply GHG emissions factor for home heating oil from the EPA/EIA [14], [15]. Emissions from residential home heating oil combustion in Baltimore City are summarized for 2017-2020 and the 2007 baseline year in **Table 11**. Relative to GHG emissions from natural gas and electricity consumption, emissions from home heating oil represent a very small portion (~1.5%) of Baltimore's stationary energy emissions.

Table 11. GHG emissions from combustion of home heating oil

Year	% HHO	Tons CO_2	Tons CH_4	Tons N_2O
2007	10.3	160,153	6.4	1.3
…	…	…	…	…
2017	5.01	74,407	2.4	0.5
2018	3.32	84,615	3.4	0.7
2019	3.98	76,738	3.1	0.6
2020	4.11	75,259	3.0	0.6

Sector 2: Transportation

Key points:

- Transportation emissions dropped 17.0% between 2017 and 2020, likely due to the impacts of the COVID-19 pandemic.
- Early in the pandemic, total traffic volume dropped by over 50%. By mid-2021, traffic volume stabilized around 6-10% below mean 2019 levels. Truck traffic, by contrast, did not show the same drop and has regularly exceeded pre-pandemic levels.
- Total on-road transportation emissions decreased by 15% between 2007 and 2019.

a) On-road vehicle fuel combustion

Overall, traffic emissions modeling by the Maryland Department of the Environment indicates that on-road transportation emissions in Baltimore City dropped from 1.78 million metric tons CO_2eq in 2017 to 1.48 million metric tons CO_2eq in 2020 (a 17.0% decrease over three years). However, 2020 was a unique year for Baltimore City due to the COVID-19 pandemic, and the large decrease in 2020 emissions is likely the result of disruptions to daily life and work caused by the pandemic, rather than changes that would result in more permanent GHG emissions reductions – such as increased fuel efficiencies for vehicles or a reduction in the amount of mileage driven in Baltimore.

To estimate GHG emissions from mobile vehicles in Baltimore, we use modeling estimates of on-road transportation emissions from the Maryland Department of the Environment (MDE) [33]. MDE provides estimates of on-road transportation emissions for each county in Maryland, including Baltimore City by itself. MDE uses the U.S. EPA tool MOVES (Motor Vehicle Emissions Simulator) 3.0 to calculate on-road vehicle emissions resulting from the combustion of mobile vehicle fuels, including gasoline, diesel, condensed natural gas (CNG), and E85 ethanol-gasoline. Since MDE publishes the state GHG emissions inventory every three years, we only have two years of on-road vehicle emissions estimates from MDE: the 2020 year, summarized in **Table 12**, and the 2017 year, summarized in **Table 13**.

The Maryland Department of Transportation (MDOT) State Highway Administration (SHA) reports annual total vehicle miles traveled (VMT) for each county in Maryland, including Baltimore City [5], [34]. These data from MDOT-SHA are summarized below in **Table 14** and indicate relatively consistent levels of on-road vehicle traffic in Baltimore City year-to-year, with the exception of 2020, which showed a dramatic drop in VMT due to the COVID-19 pandemic. VMT is given in units of million miles traveled.

In order to estimate on-road vehicle fuel combustion emissions for the 2018 and 2019 years, we simply scale the 2017 and 2020 MDE estimates by the relative change in total VMT. More specifically, we scale both the 2017 and 2020 MDE estimates by the ratio of VMT driven in each intermediate year (2018 and 2019) relative to the MOVES estimate year, and then we average the two scaled estimates. We trust that this approach is reliable because we are able to estimate 2020 emissions using the 2017 MDE MOVES estimate, and we are able to estimate 2017 emissions using the 2020 MDE MOVES estimate, both within 1%.

Table 12. On-road vehicle GHG emissions by fuel type, 2020 year

Fuel Type	Tons CO_2	Tons CH_4	Tons N_2O	Tons CO_2eq
Gasoline	1,133,438	49.77	20.43	1,140,244
Diesel	328,735	8.31	0.80	329,181.3
CNG	4,986	54.39	0.55	6,654.4
E85	1,914	0.15	0.03	1,925.0
Total	**1,469,073**	**112.6**	**21.81**	**1,478,005**

Estimates from MDE, using the EPA MOVES3 Model (units: metric tons/year).

Table 13. On-road vehicle GHG emissions by fuel type, 2017 year

Fuel Type	Tons CO_2	Tons CH_4	Tons N_2O	Tons CO_2eq
Gasoline	1,408,506	19.3	0.17	1,409,091
Diesel	361,590	0.25	0.04	361,608
CNG	6,895	–	–	6,895
E85	3,399	–	–	3,399
Total	**1,780,390**	**19.5**	**0.21**	**1,780,993**

Estimates from MDE, using the EPA MOVES3 Model (units: metric tons/year).

Table 14. Summary of total vehicle miles traveled (in millions) in Baltimore City from 2007-2020

Year	VMT	% change	% change per capita
2007	3,626	+0.00	0.00
2008	3,619	–0.19	0.16
2009	3,563	–1.74	–1.11
2010	3,551	–2.07	0.96
2011	3,527	–2.73	0.35
2012	3,457	–4.66	–2.04
2013	3,391	–6.48	–3.84
2014	3,394	–6.40	–3.95
2015	3,475	–4.16	–1.50
2016	3,554	–1.99	1.77
2017	3,601	–0.69	4.08
2018	3,602	–0.66	5.42
2019	3,557	–1.90	5.61
2020	2,971	–18.1	–10.05

Figure 16. Percent change in weekly total traffic volume for the Baltimore metropolitan region from 2019 to 2020

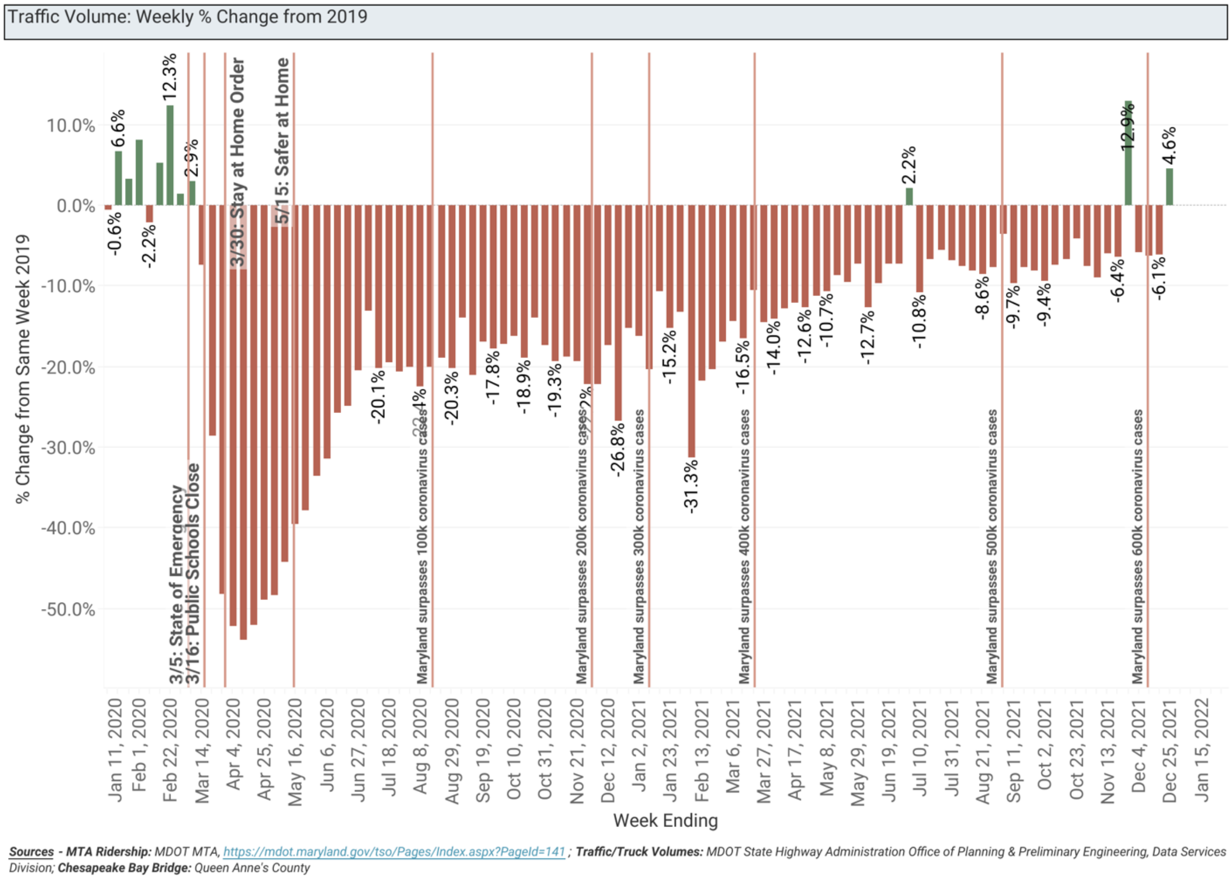
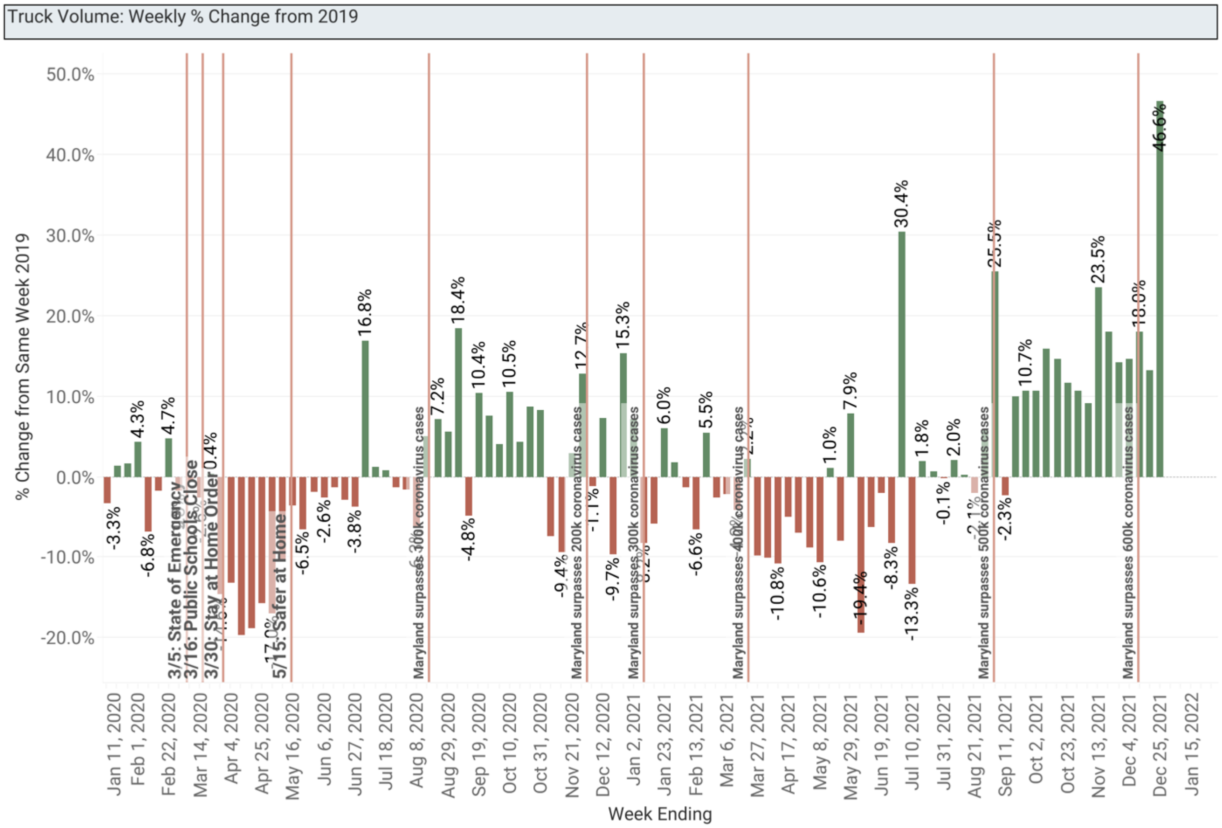


Figure 16 was created by the Baltimore Metropolitan Council [35]. The numbers for each week show the percent change relative to the same week in 2019.

Although total traffic counts dropped dramatically during the pandemic (**Figure 16)**, truck traffic did not (**Figure 17**). Early in the pandemic, total vehicle traffic dropped by over 50% before stabilizing in mid-2021 at 6-10% below 2019 levels. By contrast, truck traffic volume dropped by nearly 20% early in the pandemic but has often exceeded 2019 levels since that time. Diesel trucks are not only an important GHG source but are also a source of air pollutants like $PM_{2.5}$ and PM_{10}.

Figure 17. Percent change in weekly truck traffic volume for the Baltimore metropolitan region from 2019 to 2020



Sources - ***MTA Ridership:*** *MDOT MTA, https://mdot.maryland.gov/tso/Pages/Index.aspx?PageId=141 ;* ***Traffic/Truck Volumes:*** *MDOT State Highway Administration Office of Planning & Preliminary Engineering, Data Services Division;* ***Chesapeake Bay Bridge:*** *Queen Anne's County*

Figure 17 was created by the Baltimore Metropolitan Council [35].
The numbers for each week show the percent change relative to the same week in 2019.

Sector 3: Waste

Key points:

- GHG emissions from the Quarantine Road Landfill decreased by 5.5-6% between 2007 and 2020 (depending upon the GWP used).
- Emissions from the Wheelabrator trash incinerator have dropped slightly -- by 3.4%.
- Estimates of GHG emissions from waste are less certain than other sectors like electricity or transportation because actual emissions factors for waste can vary depending upon the characteristics of the waste stream (e.g., organic content).

a) Solid Waste – Quarantine Road Landfill

We find that solid waste emissions from the Quarantine Road Landfill have remained relatively constant between 2007 and 2020. Emissions consistently increased between 1986 (when the landfill opened) and 2005 but have stabilized in subsequent years. Notably, estimated emissions decreased by approximately 5.5-6% (depending upon the GWP used) between 2007 and 2020.

We use an analysis of GHG emissions from the Quarantine Road Landfill in Baltimore City from the Maryland Department of the Environment (MDE) to estimate emissions from solid waste disposal [33]. MDE uses the U.S. EPA tool LandGEM (Landfill Gas Emissions Model, Version 3.02) to estimate annual emissions from the landfill using annual waste acceptance data.

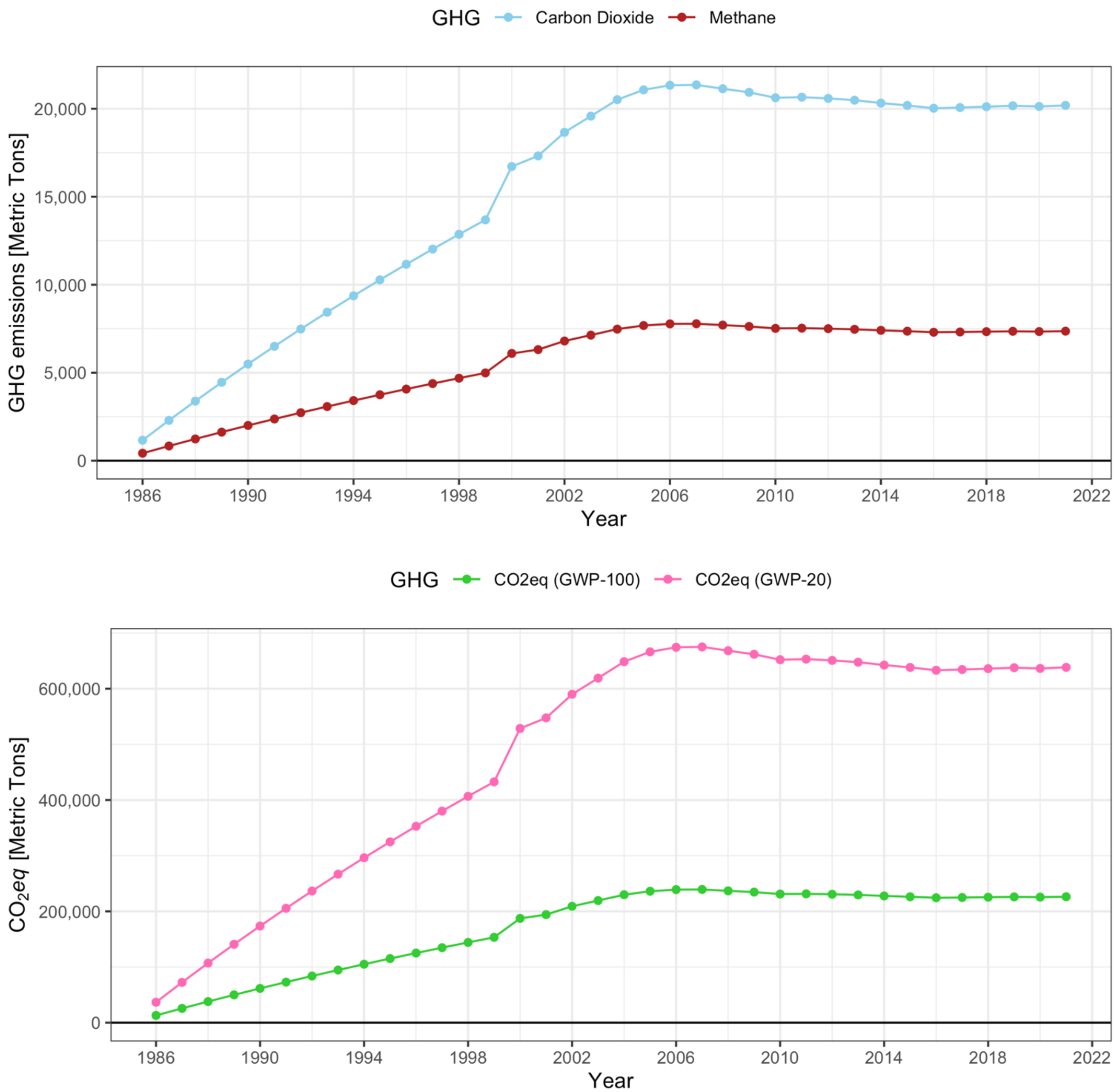
Table 15. CO_2 and CH_4 emissions from the Quarantine Road Landfill for 2007-2021

Year	Tons CO_2	Tons CH_4	Tons CO_2eq GWP-100	Tons CO_2eq GWP-20
2007	21,357	7,783.7	239,301	675,190
2008	21,141	7,704.9	236,878	668,354
2009	20,934	7,629.8	234,570	661,840
2010	20,627	7,517.7	231,122	652,113
2011	20,661	7,530.2	231,505	653,194
2012	20,589	7,503.9	230,699	650,918
2013	20,488	7,467.1	229,568	647,729
2014	20,324	7,407.2	227,726	642,532
2015	20,191	7,358.7	226,234	638,322
2016	20,030	7,300.1	224,431	633,234
2017	20,070	7,314.6	224,880	634,500
2018	20,119	7,332.6	225,433	636,061
2019	20,173	7,352.2	226,034	637,757
2020	20,132	7,337.4	225,580	636,474
2021	20,194	7,359.9	226,271	638,426

Table 15 shows the annual GHG emissions from the Quarantine Road Landfill from 2007-2021, calculated by MDE using the EPA LandGEM tool. **Figure 18** shows the annual CO_2 and CH_4 emissions, as well as the total annual 100-year GWP and 20-year GWP CO_2eq emissions of the CO_2 and CH_4 together, from the Quarantine Road Landfill from 1986-2021 (the landfill opened in 1985). Notably, total CO_2eq emissions from the Quarantine Road Landfill are markedly higher using a 20-year GWP due to the high quantities of methane emitted from the landfill.

The results presented in this section should be interpreted as an update to the landfill emissions reported in the 2017 City of Baltimore GHG Emissions Inventory, which incorrectly implied that there was a large drop in GHG emissions from landfill solid waste [2]. This error was due to the use of mismatched data sources for 2007 and 2017, which is not the case in this inventory.

Figure 18. Annual CO_2 and CH_4 emissions from the Quarantine Road Landfill



b) Incineration – Wheelabrator Baltimore

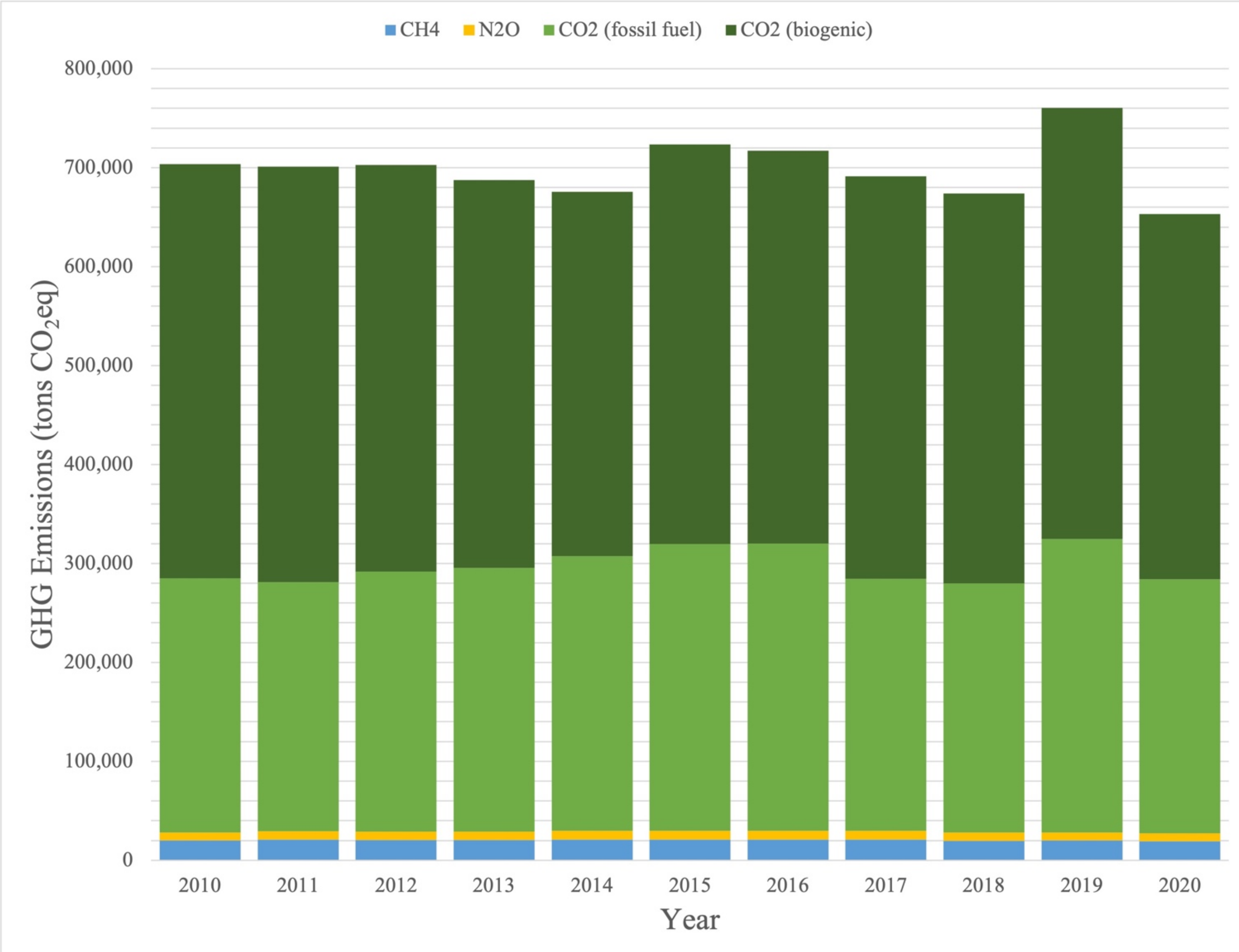
Baltimore City is home to a large municipal solid waste incinerator, Wheelabrator Baltimore. Emissions from Wheelabrator Baltimore are reported annually through the EPA Greenhouse Gas Reporting Program (GHGRP) and made publicly available via the EPA FLIGHT (Facility Level Information on Greenhouse Gases Tool) database [36]. We use these values from the EPA to report annual GHG emissions from the Wheelabrator Baltimore incinerator.

EPA GHGRP data on GHG emissions from Wheelabrator Baltimore are summarized visually in **Figure 19** and numerically in **Table 16**. CO_2-ff indicates fossil fuel-based CO_2 emissions (including plastics and synthetic fibers), CO_2-bio indicates biogenic CO_2 emissions (primarily organic food waste), and CO_2 indicates total CO_2 emissions from both fossil and biogenic sources. Emissions for the 2007 baseline year are estimated from the 2008 EPA National Greenhouse Gas Inventory since the FLIGHT database only includes data from 2010 onwards [3].

Table 16. Annual GHG emissions from the Wheelabrator Baltimore waste incinerator

Year	Tons CO_2-ff	Tons CO_2-bio	Tons CO_2	Tons CH_4	Tons N_2O	Tons CO_2eq GWP-100	Tons CO_2eq GWP-20
2007	-	-	605,820	213.7	28.00	619,224	631,163
…							
2010	256,800	418,489	675,289	238.0	31.0	690,169	703,466
2011	251,878	419,798	671,676	246.4	32.4	687,161	700,927
2012	262,807	411,057	673,864	242.3	31.8	689,073	702,610
2013	266,700	391,817	658,517	242.6	31.8	673,743	687,294
2014	277,668	368,070	645,738	249.6	32.8	661,409	675,354
2015	289,630	404,096	693,726	251.2	33.0	709,497	723,531
2016	290,412	396,956	687,368	251.2	33.0	703,140	717,175
2017	254,754	406,945	661,699	249.2	32.7	677,344	691,266
2018	251,835	393,896	645,731	236.0	31.0	660,550	673,736
2019	296,611	435,761	732,372	236.5	31.0	747,219	760,431
2020	256,655	369,332	625,987	229.5	30.1	640,395	653,216

Figure 19. Annual GHG emissions from the Wheelabrator incinerator (EPA GHGRP)



c) Treatment of municipal wastewater

We use a population-based estimate for calculating wastewater emissions using equations from the EPA, summarized in **Table 17** [5], [16], [37], [38]. CH_4, N_2O, and CO_2eq emissions are given in units of metric tons/year. Since we use a population-based estimate, and the population of Baltimore City has been steadily declining since 2007, the estimated GHG emissions from wastewater treatment have also been declining.

Notably, there have been recent concerns regarding the operation and management of Baltimore's two wastewater treatment plants (WWTPs): the Back River WWTP and the Patapsco WWTP. In 2022, MDE ordered the Maryland Environmental Service, which runs all state-owned wastewater treatment facilities, to take over operation of the Back River WWTP after a state report from MDE found systemwide "catastrophic failures" at the WWTP [39]. A similar state takeover is currently being pursued at the Patapsco WWTP as well [40]. We flag these recent findings by MDE here, but otherwise we do not account for potentially elevated GHG emissions resulting from these reported system and waste management failures.

Table 17. Population-based estimate of wastewater treatment emissions from 2007-2020

Year	Tons CH_4	Tons N_2O	Tons CO_2eq GWP-100	Tons CO_2eq GWP-20
2007	2,050	63.5	74,232	188,987
2008	2,043	63.3	73,972	188,323
2009	2,037	63.1	73,766	187,799
2010	1,989	61.6	72,001	183,307
2011	1,987	61.5	71,942	183,158
2012	1,995	61.8	72,230	183,892
2013	1,993	61.7	72,172	183,743
2014	1,997	61.8	72,311	184,096
2015	1,994	61.7	72,187	183,782
2016	1,974	61.1	71,457	181,922
2017	1,955	60.5	70,790	180,226
2018	1,930	59.7	69,857	177,853
2019	1,904	59.0	68,948	175,537
2020	1,877	58.1	67,965	173,036

Sector 4: Agriculture, Forestry, and Other Land Use (AFOLU)

No emissions reported from this sector.

Sector 5: Industrial Processes and Product Use (IPPU)

No emissions reported from this sector.

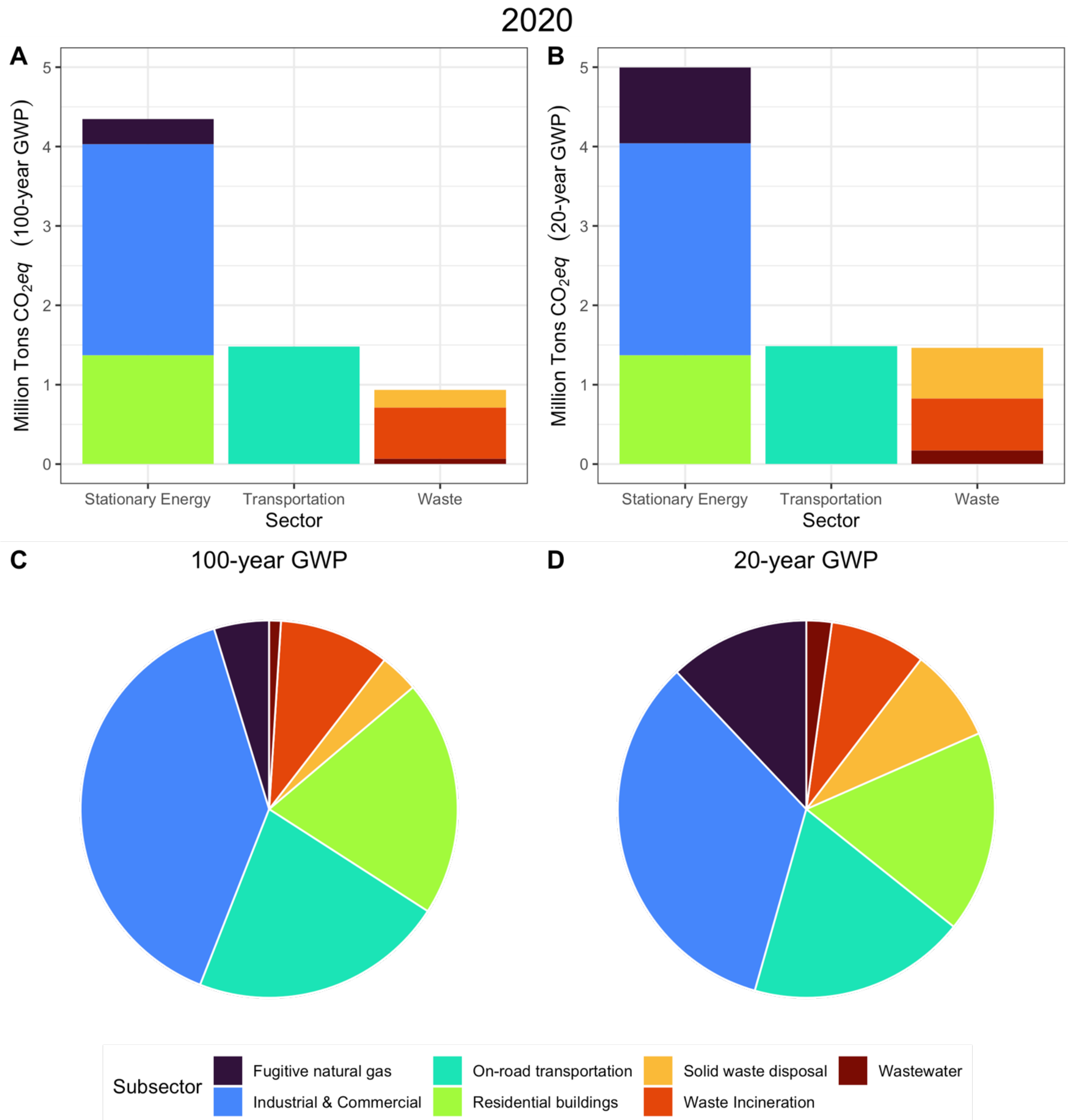
Baltimore City has some emissions that could be categorized as IPPU, but these emissions are already accounted for in Sector 1: Stationary Energy as either natural gas consumption or electricity consumption in the industrial and commercial sector.

Sector 6: Other Scope 3 Emissions

No emissions reported from this sector.

Summary of GHG emissions inventory for Baltimore City

Figure 20. Baltimore's GHG emissions by sector/subsector in 2020 (100-year GWP & 20-year GWP)



Panels A and C show CO_2eq emissions using a 100-year GWP, while panels B and D show CO_2eq emissions using a 20-year GWP. Note that Panels A and C in **Figure 20** are identical to the panels in **Figure 21**.

Following the GPC, we use the following keys to denote unreported emissions totals in **Tables 18-22**:

IE = Included Elsewhere, NE = Not Estimated, NO = Not Occurring, NA = Not Applicable

Table 18. Summary of GHG emissions from Baltimore City in 2020 (by GPC sector and scope)

Sector	Tons CO_2eq (100-year GWP)			Tons CO_2eq (20-year GWP)		
	Scope 1	Scope 2	Total	Scope 1	Scope 2	Total
Stationary Energy	2,014,166	2,333,086	**4,347,253**	2,653,980	2,341,500	**4,995,480**
Transportation	1,478,005	IE	**1,478,005**	1,484,289	IE	**1,484,289**
Waste	933,921	NA	**933,921**	1,462,692	NA	**1,462,692**
IPPU	NE	NA	NE	NE	NA	NE
AFOLU	NE	NA	NE	NE	NA	NE
Scope 3	NA	NA	NE	NA	NA	NE
Total	4,426,093	2,333,086	**6,759,180**	5,600,961	2,341,500	**7,942,461**

Figure 21. Summary of Baltimore's GHG emissions by sector and subsector in 2020

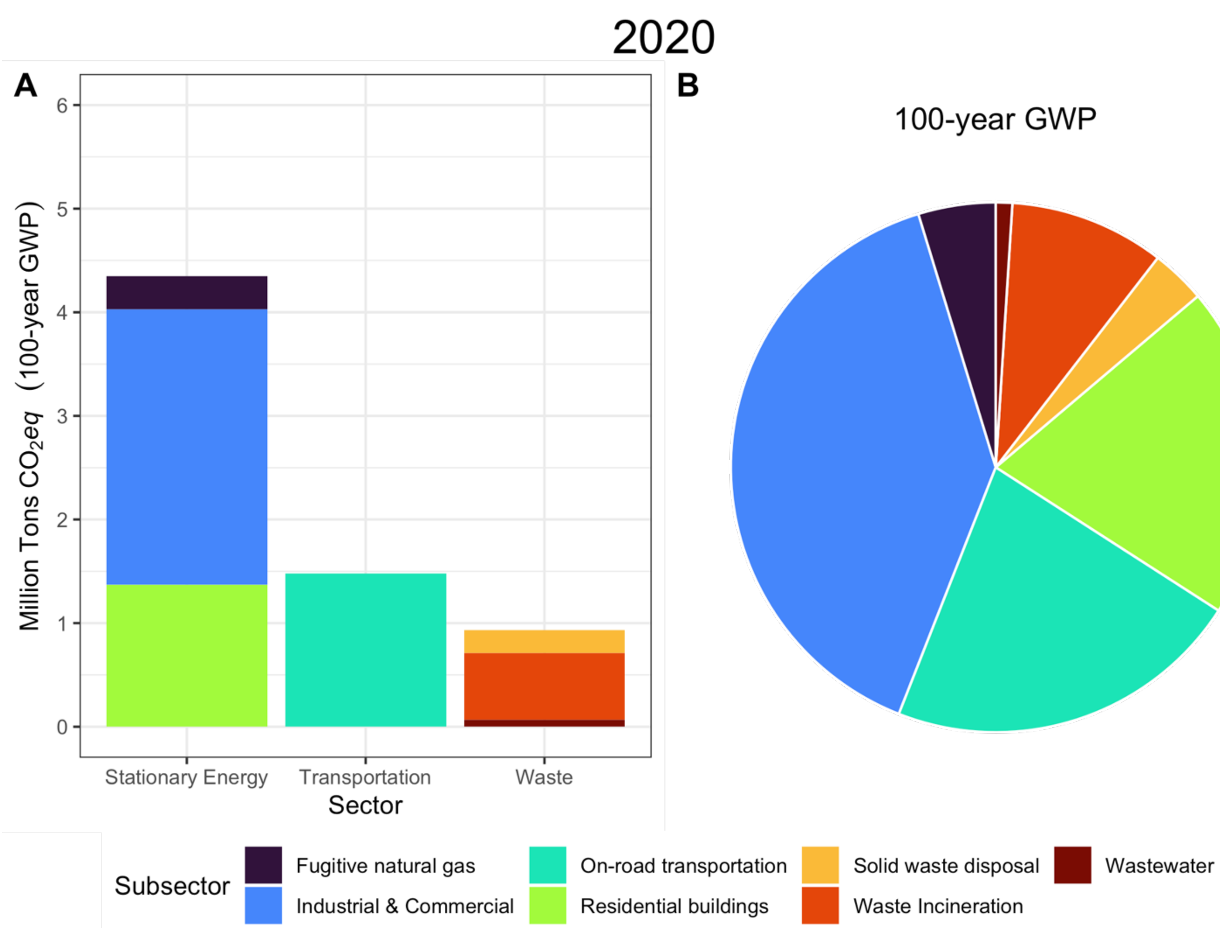


Table 19. Summary of GHG emissions from Baltimore City in 2019 (by GPC sector and scope)

Sector	Tons CO_2eq (100-year GWP)			Tons CO_2eq (20-year GWP)		
	Scope 1	Scope 2	Total	Scope 1	Scope 2	Total
Stationary Energy	2,285,775	2,643,481	**4,929,256**	3,014,720	2,653,902	**5,668,622**
Transportation	1,769,327	IE	**1,769,327**	1,776,850	IE	**1,776,850**
Waste	1,042,190	NA	**1,042,190**	1,573,692	NA	**1,573,692**
IPPU	NE	NA	NE	NE	NA	NE
AFOLU	NE	NA	NE	NE	NA	NE
Scope 3	NA	NA	NE	NA	NA	NE
Total	5,097,292	2,643,481	**7,740,773**	6,365,261	2,653,902	**9,019,163**

Figure 22. Summary of Baltimore's GHG emissions by sector and subsector in 2019

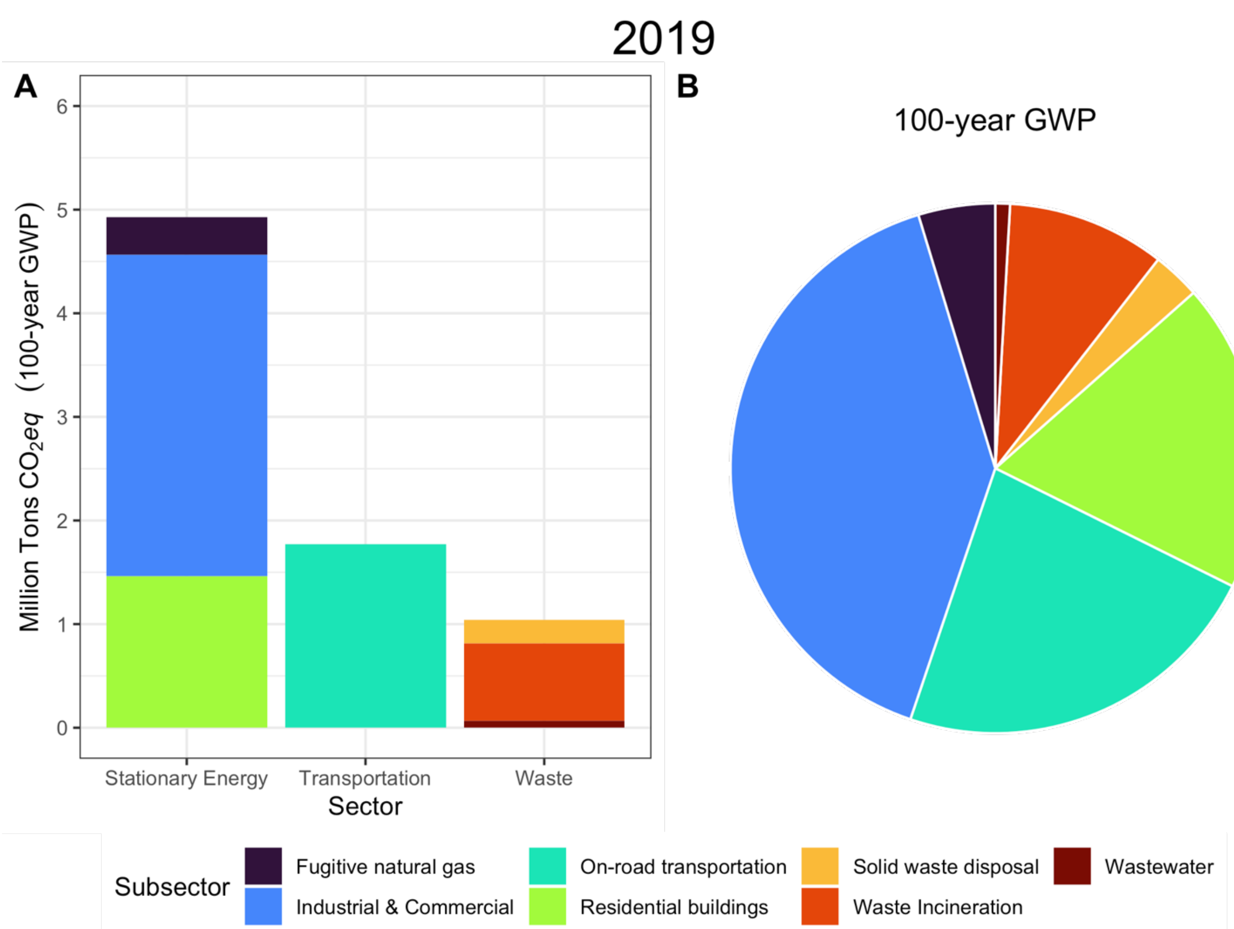


Table 20. Summary of GHG emissions from Baltimore City in 2018 (by GPC sector and scope)

Sector	Tons CO_2eq (100-year GWP)			Tons CO_2eq (20-year GWP)		
	Scope 1	Scope 2	Total	Scope 1	Scope 2	Total
Stationary Energy	2,427,916	2,951,961	**5,379,877**	3,201,167	2,964,762	**6,165,928**
Transportation	1,791,702	IE	**1,791,702**	1,799,320	IE	**1,799,320**
Waste	955,846	NA	**955,846**	1,487,677	NA	**1,487,677**
IPPU	NE	NA	NE	NE	NA	NE
AFOLU	NE	NA	NE	NE	NA	NE
Scope 3	NA	NA	NE	NA	NA	NE
Total	5,175,464	2,951,961	**8,127,425**	6,488,164	2,964,762	**9,452,925**

Figure 23. Summary of Baltimore's GHG emissions by sector and subsector in 2018

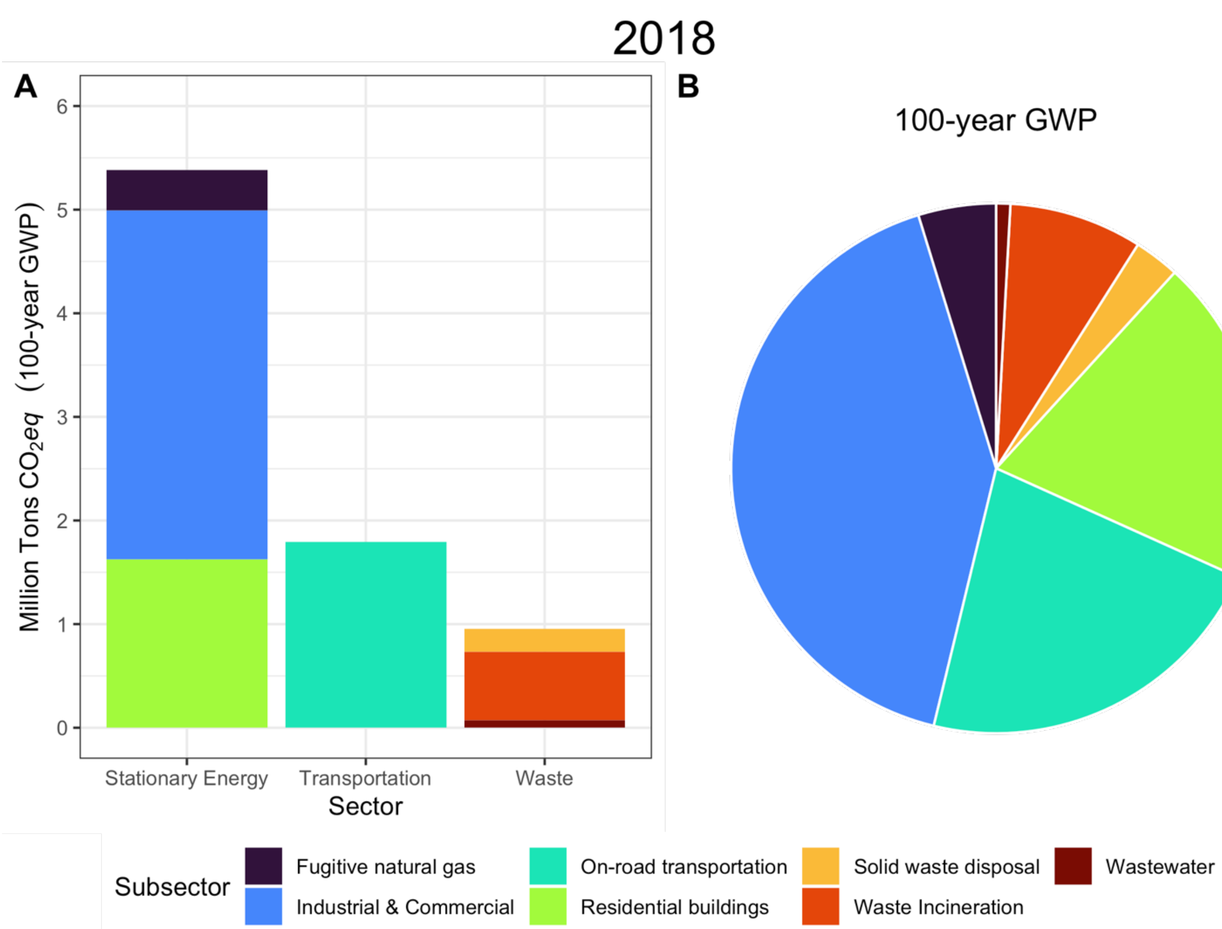


Table 21. Summary of GHG emissions from Baltimore City in 2017 (by GPC sector and scope)

Sector	Tons CO_2eq (100-year GWP)			Tons CO_2eq (20-year GWP)		
	Scope 1	Scope 2	Total	Scope 1	Scope 2	Total
Stationary Energy	2,167,283	2,784,290	**4,951,573**	2,857,643	2,797,101	**5,654,744**
Transportation	1,791,208	IE	**1,791,208**	1,798,826	IE	**1,798,826**
Waste	973,824	NA	**973,824**	1,507,044	NA	**1,507,044**
IPPU	NE	NA	NE	NE	NA	NE
AFOLU	NE	NA	NE	NE	NA	NE
Scope 3	NA	NA	NE	NA	NA	NE
Total	4,932,316	2,784,290	**7,716,606**	6,163,513	2,797,101	**8,960,614**

Figure 24. Summary of Baltimore's GHG emissions by sector and subsector in 2017

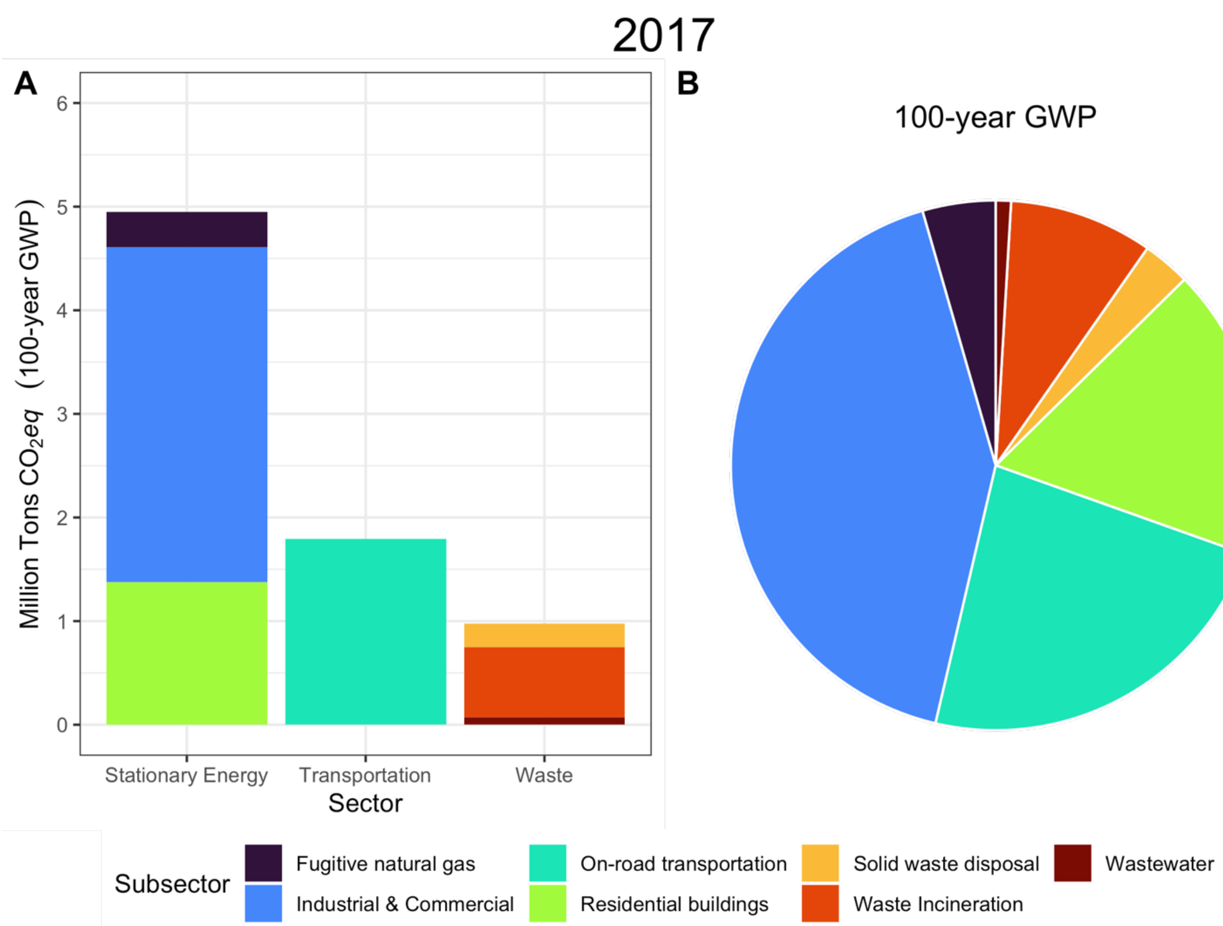


Table 22. Summary of GHG emissions from Baltimore City in 2007 (by GPC sector and scope)

Sector	Tons CO_2eq (100-year GWP)			Tons CO_2eq (20-year GWP)		
	Scope 1	Scope 2	Total	Scope 1	Scope 2	Total
Stationary Energy	2,006,795	3,774,265	**5,781,060**	2,616,037	3,795,864	**6,411,901**
Transportation	2,083,288	IE	**2,083,288**	2,090,893	IE	**2,090,893**
Waste	932,912	NA	**932,912**	1,496,832	NA	**1,496,832**
IPPU	NE	NA	NE	NE	NA	NE
AFOLU	NE	NA	NE	NE	NA	NE
Scope 3	NA	NA	NE	NA	NA	NE
Total	5,022,995	3,774,265	**8,797,260**	6,203,762	3,795,864	**9,999,626**

Figure 25. Summary of Baltimore's GHG emissions by sector and subsector in 2007

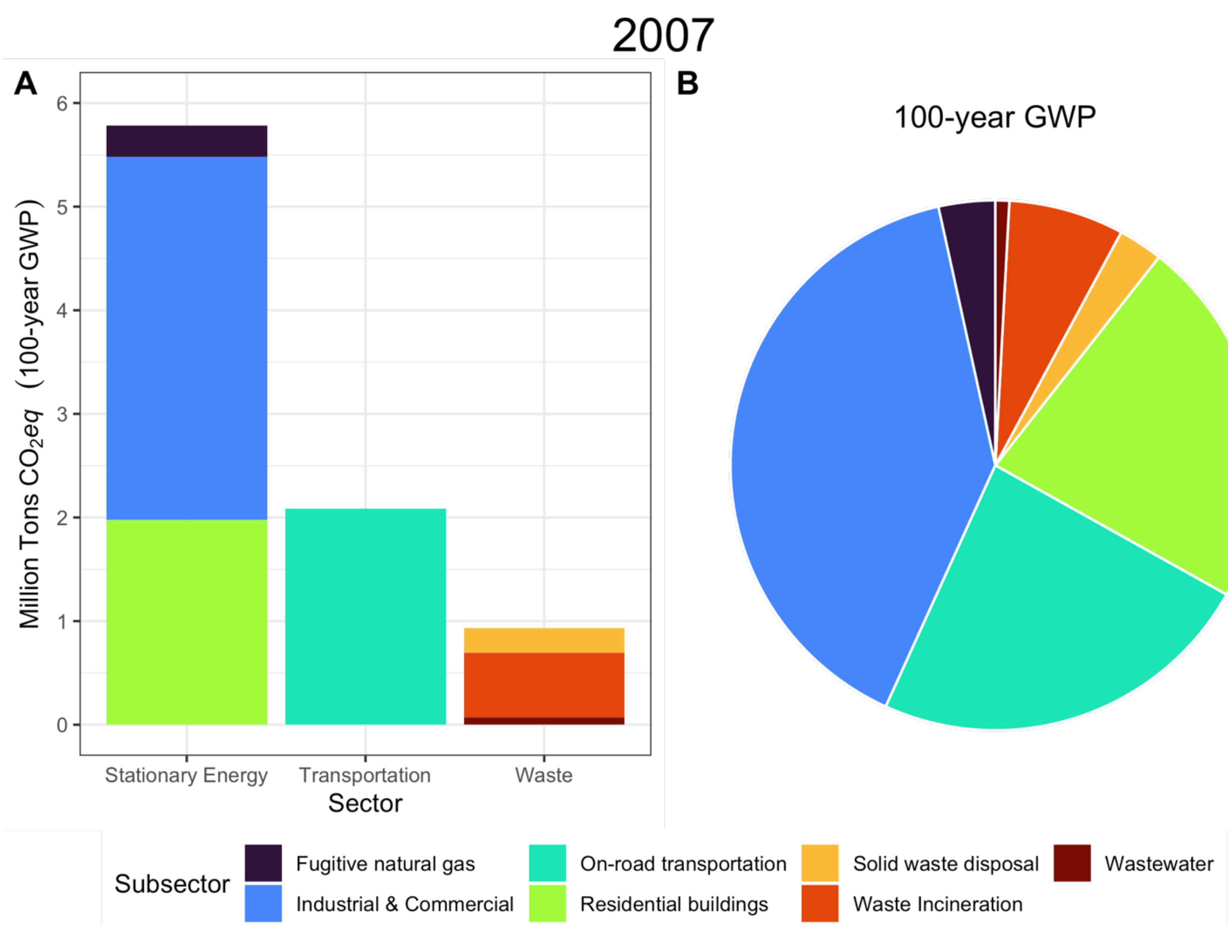


Figure 26. CO_2eq emissions per capita in 2020 (citywide and by sector)

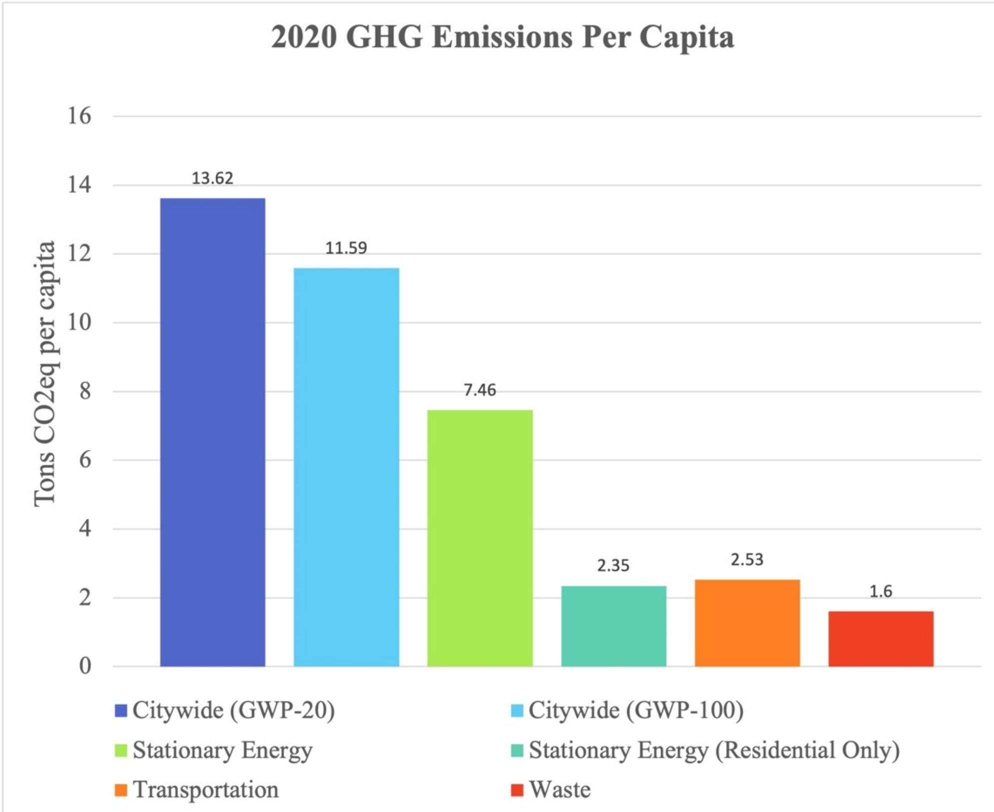


Figure 27. CO_2eq emissions per capita in 2019 (citywide and by sector)

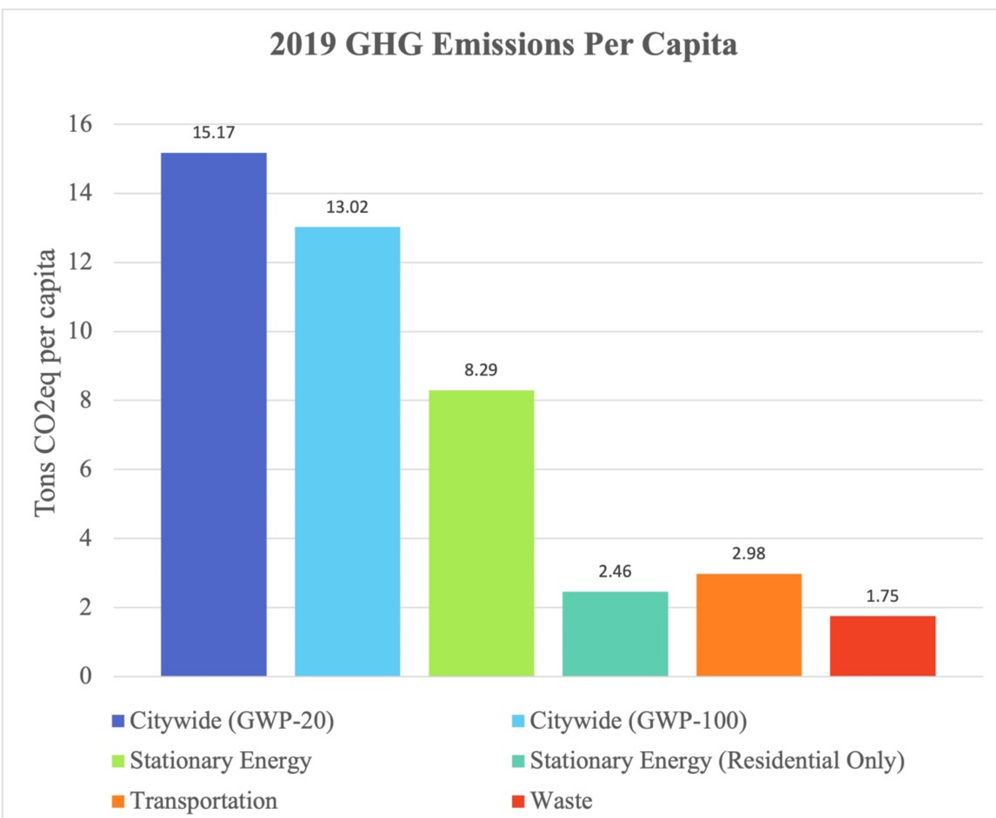


Figure 28. CO_2eq emissions per capita in 2018 (citywide and by sector)

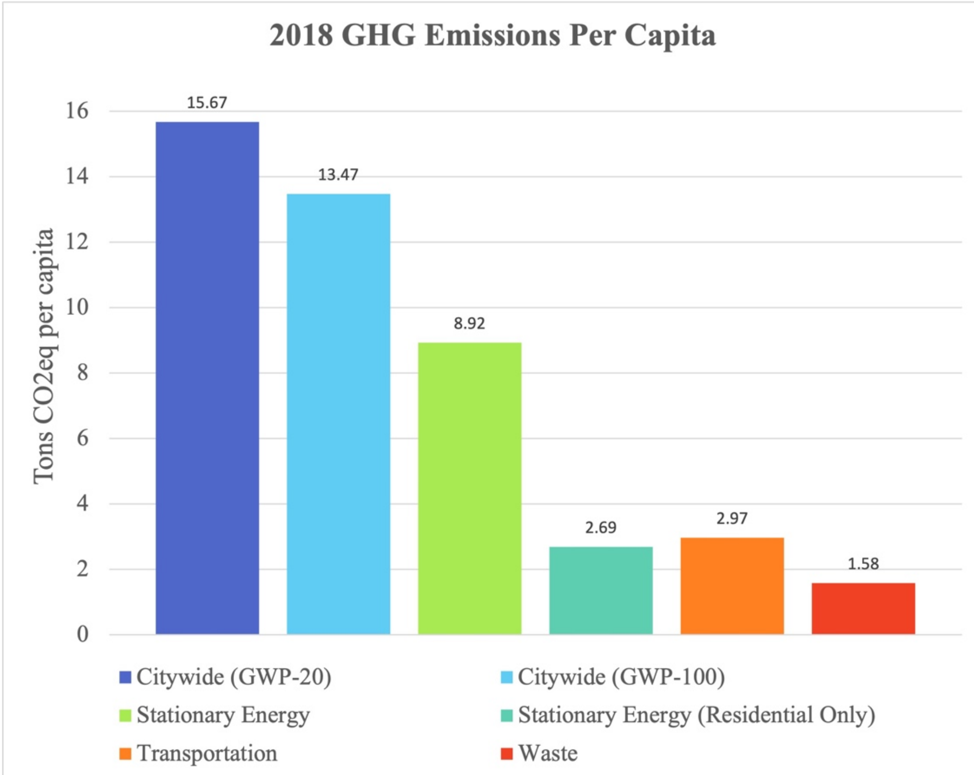


Figure 29. CO_2eq emissions per capita in 2017 (citywide and by sector)

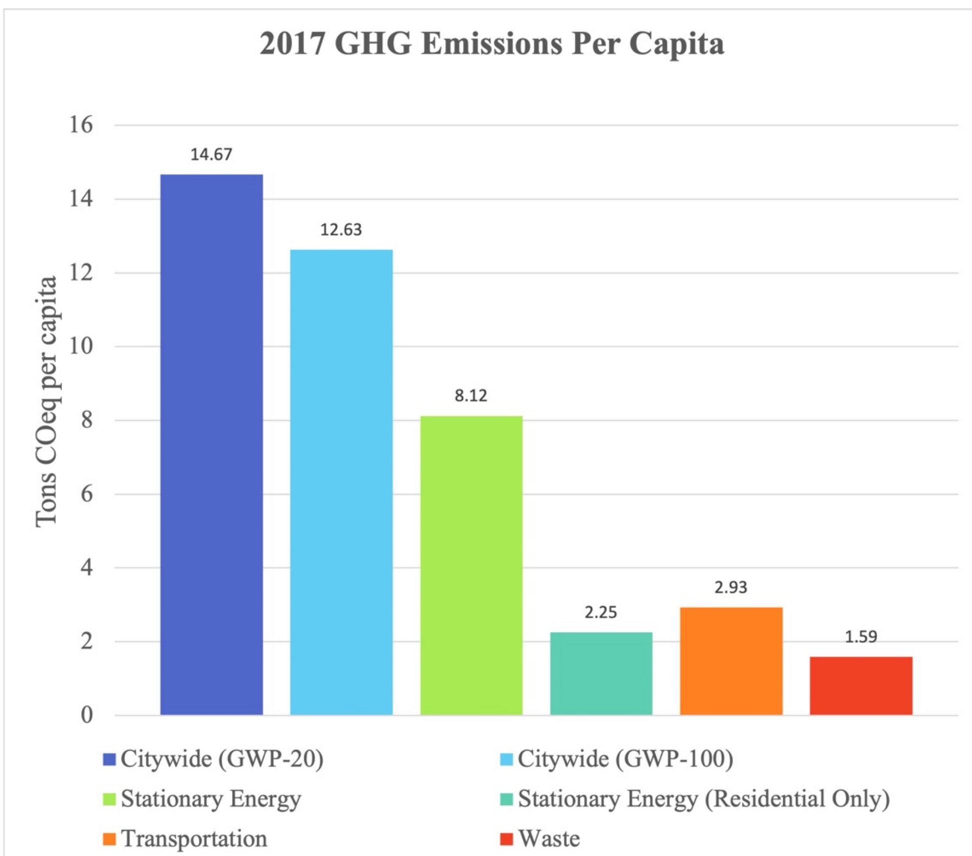
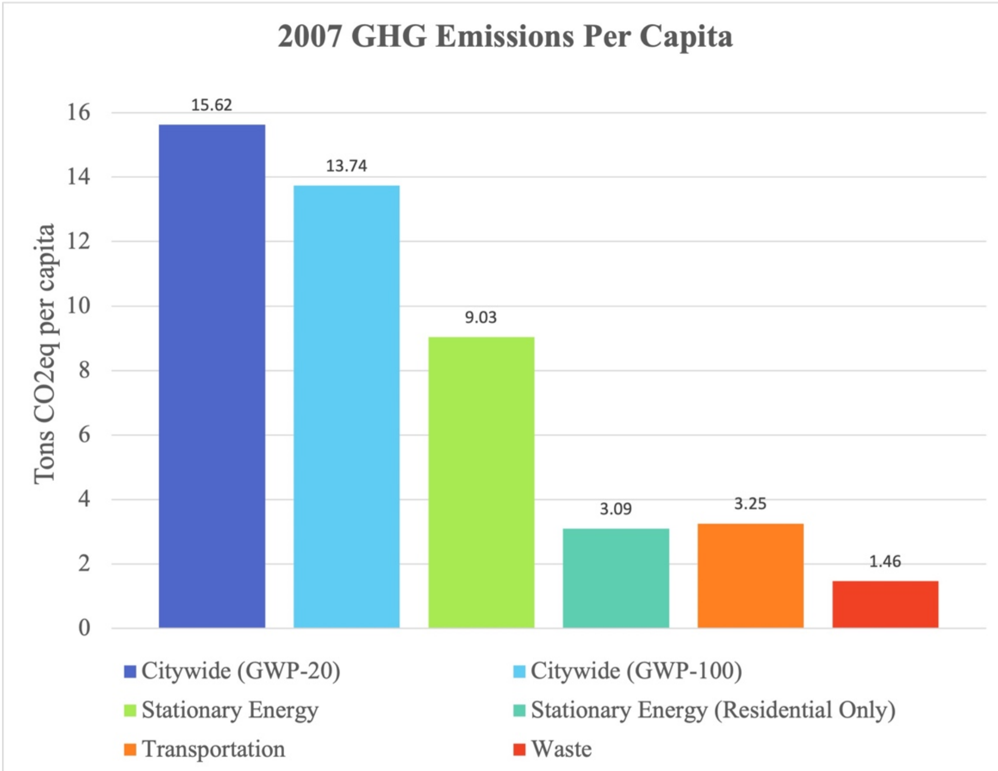


Figure 30. CO_2eq emissions per capita in 2007 (citywide and by sector)



Figures 26-30 show a breakdown of Baltimore City's GHG emissions per capita, all in units of tons CO_2eq per person. The blue bars in each of these figures show citywide totals (20-year GWP and 100-year GWP), and the other bars show the GHG emissions per capita for each sector (100-year GWP). We also show the stationary energy per capita emissions for the whole city and for the residential sector only (i.e., with industrial/commercial stationary energy emissions removed), which shows that the majority (~2/3rd) of citywide stationary energy emissions are generated by the industrial/commercial sector, rather than residential homes and buildings.

Appendix

Annual estimates of the population of Baltimore City

Table 23. Annual estimates of Baltimore City's population used in per capita calculations [17]

Year	Population	% change
2007	640,150	0.0
2008	637,901	–0.4
2009	636,128	–0.6
2010	620,942	–3.0
2011	620,493	–3.1
2012	623,035	–2.7
2013	622,591	–2.7
2014	623,833	–2.5
2015	622,831	–2.7
2016	616,542	–3.7
2017	610,853	–4.6
2018	603,241	–5.8
2019	594,601	–7.1
2020	583,132	–8.9
2021	576,498	–9.9

Point sources of GHG emissions

There are a small number of high-emitting GHG point sources in Baltimore City. These large point sources generally include energy generation and supply companies, commercial goods manufacturers, hospitals and universities, and waste treatment facilities. Emissions from each of these facilities are reported annually through the EPA GHGRP, with data currently available for 2010-2020 [36]. Emissions from each of these point sources are already accounted for elsewhere in the GHG inventory, but we include a summary of high GHG emission point sources in **Table 24** for reference and to provide additional context on how Baltimore's GHG emissions are distributed across the city.

Emissions from most of the point sources in **Table 24** are counted under industrial/commercial sector natural gas combustion from BG&E, except for the Quarantine Road Landfill and the Wheelabrator Incinerator, which are discussed separately in the **Sector 3: Waste** section of this report. We also count the estimated citywide fugitive natural gas emissions from BG&E as a point source in **Table 24** since they can be attributed to a single company, although in actuality fugitive CH_4 emissions likely occur at multiple points along BG&E's natural gas distribution network throughout the city. Overall, the Wheelabrator Incinerator is the largest point source of GHG emissions within Baltimore City, emitting nearly 14% of the City's Scope 1 GHG emissions, and 9.1% of the City's total Scope 1 and Scope 2 emissions over 2018-2020.

Table 24. Point sources in Baltimore City with high GHG emissions

Facility Name [Parent Company]	2020 Tons CO_2eq	2019 Tons CO_2eq	2018 Tons CO_2eq	% of city total
American Sugar Refining, Inc. [Fanjul Corp.]	108,847	105,035	104,232	2.2%
Baltimore Gas & Electric Co. [Exelon Corp.]	318,971	363,413	385,501	7.3%
Grace [W.R. Grace & Co.]	92,067	115,982	102,757	2.1%
Gold Bond [National Gypsum Co.]	88,944	98,630	95,720	1.9%
Gould Street [Exelon Corp.]	-	-	10,619	0.1%
Johns Hopkins Homewood Campus [Johns Hopkins University]	30,701	31,195	31,881	0.6%
Philadelphia Road Generating [Exelon Corp.]	5,084	2,318	5,929	0.1%
Quarantine Road Landfill [Mayor & Council of Baltimore]	225,580	226,034	225,433	4.6%
Saratoga Street Steam Plant [Veolia North America]	-	-	21,563	0.1%
Trigen – Leadenhall Street [Vicinity Energy]	48,079	69,727	52,179	1.2%
Trigen – North Central Ave. [Vicinity Energy]	15,910	17,148	20,759	0.4%
The Johns Hopkins Hospital [Johns Hopkins University]	97,913	106,178	107,767	2.1%
Wheelabrator Baltimore LP [Wheelabrator Technologies]	640,395	747,219	660,550	13.9%
Westport [Exelon Corp.]	2,897	38,126	26,739	0.5%

% of city total is calculated as the 2018-2020 average of the point source relative to the 2018-2020 average citywide Scope 1 GHG emissions (excluding Scope 2 electricity emissions).

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