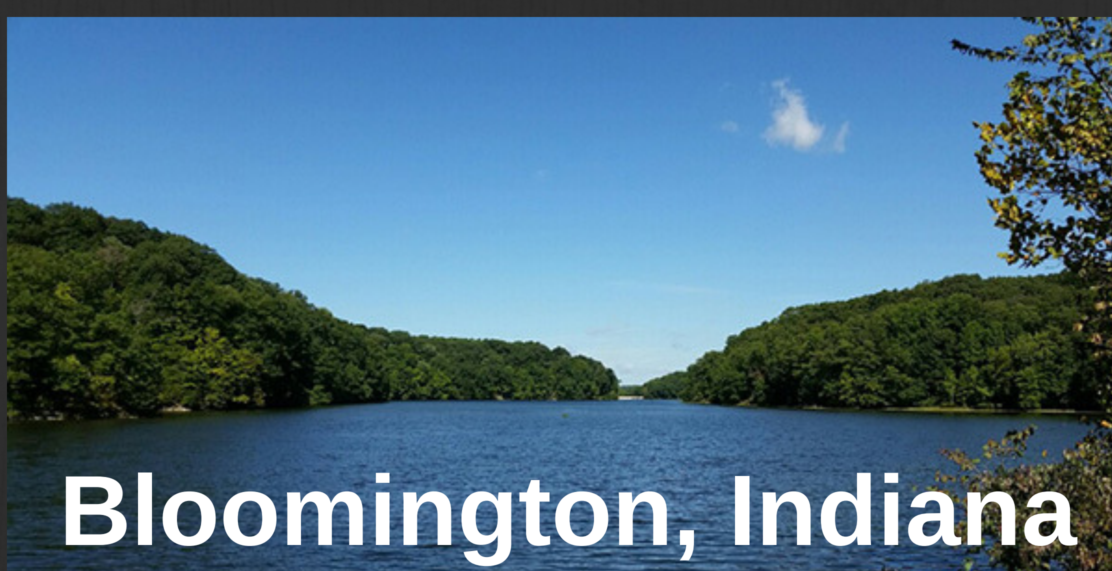
2016 Community Greenhouse Gas Emissions Inventory



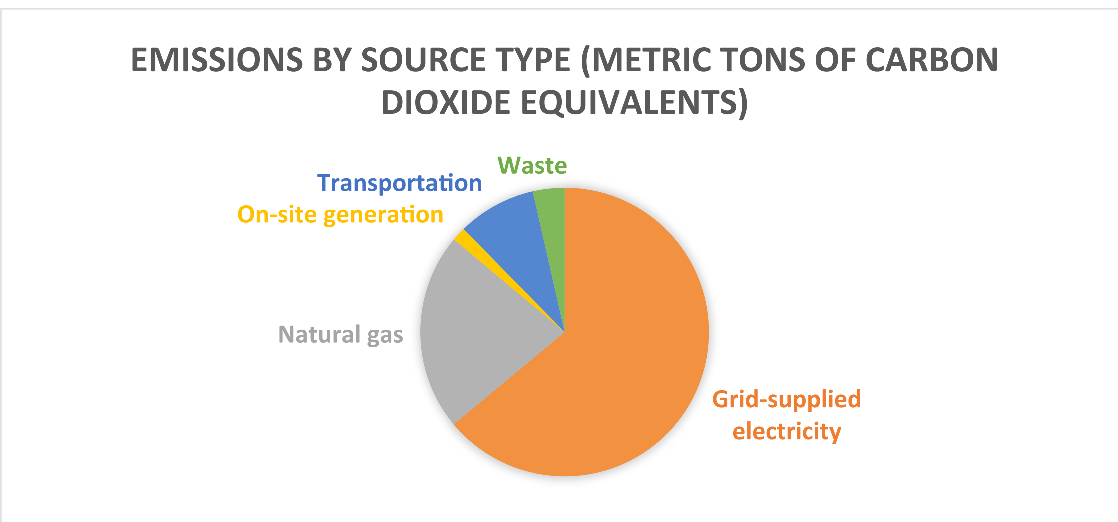
Bloomington, Indiana

Executive Summary

In an effort to better understand its greenhouse gas emissions and inform plans to curb them, the Department of Economic and Sustainable Development at the City of Bloomington compiled a community-wide greenhouse gas emissions inventory for the calendar year 2016. Using the Global Protocol for Community-wide Greenhouse Gas Emissions Inventories as a reporting template, it divides emissions into three scopes (reflecting geographic location of emissions relative to the city) and five emitting sectors. We found that, in 2016, the greatest source of emissions by far was energy production, followed by transportation. Solid waste disposal comprised the smallest source of emissions.

In 2016, Bloomington produced, directly and through energy consumption, approximately 1,375,237 metric tons of carbon dioxide equivalent in emissions. Of this total, 849,669 metric tons were emitted through the generation of electricity for Bloomington consumption; 340,663 resulted from natural gas combustion and leakage; 20,900 from on-site energy generation (using coal and fuel oil); 116,790 from the transportation sector; and 47,214 from waste disposal. In terms of scopes, 385,100 metric tons of greenhouse gases counted towards Scope 1 emissions (emissions taking place within city boundaries, excluding the generation of power to feed the power grid); 849,669 towards Scope 2 (emissions resulting from grid-supplied power, regardless of where they were produced), and 140,468 towards Scope 3 (emissions occurring outside city boundaries but occurring as a result of activities carried out by the city).

A similar greenhouse gas emissions inventory was carried out in 2009 by Bloomington's Environmental Commission using data for 2006. Comparison of the results of these two inventories (adjusting for gaps later found in the report for 2006) shows an overall decrease in emissions between 2006 and 2016, with emissions decreasing in nearly all sectors. A total of 1,582,515 metric tons of carbon dioxide equivalent (a figure which excludes some sectors for which data was not available) were emitted in 2006, showing about a 13 percent (if not more) decrease over the past ten years. The biggest reasons for the decrease in emissions are Indiana's gradual reduction of coal use in electricity generation, decreased energy use in many Bloomington sectors, and the installation of a methane capturing system at Bloomington's main waste destination.



Introduction

In May 2017, the City of Bloomington joined over 300 other cities across the country in declaring its commitment to upholding the terms of the 2015 Paris Climate Agreement, even in the absence of support at the federal level. As one of the signatories first to the 2006 US Mayors Climate Protection Agreement and now to this latest commitment to worldwide climate action, the city has undertaken a variety of activities aimed at reducing emissions, including (but not limited to) increasing energy efficiency, promoting active forms of transportation, and investing in renewable energy.

Measuring emissions facilitates strategic efforts to reduce them. To this end, Bloomington carried out its first greenhouse gas inventory in 2009 studying emissions from 2006, and after ten years, a second one is overdue.

This inventory follows the methodology laid out by the Global Protocol for Community-Scale Greenhouse Gas Emission Inventories, described below. It finds an overall reduction in greenhouse gas emissions of approximately 13%, from 1,582,515 metric tons of carbon dioxide equivalent to 1,375,237. Nearly every sector experienced a reduction in emissions.

Methodology

In planning and putting together a detailed inventory, a standard methodology and process is highly useful, if not necessary. Tracking emissions can often be challenging and messy, with the potential for omissions and double-counting. Among other things, communities must set geographic and temporal boundaries and clearly define the inventory scope.

In order to facilitate comparison and planning across large numbers of communities, a consistent approach is needed. Two predominant approaches exist in measuring greenhouse gas emissions: consumption-based approaches, focusing on the emissions associated with the consumption of goods and services by city residents, and production-based approaches, focusing on emissions directly produced by activities taking place in the city. This inventory takes a production-based approach. While consumption-based approaches can shed light on emissions that otherwise would go unaccounted for (such as emissions from international trade), they also involve a great degree of uncertainty, as emissions occurring throughout a wide geographical scale must be accounted for. Furthermore, production-based approaches minimize the risk of double-counting emissions and allow for easier cross-comparability, as they establish geographic boundaries for the area under study.

Specifically, this inventory uses the Global Protocol for Community-Scale Greenhouse Gas Emission Inventories (GPC). Developed by the World Resources Institute (WRI), ICLEI-Local Governments for Sustainability, and C40 Cities Climate Leadership Group[1], the GPC divides emissions by sector and provides a reporting framework. This framework is based on the 2006 guidelines of the International Panel on Climate Change (IPCC), and is the officially adopted protocol for greenhouse gas inventories by the International Compact of Mayors.[2]

The GPC divides emissions into five sectors, based on type of activity, and three scopes, defined by geographic area. The sectors are:

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[1] http://www.c40.org/programmes/the-global-protocol-for-community-scale-greenhouse-gas-emission-inventories-gpc

[2] https://www.compactofmayors.org

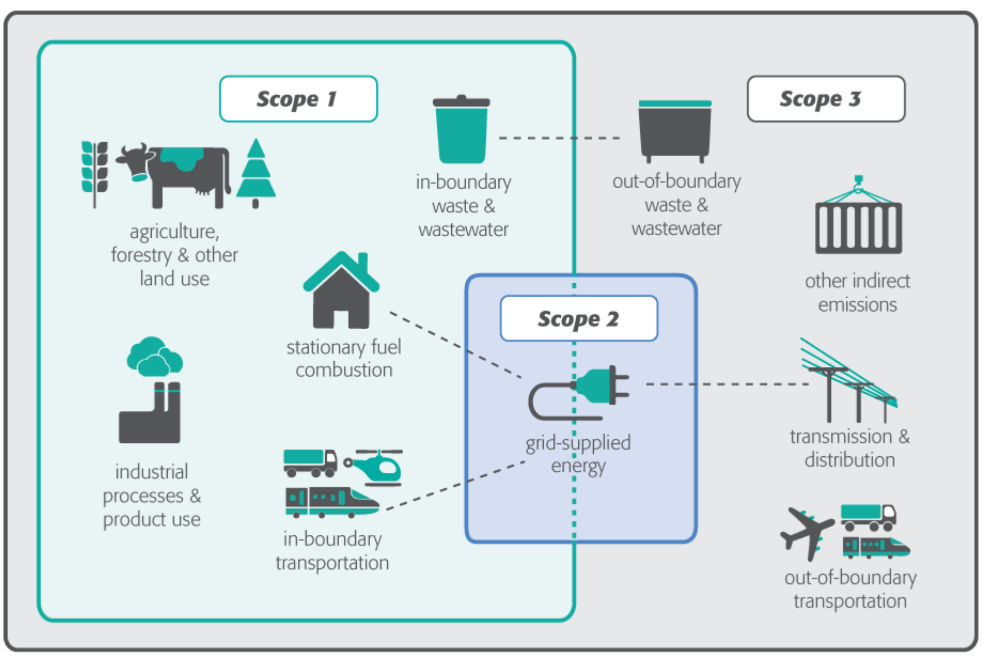
- Stationary energy
- Transportation
- Waste
- Industrial processes and product use (IPPU)
- Agriculture, forestry, and other land use (AFOLU)

The scopes (any of which can include any of the sectors), are Scope 1, Scope 2, and Scope 3, described in the table and image below.

Table 1: Scopes

Scope	Description and what it includes
Scope 1 (territorial emissions)	Emissions physically taking place inside the city; emissions from industrial processes (excluding the electricity used to power them); Transportation within city boundaries; Waste produced and treated inside the city
Scope 2	Grid-supplied energy consumed inside the city, regardless of where it was generated
Scope 3	Other emissions occurring outside the city brought about by city residents' activities and operations; Waste treated outside the city; Transportation to or from the city occurring partially outside city boundaries (whereby the segment inside the city falls into Scope 1 and that outside the city into Scope 3)

Figure 1: Sectors classified by scopes[3]



[3] Source: http://www.c40.org/programmes/the-global-protocol-for-community-scale-greenhouse-gas-emission-inventories-gpc

As total emissions are typically not measured directly, inventories make use of activity data and emissions factors, which are based on empirical data and published by entities such as the EPA and International Panel on Climate Change. These emissions factors provide the volume of total pollutant emitted from a standardized unit of activity, such as carbon dioxide emissions per kilowatt-hour of electricity used or per gallon of gasoline combusted. All the emissions factors used in this inventory, unless otherwise specified, were obtained from the EPA document "Emission Factors for Greenhouse Gas Inventories,"[4] last updated on April 4th, 2014.

The GPC calls for reporting of the same seven gases required for national inventories in the Kyoto Protocol: carbon dioxide (CO_2), methane (CH4), nitrous oxide (N2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulfur hexafluoride (SF6), and nitrogen trifluoride (NF3). Additionally, given that different gases have different global warming potentials (GWPs) due to different chemical properties (with all other gases listed having a GWP much higher than carbon dioxide), all gases are converted to carbon dioxide equivalents (CO_2-e's) to better show the full greenhouse effect. However, data was not available for all gases in all sectors, and certain gases (such as sulfur hexafluoride) have a limited range of emission and are therefore not applicable in certain sectors. Most emitting activities listed in this report have emissions factors for carbon dioxide, methane, and nitrous oxide. The global warming potentials used for this report come from the IPCC Fifth Assessment Report (the latest report published to date): 28 CO_2-e for CH_4 and 265 CO_2-e for N_2O.

Use of the GPC represents a change from Bloomington's previous greenhouse gas inventory, which does not divide emissions by scope. However, since the 2006 protocol divides emissions sectors roughly the same way as the GPC (i.e. waste, transportation, energy, etc.), comparison between the two inventories is not particularly difficult. Unless otherwise noted, the masses of emitted gases (CO_2, CH_4, and N_2O) as well as CO_2-equivalents (CO_2-e) are given in metric tons. When provided and unless otherwise stated, the masses of CH_4 and N_2O emitted are absolute metric tons of CH_4 and N_2O, not their equivalent CO_2-equivalent; the total sum of CO_2-equivalents resulting from emissions of those gases are later provided underneath.

For purposes of simplicity, the terms "greenhouse gas" and "emissions" are used synonymously throughout this report, unless otherwise stated.

Scope 1

Scope 1 consists of emissions from energy generated and used locally (that is, not from the grid), heating from combustion taking place on site, emissions resulting from industrial processes, local land use practices, transportation happening within city boundaries, and waste products treated locally.

Stationary Energy

Stationary energy includes natural gas used for heating (as it is combusted locally, even if provided from distant sources). All natural gas used in Bloomington is provided by Vectren and is measured in therms.

The data provided by Vectren records gas usage by zip code; since most Bloomington zip codes also include areas outside the city limits, the data does not perfectly reflect use within the city proper. However, zip code boundaries are not coterminous with counties either, so it is impossible with the data available to calculate with complete accuracy natural gas usage for the entirety of Monroe County without including some use in surrounding counties. The zip codes provided (47401, 47402, 47403, 47404, 47405, 47406, 47407, and

[4] https://www.epa.gov/sites/production/files/2015-07/documents/emission-factors_2014.pdf

47408) account for all of the city of Bloomington and most of the remainder of Monroe County (excluding Ellettsville).

To determine the emissions caused by natural gas heating systems, this inventory uses the corresponding emissions factor provided on the EPA emissions table. In 2016, a total of 46,591,522 therms of natural gas were consumed in the Bloomington area, according to data provided by Vectren.[5] This yielded a total of 247,028 metric tons of CO_2 released, divided by sector as follows.

Table 2: Natural gas emissions factors

Emitted gas	**CO_2**	**CH_4**	**N_2O**
Original emissions factor provided	53.06 kg/mmBtu[6]	1.0 g/mmBtu[7]	0.1 g/mmBtu
Emissions factor in metric tons per therm (mt/therm)	.0053 metric tons per therm	≈0.00 metric tons per therm[8]	≈0.00 metric tons per therm[9]

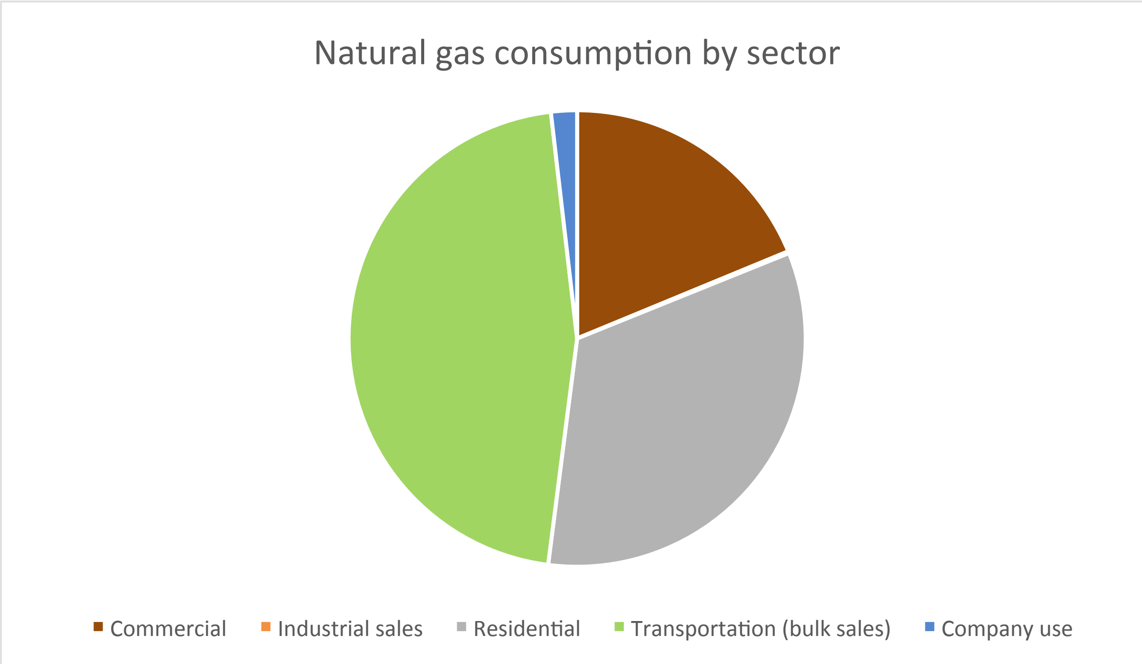
*Table 3: Bloomington natural gas usage, 2016***

	Commercial	**Industrial**	**Residential**	**Transportation[10]**	**Company use**	**Total**
Therms of natural gas used	8,741,491	61,267	15,437,766	21,494,550	856,447	46,591,522
Resulting CO_2 emissions (in metric tons)	46,371	325	81,893	114,023	4,543	247,156
Resulting CH_4 emissions in metric tons	0.87	0.0061	1.54	2.15	0.09	4.66
Resulting N_2O emissions in metric tons	0.09	0.00061	0.15	0.21	0.0086	0.47
Total in metric tons of CO_2-e	46,419	325	81,977	114,140	4,548	247,409

****Sums of emissions do not add up because CH_4 and N_2O emissions are provided in the original mass and not converted to CO_2-equivalent until the final row.**

[5] Received from Nick Kessler on January 11, 2017 from nkessler@vectren.com, personal correspondence.
[6] The abbreviation mmBtu stands for one million British thermal units, a unit of heat; one mmBtu is approximately equivalent to ten therms.
[7] Again, methane and nitrous oxide emissions are much lower than carbon dioxide emissions.
[8] More precisely, 10×10^{-8} metric tons
[9] More precisely, 10×10^{-9} metric tons
[10] Transportation in this context refers to bulk purchases by large facilities and institutions, not natural gas used for the purposes of transportation. This includes natural gas used by Indiana University.

Figure 2: Natural gas consumption by sector, 2016



**Industrial sales is not visible in the pie graph because of its extremely small share (less than .1 % of total emissions). Industry-related natural gas usage may also fall under transportation, commercial, and/or company use.

Indiana University-Bloomington has a central heating plant that can use both coal and natural gas. In the not-so-distant past it had relied primarily on coal, a much more polluting fossil fuel than natural gas when combusted. However, in recent years IU's use of coal has gone down due to the decreasing price of natural gas relative to coal. In 2016, 8,872 tons of bituminous Southern Indiana coal were burned, representing approximately 15% of the total fuel used by the heating plant[11]. Using the emissions factors provided by the EPA, IU's central heating plant produced a total of 20,801 CO_2-equivalents from coal, broken down in Table 4.

Table 4: Coal emissions

Gas	**CO_2**	**CH_4**	**N_2O**
Emissions factor	2325 kg CO_2 per short ton of coal	274 g CH_4 per short ton of coal	40 g N_2O per short ton of coal
Total metric tons emitted	20,627	2.43	0.35
Total metric tons in CO_2-equivalents	20,627	68.07	106

The central heating plant also used 9,661 gallons of #1 distillate low-sulfur fuel oil. Using the emissions factors provided by the EPA table, we calculated 98.67 metric tons of CO_2-equivalent, broken down as shown in Table 5.

[11] Obtained through correspondence with Makayla Bonney of the Indiana University Office of Sustainability and Mark Menefee of Indiana University Facility Operations

Table 5: Fuel oil emissions

Gas	CO_2	CH_4	N_2O
Emissions factors	10.18 kg CO_2 per gallon	0.42 g CH_4 per gallon	0.08 g N_2O per gallon
Total metric tons emitted	98.35	.0041	.00073
Total metric tons of that gas in CO_2-equivalents	98.35	0.11	0.20

Image 1: Indiana University Central Heating Plant

Other Scope 1 generation

Emissions resulting from the use of generators on-site to produce electricity fall into Scope 1—Stationary Energy. Various establishments and residences in Bloomington have generators, the majority of which use diesel fuel.[12] However, the majority of these generators are only run when testing or during emergencies, when grid power is disconnected. The overall amount of emissions that these produce, in light of the total amount of electrical power and resulting emissions used throughout Bloomington, is quite small. Furthermore, data for these generators are difficult to obtain. Therefore, on-site electrical generation (excluding that at IU) is not included in this inventory.

Industrial Processes and Product Use

The Bloomington area contains several industrial and manufacturing enterprises, which contribute to Scope 1 emissions under Industrial Processes and Product Use (IPPU). Industrial emissions can be of various types and from various sources, with two types predominating: emissions resulting from energy use and those resulting from chemical reactions involved in manufacturing. Emissions resulting from energy use (which make up the largest share of industrial emissions) are reported under Scope 2 (unless the energy is produced on-site, in which case it would be under Scope 1 stationary energy). Only non-energy-related emissions, such as those from chemical reactions, are listed under IPPU. Certain industrial processes, such as metal or ammonia production, generate large amounts of emissions due the specific chemical reactions involved; however, other types of manufacturing do not produce significant emissions aside from energy. Additional emissions result, among other things, from solvent use and refrigeration, and the fluorinated gases used in refrigeration have GWP's that can be thousands of times that of CO_2. However, the overall amount of these emissions, even expressed in CO_2-equivalents, is still extremely small in comparison to those resulting from energy generation and use.[13]

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[12] Information on electric generators obtained through communication with Jeff Honaker of Duke Energy.
[13] Global Protocol for Community-Scale Greenhouse Gas Emission Inventories

Bloomington has several small and mid-size manufacturing firms,[14] and these were considered when preparing this inventory with potential major emitters identified. Only a handful of firms were deemed to have the potential for large amounts of emissions (such as metal producers). When further investigated, even these were found to be too small to contribute a significant amount to Bloomington's overall emissions. The EPA requires facilities generating over 25,000 metric tons of CO_2-e a year to report their emissions in the EPA's Greenhouse Gas Reporting Program (GHGRP). Only two facilities in Monroe County, Indiana University and the Monroe County Landfill, report to the GHGRP. Because of this, one can reasonably assume that no other individual source in Monroe County produces more than 25,000 annual metric tons of CO_2-e. Furthermore, even 25,000 metric tons of CO_2-e is actually quite small in comparison to the emissions resulting from energy production (just electricity consumption in Bloomington commercial establishments amounted to 240,000 metric tons CO_2-e, nearly ten times as much). Even aggregated, Bloomington's industries do not produce more than a few percentage points at most of Bloomington's total greenhouse gas emissions. As data for industrial emissions was unavailable and would have entailed very rough estimations, this inventory does not include them (excluding grid-supplied energy, which is included in Scope 2). This is consistent with the approach in the 2006 inventory as well.

Agriculture, Forestry, and Other Land Use

Another sector defined in the GPC is Agriculture, Forestry and Other Land Use (AFOLU). As with IPPU, its share in total emissions is most likely negligible. While Bloomington does have some agricultural activities taking place within city limits, these activities have a very low carbon intensity. Furthermore, carbon released into the atmosphere by natural cycles (such as decay) is not included in the GPC. Few data were available for this sector within Bloomington city limits; therefore, it was excluded from the inventory as in the 2006 inventory.

In-boundary transportation

Given its mobile nature, transportation presents a particular challenge to calculating emissions. The GPC suggests a few different strategies for estimating emissions. One approach is finding the total amount of vehicle fuel sales within the limits of a community. This approach yields an accurate number (as opposed to an estimate) and allows for the aggregation of several communities' sales without double-counting; however, it is impossible to know how much of the fuel bought in a community was expended within that community and how much fuel bought outside was consumed inside.

Another way to calculate transportation-related emissions is to estimate the total amount of miles driven by all vehicles within an area. This, like other manners of calculating transportation-related emissions, still encounters the issue of ambiguity regarding trips that cross city boundaries. Furthermore, given the highly decentralized activity of thousands of vehicles, each with their own schedules, routines, and routes, it is impossible to obtain anything more than a rough estimate of miles traveled.

Nevertheless, because data for total fuel sales in Monroe County or Bloomington was not available, this inventory calculates emissions using estimates of miles traveled by vehicles (the latter approach). One method used throughout the U.S. to obtain these estimates is the calculation of Vehicular Miles Traveled (VMT), obtained by counting the number of cars passing through observation points placed on different types of roads (highways, city roads, rural roads, etc.) over a given time period (such as a day). These estimates can then be used to calculate average emissions by taking into account the composition of the vehicle fleet in the

[14] Data on Bloomington manufacturing enterprises was provided by the Bloomington Economic Development Corporation.

city (the types, models, and years of production of vehicles) because average fuel efficiency varies by vehicle attributes.

Specifically in the case of this inventory, we used data obtained from the Indiana Department of Transportation (INDOT), which provides VMT calculations for all Indiana counties through 2015. County-level totals are available on the website, and city-specific data was obtained through email correspondence. Data for vehicle fleet composition (i.e. models, years of manufacturing, etc.) was unavailable for the county and state level; however, the EPA provides an estimate of the average fuel efficiency for all vehicles at the national level.

INDOT has modified the way it measures VMT since 2006. Among other things, it has increased the number of roads observed and further divided roads by location and type. Because of this, there is no direct way to compare the 2015 data to that for 2006. Although the new measurements yield a lower VMT for Bloomington than that given in 2006, the VMT in Monroe County by type of road has actually remained nearly constant (it is possible that the VMT data for 2006 also included roads in other cities in Monroe County, such as Ellettsville).

INDOT provides total VMT by day as well as VMT specifically for commercial vehicles[15], allowing for the breakdown of VMT into commercial and non-commercial vehicles by subtracting commercial vehicles from the total (highly useful given the large differences in fuel efficiency). Repeating the methodology used in the 2006 inventory, these numbers were multiplied by 323 instead of 365 to obtain annual total VMT because of the significant drop in Bloomington's population during the summer (when most Indiana University students leave). Emissions factors obtained from the EPA's website were then multiplied by fuel efficiency averages obtained from the most recent version of the Federal Highway Administration's Table VM-1. The VM-1 (obtained on the FHWA website) lists average fuel efficiency in 2015 for light-duty vehicles as 22.0 miles per gallon of motor fuel, and that for larger vehicles as 6.4 miles per gallon of motor fuel[16]. Dividing annual VMT for each vehicle type by the average fuel efficiency gives an estimate of gallons used by each type of vehicle. On a national

Image 2: Cars on West Tapp Road

[15] Commercial vehicles, as per communication with Gregory Katter of the INDOT, consist of FHWA Scheme F Classes 4-13. This includes buses, large trucks, and all other on-road vehicles with at least six tires and/or more than two axles. Classes 1-3 (i.e. non-commercial vehicles in this sense) consist of motorcycles, four-wheel two-axle cars, vans, pick-up trucks, and other vehicles having four tires and two axles. This distinction is nearly synonymous with the distinction in FHWA Table VM-1 between light-duty vehicles (i.e. non-commercial vehicles) and other vehicles, save for the exclusion of motorcycles in the light-duty category. Admitting this inconsistency, this report treats these categories as synonymous for the purpose of determining fuel efficiency. For more information on FHWA vehicle classes see the FHWA Vehicle Classification Scheme F Report.

[16] See https://www.fhwa.dot.gov/policyinformation/statistics/2015/vm1.cfm. As stated in Footnote 15, there is a small difference between the categorization used by the INDOT and that used in table VM-1 in listing fuel efficiency.

level, about 22% of motor fuel sales were diesel in 2013 (the latest year for which data is available)[17]. As the FHWA provides an average for motor fuel overall, it was possible to multiply the total number of gallons of motor fuel consumed by the share of diesel in order to obtain the total amount of diesel sales.[18] Then, the emission factors provided by the EPA for gasoline, 8.87 kg CO_2 per gallon, and diesel, 10.21 kg CO_2 per gallon, gives an estimate for total emissions. The resulting emissions are then summed and divided by proportion of miles traveled by each vehicle type to divide emissions by vehicle type.

For each vehicle type (i.e. commercial or non-commercial):

Total miles traveled * 1/average fuel efficiency (i.e. miles per gallon) = total gallons of fuel consumed

Total gallons of fuel consumed * .78 * 8.87 kg CO_2 per gallon of gasoline = total kg of CO_2 emitted from gasoline

Total gallons of fuel consumed * .22 * 10.21 kg CO_2 per gallon of diesel = total kg of CO_2 emitted from diesel

Total kg of CO_2 emitted from gasoline + Total kg of CO_2 emitted from diesel = total CO_2 emissions in kg (from that vehicle type)

Table 6: Vehicle emissions

	Non-commercial vehicles	Commercial vehicles
Miles traveled per day in 2015	719,421	45,163
Total miles traveled in 2015	232,372,983	14,587,649
Gallons of motor fuel consumed	10,562,408	2,279,320
Percentage of total gallons of fuel used	82.25%	18.75%
Total emissions by vehicle type (metric tons CO_2)	96,061	20,730

The GPC also includes off-road vehicle use, such as the use of mechanized farm equipment, water vehicles, and lawnmowers, in in-boundary transportation. Given Bloomington's primarily urban characteristics, in addition to the difficulty of estimating off-road vehicle use, emissions resulting from these vehicles were not included in this inventory.

Scope 2

Scope 2 consists of energy (mainly electricity, but also steam, heat, cooling, etc.) obtained from the power grid (not generated on site). Emissions generated from grid-provided electricity consumed in 2016 were

[17] https://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/publications/bts_fact_sheets/oct_2015/html/figure_03_text.html

[18] This approach admittedly makes several assumptions. The national proportion of diesel sales may differ from that in Bloomington, and this calculation does not take into account other fuels that may be used in cars, such as compressed natural gas or electricity. Furthermore, the proportion of diesel used in heavy-duty vehicles and that used in light-weight vehicles differs significantly but is not acknowledged here. However, given the likely small share of electric cars in Bloomington, and the fact that the fuel efficiency averages for both types of vehicles include both types of fuels, further detail in this calculation was deemed unnecessary, especially given the ambiguity already present in VMT and city fleet composition.

calculated using data provided by Duke Energy, Monroe County's predominant electrical supplier (supplying nearly everyone in the city and most people in the county).The data for the Bloomington District (which includes Ellettsville) showed an aggregate total of 1,346,720,346 kilowatt hours consumed in 2016.

The carbon footprint of electrical power varies significantly depending on its source. Furthermore, since the electricity furnished by providers like Duke can be generated at any number of regional power plants (and not just those owned by the provider or the plant nearest to the user), it is necessary to obtain a regional average for the composition of electricity sources.

According to the Energy Information Administration, in Indiana the largest source of electrical power is coal (currently generating about 70% of electricity but falling in share) followed by an increasing share of natural gas (currently at about 20%). Renewables (wind, solar, biomass, hydroelectric, and geothermal energy) make up about 6% of Indiana's total energy mix.[19] Regional carbon estimates come from the EPA's eGRID publication. Here, the EPA divides the U.S. into subregions with an average carbon footprint for every kilowatt of electricity consumed in that region; this footprint takes into account the mix of sources used in any one region. The latest version of eGRID, the eGRID 2014 v2, gives the following footprint for the RFCW region, which includes Indiana[20].

Table 7: Emissions factors for electricity-related emissions

Gas emitted	**CO_2**	**CH_4**	**N_2O**
Original emissions factor provided	1,380.9 lb/MWh	150.2 lb/GWh[21]	22.0 lb/GWh
Emissions factor in metric tons	0.63 metric tons/ MWh	≈0.00 metric tons/ MWh[22]	≈0.00 metric tons/ MWh[23]

Using these estimates, electricity use and the resulting emissions are broken down by sectors in Table 8.

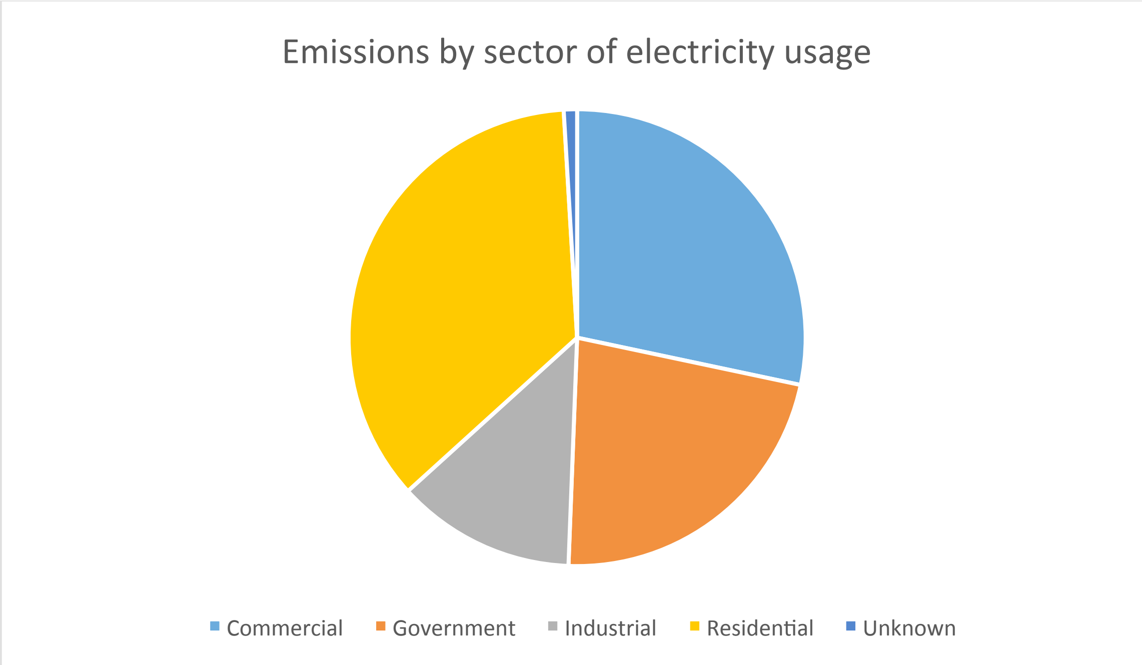
*Table 8: Bloomington electricity usage, 2016***

Type of account	**Commercial**	**Govt.**	**Industrial**	**Residential**	**Unknown**	**Totals**
Kilowatt hours consumed	381,395,225	300,100,840	170,656,456	481,897,282	12,670,543	1,346,720,346
Metric tons of CO_2 released	238,893	187,973	106,893	301,844	7,936	843,539
Metric tons of CH_4 released	25.98	20.45	11.63	32.83	0.86	91.75
Metric tons of N_2O released	3.81	2.99	1.70	4.81	0.13	13.44
Total sum of CO_2-e	240,629	189,339	107,670	304,037	7,994	849,669

**Sums of emissions do not add up because CH_4 emissions and N_2O emissions are shown in their original mass and not converted to CO_2-equivalent until the final row.

[19] https://www.eia.gov/state/analysis.php?sid=IN
[20] https://www.epa.gov/sites/production/files/2017-02/documents/egrid2014_summarytables_v2.pdf
[21] Methane and nitrous oxide emissions are much lower per unit of electricity produced than carbon dioxide; therefore, the conversion is given in gigawatt hours (equivalent to millions of kilowatt hours) instead of kilowatt hours.
[22] More precisely, 6.81×10^{-8} metric tons
[23] More precisely, 9.98×10^{-9} metric tons

Figure 3: Emissions by sector of electricity usage



Scope 3

Scope 3 consists of emissions taking place outside city limits but produced as a result of the city's activities (excluding electricity generation). This includes emissions resulting from waste disposal and treatment, losses from transmission and distribution of energy, and city-related transportation occurring outside city limits (such as trips to and/or from the city).

Waste

Waste products, both residential and commercial, comprise another significant source of greenhouse gas emissions. Organic waste in landfills decomposes over time, releasing methane. Even though many landfills are not located within city boundaries, city residents and businesses are ultimately the source of the resulting emissions, and these emissions are thus included in Scope 3.

The GPC provides for two ways of calculating emissions caused by waste: first order of decay (FOD), which examines actual emissions over a given year from waste deposited over time (as waste decomposes slowly and releases methane for several years after it is deposited), and methane commitment, which estimates the amount of methane that will eventually be released from waste deposited during a given year. While FOD methods are more accurate regarding actual emissions in any given year, methane commitment gives a better understanding of the long-term impacts of residents' waste patterns within a given year. Because of these differences, methane commitment was selected as the preferred method for this inventory.

Data for waste produced in Bloomington was difficult to find. The municipal government, which tracks waste collected, provides sanitation services for single-family homes and residential complexes of up to four individual units. However, it does not provide collection to units larger than that nor to commercial establishments. Republic Services, a private company, services much of the remainder of Bloomington and

Monroe County, excluding private haulers that may have contracts with individual companies. Both Republic and the City of Bloomington's Sanitation Department transport their waste to Sycamore Ridge Landfill near Terre Haute, Indiana where the waste is weighed and recorded by county of origin. However, some Republic pickup routes in Bloomington (and that would thus be recorded as originating in Monroe County) also enter other counties, and the residents of surrounding counties can deposit waste in Bloomington collection centers. As such, there is no way of quantifying with complete accuracy the amount of waste generated in the city of Bloomington (or in Monroe County for that matter). There is a Monroe County Landfill, which reports its emissions to the EPA. However, the landfill is closed and has not accepted waste since 2004; the emissions reported reflect only waste that has accumulated and been decomposing from previous years. Therefore, these emissions are not included.

Image 3: Sycamore Ridge Landfill

Since waste data for Monroe County is not perfectly in line with county boundaries, some simplification is necessary, and some degree of error is inevitable. It is possible that some waste generated in Monroe County could also end up attributed to other counties, so calculations use the data for waste listed as originating in Monroe County, but for no other county. Data for waste by county of origin, classified by type of waste, can be obtained on the Indiana Department of Environmental Management's Office of Land Quality page[24].

A few other destinations besides Sycamore Ridge Landfill also receive waste from Monroe County, though in much smaller amounts. All landfills that received over 1,000 cumulative tons of waste in 2016 were included, yielding Sycamore Ridge, Medora Landfill in Medora, Indiana, and South Side Landfill in Indianapolis, covering over 99.8% of all the waste produced in Monroe County**.** A total of 140,675 tons of municipal solid waste, 4,390 tons of construction and demolition debris, and 20,753 tons of non-municipal "other" waste (such as solid residue from wastewater treatment or industrial waste) from Monroe County was deposited in these landfills in 2016[25].

Information for solid waste composition was estimated based on a study of Indiana landfills carried out by Purdue-Calumet University in 2012. This study examined landfills of different types (urban, suburban, rural, and mixed). The data given for urban/suburban landfills was used here, as Monroe County waste (the data available) comes from a combination of urban, suburban, and rural residences. The study breaks down waste by percentages for mixed urban/suburban landfills as follows (not all categories are listed here).[26][27]

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[24] http://www.in.gov/idem/landquality/2406.htm. 2016. Specifically see http://www.in.gov/idem/landquality/files/sw_quarterly_report_2016.txt

[25] The tons provided by the IDEM landfill reports are in short tons; these were converted into metric tons before calculating emissions.

[26] http://www.in.gov/idem/recycle/files/msw_characterizarion_study.pdf

[27] It is possible that Bloomington's waste patterns differ significantly from other cities in Indiana due to its high proportion of student residents. However, there is no data to address this.

Table 9: Landfill composition in urban/suburban landfills in Indiana

Type of material	Average percentage of total landfill
Paper	29.63
Plastic	15.95
Metal	5.41
Glass	3.37
Yard waste	8.04[28]
Food waste	10.91
Wood	6.27
Textiles/leather	4.99
Demolition/renovation/construction debris	3.80
Fines/supermix	1.44

Formulas to estimate emissions from landfills were provided by the GPC publication. The IPCC 2006 Guidelines (which form the basis for much of the GPC) state that CO_2 emissions from organic solid waste are typically not counted as they are part of natural processes and recorded under AFOLU. Methane, however, is not naturally released in such large amounts from decomposition of organic matter. To calculate methane emissions, one must first find the Degradable Organic Content (DOC) of the waste matter. This is calculated from the composition of the waste using the formula provided by the GPC.

$$\mathbf{DOC = (0.15 \times A) + (0.2 \times B) + (0.4 \times C) + (0.43 \times D) + (0.24 \times E) + (0.15 \times F)}$$

A = Fraction of solid waste that is food
B = Fraction of solid waste that is garden waste and other plant debris
C = Fraction of solid waste that is paper
D = Fraction of solid waste that is wood
E = Fraction of solid waste that is textiles
F = Fraction of solid waste that is industrial waste

(Equation 8.1 from GPC)

The DOC is then used to calculate the methane generation potential (L_0).

$$\mathbf{L_0 = MCF \times DOC \times DOC_F \times F \times 16/12}$$

MCF = methane correction factor based on landfill type (1.0 for managed landfills)
DOC_F = fraction of DOC that is ultimately degraded (assumed to equal 0.6)
F = fraction of methane in landfill gas (usually shown as 0.5)

(Equation 8.4 from GPC)

The methane generation potential then is used to calculate the total amount of methane generated, based on the mass of waste produced (measured here in metric tons).

$$\mathbf{CH_4\ emissions\ (in\ metric\ tons) = MSW_X \times L_0 \times (1\text{-}f_{rec}) \times (1\text{-}OX)}$$

[28] As per correspondence with the director of Bloomington's sanitation program, Bloomington's share of yard waste is lower than 7 percent because most is diverted via the yard waste collection and composting program; therefore, a share of 5 percent was assumed.

MSW_X = mass of solid waste sent to landfill in year examined (metric tons)
f_{rec} = fraction of methane recovered at the landfill (flared or energy recovered)
OX = oxidation factor (0.1 for well-managed landfills)

(Equation 8.3 from GPC)

The study by Purdue-Calumet only examined Municipal Solid Waste; therefore, the percentages were readjusted to account for the other types of waste (i.e. non-municipal solid waste, foundry waste, etc.) collected. These other categories of waste were included under industrial waste, which was calculated as the sum of all categories other than municipal solid waste plus the share of municipal solid waste that was construction-related debris and fines/supermix waste. This yields a breakdown outlined in Table 10.

Table 10: Landfill composition adjusted for other categories of waste

Type of material	**Readjusted percentage of share of total landfill**
Food	9.26
Garden	4.24
Paper	25.14
Wood	5.32
Textiles/leather	4.23
Industrial*	4.45

Inserting these percentages (as fractions) into Equation 8.1 yields the following DOC: 0.16. Using this DOC in Equation 8.1, Equation 8.4 yields the following methane generation potential: 0.065.

Using this methane generation potential, Equation 8.3 can be used to find the total mass of methane emissions. Both Sycamore Ridge and South Side landfills have a gas extraction system with an assumed 75% collection efficiency; Medora Landfill does not, as it is not required to because of its lower total emissions. Assuming that each landfill has the same waste composition (a potentially problematic assumption, but the best one given the limited data), inserting the volume of Monroe County waste deposited at each landfill into Equation 8.3 yields an aggregate estimate of 2,918 metric tons of methane released for Monroe County. Assuming that county residents produce the same amount of waste per capita regardless of where they live, this amount can be scaled by the share of Monroe County's population living within Bloomington limits. In 2016, Bloomington's population was estimated at 84,067, or 58% of Monroe County's population of 145,496[29]. Scaled down to reflect Bloomington's proportion of the population, we estimate that Bloomington produces about 1,686 metric tons of methane from its waste; expressed in CO_2-equivalents, this yields 47,214 metric tons.

Wastewater treatment is also a source of emissions. However, Bloomington itself has no heavy industry that would add significantly to wastewater emissions, and emissions resulting from sewage treatment only contribute a fraction of a percent to total emissions in many other cities; therefore, it was deemed unnecessary to investigate these further, especially given the limited range of actions cities can take with regard to sewage.

Natural gas distribution and transmission losses

Emissions resulting from losses and leaks in natural gas transmission and distribution can be a less obvious but significant source of emissions. To best estimate the amount of leakage associated with Bloomington's

[29] https://www.census.gov/quickfacts/fact/table/monroecountyindiana,bloomingtoncityindiana#viewtop

gas usage, we divided the amount of leakage estimated at a nation-wide level by the amount of total natural gas consumption nationwide, then applied this ratio to Bloomington's total consumption. The 2015 national EPA Greenhouse Gas Inventory provides these estimates for both methane (already in CO_2-equivalent) and carbon dioxide leaked (given that natural gas consists primarily of methane but also other gases, including carbon dioxide).[30]

Table 11: Emissions from natural gas leakage

Gas	Methane	Carbon dioxide
Leakage nationwide in 2014 in CO_2-equivalent	176.1 million metric tons	42.4 million metric tons
Ratio to total amount of natural gas consumed	.00065 metric tons per therm	.00016 metric tons per therm
Ratio multiplied by Bloomington consumption	30,064 metric tons in CO_2-equivalent	7,238 metric tons in CO_2-equivalent

This yields a total of 37,302 metric tons of CO_2-equivalent released into the atmosphere by natural leakage.

Studies by various bodies, including the National Academy of Engineering[31] and the Environmental Defense Fund[32], estimate that the EPA underestimates leakage by a factor of 1.5 if not more. We decided to average the estimate provided by the EPA's methodology and that by other studies, therefore multiplying the leakage emissions by 1.25. This yields an estimate of 46,627 metric tons of CO_2-equivalent.

Out-of-boundary transportation

Scope 3 also includes city-related transportation occurring outside of city limits. Such transportation would include road travel by city residents to other locations, air travel by city residents leaving or coming to the city, transportation of goods to or from the city, and other types of related travel, such as freight. Although this aspect of the transportation sector would be a significant source of emissions, due to the complex calculations and highly imprecise estimates that would be involved, out-of-boundary transportation is not included in this inventory.

Total greenhouse gas emissions in 2016

In 2016, a total 1,375,237 metric tons of CO_2-equivalent were emitted in Bloomington. These were divided by scope and source type as follows:

Table 12: Greenhouse gas emissions by scope

Emissions by scope (metric tons of carbon dioxide equivalent)	
Scope 1	385,100
Scope 2	849,669
Scope 3	93,841

[30] https://www.epa.gov/sites/production/files/2016-04/documents/us-ghg-inventory-2016-main-text.pdf
[31] https://www.nae.edu/Publications/Bridge/140630/140642.aspx
[32] http://www.edf.org/sites/default/files/methane_studies_fact_sheet.pdf

Figure 4: Greenhouse gas emissions by scope

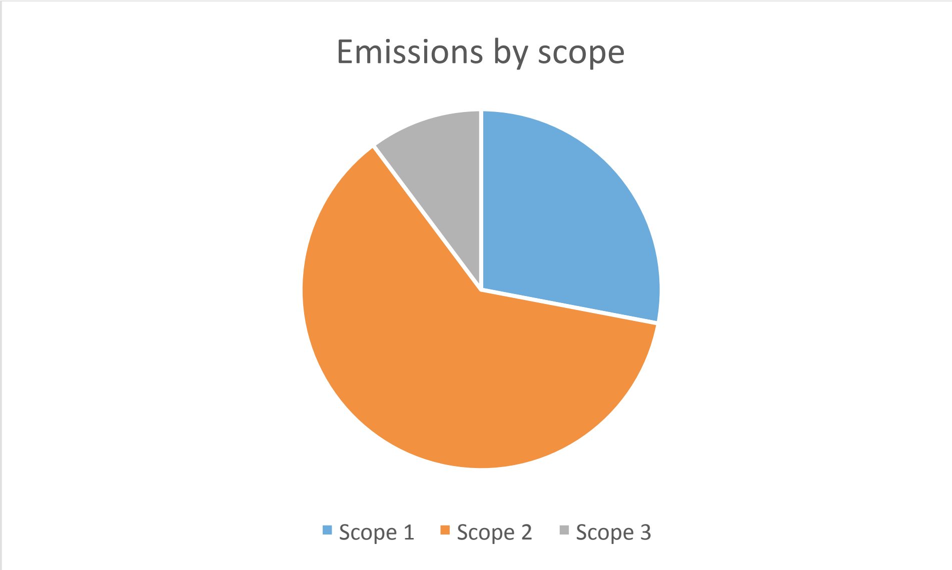
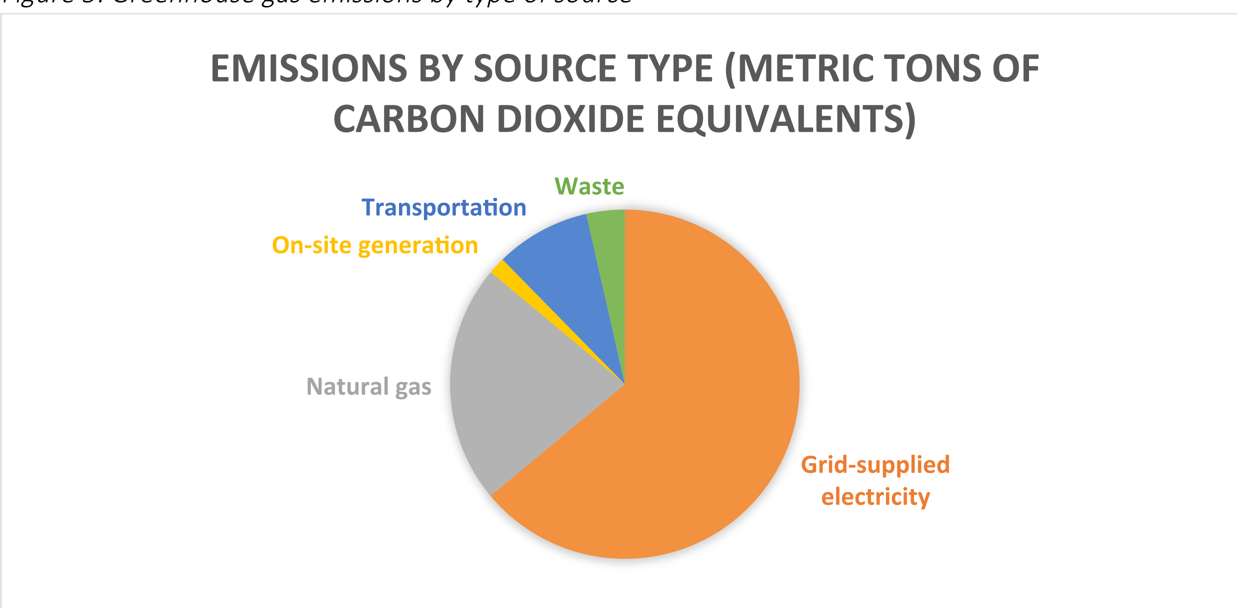


Table 13: Greenhouse gas emissions by type of source

Emissions by source type (in metric tons of carbon dioxide equivalent)	
Grid-supplied electricity*	849,669
Natural gas (combustion + leakage)*	340,663
On-site generation*	20,900
Transportation	116,790
Waste	47,214

*Emissions from grid-supplied electricity, natural gas usage and leakage, and other on-site energy generation all count toward the stationary combustion sector but fall under different scopes.

Figure 5: Greenhouse gas emissions by type of source



Discussion

One of the most important purposes greenhouse gas inventories can serve is comparison across different years to track improvements and trends. A partial greenhouse gas inventory was released by the city's Environmental Commission in 2009 using data from 2006, and a more recent one was released in 2014 as part of the city's Environmental Action Plan. This updated 2016 report seeks to build off the previous reports and understand trends taking place and areas for improvement.

One issue complicating comparison between the two inventories is inconsistencies in data collection and different methodologies. When the 2006 inventory was developed, the Environmental Commission had access to software provided by ICLEI, which greatly facilitated calculations, but also made the source and use of emissions factors less transparent; in contrast, when the current inventory was written, the municipal government had no access to the same software (as the license was not renewed), and thus had to use methodologies and emissions factors provided by the GPC, EPA, and adopted from other cities' inventories. Assuming that the ICLEI software itself and the researchers developing the 2016 inventory largely relied on the same sources (EPA, national averages, IPCC, etc.), it is unlikely that this difference would result in large discrepancies, but it is important to make note of nonetheless.

Second, the 2006 inventory does not have complete data for all sectors, causing significant underestimation. In other sectors, the numbers provided by the 2006 report differ significantly from the numbers for 2006 consumption in the data used to compile the current inventory (that is, the data we were able for 2006 during the present inventory effort didn't match the numbers included in the 2006 inventory). These issues are addressed and corrected when they appear in this discussion.

Energy

The 2006 report does not divide energy-related emissions by type (grid-supplied vs. stationary energy), dividing them instead by sector. Because of that, it is easier to aggregate energy-related emissions for both years and compare them. The aggregate from the 2006 report for emissions from energy usage across all sectors is 588,853 metric tons of CO_2-equivalent; in comparison, the current report found 1,164,605 metric tons of CO_2-equivalent. However, the 2006 inventory only considered certain sectors and therefore significantly underestimated total Bloomington emissions.

According to the spreadsheets used for the current report provided by Vectren and Duke, total energy usage in 2008 consisted of 41,973,045 therms of natural gas and 1,517,734,078 kilowatt-hours of electricity in 2008 (2008 was used for both types of energy because the Duke Energy spreadsheet only goes back to 2008). Converting all to kilowatt-hours as done in the 2006 report (using the conversion factor of 1 therm = 29.3001 kilowatt-hours), this yields 2,747,548,487 kilowatt-hours of energy in 2008. In 2016, the same spreadsheets show 46,591,522 therms of natural gas and 1,346,720,346 kilowatt-hours of electricity consumed, or a total 2,711,856,600 kilowatt-hours of energy consumed. This is actually a 1.3% decrease in total energy usage from 2008 to 2016. It is highly unlikely that energy use doubled between 2006 and 2008 and then decreased by 1.3%; what is more likely is that the 2006 inventory excluded certain users and types of use in Bloomington. The 2006 inventory lists energy usage from three different sectors: residential, commercial, and industrial. However, the information provided by Duke Energy and Vectren divides Bloomington energy use into five to six sectors: residential, commercial, industrial, government, and unknown (i.e. unknown or unspecified users, which use an extremely small share of Bloomington's electricity, well under two percent) for Duke, and residential, commercial, industrial, transportation (bulk sales), and company use for Vectren.

To verify that the 2006 inventory does exclude certain sectors (and does not just subsume them under others), we compared the usage numbers for the sectors listed in the 2006 report to the numbers for those sectors in the spreadsheets used. Since only the Vectren spreadsheet goes back to 2006, and since the 2006 inventory divides energy use by source fuel (i.e. coal or natural gas) and not provider (i.e. Duke or Vectren), it is impossible to just check whether the natural gas numbers match (as natural gas is not solely provided by Vectren but also contributes to electricity generation through Duke). Therefore, 2008 energy usage in these three sectors was combined to compare with the sectors listed in the 2006 inventory (while Vectren did provide data back to 2006, Duke provided back to 2008, and for the sake of consistency 2008 was used for both sectors). Bloomington's energy usage across the commercial, residential, and industrial sectors in 2008 totaled 2,040,299,376 kilowatt-hours; the sum of energy use across the sectors given in the 2006 inventory equals 1,875,338,987 kilowatt-hours. This is only an 8% difference, suggesting that the 2006 inventory only took these three sectors into account and did not include other ones in its calculations. As such, total energy usage (across all sectors provided by both Vectren and Duke) in 2008, 2,747,548,487 kilowatt-hours, is likely much more reflective of total energy usage in 2006 than the numbers provided in the 2006 inventory itself. Consequently, total energy-related emissions for 2008 are a much better baseline for comparison. These can be calculated using emissions factors for natural gas and regional electricity production (the latter obtained from the eGRID spreadsheet). As the make-up of sources used to generate electricity changes over time (with coal, for instance, being slowly replaced by natural gas), eGRID provides updated data every few years. The most accurate emissions factors for 2008 can be found on eGRID's publication for the year 2007. Using the emissions factors provided in this edition (plus emissions factors for natural gas usage), we get a total 1,296,798 metric tons of CO_2-equivalents emitted in 2008 from energy usage. Comparing these two years, we see a 10% ***REDUCTION*** in energy-related emissions. This reduction, however, is likely higher if the change in coal consumption by Indiana University is taken into account; Indiana University has increasingly used natural gas in place of coal to power its Central Heating Plant. However, since the 2016 data includes both the coal (which decreased) and natural gas (which increased) used by IU, while the 2008 data only includes the natural gas used, the data shows an increase in natural gas-related emissions without showing the corresponding decrease in coal-related ones (coal usage data for IU is not available before 2009). As such, the reduction of energy-related emissions is almost certainly higher than 10%.

Transportation

Another sector with significant discrepancies between the two years is transportation. Both the 2006 and 2016 inventories use VMT estimates provided by the Indiana Department of Transportation. However, the numbers reported for Bloomington VMT in the 2006 report do not align with those for 2006 in the spreadsheet used for the current inventory. The way VMT is measured in Indiana was updated in 2009[33], making it difficult to compare current data with data available in years before 2009. The spreadsheet used to create this report goes back to 2006, so the current spreadsheet can be used in lieu of the data from the 2006 report to understand any change.

The VMT spreadsheet used for the current report lists total daily VMT by county, dividing VMT into state roads and city and/or county roads. In 2011, the INDOT started dividing city and county roads, and since 2012 also provides the total commercial vehicle miles traveled as a subset of total vehicle miles traveled. The INDOT-provided 2016 VMT on city roads in Monroe County; Bloomington VMT for that year could then be used to approximate that for previous years by dividing Bloomington VMT by total city road VMT or Monroe County VMT. Doing so, we found daily Bloomington VMT in 2006 to be 746,064, or 240,978,672 in annual VMT (if daily VMT is multiplied by 323, as done earlier in this report). 2016 daily VMT in Bloomington was

[33] As per correspondence with Gregory Katter of the INDOT.

764,923, giving an annual VMT of 247,070,129. This is less than a three-percent change; furthermore, daily VMT oscillates somewhat by year, and there does not seem either an upward or downward trend. Save for small improvements in fuel efficiency, this does not seem to be a sector where emissions have (or should be expected to have) changed much.

According to statistics published by the Bureau of Transportation Statistics[34] and the Energy Information Administration[35], average fuel economy of vehicles in 2006 was 20.4 miles per gallon for light-duty vehicles and 5.9 mpg for heavy-duty trucks. Assuming that vehicle fleet composition (i.e. proportion of light-duty and heavy-duty vehicles) in Bloomington has remained constant over the past decade, using the same method as when estimating 2016 emissions[36], we estimate a total of 123,977 metric tons of CO_2-equivalents from transportation in 2006, compared to 116,791 metric tons in 2016. This is about a 6% decrease.

Solid waste

Emissions resulting from solid waste management are remarkably similar between the two reports, showing less than a seven percent increase. This is surprising because the 2016 report takes into account the emissions reductions resulting from the implementation of the methane-capturing system at Sycamore Ridge Landfill. Monroe County generated a total of 146,126 short tons (U.S. tons) of solid waste in 2006 (as per the 2006 inventory), and a total of 140,675 tons in 2016. However, given that a methane-capturing system was installed starting in 2008 and is currently active, methane emissions (and thus overall greenhouse gas emissions) should be much lower. It is likely that the calculations carried out by the ICLEI software for the 2006 inventory resulted in an underestimation of carbon emissions for that year (furthermore, as the equations used in the 2006 report are not provided explicitly, it is impossible to find the exact source of the discrepancy). The similarity between the two numbers should not be read as reflective of the actual change in emissions, as it is almost certain that greenhouse gas emissions from Bloomington's solid waste disposal have decreased significantly. While the 2016 inventory does not take into account the carbon dioxide resulting from flaring landfill gas, the resulting emissions should nonetheless be much lower than before flaring, given the differences in global warming potential between carbon dioxide and methane. Furthermore, while the 2016 inventory does not account for the transportation of waste to landfills nor for emission of any greenhouse gas other than methane resulting from landfill gas leakage, neither does the 2006 inventory.

In this situation, a much better way of calculating reductions in waste-related emissions is by estimating the expected reduction due to the collection system. We can calculate a rough estimate of the expected reductions in waste-related emissions making the following assumptions**:

- A 75% collection efficiency of the installed landfill gas collection system
- Waste stream composition has not changed much since 2006
- A 1-to-1 methane-carbon dioxide conversion ratio on the molecular level (as per the methane combustion equation $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$)
- Complete combustion of methane flared

**These assumptions, particularly the latter two, are admittedly very oversimplified; there are likely many more chemical reactions involved, and complete combustion is a highly unlikely assumption. However, given the information and resources

[34] https://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/publications/national_transportation_statistics/html/table_04_23.html

[35] https://www.eia.gov/totalenergy/data/annual/showtext.php?t=ptb0208

[36] The share of diesel and gasoline vehicles was the same in 2006 as in 2013, the most recent year for which data is available.

available, it was decided that this calculation would still yield a much better estimate of emissions reductions than comparison of the two reports.

Emission reduction estimation methodology:

2006: 100% (amount of landfill gas emitted as methane)* 16.04 grams (mass of one mole of methane) * 28 (global warming potential of methane) = 449.12 grams of CO_2-equivalent from one mole of methane produced in the landfill

2016: [25% (amount of landfill gas emitted as methane) * 16.04 grams (mass of one mole of methane) * 28 (global warming potential of methane) + 75% * 44.01 grams (mass of one mole of carbon dioxide) * 1 (global warming potential of carbon dioxide)] * .90 (percentage of waste going to Sycamore Ridge and South Side Landfill, both of which have methane capture systems) + 100% (amount of landfill gas emitted as methane)* 16.04 grams (mass of one mole of methane) * 28 (global warming potential of methane) * .10 (percentage of waste going to Medora Landfill, which does not have a methane capture system) = 175.67 grams of CO_2-equivalent from one mole of methane produced in the landfill, after the installation of the methane collection system

Percent change from 2006 to 2016: (175.67 – 449.12) / 449.12 = -0.61; a 61% decrease

Using this estimated decrease, we can retroactively calculate waste-related emissions from 2006:

47,214 metric tons of CO_2-equivalent (*2016 emissions*) / (1-.61) (*amount of the decrease*) = 120,708 metric tons of CO_2-equivalent emitted from solid waste disposal in 2006

Natural gas leakage

Although, in comparison to other areas, leakage from natural gas systems is an area over which Bloomington has much less control, comparison across years is still useful for the purposes of viewing total emission reductions. The 2016 EPA National Greenhouse Gas Inventory, documenting emissions from 1990 to 2014, does not explicitly address leakage in 2006, but it does for 2005; 2005 emissions were chosen here to approximate 2006 emissions. The most updated version of the inventory estimates emissions from natural gas systems leakage in 2005 at 177.3 million metric tons of CO_2-e of methane and 30.1 million metric tons of CO_2. Divided by total U.S. consumption in 2005, 22,014,434 million cubic feet, this yields a ratio of .00078 metric tons of CO_2-e of methane per therm of natural gas consumed and .00013 metric tons of CO_2 per therm of natural gas. Multiplied by Bloomington usage, this yields a total of 32,825.45 metric tons of CO_2-equivalent. Multiplied by the 1.25 factor to account for possible EPA underestimation, we get an estimate of 41,032 metric tons of CO_2-equivalents emitted from transmission and distribution losses from natural gas systems in 2005. This shows a 14% increase in indirect emissions from natural gas usage between 2005 and 2016.

Overall change in emissions

Bloomington's total estimated emissions in 2006 are 1,582,515 metric tons of CO_2-equivalent; in 2016 emissions were estimated at 1,375,237 metric tons. This shows a 13% decrease in greenhouse gas emissions from 2006 to 2016, with emissions falling in all areas except in transmission and distribution of natural gas, where there was a small increase. The reasons for this fall in emissions are numerous and discussed below.

Table 14: Bloomington emissions in 2006 and 2016

Year	2006	2016
Energy	1,296,798	1,164,605
Transportation	123,977	116,791
Solid waste	120,708	47,214
Natural gas leakage	41,032	46,627
Total	1,582,515	1,375,237

Figure 6: Bloomington emissions in 2006 and 2016

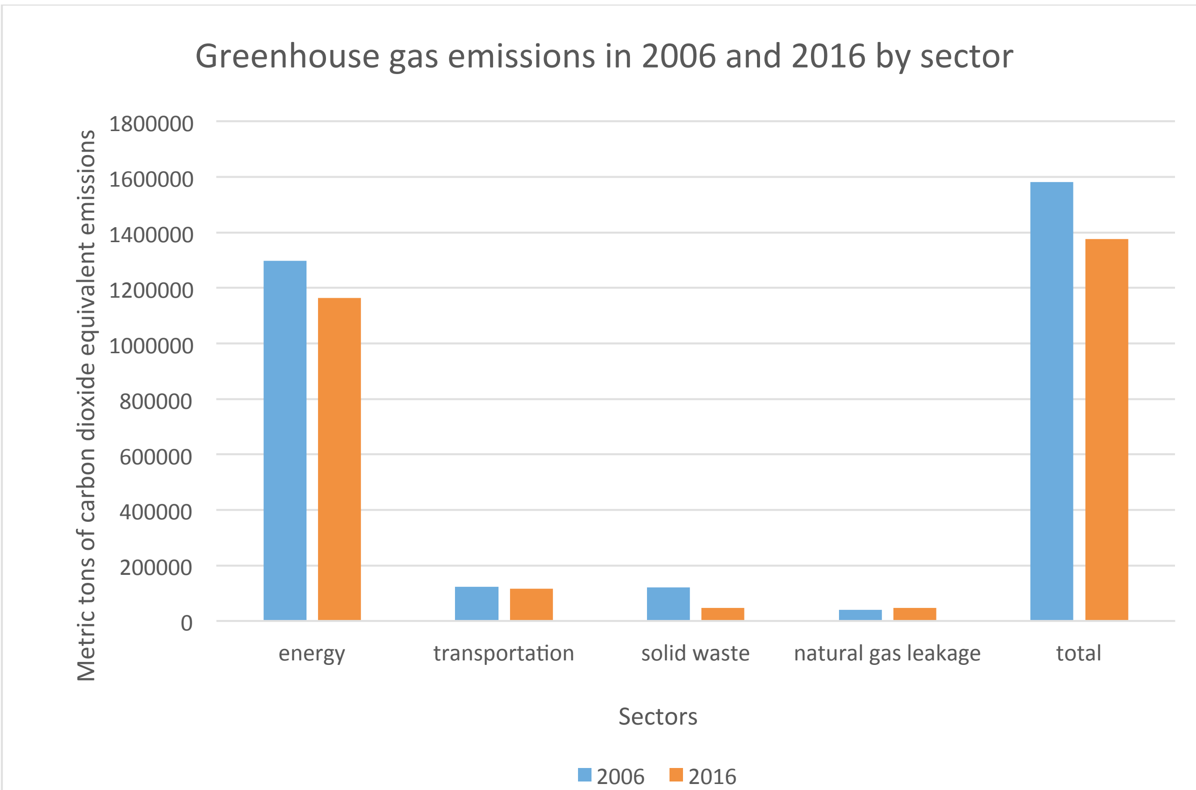
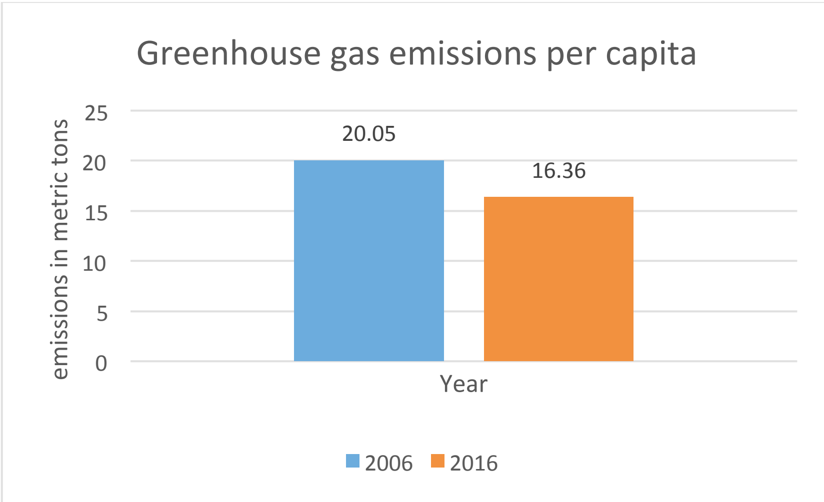


Table 15: Yearly greenhouse gas emissions per capita (in metric tons CO_2-equivalent) **

Year	2006	2016
Emissions (metric tons)	20.05	16.36

**See section below titled "Efficiency Improvements" for explanation of how population was calculated

Figure 7: Greenhouse gas emissions per capita



Change in energy mix

The decrease in Bloomington's energy-related emissions follows the national trend. According to EIA reports, U.S. carbon dioxide emissions related to energy dropped 12% between 2005 and 2015.[37] This largely has to do with the decreased use of coal and increased use of natural gas, a much less carbon-intensive fuel, in electric generation. This change is reflected in the difference in emissions factors provided in the eGRID's 2007 and 2014 editions: eGRID's edition for 2007 emissions gives an emissions factor of 1,559.94 pounds of CO_2-equivalent per megawatt-hour consumed of electricity in the RFC West Region (where Indiana is located), while that for 2014 gives an emissions factor of 1390.9 pounds of CO_2-equivalent per megawatt-hour of electricity, showing an 11% drop in overall emissions per unit of electricity consumed (interestingly, methane emissions per unit of electricity consumed experienced a significant rise between these two years, likely a result of the increased use of natural gas for electricity production). In Bloomington specifically, as stated above, Indiana University has increasingly used natural gas instead of coal for its Central Heating Plant due to its currently lower price, contributing to a drop in emissions.

Efficiency improvements

Another factor contributing to decreases in emissions both in Bloomington and nationwide lies in energy efficiency improvements. Between 2008 and 2016, Bloomington's population increased by about six percent[38]; however, consumption of purchased electricity during the same time decreased by 11%. As such, there has been a decrease in energy consumption per capita in Bloomington**.** The clearest decrease in energy use has been the municipal government, which has pursued energy-saving policies of various types, including installation of LED lights, motion sensors, and HVAC upgrades in its buildings. Overall, municipal electricity use has decreased by 19% between 2008 and 2016. The residential sector has also seen some decreases in electricity consumption, with consumption nearly 10% lower in 2016 than in 2008, though there is less consistent of a trend. In particular, the Monroe County Energy Challenge, initially started as part of a national competition, has actively worked to promote energy efficiency in Bloomington, spreading awareness of its importance and conducting free energy assessments and home weatherization visits, among other things.

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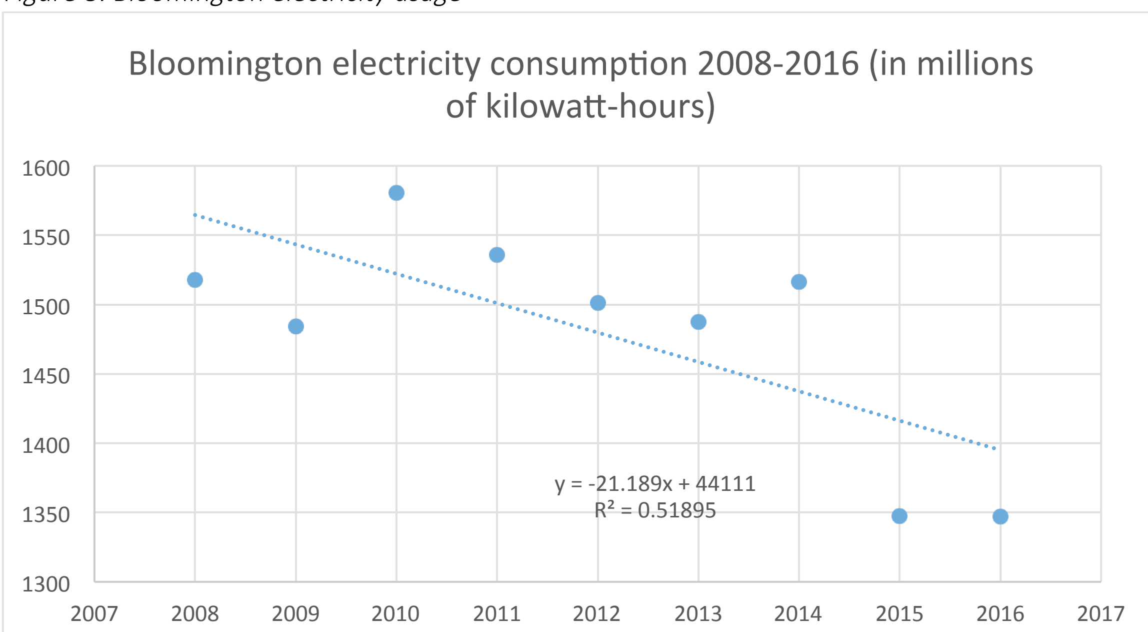
[37] https://www.eia.gov/todayinenergy/detail.php?id=26152#

[38] Bloomington's population change was estimated by multiplying Monroe County's 2006 population (available in the U.S. Census Bureau's intercensal tables) by the percentage of Monroe County's residents living in Bloomington in 2006 (provided in the 2006 inventory), then comparing that to the 2016 population.

To some extent, these improvements reflect nationwide improvements in energy efficiency in various areas. While improvements in some areas, such as adoption of certain industrial technologies, have been extremely small, other areas have seen significant improvements. Both the municipal and residential sectors have seen decreases in energy use (with the municipal sector in particular seeing big improvements). Together with changes in how electricity is produced, these efficiency gains have contributed to a 14% decrease in greenhouse gas emissions per dollar of GDP between 2006 and 2014 and a similar decrease in emissions per capita during the same period[39].

Image 5: The Energy Bus, a joint initiative of the Monroe County Energy Challenge and South-Central Community Action Program

Figure 8: Bloomington electricity usage



**Note that the y-axis does not extend to zero, so the downward trend may seem greater than it actually is.

This downward trend is statistically significant, with a *t*-value of 2.75 (surpassing the critical value 2.365).

Fuel efficiency improvements

While improvements in average fuel efficiency did have an effect on Bloomington's transportation-related emissions, this improvement was much smaller than that seen in other sectors: a mere six percent. While fuel efficiency standards have steadily increased for new car models (surpassing 50 mpg in the 2025 model year),

[39] https://www.epa.gov/climate-indicators/climate-change-indicators-us-greenhouse-gas-emissions

these result in a slower decrease in emissions due to (as is to be expected) slower automobile replacement rates.

Methane capture

The sector that experienced the largest decrease in emissions was the solid waste sector, with a 68% decrease simply due to the installation of a landfill gas extraction system at Sycamore Ridge Landfill. While not Bloomington's largest emitting sector, this sector does demonstrate that some simple (or at least straightforward, albeit expensive) steps can have significant impacts in decreasing emissions.

Comparison to targets

While in itself an encouraging finding, Bloomington's reduction in emissions should be compared to broader emissions targets and goals to judge its performance. The 2006 report set emissions goals for the year 2012, in line with the U.S. Mayors' Climate Protection Agreement, based on retroactively calculated 1990 emissions. Due to the questionable validity of the 1990 estimates, performance in terms of this goal (a 7% reduction in emissions by 2012 using 1990 as a baseline) is not assessed here; instead, national targets for more recent years are used.

In 2011, the U.S. set a preliminary goal (in conformity with anticipated legislation) of reducing economy-wide emissions by 17% from 2005 levels by 2020[40]. In preparation for the Paris Agreement, it set an intended nationally determined contribution (INDC) of reducing emissions by 26-28% by 2025, again using 2005 as a baseline[41]. Both these proposals designed to align with the widely agreed-upon goal of reducing greenhouse gas emissions by 80% from 2000 levels by 2050. This long-term goal, according to widespread scientific consensus used to inform the Paris talks, would result in a 50% chance of preventing average global temperatures from rising more than 2°C (3.6°F) and a 67% change of preventing a rise of more than 3°C[42].

Bloomington has taken steps to meet these goals, but could make a much more significant commitment. While there are moderate yearly fluctuations in emissions due to differences in weather from year to year**,** there has been a general downward trend, largely as a result of efficiency improvements and decreased reliance on coal, as discussed above – both areas where the community has only limited impact. So although these findings are encouraging, they should not be received with complacency.

Globally, emission reduction goals have failed numerous times in the past (making subsequent goals increasingly urgent). Furthermore, even the 80% reduction goal for 2050 leaves a significant risk (50%) of temperatures increasing by more than 2°C, widely considered a threshold, the surpassing of which can lead to far-reaching and catastrophic changes in weather patterns and sea-level rise, among other things. Even less than a 2°C change is considered dangerous in many estimations; the 1°C increase that we have experienced since pre-industrial levels has already resulted in significant consequences for many ecosystems and millions of people around the world. It is worthwhile to mention that, while emissions per capita in the U.S. (and specifically in Bloomington) have been decreasing, they are still much higher than those in many other industrialized countries. U.S. per capita emissions in 2013 were approximately 16.4 metric tons of carbon dioxide per year (slightly higher than the Bloomington level), in comparison to 9.2 in Germany and 7.1 in the U.K. Furthermore, it is important to note that much of the emissions reduction achieved in Bloomington is due to the replacement of coal with natural gas in response to market prices. If prices revert (an admittedly unlikely scenario), this progress could stagnate or be reversed.

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[40] http://unfccc.int/resource/docs/2011/sb/eng/inf01r01.pdf
[41] http://www.wri.org/blog/2015/04/us-climate-commitment-should-spur-other-countries-act
[42] http://www.ucsusa.org/sites/default/files/legacy/assets/documents/global_warming/emissions-target-fact-sheet.pdf

When discussing emissions reductions, it is important to acknowledge emissions unaccounted for in official inventories but over which city residents still have influence. Many (if not most) goods and services consumed in the Bloomington area originate elsewhere, and as a result many of the emissions associated with their production and provision are not accounted for in this inventory, although Bloomington residents do benefit from their consumption. As stated in the inventory's introduction, compiling a consumption-based emissions inventory was outside of the purview and scope of this project (which does not, of course, exclude the possibility of such a project being done in the future). However, if carried out, it would likely show a much higher total for greenhouse gas emissions, as it would expose the high degree of emissions associated with many geographically separated production chains. Nonetheless, residents can still take individual and collective steps to reduce this type of consumption-related emission, including (but not limited to) reducing meat consumption, reducing food waste, and limiting purchases of goods known to be associated with high levels of deforestation (such as products containing palm oil).

While the purpose of this inventory is not to prescribe a plan of action, the trends it presents can be used as the foundation for a broader community planning effort to direct local action and contribute to global efforts long into the future.