Operational Emissions Accounting for Commercial Buildings

Heather Goetsch and Michael Deru

National Renewable Energy Laboratory

NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy
Operated by the Alliance for Sustainable Energy, LLC

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

Contract No. DE-AC36-08GO28308

Technical Report
NREL/TP-5500-81670
July 2022

Operational Emissions Accounting for Commercial Buildings

Heather Goetsch and Michael Deru

National Renewable Energy Laboratory

Suggested Citation

Goetsch, Heather, and Michael Deru. 2022. O*perational Emissions Accounting for Commercial Buildings*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-5500-81670. https://www.nrel.gov/docs/fy22osti/81670.pdf.

NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy
Operated by the Alliance for Sustainable Energy, LLC

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

Contract No. DE-AC36-08GO28308

Technical Report
NREL/TP-5500-81670
July 2022

National Renewable Energy Laboratory
15013 Denver West Parkway
Golden, CO 80401
303-275-3000 • www.nrel.gov

NOTICE

This work was authored by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by the U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Building Technologies Office. The views expressed herein do not necessarily represent the views of the DOE or the U.S. Government.

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

U.S. Department of Energy (DOE) reports produced after 1991 and a growing number of pre-1991 documents are available free via www.OSTI.gov.

Cover Photos by Dennis Schroeder: (clockwise, left to right) NREL 51934, NREL 45897, NREL 42160, NREL 45891, NREL 48097, NREL 46526.

NREL prints on paper that contains recycled content.

Acronyms

EEI	Edison Electric Institute
eGRID	Emissions and Generation Resource Integrated Database
EIA	U.S. Energy Information Administration
EPA	U.S. Environmental Protection Agency
GHG	greenhouse gas
GWP	global warming potential
IPCC	Intergovernmental Panel on Climate Change

Table of Contents

List of Figures

List of Tables

1 Introduction

Buildings are the largest consumers of energy and one of the largest sources of greenhouse gas (GHG) emissions. Buildings in the United States account for about 70% of electricity use, about 40% of the total U.S. primary energy consumption, and about 30% of operational GHG emissions (EIA 2021; EPA 2021). Carbon dioxide (CO_2) emissions from energy use in buildings account for about 37% of global CO_2 emissions in 2020 (UNEP, IEA 2021). Accurate GHG emissions accounting is critical to inform decisions for emissions reduction.

The U.S. Department of Energy's Building Technologies Office is interested in helping its commercial building partners make energy- and emissions-informed operational decisions. Commercial building owners and portfolio managers have expressed interest in accounting their operational GHG emissions and evaluating alternatives for reducing these emissions.

The objectives of this project were to investigate existing operational GHG emissions accounting frameworks and identify opportunities for immediate deployment. Included in the project is an investigation of available frameworks, data sources, and methodologies. This final report summarizes the findings, including a review of existing approaches and data sources for emissions accounting, a review of challenges in emissions accounting, results from testing emissions accounting frameworks and emissions factors with example data from two buildings, and resulting recommendations while using an emissions accounting framework. Not discussed in this report are embodied GHG emissions, or emissions attributed to materials and energy used in construction, maintenance, and deconstruction in existing buildings or emissions from major retrofit construction activities.

2 Existing Emissions Accounting Frameworks and Tools

GHG emissions associated with operating buildings have several sources; the largest is typically from the combustion of fossil fuels for generation of electricity, or on-site heat and power generation that result in the release of CO_2, methane, and nitrous oxide. Methane can also be released to the atmosphere from leakage in pipes, valves, and equipment. GHG emissions can also result from leakage of refrigerants from refrigeration and heat pump equipment during installation, maintenance, and operation. Combined, these emissions are often expressed as CO_2 equivalents by considering the global warming potential (GWP) of the various responsible compounds. Refrigerants can have GWPs several orders of magnitude larger than CO_2. GWPs are discussed further in Section 3 of the report.

Several frameworks and tools exist to help users in their GHG emissions accounting, and some of the most commonly used ones are listed in Table 1. Here, frameworks refer to a system and approach to emissions accounting, whereas a tool combines information from the user to provide output to help the user make informed decisions. Table 1 describes what each of these frameworks and tools include in terms of scope 1, 2, and 3 emissions. Scope 1 emissions refer to direct emissions from sources that are within the company or building's control (e.g., on-site combustion, refrigerant leakage, company owned vehicles). Scope 2 emissions refer to indirect emissions that result from purchased electricity, heat, or steam. Scope 3 emissions refer to all other indirect emissions that result from the company or building's activities. Most of the frameworks and tools listed in Table 1 include scope 1 and 2 emissions and all include the major operational emissions.

Table 1. Scope Emissions Included in Common Emissions Accounting Frameworks and Tools

Type and Scope of Emissions		Framework			Tool	
		GHG Protocol Corp. Acc. & Reporting Std (Global)	Zero Carbon Building Perf. Std. v2 (Canada)	Building System Carbon Framework (Global)	ENERGY STAR® Portfolio Manager (U.S.)	EPA Simplified GHG Emissions Calculator
Major Operational Emissions	1: On-site operational emissions	X	X	X	X	X
	2: Purchased electricity	X	X	X	X	X
Minor Operational Emissions	1: On-site refrigeration	X	X			X
	2: Purchased chilled water/ steam	X			X	X
Work-Related Travel	1: Company vehicles	X				X
	3: Business travel and commuting	X				X
End of Life Emissions at Facility	3: End of life treatment of products		X	X		
Event-Based Emissions	3: Purchased goods and services, etc.	X	X	X		

Table 2 compares the intended purpose, references, transparency, source of emissions factors used, and the limitations of the available frameworks and tools. The frameworks provide mitigation strategies generally, whereas the tools provide reporting. The GHG Protocol for Corporate Accounting and Reporting Standard is used as the basis for other tools or frameworks (Table 2). The level of transparency across the frameworks and tools varies from providing no guidance on how emissions are calculated, to providing emission factors and sources of those emission factors, and to providing calculation methods within the standard or a supplemental workbook. Limitations of the frameworks and tools also vary. Several of the frameworks are a high-level guidance that provide a holistic approach but no step-by-step guide for a user. Tools can also capture the past performance of the building without guidance for improvements or mitigation strategies.

Table 2. Attribute Comparisons for Carbon Accounting Frameworks and Tools

Attributes	**Framework**			**Tool**	
	GHG Protocol Corp. Acc. & Reporting Std (Global)	Zero Carbon Building Perf. Std. v2 (Canada)	Building System Carbon Framework (Global)	ENERGY STAR Portfolio Manager (U.S.)	EPA Simplified GHG Emissions Calculator
Intended purpose	Provides calculations and reporting standard	Provides mitigation strategies and certification	Provides mitigation strategies	Reporting and Certification	Estimate and inventory emissions
Inventorying Alignment/ Reference	GHG Reporting Protocol	GHG Reporting Protocol	GHG Reporting Protocol, EN 15978, EN 15804	GHG Reporting Protocol	EPA Center for Corporate Climate Leadership (aligned with GHG Reporting Protocol)
Transparency	Calculation methods, protocols provided, default emission factors provided	Emission factors provided in workbook	N/A	Emission factors provided	Emission factors provided
Source of emission factors (if available)	eGRID, IPCC Emission Factor Database	Canada's National Inventory Report	N/A	eGRID	eGRID
Limitations	Level of effort and expertise required is high	Canada application, emission factors are not applicable for U.S.	Without the spreadsheet, difficult to implement approach	Does not allow user to enter more specific emission factors; only includes emissions from operational energy consumption	Expertise required may be high; strategies for reduction not part of calculator

The **GHG Protocol for Corporate Accounting and Reporting Standard** is the most comprehensive framework in terms of inclusion of different scope emissions. This protocol introduces reporting and accounting principles and defining inventory boundaries, specifies reporting requirements and guidance for data and calculating emissions, and shows how the inventory might be useful to set goals and track performance. The GHG Protocol has released an Excel-based tool based on the framework provided to help users account for their emissions. This spreadsheet tool includes emission factors for electricity from the U.S. Environmental Protection Agency's (EPA's) eGRID data and Green-e Residual Mix Emission Rates and methods for calculating emissions for the other types of emissions listed in Table 1. Users may enter their own emission factors for customized calculations.

The **Zero Carbon Building Performance Standard** focuses on embodied carbon in construction materials, energy grids and buildings, and on-site renewables. Emission factors are provided (natural gas and scope 2 and 3 emission data are from a Canadian national report). Residual mix emissions factors may be used if the local utility has provided it. It also offers resources for conducting life cycle assessments and choosing low-carbon materials.

The **Building System Carbon Framework** proposes a common language of carbon emissions determined by representatives from all aspects of the built environment. With this common language for metrics and a life cycle approach, the framework intends to align actions from different stakeholders within the value chain for a common goal of a net zero built environment. This framework document relies on the standard life cycle stages and demonstrates the importance of choices within "building layers," as each layer has a different purpose and duration.

The **ENERGY STAR® Portfolio Manager** is widely used by commercial building owners to track energy and water consumption. It is a user-friendly online tool that requires minimal data to benchmark the commercial property. Data required can vary depending on the property type but generally includes total gross area of property, occupancy, number of buildings, 12 consecutive months of energy data, and gross building floor area. The current version of Portfolio Manager tracks "direct" and "indirect" emissions. "Direct" emissions are emissions from on-site fuel combustion only and do not include on-site methane or refrigerant leakage. "Indirect" emissions here are associated with purchasing of electricity, district steam, district hot water, or district chilled water. On-site green power tracked in the Portfolio Manager includes only power from solar and wind. Energy from these systems is "green" only if the renewable energy credits are owned by the building owner. Off-site green power sources in the Portfolio Manager include solar, wind, geothermal, biogas, biomass, and small hydropower if either the green power is purchased from the building-connected utility or independently by the building owner. For direct emissions, 100-year GWP values are used (IPCC 2007). Fuel and biomass emission factors that are provided are single national factors. Emission factors associated with electricity are regional factors using eGRID (Emissions and Generation Resource Integrated Database). eGRID subregions are discussed further in Section 3. Avoided emissions are calculated at the regional level with non-baseload factors.

The **EPA Simplified GHG Emissions Calculator** is a tool designed to help organizations (primarily small business and low emitter organizations) estimate and track their emissions annually. The methodology used is based on the Center for Corporate Climate Leadership

Guidance, which is aligned with the GHG Protocol Corporate Standard. This calculator, which takes the form of a downloadable Excel spreadsheet, helps quantify the direct and indirect emissions from several activities of the organization, including most scope 1 and 2 emissions and some scope 3 emissions. There is also an opportunity to report purchased carbon offsets.

In addition to the tools and frameworks listed above, there are several standards focused on decarbonization. ASHRAE Standard 105-2021 provides a standard methodology to determine, express, and compare building energy and GHG performance (ASHRAE 2021). ASHRAE standard 189.1-2020 is a design standard for energy efficient buildings that provides green building design strategies (ASHRAE 2020). ASHRAE standard 228P is a proposed standard method to evaluate zero energy and zero net carbon building performance (ASHRAE 2022). This proposed standard method follows a similar approach to the frameworks listed above, currently focused on operational energy and carbon. The purpose of the proposed standard is to set requirements for evaluating a building to meet a net zero energy and net zero carbon definition and provides a consistent method to evaluate this determination for new and existing buildings.

LEED version 4.1 is the most recent update to the standard for green building design, construction, operations, and performance (managed by the U.S. Green Building Council). This version expands previous versions by helping guide buildings to reduce their carbon emissions, reduce the use of toxic materials, and prioritize sustainable materials. Consistent with the LEED standard, this version does not provide numerical values of GHG emissions and is based on a point system.

3 Existing Data Sources

The emissions accounting frameworks described in Tables 1 and 2 rely on emission factors to estimate emissions. There are many gases from natural and human sources that contribute to the greenhouse effect. Each of these GHGs have different radiative impacts and different atmospheric lifetimes. We can relate the impact of each GHG compared to CO_2 using GWP for different time horizons. The Intergovernmental Panel on Climate Change (IPCC) periodically produces scientific assessments on climate change. The 100-year and 20-year GWP values from the IPCC's Fifth Assessment Report (AR5) for several GHGs of interest for building operations are shown in Table 3. Historically, the 100-year GWP values have been used when determining emission factors; however, there has been a growing interest by practitioners to also use the 20-year GWP value to reflect short-term impact and the speed at which climate change is occurring.

Table 3. GHG Global Warming Potentials

Gas	Commercial Building Source	AR5 (IPCC 2013)	
		20-year	100-year
CO_2	Off-site electricity generation, on-site fuel combustion	1	1
CH_4	Off-site electricity generation, on-site fuel combustion	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

GHG emission factors for different activities are estimated with different assumptions, analysis methods, and source data. It may not be important to understand all the details, but it is important to understand the main assumptions and scope for each application. GHG emission factors for electricity production are available from multiple sources and offer different temporal and spatial scales (EPA 2020, ASHRAE 2021, NREL 2020, WattTime 2020). GHG emission factors for on-site consumption of natural gas and other fuels are also available from multiple sources (EPA 2020, ASHRAE 2021, Deru and Torcellini 2007). A summary of many of the sources of energy-related GHG emission factors is provided in Table 4.

Table 4. Sources of GHG Emissions Data

Source	Energy /Fuel	Scope	Time Scale	Region	Background Data Source (year)	GWP-year
EPA eGRID[1]	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
EPA[2]	Fuels, refrigerants, and others	Combustion or direct atmospheric release	Event based	U.S.	Multiple (see resource documentation)	AR4, 100-yr
Green-e[3]	Electricity	Combustion to end use for residuals	Annual average	U.S., eGRID subregions	eGRID, Green-e certified sales	AR4, 100-yr
EEI GHG database[4]	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
ASHRAE 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[5]	Electricity	Full life cycle	15-minute average and marginal	U.S., regional assessment zones, balancing areas	Simulated, future energy scenarios with 2012 weather	AR4, 100-yr

As observed in Table 4, most data sources provide annual averages. The U.S. Energy Information Administration (EIA) provides hourly generation data by source (e.g., wind, solar, coal, natural gas). While it does not include emissions, a user could apply general emission factors to the energy generation to estimate hourly emissions (EIA 2022).

[1] EPA 2020. eGRID. https://www.epa.gov/egrid.
[2] EPA 2020. Greenhouse Gas Equivalencies Calculator, https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator
[3] Green-e Residual Mix Emission Rates. https://www.green-e.org/residual-mix
[4] 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
[5] NREL 2020. Cambium hourly emissions data. https://cambium.nrel.gov

When selecting electricity emission factors, it is important to understand the year of data, the regional representation, the time scale, calculation methodology, and the difference between average and marginal emissions. It is recommended to use emission factors from within two years of the actual electricity consumption because generation mixes vary year-to-year (e.g., emissions data from years 2019–2021 would be appropriate to use for operational data from year 2020). Understanding the regional variation of the electricity generation is also important. The electric grid is a complex web of several generation sources, storage, and distribution networks. The national grid is divided into three mostly independent grids, which are further divided into 66 balancing authorities. The balancing authorities are responsible for maintaining reliable electricity delivery within their distribution systems. EPA defined 13 regions, called eGRID subregions, to simplify tracking of electricity generation and emissions. These subregions are generally accepted as providing good approximations of emissions for use with buildings; however, there are some eGRID subregions with large variations across the subregion.

Most reported emission factors are annual average values and do not account for seasonal or hourly variations. Annual average values provide reasonable approximations if the building seasonal and daily consumption profiles are similar to the generation profiles. If there are large variations, then it may be better to use emission factors that account for these variations.

Understanding how emission factors are calculated and what they represent is very important for proper application. Average emission factors are calculated by dividing the total emissions by the total generation of electricity, whereas residual emission factors are calculated by dividing the total emissions by the total generation of electricity with certified renewable energy sales removed. Residual emission factors (also referred to as market-based emissions) may provide more accurate representations of the emissions from purchased electricity compared to the total average emission factors; however, they are not always available and calculation methodologies may vary with the source of the emissions data. The difference between the total average and residual emission factors is typically small; however, the difference is growing as energy suppliers sell more certified renewable energy.

Non-baseload output emission rates were developed by the EPA to provide an estimate of emission reduction benefits from energy efficiency and clean energy projects that contribute to reducing the demand on the electricity grid. Non-baseload emission rates give greater weight to plants that operate coincident with the peak demand for electricity. Baseload generation refers to those generation sources that supply electricity nearly all the time (greater than 80% for this method). Estimating marginal emissions is another approach to determine variations in the grid and the impacts of load shedding or load shifting. Marginal emission rates are the emission rates associated with new generation sources that come online to meet the next incremental demand. Marginal emission rates can also be thought of as the emission rates associated with the first generation sources to cut back or go offline when there is a reduction in power demand on the grid.

The carbon impacts of load shifting depends on location, timing, and size of the load shift. Peak shedding can result in emissions savings, while peak shifting may result in an increase or no change in emissions (Satre-Meloy and Langevin 2019). The change in emissions depends on the match of energy load profiles and electricity generation emission profiles. Emissions may actually increase when shifting energy consumption profiles even with a reduction in overall energy consumption if energy consumption is shifted to times with higher emission rates.

There are several calculators and data available for estimating travel emissions. Emissions for material purchases are more difficult but will most likely come from environmental product declarations and other GHG estimation sources.

4 Carbon Offsets

The purpose of the above frameworks and tools is to primarily provide consistency of emissions accounting associated with a building or group of buildings. The results can be used to guide opportunities to reduce emissions through energy efficiency efforts, adding renewable energy production, and purchasing of clean energy. In order to balance remaining emissions, the building owner can purchase carbon offsets through financing specific projects that sequester carbon or reduce carbon emissions. The reduction in emissions from these projects can count toward the balance of the entity purchasing the offset and not the owner of the project or location where the project exists. Inclusion of the offset can be controversial. Verifying the carbon-reducing aspects of these projects, understanding the timeframe and duration of the reductions, and not double counting the reduction in emissions becomes very important and is often not standard or transparent. In addition, carbon offsets are available to those who can afford to purchase them. Carbon offsets that finance projects for carbon reduction can also have unintended consequences, such as transferring the burden to less wealthy or less influential communities, resulting in other detrimental activities beyond reducing carbon emissions (Carton et al. 2020).

Some of the frameworks include carbon offsets in their accounting. The Net Zero Carbon Buildings framework references offsetting remaining carbon as the last step in achieving a net zero carbon building, specifying that a recognized offsetting framework be used to verify the offset (Clean Development Mechanism and The Gold Standard are specifically named). The Zero Carbon Building Performance Standard also includes options to account for avoided emissions by investing in carbon offsets and exported green power. The standard provides guidance on what type of green power can be used in this category, specifying that marginal electricity grid emission factors are used for the exported green power to reduce indirect emissions. Transparent carbon offsets can be used to offset direct or indirect emissions. The standard specifies certification requirements and provides additional resources for carbon offset accounting. The Building System Carbon Framework also mentions carbon compensation and provides a line item for noting the offset. However, it does not provide guidance for what can be considered a verified credit or how to obtain one. The GHG Corporate Accounting and Reporting Standard references the GHG Protocol Project Quantification to be used for accounting of emissions for offsets or credits of a project. The standard highlights the issues described earlier as necessary to be addressed, including the selection of a baseline scenario, additionality demonstration, identifying secondary effects, considering reversibility, and avoiding double-counting.

5 Comparing Approaches With Operations Data

Of the existing approaches, the ENERGY STAR Portfolio Manager and the GHG Protocol Corporate Accounting and Reporting Standard are recommended based on relative ease and coverage of major scope emissions. This section examines these approaches and tests them with example building operations data and available emissions factors to calculate emissions.

5.1 Example Buildings and Building Data

Two different commercial buildings were used as examples in this study. Data came from a retail building and an office building, both located in Colorado. Monthly electricity and natural gas data for three consecutive years were provided for the retail building (Figure 1), along with one year's worth of hourly electricity data. Examples of the hourly electricity data for the retail building are shown for four different weeks throughout the year, one from each season (Figure 2).

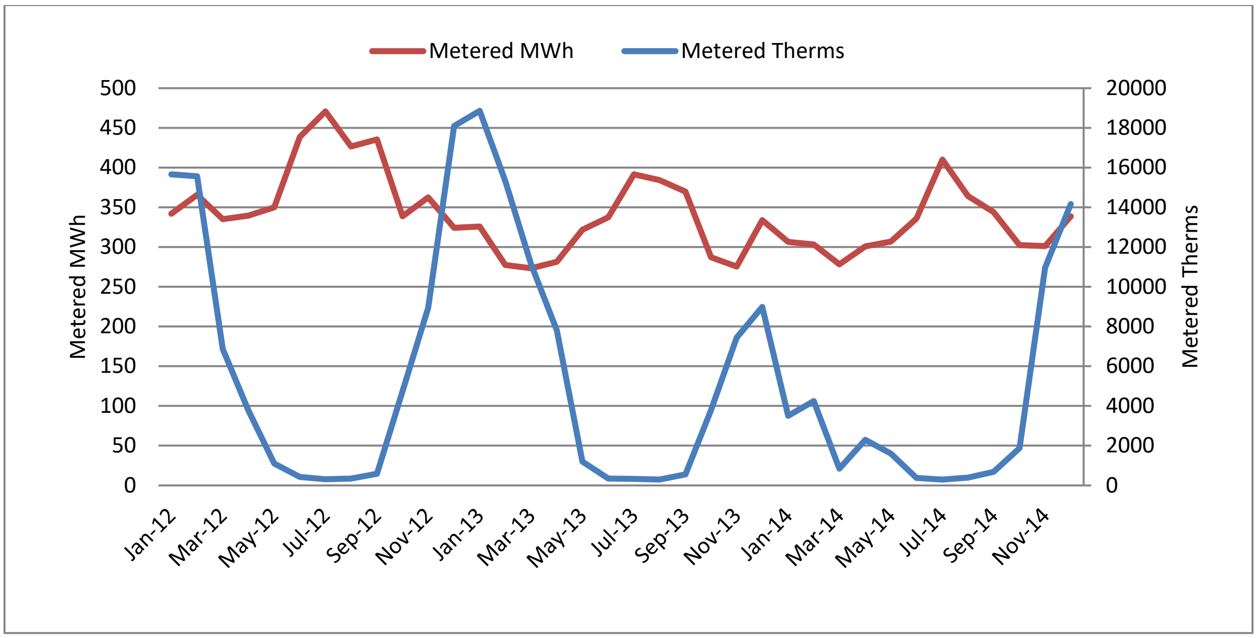

Figure 1. Electricity (red, left y-axis) and natural gas (blue, right y-axis) data for three consecutive years for a retail building in Colorado

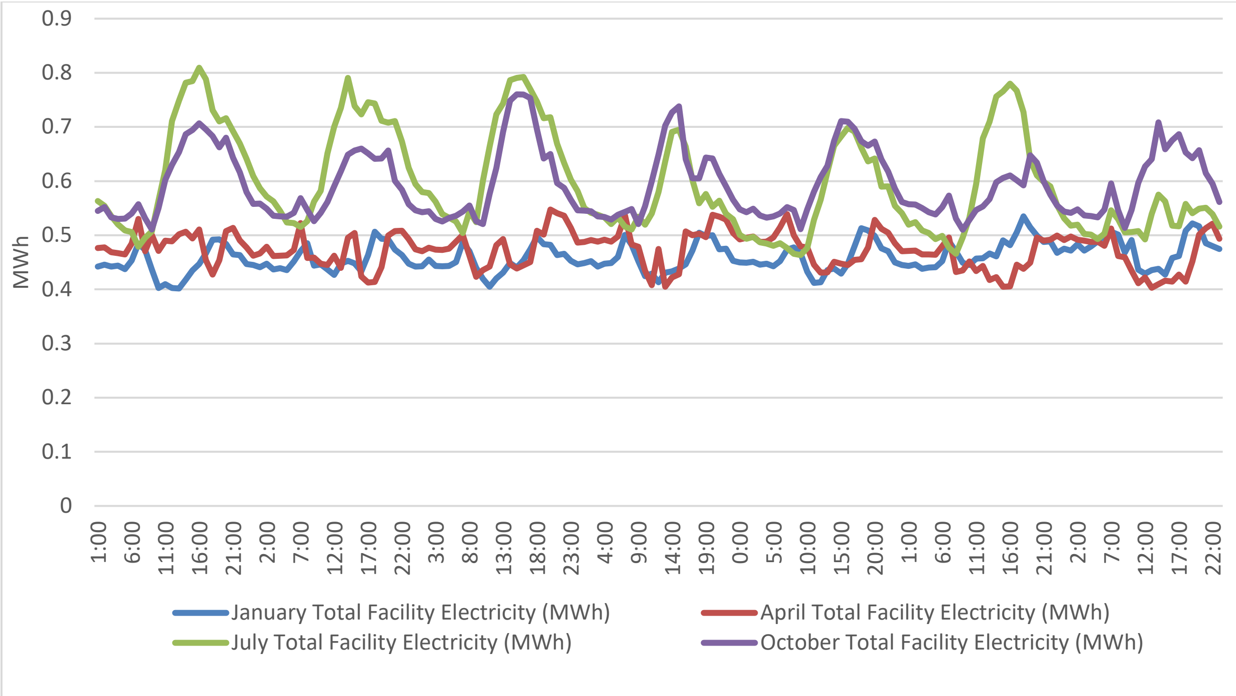

Figure 2. Example hourly data for four weeks (first week of January, April, July, and October) throughout one year of operation at a retail building in Colorado

Electricity data were provided for an office building that also has on-site PV generation. The load profile for the office building is provided in monthly increments over one year (Figure 3) as well as hourly increments over four example weeks throughout the year (Figure 4). These profiles represent exported electricity subtracted from imported electricity to account for generated PV on a monthly basis. The negative MWh values indicate more PV generated and exported to the grid than electricity imported. Generating more electricity than is needed by the facility can happen throughout the year. There are different power purchasing and interconnect agreements that define what happens in the case for excess electricity. Building owners do not always receive money for exported electricity. In fact, some interconnect agreements prohibit exporting electricity to the grid. The location and time of year can result in more generation than load, where generation needs to be curtailed or added to an energy storage system. This situation will become more prevalent as renewable energy generation is added to the grid. In the case when a building is a net generator, it does not mean that their emissions are zero, because purchased electricity from the grid still has associated emissions. Total emissions include all building end uses, including uses that do not require electricity.

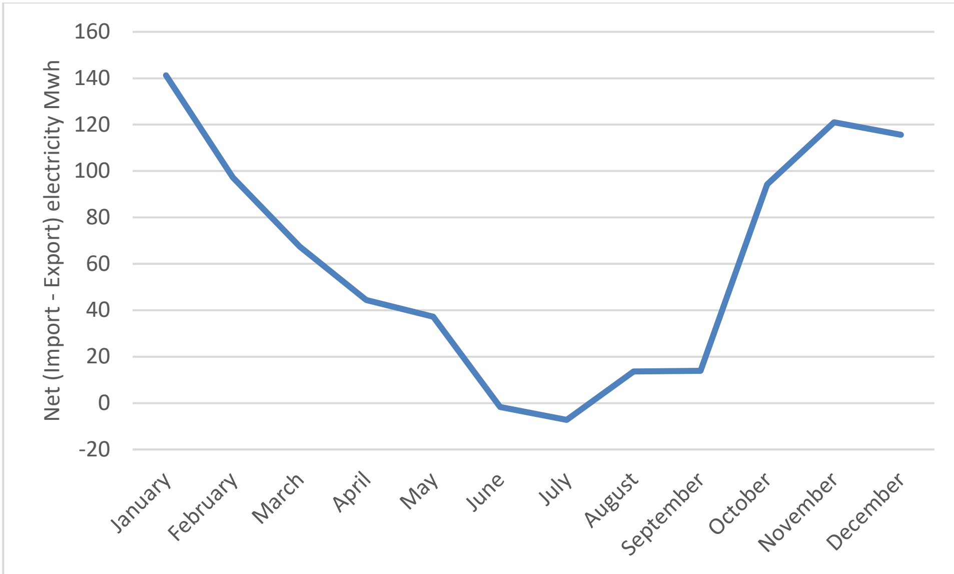

Figure 3. Annual electricity load profile for an office building in Colorado that includes on-site PV generation

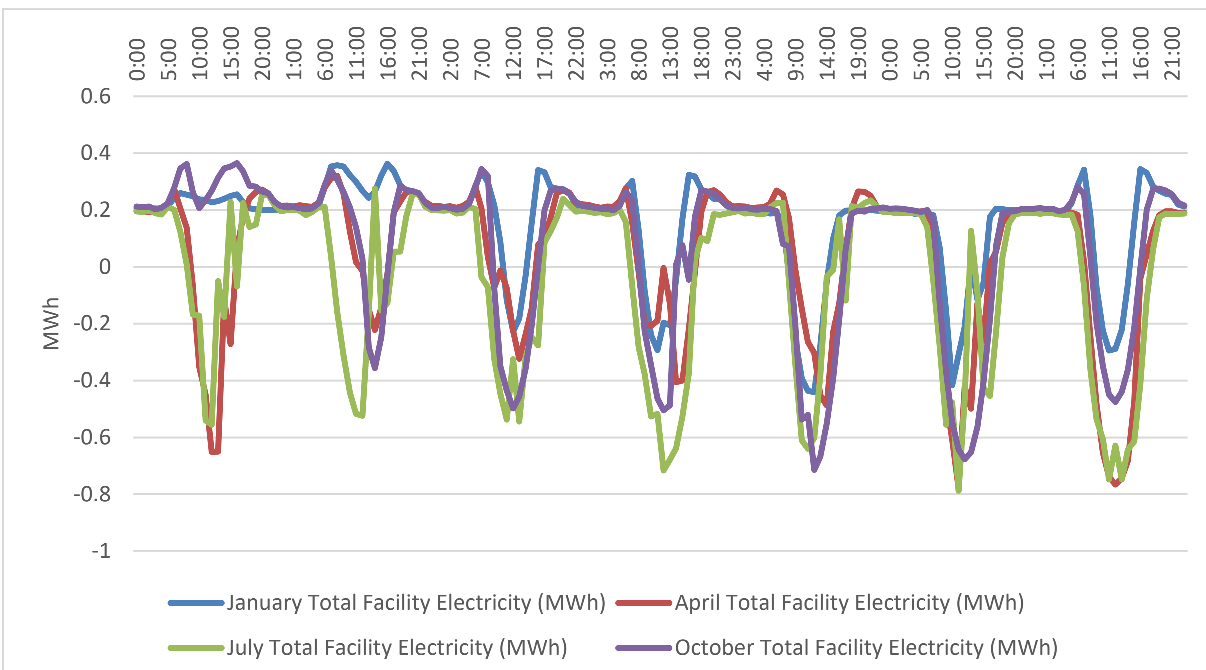

Figure 4. Electricity hourly load profile for an office building in Colorado that includes on-site PV generation. Hourly load profile is provided for four example weeks throughout the year.

5.2 General Approach

ENERGY STAR Portfolio Manager allows the user to add monthly electricity bill data. After adding the building (square footage, etc.) and the monthly electricity data, total annual GHG emissions can be determined based on eGRID emission factors.

The GHG Protocol Corporate Accounting and Reporting Standard released a beta version of an Excel spreadsheet to aid users in calculating building GHG emissions. Various GHG emission factors are provided in the spreadsheet. The user can also add their own GHG emission factors (e.g., utility provided GHG emission factors that may be more specific than the electricity grid subregion GHG emission factor). The user adds annual operational information (e.g., electricity use, fuel combustion, refrigerant amounts), and the summary tab displays final calculations of GHG emissions.

The general approach for estimating GHG emissions is straightforward—the GHG emissions can be calculated by multiplying the GHG emission factor (the value that relates the quantity of a pollutant like CO_2, to the activity associated with that pollutant) by the activity (e.g., electricity purchases). Keeping units consistent is important as some emission factors can be given in lb or kg of CO_2 per kWh or MT per kWh.

5.3 Comparing GHG Emission Factors

We used a variety of emission factors to examine how they may lead to different results. The ENERGY STAR Portfolio Manager uses eGRID emission factors. The GHG Protocol beta spreadsheet has default emission factors to support user preferences. For buildings located in the United States, 2018 eGRID subregion emission factors are used for location-based emissions. When this report was prepared, 2019 eGRID data were the most recent values available and could be added by the user. These eGRID total output emissions subregion data are the default value recommended by the EPA to assign scope 2 emissions from electricity use. For market-based emissions, 2018 Green-e energy residual mix emission rates are used by default, but 2019 values are also available. Some U.S. utilities provide annual average and residual mix emissions rates and have been recently compiled by the Edison Electric Institute (EEI) into a publicly available database. The most recent data available are from 2019.

The NREL Cambium database provides simulated emissions associated with electricity for years 2018–2050. The database provides hourly and annual data for states, balancing authorities, and eGRID subregions. While marginal rates are available, the load end-use averages were the most applicable for comparisons in this analysis. The Cambium data set's strength lies in future forecasting of the electricity grid and emissions comparisons of different future scenarios, not necessarily retrospective, absolute emissions accounting.

In order to use the hourly Cambium data and compare results using annual data, hourly emission rates are multiplied by hourly electricity data and then summed over one year. Annual emission rates are multiplied by cumulative electricity data over one year for annual emissions. These two annual values are then compared.

6 Results of Testing Approaches

6.1 Retail Building Emissions

Scope 2 emissions from purchased electricity were calculated using several methods, and results are shown in Figure 5. The left half of the figure (data in red) compares emissions using average emission factors, whereas the right half of the figure (data in orange) compares emissions calculated using residual emission factors. Average emissions calculated from the EEI database are within 6% of the emissions calculated using the GHG protocol. This difference is due to calculation from different data sources—the eGRID subregion compared to the utility specific region. Residual emissions from the EEI are slightly different (within 5%) due to the differences in utility and eGRID subregion areas. There can also be different definitions and methods for calculating residual mixes because there is no standard for this calculation. Green-e values are determined by subtracting all unique green-e energy certified sales from the total generation within each eGRID subregion. Total CO_2 emissions for each region are then divided by this new generation number. Specific residual mix emission rates from the EEI database are the average annual CO_2 emissions rate of electricity delivered to customers with accounting adjustments made for specified products. These specified products can include renewable energy credits that are retired on behalf of customers.

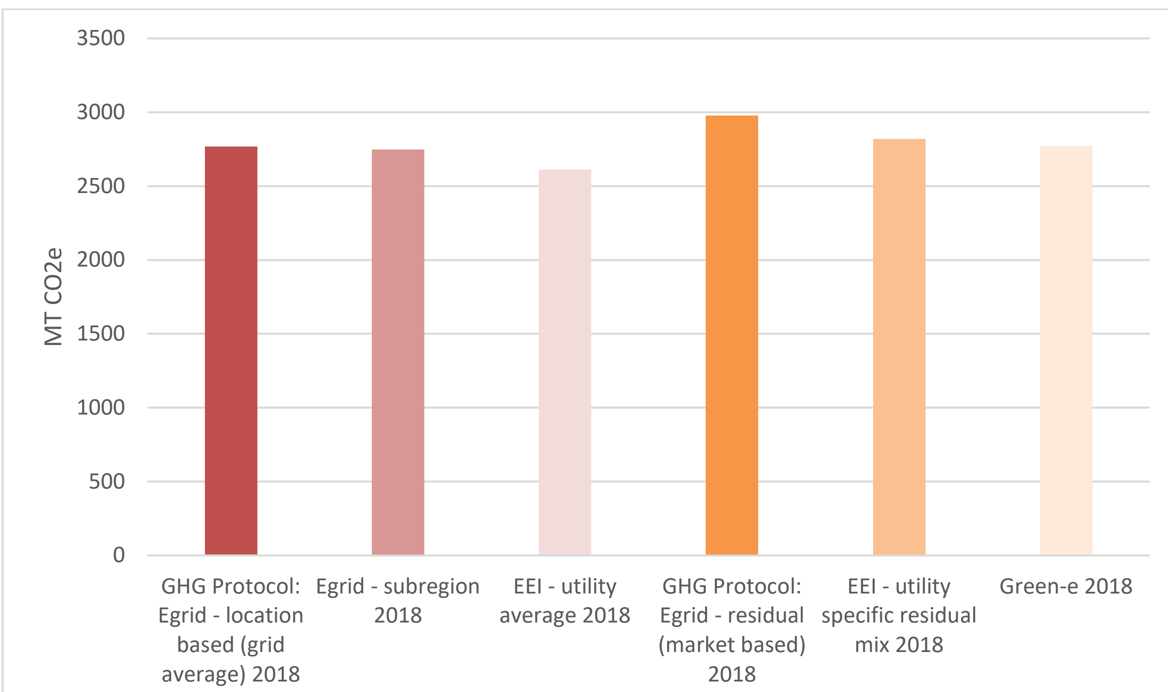

Figure 5. Scope 2 emissions for electricity use of a retail building using 2018 data. Data are organized by average and residual emission factors used. Average emissions are in red on the left side of the figure. Residual emissions are in orange on the right side.

Using the GHG Protocol, scope 1 and 2 emissions were calculated for three subsequent years. Results are shown in Figure 6. Scope 1 emissions associated with refrigerant leakage is estimated using 100-year GWP values. These emissions can make up 15%–20% of the total emissions when using Colorado electricity emissions data and could increase if GWP-20 values are used. If the analysis is completed in a location with a cleaner grid, such as California, emissions associated with refrigerant leakage make up a larger proportion of the total emissions.

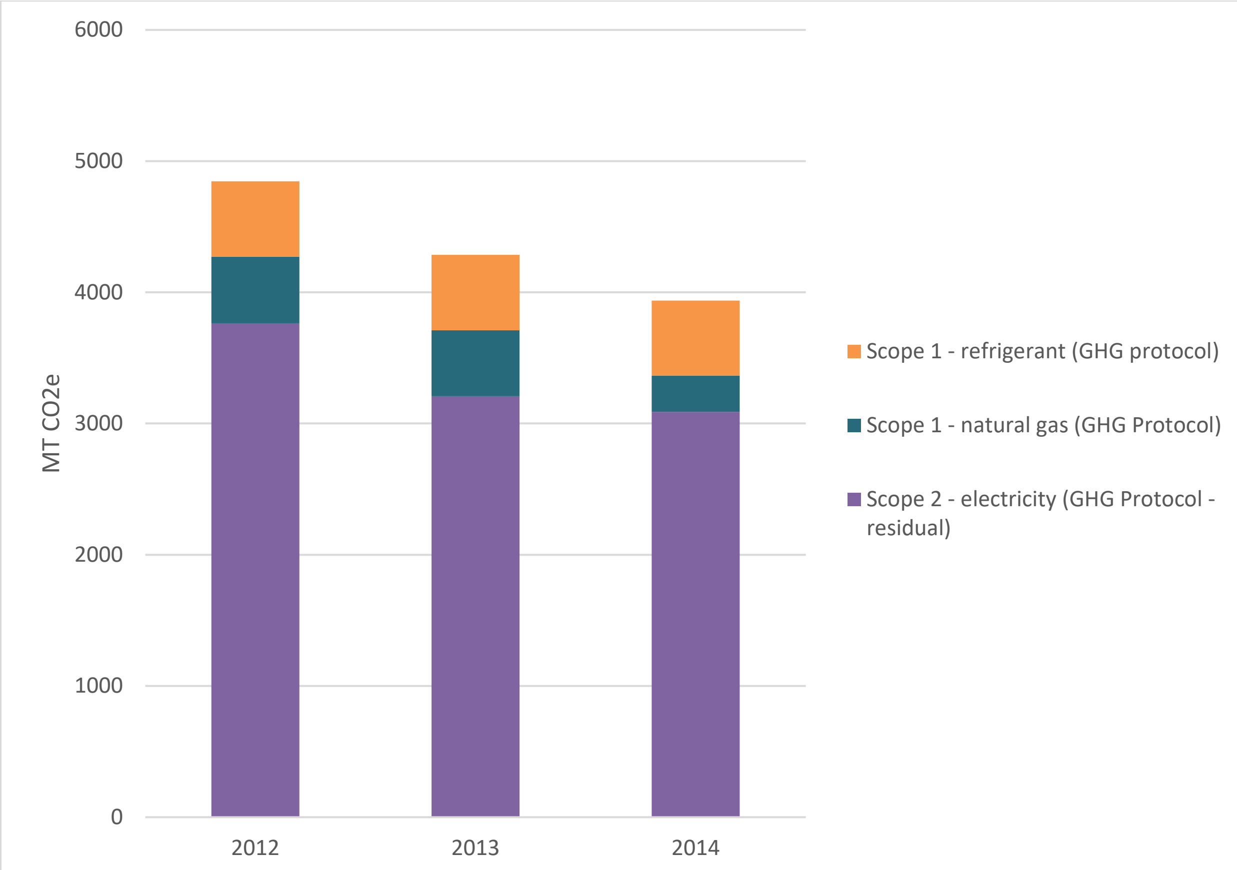

Figure 6. Scope emissions for retail building over three consecutive years for Colorado-based building in eGRID region RMPA using 2012 (for 2012 and 2013 electricity data) and 2014 (for 2014 electricity data) total output emission rate factors for scope 2 emissions.

Scope 1 emissions from natural gas decreased over the three years. Efficiency efforts may have caused a reduction of natural gas used. Similarly, we can see a decrease in emissions from electricity. Reasons could include efficiency efforts employed that resulted in less electricity used or a cleaner electricity grid resulted in less emissions. Weather patterns could also cause a reduction in electricity use, but this did not explain the reduction in this study.

6.2 Office Building Emissions

Similarly, emissions for the office building were compared using different available emission factors. Results comparing emissions from emission factors from the same year (2018) are shown in Figure 7. The left half of the figure (data in blue) compares emissions from average emission factors; the right half of the figure (data in purple) compares emissions from residual emission factors. Average emissions from the GHG Protocol, ENERGY STAR Portfolio Manager, and eGRID values were similar as expected. Average emissions calculated from the utility were 5% lower, which may be due to regional differences between utility service area and eGRID subregion. Residual emissions were within 7% of the GHG Protocol estimates, similar to the emission results for the retail building.

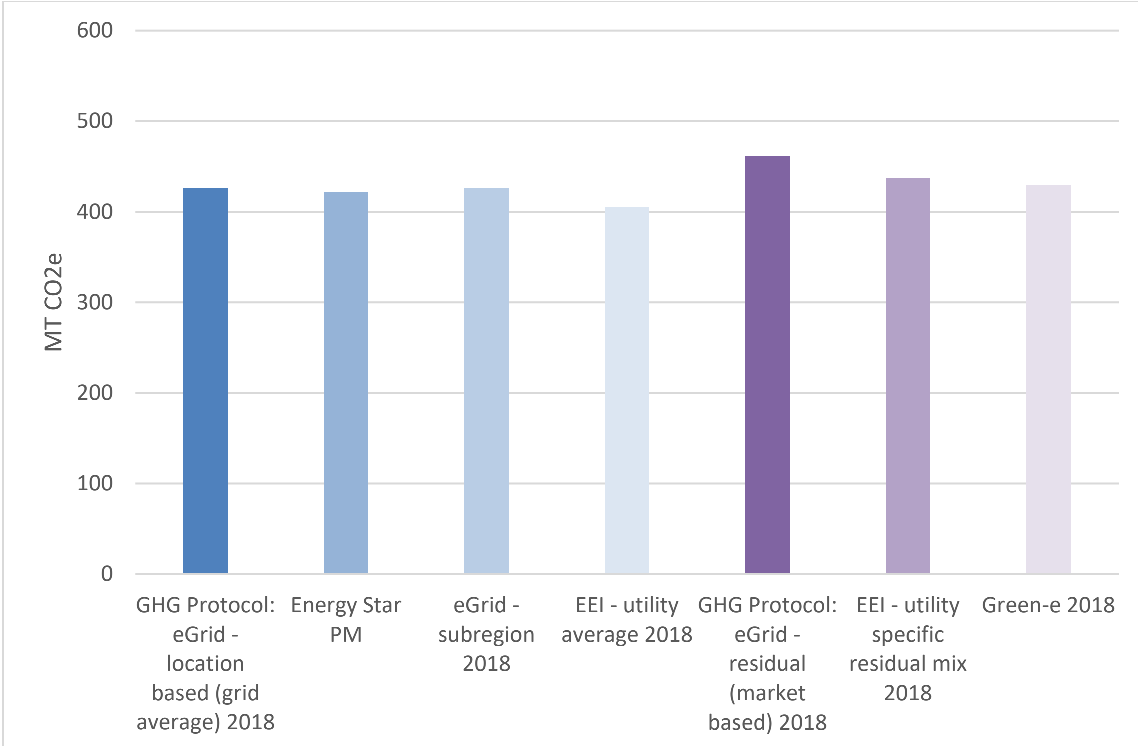

Figure 7. Scope 2 emissions for electricity use in office building using 2018 data

6.3 Emission Factor Comparison (Source)

To demonstrate the differences in emission factors, Figure 8 compares emission factors across different geographical locations. Average emission factors for eGRID subregions are in solid colors, average emission factors for state regions are patterned (diagonal lines), and residual emission factors are patterned (horizontal lines). Dark blue bars refer to emission factors from EPA eGRID, purple bars refer to emission factors from EEI, orange bars refer to data from Green-e.

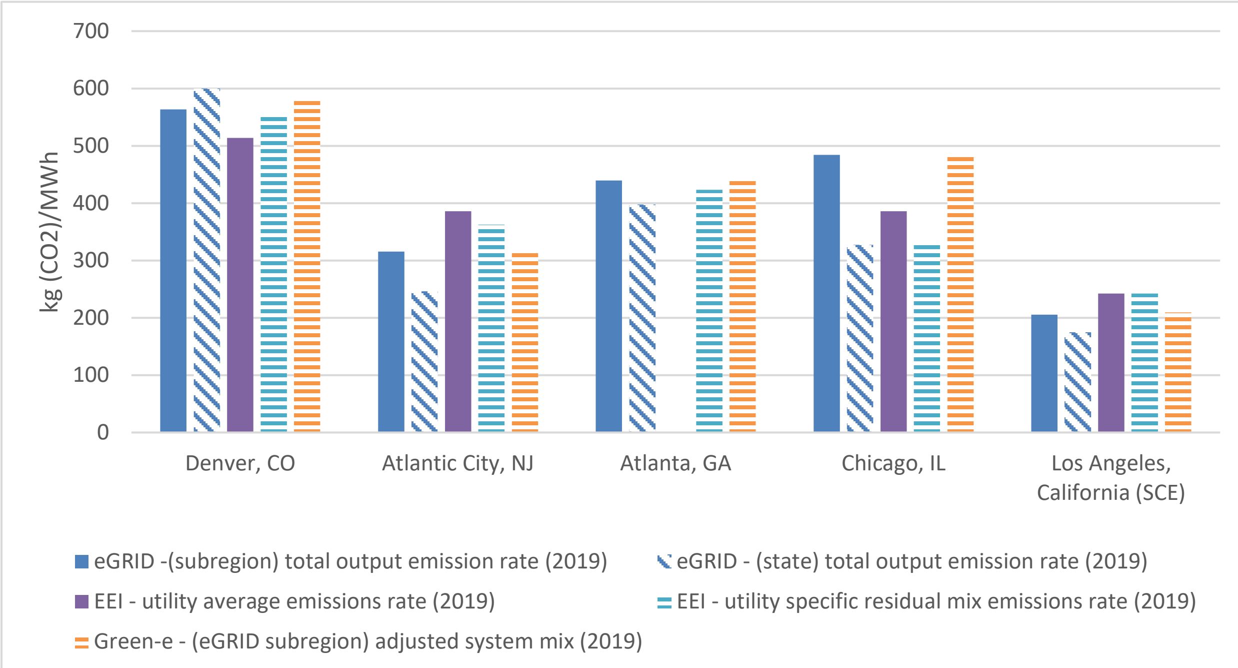

Figure 8. Emission factors for different locations across the United States. Data are organized by regional representation and by source of emission factor.

The highest and lowest emission factors vary by region. These emission factors can have significant ranges; for example, in Chicago, IL, the lowest emission factor is roughly 160 kg of CO_2 /MWh lower than the highest emission factor. Emission factors can be up to 33% different from the eGRID subregion factor, which is often used as the default factor. Factors that remove certified renewables (Green-e and EEI residual mix) are not similar, and one is not consistently higher than the other across regions. We expect residual emission factors to be equal or higher than the average by the definition of how they are calculated. Because this was not observed in every instance, it is important that users take a critical look at the data and compare to other sources when deciding what data to use, especially if the data are from less well-known sources.

We also compared eGRID emission factors over time, as shown in Figure 9. Emission factors tend to decrease over time, from 2004 to 2009 to 2018 for most eGRID subregions, indicating a cleaner electricity grid over time. However, this trend is not observed for all subregions (e.g., AKMS).

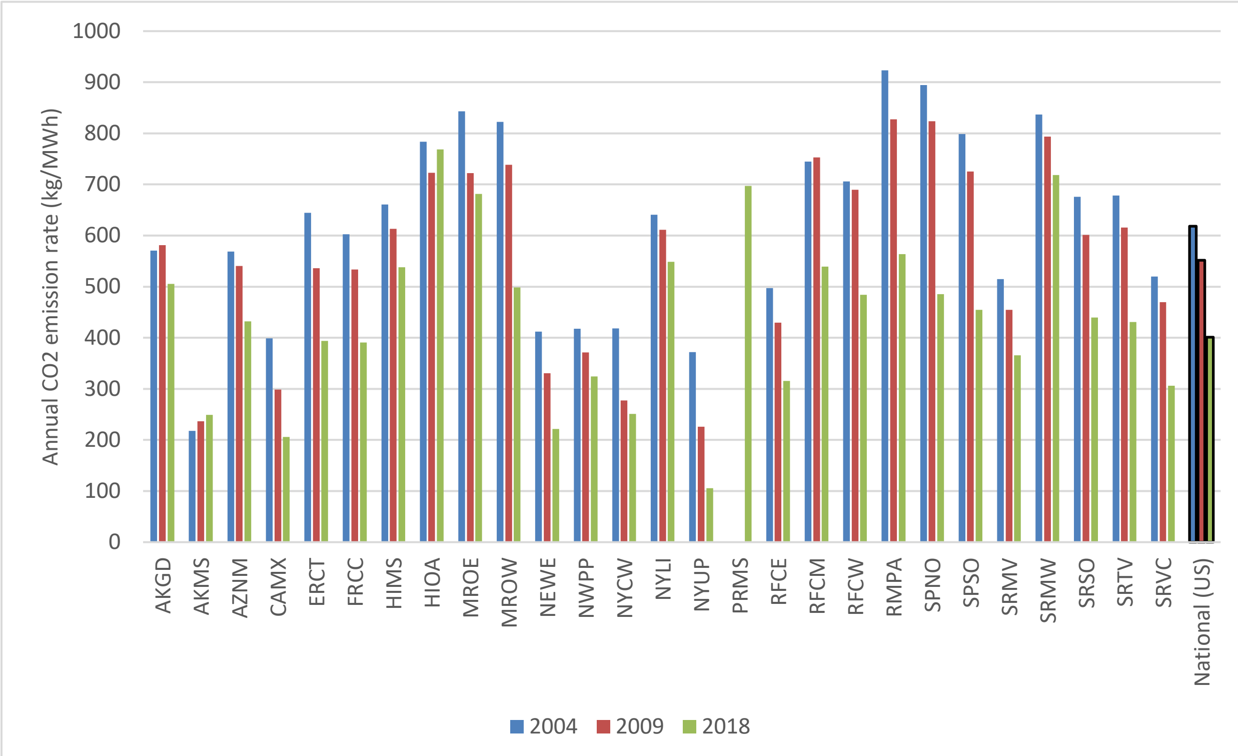

Figure 9. eGRID emission factors over time for eGRID subregions

6.4 Emission Factor Comparison (Hourly vs. Annual)

The NREL Cambium data set provides both annual and hourly emission rates, for state and balance authority regions.

To demonstrate the differences in emissions calculated by annual vs. hourly emissions, we compared annual emissions calculated using Cambium state annual and hourly data from different states, as shown in Figures 10 and 11.

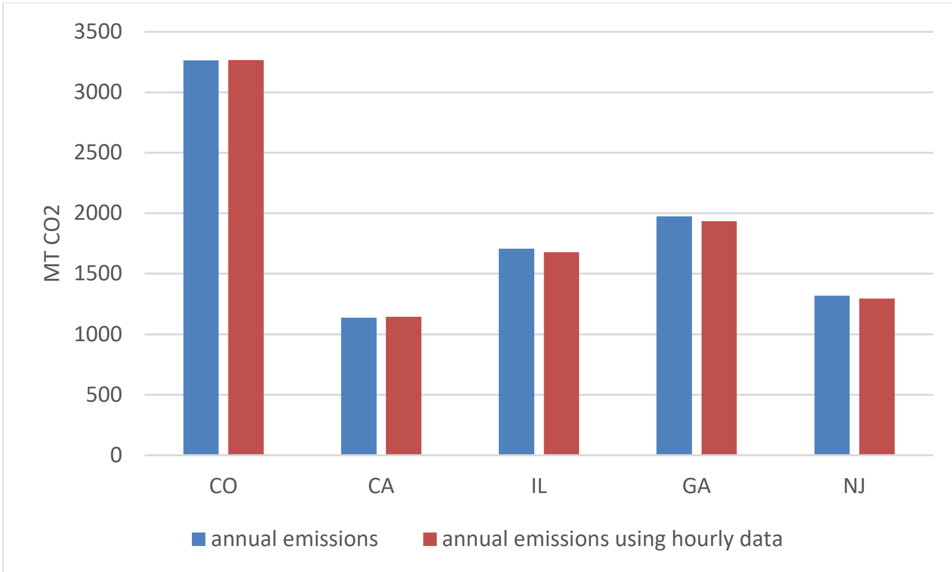

Figure 10. Emissions using annual and hourly emission factors from Cambium using example retail building data (2018)

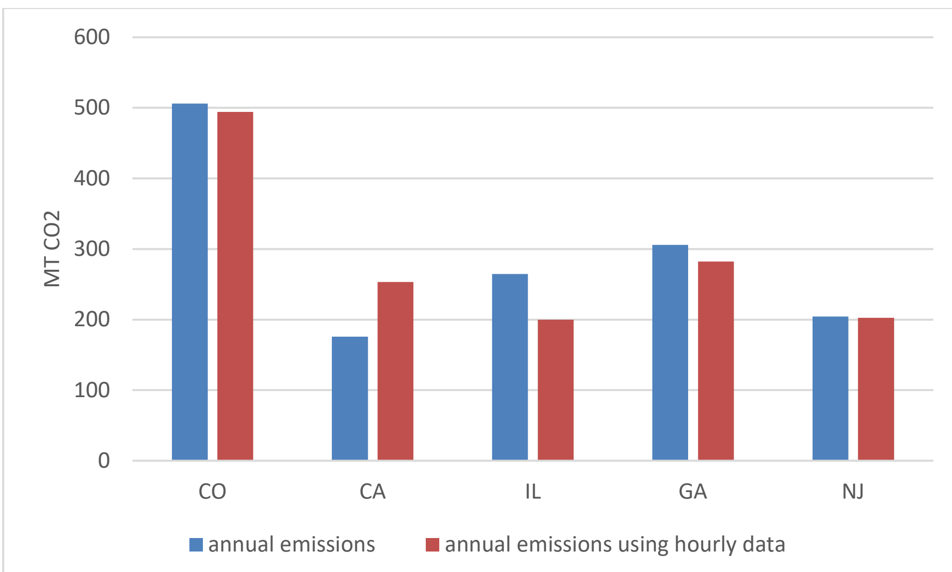

Figure 11. Emissions using annual and hourly emission factors from Cambium using example office data (2018)

Similar results between hourly and annual data for the retail building were observed. This observation is likely due to the load profile being consistent with the carbon emissions profile of the supply across the different regions. The office building data includes imported and exported electricity (on-site PV is included in this calculation). Load profiles across the United States differ due to when renewables or cleaner electricity sources are supplying the grid. California generally has a cleaner grid during the day when solar energy is online. Illinois relies on nuclear energy, and so the baseload of electricity is cleaner in the evening. This could explain the differences observed for annual and hourly results for California and Illinois in Figure 11.

As mentioned earlier, the Cambium database provides simulated emissions associated with electricity and is best used for future forecasting of the electricity grid and emissions comparisons and not for back casting or absolute emissions accounting. The actual mixture of generation will be different from what is modeled, driven by differences in weather, fuel costs, and sourcing.

7 Decision Support

One of the objectives of this project was to provide information to support decisions and approaches for reducing emissions. One of the first steps to reducing emissions is to measure current emissions. In Figure 6 we show an example of major emissions that a commercial building owner may observe. For this example, about 12% of total emissions comes from refrigerant leakage, 11% comes from natural gas usage, and the rest (77%) comes from electricity use. We estimate the emissions from electricity consumption by major end use: refrigeration (24% of total emissions), miscellaneous electric loads (22.5%), lighting (21.5%), and HVAC (9%). There are many ways to reduce these emissions, including implementing energy efficiency measures, replacing refrigerants with lower-GWP options, controlling refrigerant leaks, installing renewable energy generation, or purchasing green power or carbon offsets. Taking an accurate inventory of emissions is the first step in developing a decarbonization plan.

Table 5 shows an example of how a building owner or facility manager can consider alternate scenarios to reduce emissions. Starting with the baseline or business as usual (BAU) scenario, alternative solutions are considered for energy efficiency measures, improved refrigerant management, electrification, and renewable energy purchases. The table includes a partial list of measures. The format of the table allows the user to estimate the emissions savings and the cost per metric ton (MT) of avoided emissions. Example savings and emission reductions are based on a separate energy modeling project for a retail building and are provided for demonstration purposes. These calculations can be projected into the future with assumptions about changes in the grid emissions to develop a plot as shown in Figure 12. For future scenario planning, the Cambium data set provides estimated emissions for future grid scenarios. Finding the optimal solution may require iterations or an optimization routine. Installing energy efficiency measures to reduce the total electricity demand and meeting all or a portion of the remaining demand through renewable energy is generally the most cost-effective approach and should be considered by building owners (Alajmi et al. 2020; Allouhi et al. 2021).

Table 5. Representation of Emissions Reduction Scenarios

Scenario	Measure Cost	Energy Savings (MWh)	Emissions Factor (kg/MWh)	Emissions Reductions (MT)	Cost/MT CO_2 avoided
Baseline/BAU	NA	NA	NA	NA	NA
Lighting retrofit	$1,080,000	600,000	553	331,800	$3.25
Roof replacement, added insulation, and envelope air tightness	$1,800,000	130,000	553	71,890	$25.04
High-efficiency HVAC and ventilation control	$2,700,000	230,000	553	127,190	$21.23

Scenario	Measure Cost	Energy Savings (MWh)	Emissions Factor (kg/MWh)	Emissions Reductions (MT)	Cost/MT CO_2 avoided
Refrigeration system tune-up	$360,000	120,000	553	66,360	$5.42
Reduce refrigerant leakage					
Replace gas equipment with electric equipment					
Install onsite RE					
Purchase offsite RE					

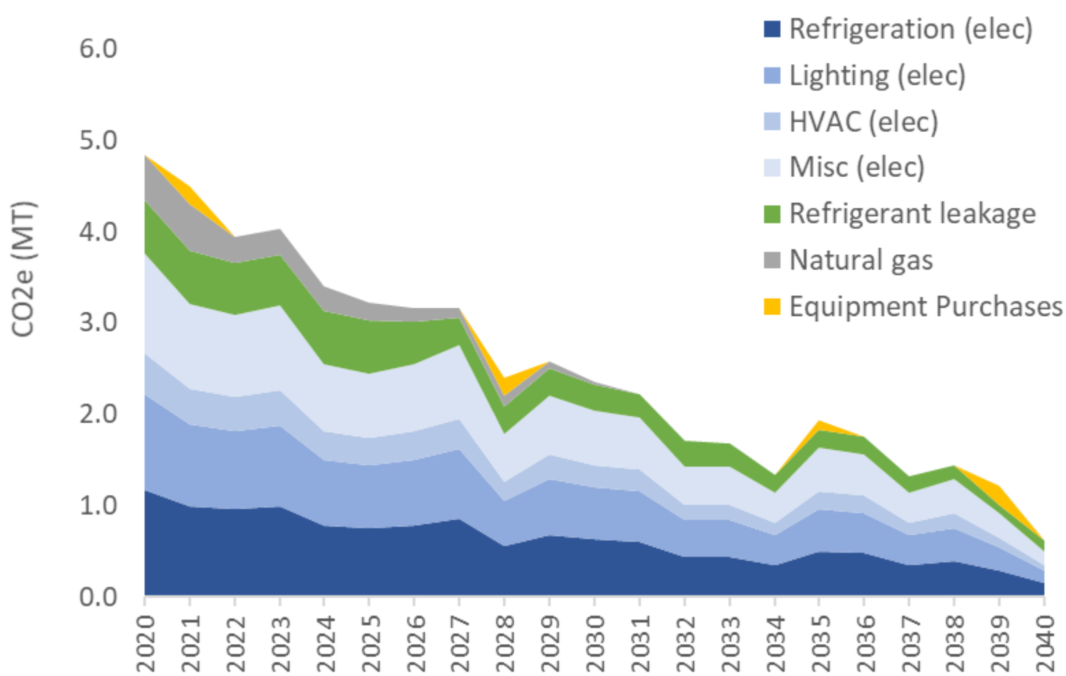

Figure 12. Example emissions reductions from efficiency measures, renewable energy purchases, and cleaner grid

8 Recommendations and Guidance

Throughout this report we describe existing approaches to emissions tracking, provide sources of emission factor data, compare the use of approaches and different sources of data using example building data, and describe how the approach can inform emissions reduction goals. Despite the availability of approaches and data, there can be several challenges associated with emissions tracking users should be aware of and consider when tracking their emissions (Deru 2010). Regardless of the framework or tool used, the following best practices can help commercial building owners address some of the challenges described previously.

1. Determine the goal of using a framework or tool; define the needs and what will be accomplished

2. Determine what level of uncertainty and risk is acceptable—historical and estimated data carry high levels of uncertainty, but real-time building energy data and utility grid data that provide more certainty are not readily available and can be cumbersome to handle

3. Determine the scope and clearly define boundaries for the analysis, specifically:

    a. The emission sources that will be included in the analysis and what detail levels are available
    b. The temporal and physical boundaries to define the time frame and what specifically will be included in the analysis (e.g., time frequency of data, types of fuels, building energy use, total facility energy use)
    c. The assumptions that are deemed acceptable (e.g., eGRID values for a particular year) because it is impossible to know where the energy comes from on the utility grid at every moment

In addition, there are several factors that should be considered during planning, analysis, and reporting:

1. Purchased off-site renewable electricity, which includes green power purchases and renewable energy credits, can be challenging to account for because the profile of the generated electricity is often not known.
2. 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.
3. On-site electric vehicle charging is growing and can have a significant impact on building energy consumption and the building load profile. Electric vehicle charging and discharging should be metered so that they can be properly included or subtracted from the building energy consumption.
4. Purchased carbon offsets are not all equal so it can be difficult to fully credit carbon offsets to building emissions.
5. Using different emission factors can result in variable results, as demonstrated above. Thus, it is important to choose the emission factors wisely.

a. It is important to be internally consistent in accounting in terms of tools and emission factors. Using different emission factors and comparing against a baseline calculated using different emission factors will result in false comparisons which may lead to actions that do not have intended effects of emissions reduction.
b. Consider using 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.

References

Alajmi, A., Short, A., Ferguson, J., Poel, K., Griffin, C. 2020. “Detailed energy efficiency strategies for converting an existing office building to NZEB: a case study in the Pacific Northwest.” *Energy Efficiency* 13 1089-1104.

Allouhi, A., Rehman, S., Krarti, M. 2021. “Role of energy efficiency measures and hybrid PV/biomass power generation in designing 100% electric rural hours: A case study in Morocco.” *Energy and Buildings* 236 110770.

ASHRAE 2020. *Standard for the Design of High-Performance Green Buildings Except Low-Rise Residential Buildings*. ANSI/ASHRAE/USGBC/IES Standard 189.1-2020. Atlanta, GA.

ASHRAE 2021. *Standard Methods of Determining, Expressing, and Comparing Building Energy Performance and Greenhouse Gas Emissions*. ANSI/ASHRAE Standard 105-2021. Atlanta, GA.

ASHRAE 2022. *Standard Method for Evaluating Zero Net Energy and Zero Net Carbon Building Performance.* BSR/ASHRAE Standard 228P. Atlanta, GA.

Canada Green Building Council. 2020. “Zero carbon building standard.” https://www.cagbc.org/zerocarbon.

Carton, W., A. Asiyanbi, S. Beck, H. Buck, J. Lund. 2020. “Negative emissions and the long history of carbon removal.” *WIREs Climate Change*. https://doi.org/10.1002/wcc.671

Deru, M.; Torcellini, P. 2007. *Source Energy and Emission Factors for Energy Use in Buildings (Revised).* 39 pp.; NREL Report No. TP-550-38617. https://www.nrel.gov/docs/fy07osti/38617.pdf.

Deru, M. 2010. “Moving Toward Better GHG Calculations for Buildings.” ASHRAE Annual Meeting, June 2010. ASHRAE Transactions Vol. 116 (2) 1 October 2010 pp. 652-661.

EIA 2021. “Monthly Energy Review, preliminary data for 2020.” U.S. Energy Information Administration: Washington, DC. https://www.eia.gov/totalenergy/data/monthly.

EIA 2022. Hourly Electric Grid Monitor U.S. Energy Information Administration: Washington, DC. https://www.eia.gov/electricity/gridmonitor/dashboard/electric_overview/US48/US48.

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.

ENERGY STAR Portfolio Manager. https://www.energystar.gov/buildings/benchmark.

EPA Center for Corporate Climate Leadership. “Simplified GHG Emissions Calculator.” https://www.epa.gov/climateleadership/simplified-ghg-emissions-calculator.

EPA. 2020. "Emissions & Generation Resource Integrated Database (eGRID)." U.S. Environmental Protection Agency: Washington, DC. https://www.epa.gov/egrid.

Green-e Residual Mix Emission Rate. https://www.green-e.org/residual-mix

Greenhouse Gas Protocol Corporate Standard. World Resources Institute: Washington, D.C. and WBCSD: Geneva, Switzerland. https://ghgprotocol.org/calculation-tools#cross_sector_tools_id.

IPCC 2007: The Intergovernmental Panel on Climate Change (IPCC), "Climate Change 2007: The Physical Science Basis," Chapter 2, Changes in Atmospheric Constituents and in Radiative Forcing. https://archive.ipcc.ch/report/ar4/wg1/.

IPCC 2013: The Intergovernmental Panel on Climate Change (IPCC), "Climate Change 2013: The Physical Science Basis," Chapter 8, Anthropogenic and Natural Radiative Forcing. https://archive.ipcc.ch/report/ar5/wg1/.

NREL. 2020. "Cambium emissions data." National Renewable Energy Laboratory: Golden, CO. https://cambium.nrel.gov/.

Satre-Meloy, A. and Langevin, J. 2019. "Assessing the time-sensitive impacts of energy efficiency and flexibility in the US building sector." *Environ. Res. Lett.* 14, 124012.

UK Green Building Council. 2019. "Net Zero Carbon Buildings Guide." https://www.ukgbc.org/ukgbc-work/net-zero-carbon-buildings-a-framework-definition/.

UNEP, IEA 2021. International Energy Agency for the Global Alliance for Building and Construction (GlobalABC). GlobalABC 2021 Global status report.

U.S. Green Building Council. LEED v4.1. Operations and Maintenance Guide. https://www.usgbc.org/leed/v41.

WattTime 2020. "Near real time hourly emissions data." https://www.watttime.org/.

World Business Council for Sustainable Development. 2020. Building System Carbon Framework. https://www.wbcsd.org/Programs/Cities-and-Mobility/Sustainable-Cities/Transforming-the-Built-Environment/Decarbonization/Resources/The-Building-System-Carbon-Framework.

World Business Council for Sustainable Development and World Resources Institute. 2014. Global Protocol for Community-Scale GHG Emissions Inventories. https://www.c40knowledgehub.org/s/article/The-Global-Protocol-for-Community-Scale-Greenhouse-Gas-Emission-Inventories-GPC?language=en_US