UrbanFootprint Technical Documentation
Emissions Analysis

Overview

The UrbanFootprint Emissions module estimates greenhouse gas (GHG) emissions associated with passenger vehicle transportation and building energy and water use. Comparative results for greenhouse gas emissions demonstrate differences between scenarios. The differences are due to scenario travel characteristics and building programs, which impact vehicle miles traveled (VMT), energy use, and water use results. GHG emissions are also subject to technical assumptions for vehicle and building performance, as well as emissions rates of energy sources for transportation and building energy. This section focuses on the emissions calculations. The VMT, building energy, and water use calculations with which GHG emissions are estimated are described in the Transportation, Energy Use, and Water Use modules' documentation.

Along with transportation GHG emissions, the module estimates criteria pollutant emissions from passenger vehicle transportation, including nitrogen oxides (NO_x), particulate matter (PM2.5 and PM10), sulfur oxides (SO_x), carbon monoxide (CO), and volatile organic chemicals (VOC). These emissions are calculated at the project scale on the basis of per-mile factors.

Emissions into the future are subject to assumptions reflecting fuel economy improvements; GHG emissions rates for transportation fuel, electricity, and natural gas; and criteria pollutant emission rates.

Analysis is run at the scale of the project canvas (generally parcels or census blocks), yielding a mapped spatial output layer and corresponding data table; both can be used within UrbanFootprint for mapping and data exploration, and exported. The module also reports individual and comparative scenario results via summary charts, and generates a spreadsheet summary in Excel format.

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Methodology

The module estimates emissions on the basis of the VMT, energy use, and water use outputs generated by the Transportation, Energy Use, and Water Use modules. Please refer to the documentation for these modules for details about how these outputs are calculated.

Estimated emissions are also determined by input assumptions about vehicle performance, transportation fuel emissions, and electricity and natural gas emissions. The following sections describe the calculations and assumptions.

Transportation GHG and Criteria Pollutant Emissions Calculations

The Transportation module estimates annual VMT, annual VMT per household, and annual VMT per capita. Transportation GHG emissions are calculated on the basis of fleet-wide average vehicle fuel economy and an average fuel emission rate. These assumptions can be set separately for the base and individual future-year scenarios.
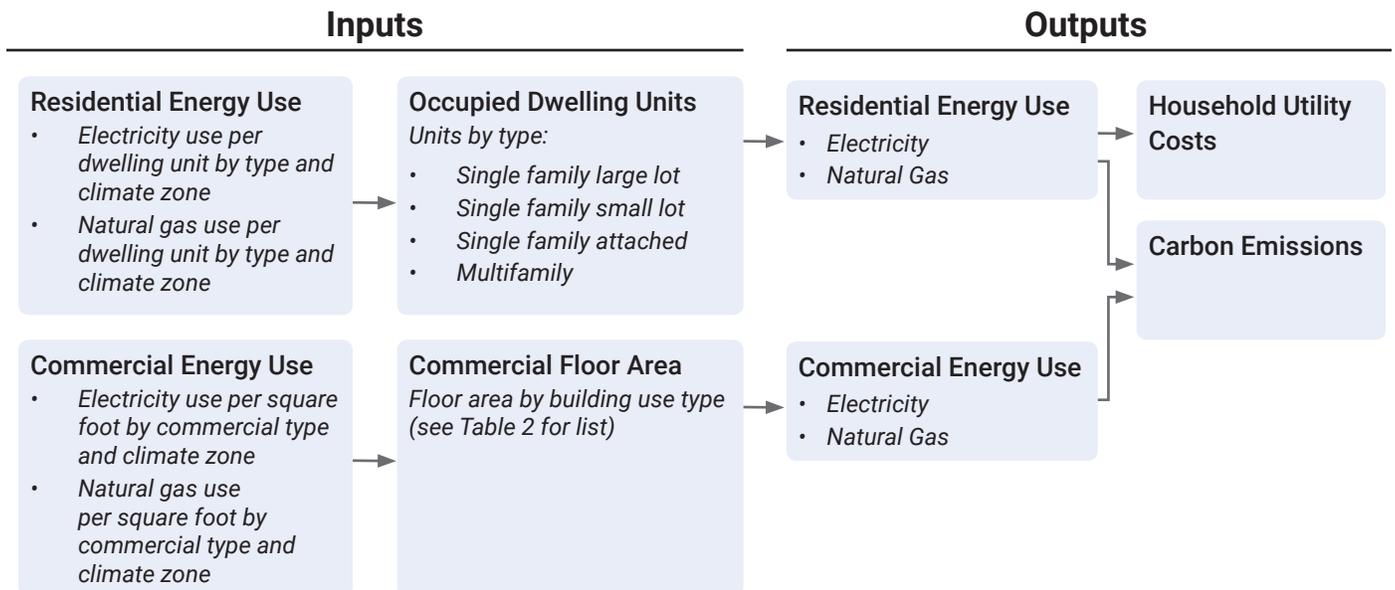
Fuel economy (in miles per gallon) is applied to VMT to calculate fuel consumption. The fuel emission rate (in pounds of carbon dioxide equivalent [CO_2e] per gallon) is applied to fuel consumption for the GHG emissions calculation. The following equation summarizes the calculation:

$$GHG_{transportation} = \frac{VMT\ (miles)}{FuelEconomy\ (miles\ /\ gallon)} * FuelEmissionRate\ (lbs\ /\ gallon)$$

To estimate air pollutant emissions, the module applies emission factors (in grams per mile) for each pollutant to VMT. For example, the equation for estimating annual SO_x emissions is as follows:

$$SOx = VMT\ (miles) * SOxEmissionRate\ (grams\ /\ mile)$$

Figure 1. Emissions Analysis Flow

Inputs		Outputs	
Residential Energy Use • *Electricity use per dwelling unit by type and climate zone* • *Natural gas use per dwelling unit by type and climate zone*	**Occupied Dwelling Units** *Units by type:* • *Single family large lot* • *Single family small lot* • *Single family attached* • *Multifamily*	**Residential Energy Use** • *Electricity* • *Natural Gas*	**Household Utility Costs**
Commercial Energy Use • *Electricity use per square foot by commercial type and climate zone* • *Natural gas use per square foot by commercial type and climate zone*	**Commercial Floor Area** *Floor area by building use type (see Table 2 for list)*	**Commercial Energy Use** • *Electricity* • *Natural Gas*	**Carbon Emissions**

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Building Energy GHG Emissions Calculations

The Energy Use module estimates electricity and natural gas use for residential and commercial buildings. Building energy GHG emissions from electricity and natural gas use are calculated, in turn, on the basis of emissions rate assumptions that can be set separately for the base and individual future-year scenarios. The equation for calculating GHG emissions generated by residential and commercial buildings' electricity use is as follows:

$$GHG_{electricity-use} = Electricity\ (kwh)\ *\ ElectricityEmissionRate\ (lbs\ /\ kwh)$$

Water-Related GHG Emissions Calculations

The Water Use module estimates residential and commercial indoor and outdoor water use. GHG emissions associated with the treatment and distribution of estimated water use are calculated using assumed indoor and outdoor water-energy use rates (expressed in electricity use per volume of water) and a GHG emissions rate for electricity. Assumptions can be set separately for the base and individual future-year scenarios. The equation for calculating GHG emissions associated with water-energy use is as follows:

$$GHG_{water-use} = IndoorWaterUse\ (gallons)\ *\ IndoorWaterEfficiencyFactor\ (kwh\ /\ gallon)$$
$$*\ ElectricityEmissionRate\ (lbs\ /\ kwh)$$

Input Parameters

UrbanFootprint comes loaded with a set of default electricity and natural gas use rates, which are derived from the EIA Residential Energy Consumption Survey (RECS)[1] and Commercial Building Energy Consumption Survey (CBECS) datasets[2]. This section describes the development of the EIA-based assumptions.

The default inputs can be replaced with localized baseline inputs, if available, via the Analysis Assumptions editor. Different energy use inputs can be set for each scenario, and can be used to test the impact of energy efficiency measures into the future. By changing the inputs for future-year scenarios, you can test the impact of more efficient buildings in the context of new growth. You can also create scenarios that replicate the base canvas and change the energy use inputs to test the impacts of efficiency measures for existing buildings.

Transportation Emissions Input Parameters

The Emissions module currently applies an on-road average fuel economy for all cars, and an average emissions rate for gasoline. While the inputs do not directly account for alternative vehicle and fuel types, users could test the impacts of technological advancements by developing composite assumptions in some manner outside of UrbanFootprint, or exporting VMT results from UrbanFootprint as a basis for an extended analysis of VMT, transportation energy use, and emissions with respect to a projected distribution across multiple vehicle types.

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1 https://www.eia.gov/consumption/residential/index.php
2 https://www.eia.gov/consumption/commercial/

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Table 1 summarizes the input parameters used to calculate transportation GHG emissions, and the default baseline values used by UrbanFootprint. National average on-road passenger vehicle fuel economy and GHG emissions are based on U.S. Environmental Protection Agency (EPA) data. National average criteria pollutant emissions rates are from the EPA Motor Vehicle Emission Simulator (MOVES) model. If available, users can input localized baselines and projected future-year values for more accurate and/or policy-oriented analysis.

Table 1: UrbanFootprint Default National Auto Fuel Economy and Emissions Rate Assumptions

Parameters	Default Baseline Values
Average on-road passenger vehicle fuel economy	22 miles/gallon of gasoline
Fuel emissions rate	19.61 lbs CO_2e/gallon of gasoline
NO_x emissions per mile	0.9018 grams/mile
PM10 emissions per mile	0.0203 grams/mile
PM2.5 emissions per mile	0.018 grams/mile
SO_x emissions per mile	0.0087 grams/mile
CO emissions per mile	7.2933 grams/mile
Volatile Organic Compound (VOC) emissions per mile	0.686 grams/mile

Building Energy Emissions Input Parameters

Emissions rates into the future can be based on policy targets or energy portfolio scenarios, and may be defined based on local, regional, or broader scales.

Default electricity GHG emission rates in UrbanFootprint are based on data from the EPA Emissions & Generation Resource Integrated Database 2016 (eGRID)[3]. The dataset contains the environmental characteristics of almost all electric power generated in the United States, including emissions rates, net generation, resource mix, and air emission of nitrogen oxides, sulfur dioxide, carbon dioxide, methane, and nitrous oxide. Specifically, the Emissions module uses annual CO_2-equivalent (CO_2e) total output emission rate averaged by state (measured in lbs. per megawatt-hour).

The GHG emissions rate for natural gas is a constant as indicated by the EPA[4]. Table 2 summarizes the input parameters used to calculate building energy GHG emissions and the default baseline values used by UrbanFootprint. Users can input localized baselines and projected future-year values for more accurate and/or policy-oriented analysis.

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3 https://www.epa.gov/energy/emissions-generation-resource-integrated-database-egrid
4 https://www.epa.gov/energy/greenhouse-gases-equivalencies-calculator-calculations-and-references

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Figure 1. Map of eGRID 2016 CO_2 Equivalent Emissions Rates by State
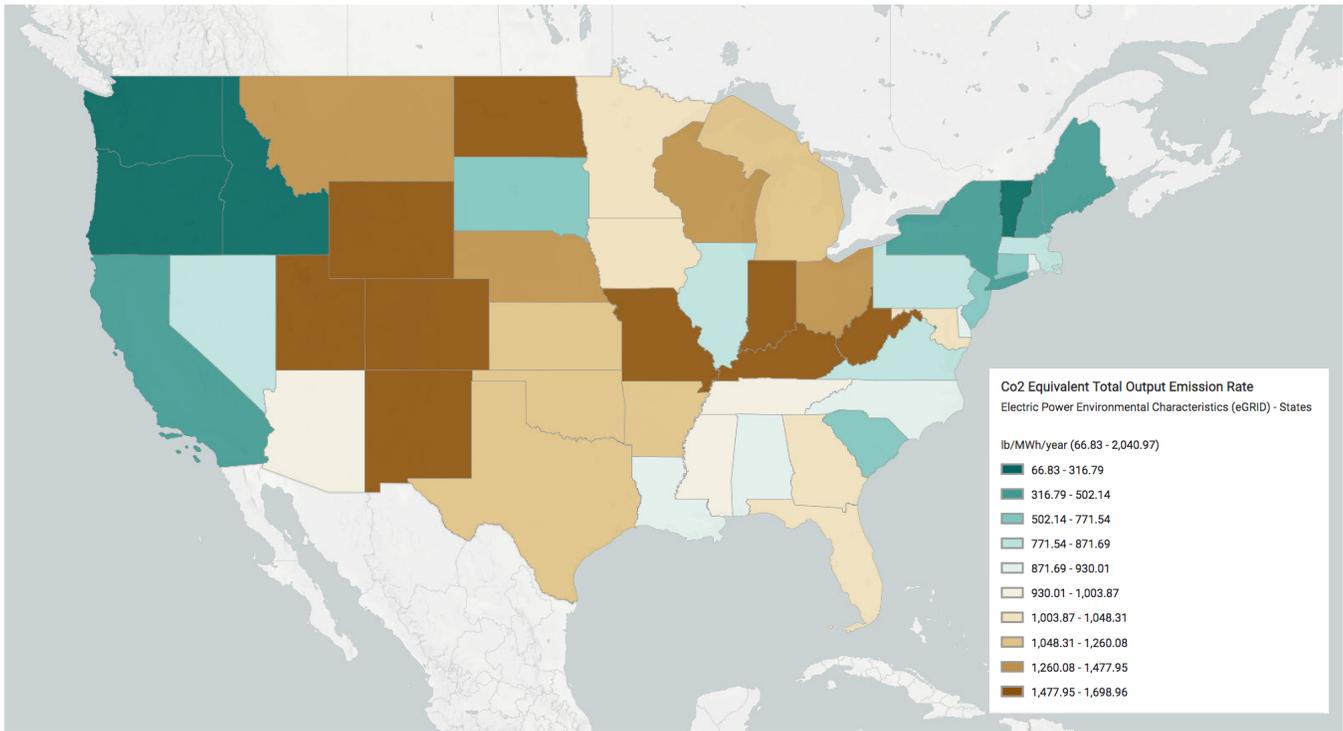

Table 2: Default Input Parameters for Building Energy Emissions

Parameters	Default Baseline Values
GHG emissions rate, electricity	Values differ by eGRID subregions
GHG emissions rate, natural gas	11.83 lbs CO_2e/therm

Water-Related Emissions Input Parameters

The energy use associated with water supply — including treatment and pumping for conveyance and distribution — varies depending on the characteristics of local water systems and source water supply. While there is wide variability across the U.S., the module assumes a default national average that can serve to gauge the order of magnitude of water-energy emissions. The default national rate comes from a study that references EPA Portfolio Manager data for water and wastewater facilities as collected by Lawrence Berkeley National Laboratories (LBNL), assuming water systems with a 5 to 20 million gallon daily (MGD) flow rate.[5] The weighted average water-energy use intensities for systems of other sizes are shown in Table 3.

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5 Electricity Use and Management in the Municipal Water Supply and Wastewater Industries, Electric Power Research Institute and the Water Research Foundation, 3002001433, Final Report, November 2013. Available at http://www.waterrf.org/Pages/Projects.aspx?PID=4454

**Table 3. Water Energy-Use Intensities
(Weighted Average Values for Water System Parameters from Filtered Energy Star Dataset[6])**

Average Daily Flow Range (million gallons per day, or MGD)	Energy Use Intensity (kWh per million gallons)
< 3 MGD	2,000 kWh/MG
3 to 5 MGD	1,400 kWh/MG
5 to 20 MGD	1,600 kWh/MG
20 to 600 MGD	1,500 kWh/MG

UrbanFootprint assumes the same GHG emissions rate for water-related electricity use as specified for building electricity use.

Table 4 summarizes the input parameters used to calculate water-energy GHG emissions and the default baseline values used by UrbanFootprint. If available, users can input localized baselines and projected future-year values for more accurate and/or policy-oriented analysis.

Table 4: Default Input Parameters for Water Use Emissions

Parameters	Default Baseline Values
Indoor water supply electricity use (indoor water-energy use intensity)	1,600 kWh/million gallons
Outdoor water supply electricity use (outdoor water-energy use intensity)	1,600 kWh/million gallons
GHG emissions rate, electricity	Values vary by eGRID subregions

Output Metrics

The Emissions module generates a mapped spatial output layer and corresponding data table; both can be used within UrbanFootprint for mapping and data exploration, and exported. The module also reports individual and comparative scenario results via summary charts, and generates a spreadsheet summary in Excel format. The attributes of the spatial output/data table are summarized in Table 5.

Table 5: Emissions Module Outputs

Attribute(s)	Description
Residential Water GHG Emissions	Annual GHG emissions associated with residential water use
Commercial Water GHG Emissions	Annual GHG emissions associated with commercial water use

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6 Ibid.

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Attribute(s)	Description
Total Water GHG Emissions	Total GHG emissions from residential and commercial water use
Residential Water GHG Emissions per Capita	Annual GHG emissions from residential water use, per capita in a parcel or census block
Commercial Water GHG Emissions per Employee	Annual GHG emissions from commercial water use, per employee in a parcel or census block
Water GHG Emissions per Household	Annual GHG emissions from residential water use, per household in a parcel or census block
Transportation GHG Emissions	Annual GHG emissions from passenger vehicle transportation
Residential Building Energy GHG Emissions	Total annual GHG emissions from residential building energy use
Commercial Building Energy GHG Emissions	Total annual GHG emissions from commercial building energy use
Total Building Electricity GHG Emissions	Total annual GHG emissions from residential and commercial building electricity use
Building Natural Gas GHG Emissions	Total annual GHG emissions from residential and commercial building natural gas use
Total Building Energy GHG Emissions	Total annual GHG emissions from residential and commercial building energy use
Residential Building Energy GHG Emissions per Capita	Annual GHG emissions from residential building energy use, per capita
Commercial Building Energy GHG Emissions per Employee	Annual GHG emissions from commercial building energy use, per employee
Residential Building Energy GHG Emissions per Household	Annual GHG emissions from residential building energy use, per household
Passenger Vehicle Emissions per Household	Annual GHG emissions from residential passenger vehicle transportation, per household
Passenger Vehicle Emissions per Capita	Annual GHG emissions from residential passenger vehicle transportation, per capita
Total Passenger Vehicle Emissions	Annual GHG emissions from residential passenger vehicle transportation
Total GHG Emissions	Annual total GHG emissions from passenger vehicle transportation, building energy use, and water use
GHG Emissions per Capita	Annual GHG emissions from residential passenger vehicle transportation, residential building energy use, and residential water use, per capita
GHG Emissions per Employee	Annual GHG emissions from commercial building energy and commercial water use, per employee
Total NO_x Emissions	Annual NO_x emissions associated with residential VMT attributed to households in parcel or census block

Attribute(s)	Description
Total PM10 Emissions	Annual PM10 emissions associated with residential VMT attributed to households in parcel or census block
Total PM2.5 Emissions	Annual PM2.5 emissions associated with residential VMT attributed to households in parcel or census block
Total SO_x Emissions	Annual SO_x emissions associated with residential VMT attributed to households in parcel or census block
Total CO Emissions	Annual CO emissions associated with residential VMT attributed to households in parcel or census block
Total VOC Emissions	Annual VOC emissions associated with residential VMT attributed to households in parcel or census block
Total Pollutant Emissions	Total annual criteria pollutant emissions, including NO_x, PM10, PM2.5, SO_x, CO, and VOCs, attributed to households in parcel or census block

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