Photo by Dennis Schroeder, NREL 23201

Greenhouse Gas Emissions Accounting in Buildings

Building operations in the United States account for about 70% of electricity use, about 40% of the total U.S. primary energy consumption,[1] and about 30% of greenhouse gas (GHG) emissions.[2] Carbon dioxide (CO_2) emissions from building energy use and embodied emissions accounted for about 37% of global CO_2 emissions in 2020.[3] Thus, accurate GHG emissions accounting is critical to inform decisions for emissions reduction. This fact sheet provides an introduction to GHG emissions accounting for operation of buildings including equipment replacements and operational material purchases. It does not include embodied GHG emissions in existing buildings or from major retrofit construction activities.

What are operational activities that result in emissions and where are the opportunities to reduce emissions from commercial buildings?

The majority of GHG emissions from building activities come from combustion of fossil fuels for energy, either remotely for generation of electricity or on-site for heat and power generation. Carbon dioxide, methane, and nitrous oxide are all GHGs associated with combustion. Methane can also be released to the atmosphere from leakage in pipes, valves, and equipment. Refrigerants are very powerful GHGs and can leak from refrigeration and heat pump equipment during installation, maintenance, and operation. Annual refrigerant leakage varies significantly and is most often estimated to be between 1% and 10% of the total system refrigerant charge, but can be much higher if there is a catastrophic failure in the system.[4]

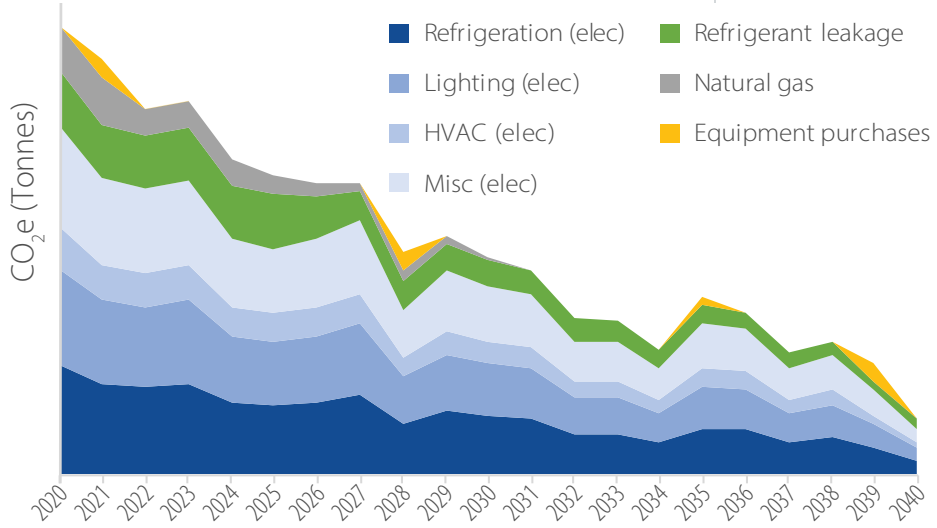

Figure 1.
Example operational activities that impact emissions, representing an 87% reduction in GHG emissions. Data are for demonstration purposes only for a supermarket. Equipment purchases can refer to furniture purchases such as desks, chairs, and partitions for commercial building use.

1 EIA 2021. Monthly Energy Review, preliminary data for 2020. *https://www.eia.gov/totalenergy/data/monthly*. US Energy Information Administration: Washington DC.
2 US EPA 2021. Sources of Greenhouse Gas Emissions. *https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions*. Washington DC.
3 UNEP, IEA 2021. Global ABC 2021 Global status report.
4 Integral Group 2020. "*Refrigerants + Environmental Impacts: A Best Practice Guide*" *https://www.integralgroup.com/news/refrigerants-environmental-impacts/*. See Appendix A.4 for more data on leakage rates for HVAC systems.

What are the types of emissions?[5]

Scope 1 emissions: direct emissions from sources that are owned or controlled (includes on-site fuel combustion)

Scope 2 emissions: indirect emissions from sources that are owned or controlled (includes emissions that result from the generation of electricity, heat, or steam purchased from a utility provider)

Scope 3 emissions: emissions from sources not owned or directly controlled but related to activities (includes employee travel and commuting; emissions associated with contracted solid waste disposal and wastewater treatment; transmission and distribution losses associated with purchased electricity)

How do you calculate GHG emissions?

GHG Emissions = **Activity** (e.g., electricity or natural gas purchased) * **Emission Factor**

Emission Factor: value that relates a quantity of a pollutant to an activity, usually put in terms of CO_2 equivalent using global warming potential (GWP). GWP values are determined on 100-year or 20-year time horizons (fixed point in the future when the emissions would be evaluated). The 100-year values are most commonly used; however, 20-year values are sometimes used to emphasize the impacts of high-impact, short-lived emissions such as methane and some refrigerants.

What are example global warming potentials?

GHG Global Warming Potentials			
Gas	**Commercial Building Use**	**AR5 (IPCC Fifth Assessment Report 2013)**	
		20-Year Values	**100-Year Values**
CO_2	Off-site electricity generation, on-site fuel combustion	1	1
CH_4	On-site fuel combustion for heating	84	28
N_2O	Off-site electricity generation, on-site fuel combustion	264	265
R134A	Refrigeration	3,710	1,300
R404A	Refrigeration	6,437	3,943
R410A	Refrigeration	4,260	1,924
R32	Refrigeration	2,430	677

What are common frameworks or tools that can be used for operational emissions accounting and what emissions are included?

When selecting a tool, it is important to determine the scope and clearly define the boundaries for the analysis, specifically:

- The emission sources that will be included and what detail level is available and acceptable
- The temporal and physical boundaries (e.g., time frequency of data points, types of fuels, building energy use, total facility energy use)
- GHG emissions from sources of interest (such as company-owned vehicles), that are not included in some of these tools and frameworks, can be estimated from other tools or spreadsheet calculations.

Other useful carbon emissions terminology:

Greenhouse gas emissions (GHG): carbon dioxide equivalent emissions from different greenhouse gases based on their global warming potential.

Carbon dioxide equivalent (CO_2e): measure that relates the impact of different greenhouse gases to that of carbon dioxide using the global warming potential.

Global warming potential (GWP): measure that estimates the impact and contribution to global warming of emissions of different greenhouse gases.

Operational carbon emissions: refers to the greenhouse gas emissions attributed to operation and use of the building.

Embodied carbon emissions: commonly refers to the greenhouse gas emissions attributed to materials and energy used in construction, maintenance, and deconstruction activities of buildings. They can be estimated by spreadsheet calculations if not included in the listed tools and frameworks.

5 US EPA 2021. GHG Inventory Development Process and Guidance. *https://www.epa.gov/climateleadership/scope-1-and-scope-2-inventory-guidance*. Washington DC.

Type and Scope of Emissions		Tool		Framework		
		ENERGY STAR® Portfolio Manager (U.S.)	Environmental Protection Agency (EPA) Simplified GHG Emissions Calculator	GHG Protocol (Global)	Zero Carbon Building Perf. Std. v2 (Canada)	Building System Carbon Framework (Global)
Major operational emissions	1: On-site operational emissions	✔	✔	✔	✔	✔
	2: Purchased electricity	✔	✔	✔	✔	✔
Minor operational emissions	1: On-site refrigeration		✔	✔	✔	
	2: Purchased chilled water/steam	✔	✔	✔		
Work-related travel	1: Company vehicles		✔	✔		
	3: Business travel and commuting		✔	✔		
End-of-life emissions at facility	3: End-of-life treatment of products				✔	✔
Event-based emissions	3: Purchased goods and services, etc.			✔	✔	✔

Are there different types of emission factors for electricity?

Emission factors for electricity are generally calculated as the total emissions from all the input sources divided by the total electricity generated. However, there are several terms and variations that should be understood to ensure proper selection and application.

Location Based vs. Market Based: Location based emission factors reflect the emission factors based on the local grid operations for the location in question. Market based emission factors reflect the purchased electricity, which may include one or more power purchase agreements.

Total vs. Residual: Total emissions represent the emissions from the total electricity generated, while residual emissions are determined after removing certified renewable energy sales from the total generated electricity. Residual emission factors are considered to be a more accurate accounting method; however, definitions and accounting methods differ for residual emission factors, which may result in slightly different results.

Average vs. Marginal: Average emission factors represent total emissions averaged over a set period, while marginal emission factors represent the emissions associated with the last generation source(s) used to meet an increase in demand. Average emission factors are more accurate for carbon footprints while marginal emission factors may be appropriate for estimating carbon reductions from implementing energy efficiency measures.

National vs. Regional vs. Utility: Emission factors can be calculated for different locations: national, regional, or utility. The most common regional values are based on the 26 eGRID subregions defined by the EPA. State-level emission factors may not be good representations of local emissions and are not recommended. Some utilities and the Edison Electric Institute provide utility-level emission factors.

Annual vs. Hourly: Emission factors are calculated for a set period, most often on an annual basis. Hourly emission factors are recommended when there are large variations in the hourly generation mix and hourly load profiles that lead to significant variations in emissions.

100-Year GWP vs. 20-Year GWP: Greenhouse gases have different atmospheric lifetimes and different temporal radiative forcing impacts, which are reflected in the GWP values calculated over different time horizons. Most GHG emissions are estimated using the 100-year GWP values; however, 20-year GWP values are sometimes used for high-impact, short-lived GHGs.

Emissions factors are also available for other activities such as refrigerant leakage or combustion of natural gas in a furnace.

Where can I find emission factors?

Source	Energy /Fuel	Scope	Time Scale	Region	Background Data Source	GWP-Year
EPA eGRID[6]	Electricity	Combustion to end use	Annual average and non-baseload	U.S., NERC regions, eGRID subregions, state, balancing areas	CAMD, EIA-860, EIA-923 (2019)	AR4, 100-yr
Green-e[7]	Electricity	Combustion to end use for residuals	Annual average	U.S., eGRID subregions	eGRID, Green-e certified sales	AR4 100-yr
Edison Electric Institute GHG database[8]	Electricity	Combustion to end use for total and residuals	Annual average	Utility (43% of country)	Utility data, (2018 and 2019)	AR4 100-yr
ASHRAE Standard 105-2021	Electricity & fuels	Full life cycle	Annual average and non-baseload	U.S., eGRID subregions	eGRID plus (2014, 2019)	20-yr & 100-yr
ASHARE Standard 189.1-2020	Electricity & fuels	Full life cycle	Annual average	U.S., eGRID subregions	EIA 2017	20-yr & 100-yr
Wattime	Electricity	Combustion to end use	15 minute marginal	Balancing areas	Real time	AR4, 100-yr
Cambium, NREL[9]	Electricity	Future projections	15 minute, hourly, average and marginal	U.S., regional assessment zones, balancing area	Simulated future energy scenarios with 2012 weather	AR4, 100-yr
EPA[10]	Fuels, refrigerants and others	Combustion or direct atmospheric release	Event-based	U.S.	Multiple (see resource documentation)	AR4, 100-yr

Additional guidance:

- Determine what level of uncertainty is satisfactory. Historical and estimated data are less certain, but real-time building energy data and utility grid data that provide more certainty are not always available and can be cumbersome.
- Be internally consistent in the approach and emission factors used. Comparing against a baseline calculated using different approaches may result in false comparisons which may lead to unintended effects.
- Choose emission factors wisely to estimate real emissions most accurately.
- Consider using market-based or residual emission factors where possible. With the growth of more privately owned certified or contracted renewables on the grid, residual emission factors are more representative of the emissions from the general purchased electricity.
- Combined heat and power plants can be on-site or a shared resource between buildings, which makes allocation of emissions and boundary accounting important. Estimating these emissions can also be difficult since plants generating the steam or chilled water do not provide data on operations.
- On-site renewable energy production (e.g., electric or thermal energy production) may be exported from the building and should be accounted for with hourly or time of use emissions data.
- On-site electric vehicle charging can have a significant impact on the building energy consumption and load profile. Electric vehicle charging and discharging should be metered so that they can be included or subtracted from the building energy consumption as appropriate.
- Purchased carbon offsets are not all equal, so it can be difficult to fully credit carbon offsets to building emissions.

For more information see *Operational Emissions Accounting for Commercial Buildings* at *www.nrel.gov/docs/fy22osti/81670.pdf*

6 EPA 2020. eGRID. *https://www.epa.gov/egrid*
7 Green-e Residual Mix Emission Rates. *https://www.green-e.org/residual-mix*
8 EEI 2020. Edison Electric Institute. Electric Company Carbon Emissions and Electricity Mix Reporting Database, reported by each utility following The Climate Registry or WRI GHG protocols. *https://www.eei.org/Pages/CO2Emissions.aspx*
9 NREL 2020. Cambium hourly emissions data. *https://cambium.nrel.gov*
10 EPA 2020. Greenhouse Gas Equivalencies Calculator. *https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator*

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