On the Comparison of Greenhouse Gas (GHG) Emissions Estimation Standards

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1. Introduction

The aim of this case study is to provide a panoramic view of existing GHG standards. This panoramic view includes (1) what is GHG emission estimation/calculation method used by each Canadian and major international body, (2) what are the online/offline tools they are providing for GHG emissions calculation, (3) if they are providing Web services or APIs for machine-to-machine communications that can facilitate GHG data sharing and educating individuals and enterprises on GHG, (4) if they provide open data free accessible by public users, and (5) if the calculations differ by various Canadian and major international bodies, why so.

GHG standards from different bodies are focused on specific sectors or regions, and they are not the competitor of each other. Most of the cases standards rely on emission factors provided by IPCC (Intergovernmental Panel on Climate Change) for different fuel types with an exception for ISCC (International Sustainability and Carbon Certification) as it uses its own emission factors. Calculation methods also vary depending on the sector. Each standard may support multiple estimation methods. For example, all most all the standards support emission factor-based estimation, which is an approximation-based technique. However, the ECCC (Environment and Climate Change Canada), for example, also propose other types of estimation, e.g., Monitoring or Direct Measurement, Mass Balance, and Engineering Estimates.

In general, it is not obvious that one can make a direct comparison to conclude any specific standard is better than others. Nevertheless, if one wants to calculate and compare GHG emissions from two properties located in two different countries/regions, he needs to make sure that he is applying country-specific emission factors for each fuel. There are certain online tools, however, there is no generic and complete tool available for GHG emission estimation regardless of regions/countries and sectors.

It is important to estimate and track GHG emissions over time. One wants to estimate or track the reduction of GHG emissions as it will save energy and thus his bills. The ultimate goal of GHG reduction is to prevent the impact of climate change. This case study will be useful for individuals who want to have a clear understanding of GHG estimation methods by major GHG standards. Also, small companies and research agencies whose interest of business aligns with GHG emission can find it useful. Developers and environmentalists who continuously look to develop/improve their tools to measure GHG emissions can easily target this case study.

1.1 Background

Greenhouse Gas (GHG) is a gas in the atmosphere that absorbs and emits radiation, which increases the global temperature over time as the GHG in the atmosphere increases. This process is known as the greenhouse effect. The goal of this case study is to document commonality between standards and review ease of use of standards throughout the world in calculating GHG emissions. We look to see if there are differences in the varying GHG calculations when considering using the calculation on a single building footprint to manage its “carbon footprint”.

We also look at the reuse of the standards to consider management and baselining of a portfolio of buildings throughout the world.

Primary greenhouse gases include Carbon Dioxide ($\text{CO}_2$), Methane ($\text{CH}_4$), Nitrous Oxide ($\text{N}_2\text{O}$), and Sulfur Hexafluoride ($\text{SF}_6$). There are 24 different types of GHG including those four major ones, 13 variations of Hydrofluoro Carbons (HFCs), and seven variations of Perfluoro Carbons (PFCs), which are known as the Kyoto Protocol GHGs. All these GHG have different global warming potentials (GWP). The GWP is a relative measure of how much heat a greenhouse gas traps in the atmosphere. It compares the amount of heat trapped by a certain mass of the gas in comparison to the amount of heat trapped by a similar mass of $\text{CO}_2$. All the measures are done compared to $\text{CO}_2$ since this is the most commonly emitted GHG (the complete list of GHGs is presented in Appendix, Table 3).
The term ‘carbon footprint’ is a common way to express GHG emissions in a universal manner. Wright, Kemp, and Williams, have suggested to define the carbon footprint as "a measure of the total amount of carbon dioxide (CO₂) and methane (CH₄) emissions from a defined population, system or activity, considering all relevant sources, sinks and storage within the spatial and temporal boundary of the population, system or activity of interest, calculated as carbon dioxide equivalent using the relevant 100-year GWP." GHGs can be emitted through land clearance and the production and consumption of food, fuels, manufactured goods, materials, wood, roads, buildings, transportation and other services. For simplicity of reporting, it is often expressed in terms of the amount of carbon dioxide, or its equivalent of other GHGs, emitted.

1.2 GHG Emissions Due to Human Activities - Buildings

GHG emission has harmful effects on our ecosystem and biodiversity. It has been estimated that all commercial buildings are responsible for around one-fourth of total GHG emissions. The GHG emissions are mainly from two areas (1) direct emission (e.g., oil, gas, etc.) and (2) indirect emission (e.g., electricity, district steam, district heating, district cooling, etc.). There is another category of emission that is based on biomass emissions. This can be caused by, for example, burned wood.

In Canada, all parties who operate a facility with emitting Carbon Dioxide (CO₂) equivalent GHG equal to or more than 50 kilo-tonne (kt) must report their total GHG emissions by June 1st every year. This is known as the reporting threshold. Anyone not crossing the threshold can optionally report their GHG emissions. In contrast to the GHG, there exists green power which includes solar, wind, geothermal, low-impact biomass/hydro resources. All these together represent renewable energy, which will also be touched on in this report.

In reducing and–or managing GHG emissions, we need to objectively measure and find ways for comparison, but there are challenges in doing this. From a GHG point of view, different gases have different impacts on global warming. The GWP is an index which attempts to make these different impacts comparable by calculating the global warming impact over a period of 100 years of the different gases in comparison to CO₂.

Scientists, and in turn the calculations, aggregate all the gases into one category of ‘carbon dioxide equivalent’, yet it is widely acknowledged that this faces many difficulties and challenges with accuracy, introducing some margin of error [10]. This accuracy error further escalates in trying to measure GHG emissions. The Intergovernmental Panel on Climate Change (IPCC) guidelines on how to calculate and account for GHGs suggest that uncertainties for carbon dioxide are up to 10% for electricity generation and industrial processes including cement and fertilizer production, and up to 60% for land use change and forestry.

Electricity and natural gas consumption are often the largest sources of emissions within individual and corporate GHG inventories, and it is, therefore, important to report these emissions correctly. Unfortunately, it is common for reporting parties to misreport the emissions associated with transmission and distribution (T&D) losses [11].

To further complicate things, there are issues in GHG emissions calculations at the national and international level. Recent BBC findings [12], [13] show that several climate-warming gases are being emitted into the atmosphere but are not being recorded in official inventories. For example, air monitors in Switzerland have detected large quantities of one gas coming from a location in Italy but the Italian submission to the UNFCCC records just a tiny amount of the substance being emitted. As well, levels of some emissions from India and China are so uncertain that experts say their records might vary 100%. All these flaws pose a threat to the Paris climate agreement and automating the calculating of GHGs as commonality and standardization of calculating GHG and access to common data sets is still in its infancy.

1.3 GHG Standards and Emission Estimation

To properly calculate the GHG emissions a clear understanding of standards, their relationships, the similarities and dissimilarities among them is important. In this case study, we try to achieve these goals by presenting the standards in brief and as simple as possible terms, then compare them at a high-level. Our findings suggest that GHG calculations may vary based on the estimation methodology one follows and the default CO₂-equivalent emission
factors one applies. We also found that besides many natural and agricultural factors, human and manufacturing activities inside residential and industrial buildings play a major role in GHG emissions. This case study highlights key differences in each GHG emission estimation standard, i.e., how they estimate GHG emissions and why they vary in final emission value if a variance exists.

In the following section, we identify and relate the major international and Canadian bodies that deal with GHG emissions. Section 1.4 provides a “sample” property located in Toronto, Canada for which we will calculate the GHG standards from different international and Canadian bodies. The international and Canadian bodies in this case study include: Environment and Climate Change Canada (ECCC), Natural Resources Canada (NRCan), and Government of Ontario (ONgov) in Section 2, United Nations Environment Programme (UNEP) in Section 3, United States Environmental Protection Agency (EPA) in Section 4, International Sustainability and Carbon Certification (ISCC) in Section 5, World Resources Institute (WRI) in Section 6, European Environment Agency (EEA) in Section 7, and Food and Agriculture Organization of the United Nations (FAO) in Section 8. In Section 9, we discuss the similarities and differences, then we conclude the case study in Section 10.

1.4 Actors and Responsibilities in GHG Inventory

The Intergovernmental Panel on Climate Change (IPCC) is the leading international body for the assessment of climate change. It was established in 1988 by the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO), to provide the world with a clear scientific view on the current state of knowledge on climate change, and its potential environmental and socio-economic impacts.

Since 1992, the IPCC has prepared methodologies and guidelines (IPCC National Greenhouse Gas Inventories Programme) to assist the parties to the United Nations Framework Convention on Climate Change (UNFCCC) and its Kyoto Protocol in preparing national inventories of GHG emissions by sources and removals by sinks. A source is any process or activity through which a GHG is released into the atmosphere and a sink is an element or reservoir that takes up a chemical element or compound (e.g. CO2) from another part of its natural cycle. Examples of the sink are trees/vegetation that can carbon dioxide as they grow and oceans that absorb carbon dioxide released into the atmosphere through human activities.

In summary, based on the 1995 report from IPCC, the Kyoto Protocol was proposed in 1997. According to the Kyoto Protocol parties are legally committed to reduce or limit GHG emissions. This protocol also acts as the basis for GHG emission data for the parties to report their GHG emissions to UNFCCC. UNFCCC foresees industrial countries to stabilize their GHG emission level and facilitate its member countries with the budget, technology, and capacity transfer. Each member country is responsible for submitting annual GHG emission data to UNFCCC. Corporate groups and large manufacturing companies also prepare and submit their GHG emission reports to WRI based on its own GHG Protocol. WRI facilitates businesses and corporate bodies with accounting, reporting standards, calculation tools, and training. EEA is also in compliance with UNFCCC and IPCC standards and compiles its GHG emissions report to UNFCCC. The US counterpart of EEA – the EPA – follows the WRI guidelines for GHG emissions calculations.
With each standard having its own estimation methodology, constraints, and thresholds/emission factors, the greenhouse gas emissions estimation is not a straightforward task. Different bodies are required to cooperate, due to their interdependency. For example, all governmental bodies should adhere to UNFCCC framework for GHG inventory, the UNFCCC itself should maintain consistency with IPCC that is the highest intergovernmental body. Again, the IPCC accounts to UNEP. In summary, with every party in operation, it becomes difficult to be consistent and without discrepancy.

1.5 An Example Property

In this case study, in addition to summarizing the calculation process for each standard, we will also reflect the GHG emission calculations using common property in Toronto, Canada. To standardize our results, we will be using a record from the publicly available energy usage data for the year 2011 for a facility. The table below summarizes the energy consumption data of this location which is also publicly available here. We randomly chose this facility as our running example facility to replicate each GHG emission estimation methodology.

Previously this facility hosted only 'Albion Neighbourhood Services' and starting from March 1st, 2012 it is hosting 'Rexdale Community Hub'. Thus, the reported electricity and gas consumption values are only for 'Albion Neighbourhood Services'. This is the reason from the year 2012 the electricity and natural gas use are not steady, i.e., in the years 2012-2014, at least 25% higher than the year 2011.
2. Greenhouse Gas Emission Reporting Standards in Canada

In this section, we will focus on three parties in Canada who are dealing with GHG emissions and GHG inventory namely Environment and Climate Change Canada (ECCC) - Section 2.1, Natural Resources Canada (NRCan) - Section 2.2, and Government of Ontario (ONGov) - Section 2.3.

2.1 Technical Guidance on Reporting Greenhouse Gas Emissions by Environment and Climate Change Canada (ECCC) [1]

The current Canadian GHG reporting requirements demand that all individuals and businesses who operate a facility that emits 50,000 tonnes of carbon dioxide (CO₂) equivalent, i.e., the reporting threshold, or more of GHGs in the calendar year must report their emissions information to Environment and Climate Change Canada (ECCC). In general, the total GHG emissions are calculated as the sum of the total mass of each of the gases or gas species multiplied by their respective GWP as shown in the equation below.

\[
\text{Total Emissions} = \sum \left( \frac{E_{\text{CO}_2} \times GWP_{\text{CO}_2}}{i} \right) + \sum \left( \frac{E_{\text{CH}_4} \times GWP_{\text{CH}_4}}{i} \right) + \sum \left( \frac{E_{\text{N}_2\text{O}} \times GWP_{\text{N}_2\text{O}}}{i} \right) + \sum \left( \frac{E_{\text{HFC}} \times GWP_{\text{HFC}}}{i} \right) + \sum \left( \frac{E_{\text{PFC}} \times GWP_{\text{PFC}}}{i} \right) + \sum \left( \frac{E_{\text{SF}_6} \times GWP_{\text{SF}_6}}{i} \right)
\]

where,

\( E \) = total emission of a particular gas or gas species from the facility (tonnes);
\( GWP \) = global warming potential of the same gas or gas species;
\( i \) = each emission source;

Like in the WRI standard for GHG emissions (as followed by EPA), the CO₂ emissions from biomass materials must not be included in the threshold calculation. But if a party’s reporting requirements are met, the CO₂ emissions from biomass combustion must be calculated and reported separately as part of its GHG information. Unlike the WRI standard, Methane (CH₄) and Nitrous Oxide (N₂O) emissions from biomass-related sources must be included in the reporting threshold calculation and reported as part of the GHG emission totals, to meet reporting requirements.
GHGs that are subject to mandatory reporting are listed in Table 2, which is also mandated by the WRI standard and followed by EPA. The GWPs listed in Table 2 are updated values suggested by the Intergovernmental Panel on Climate Change (IPCC).

As described in Section 1 and well documented in the ECCC guidelines, there are several methods for GHG estimation: (i) Monitoring or Direct Measurement – through continuous emission monitoring system, predictive emission monitoring, or source testing, (ii) Mass Balance – involves the application of the law of conservation of mass to a facility, process or piece of equipment, (iii) Emission Factors – estimates the rate at which a pollutant is released into the atmosphere as a result of some process activity or unit throughput, (iv) Engineering Estimates – involves estimating emissions based on engineering principles and judgment, using knowledge of the chemical and physical processes involved, the design features of the source, and an understanding of the applicable physical and chemical laws. However, the method in (i) and (iii) are the most commonly used for GHG emissions estimation. Accordingly, the general method to calculate GHG emissions looks like:

\[ \text{Emissions}_{\text{GHG,fuel}} = \text{Fuel Consumption}_{\text{fuel}} \times \text{Emission Factor}_{\text{GHG,fuel}} \]

where,
\[ \text{Emissions}_{\text{GHG,fuel}} = \text{emission of a given GHG by type of fuel (Kg GHG)} \]
\[ \text{Fuel Consumption}_{\text{fuel}} = \text{amount of fuel combusted (TJ)} \]
\[ \text{Emission Factor}_{\text{GHG,fuel}} = \text{default emission factor of a given GHG by type of fuel (kg gas/TJ). For CO}_2, \text{ it includes the carbon oxidation factor, assumed to be 1.} \]

2.1.1 Calculation of GHG in Detail

The ECCC calculations cover the GHG emissions from general stationary combustion for example from fossil fuels, biomass, and other fuels listed in Table 20-1. However, these calculations are appropriate for generation sites and may not suitable for energy use at the residential and commercial buildings.

Calculation of CO₂ Emissions:

For the calculation of CO₂, CH₄ or N₂O emissions ECCC provides multiple methodologies. In the following, we briefly discuss a few of them.

The Calculation Methodology 1 uses one of the following equations to calculate the annual CO₂ emissions from the combustion of each type of fuel:

\[ \text{CO}_2 = \text{Fuel} \times (\text{HHV} \times \text{EF}) \times 0.001 \]
\[ \text{CO}_2 = \text{Fuel} \times \text{EF}_c \times 0.001 \]

where,
\[ \text{CO}_2 = \text{Annual CO}_2 \text{ emissions from the combustion of the specific fuel type, expressed in tonnes.} \]
\[ \text{Fuel} = \text{Quantity of the fuel combusted in the calendar year, expressed in tonnes for solid fuels, standard cubic meters for gaseous fuels, and kilolitres for liquid fuels as measured in accordance with ON.25(b).} \]
\[ \text{HHV} = \text{Default high heat value of the fuel contained in Table 20-1 or Table 20-1a, expressed in GJ per tonne of solid fuel, GJ per kilolitre of liquid fuel, or GJ per cubic meter of gaseous fuel.} \]
\[ \text{EF} = \text{Fuel-specific default CO}_2 \text{ emission factor contained in Tables 20-1a, 20-2, 20-3, 20-5, or 20-7, expressed in kg of CO}_2 \text{ per GJ.} \]
\[ \text{EF}_c = \text{Fuel-specific CO}_2 \text{ default emission factor from Tables 20-2, 20-3, or 20-5, expressed in kg of CO}_2 \text{ per tonne of solid fuel, kg of CO}_2 \text{ per kilolitre of liquid fuel, or kg of CO}_2 \text{ per cubic meter of gaseous fuel.} \]
\[ 0.001 = \text{Conversion factor from kilograms to tonnes.} \]
On the other hand, the *Calculation Methodology 2* calculates the annual CO\textsubscript{2} mass emissions using the equation below and using a default fuel-specific CO\textsubscript{2} emission factor and a high heat value provided by the supplier or measured by the person.

\[ CO_2 = \sum_{p=1}^{n} \text{Fuel}_p \times HHV_p \times EF \times 0.001 \]

where,
- \(CO_2\) = Annual CO\textsubscript{2} emissions from the combustion of the specific fuel type, expressed in tonnes.
- \(n\) = Number of required heat content measurements for the year as specified in ON.25.
- \(\text{Fuel}_p\) = Quantity of the fuel combusted during the measurement period “\(p\)”, expressed in tonnes for solid fuels, standard cubic meters for gaseous fuels, and kilolitres for liquid fuels as measured in accordance with ON.25(b).
- \(HHV_p\) = High heat value of the fuel for measurement period “\(p\)” calculated in accordance with ON.25(d) and ON.25(e), expressed in GJ per tonne of solid fuel, GJ per bone-dry tonne of biomass solid fuel, GJ per kilolitre of liquid fuel, or GJ per cubic meter for gaseous fuels.
- \(EF\) = Fuel-specific default CO\textsubscript{2} emission factor contained in Tables 20-1a, 20-2, 20-3, 20-5, or 20-7 expressed in kg of CO\textsubscript{2} per GJ.
- 0.001 = Conversion factor from kilograms to tonnes.

The *Calculation Methodology 3* uses any of the equations below as applicable to calculate the annual CO\textsubscript{2} emissions from the combustion of each type of fuel:

For a solid fuel:

\[ CO_2 = \sum_{i=1}^{n} \text{Fuel}_i \times CC_i \times 3.664 \]

where,
- \(CO_2\) = Annual CO\textsubscript{2} emissions from the combustion of the specific solid fuel, expressed in tonnes.
- \(n\) = Number of carbon content determinations for the year as specified in ON.25(a) and (j).
- \(\text{Fuel}_i\) = Quantity of the solid fuel combusted in measurement period “\(i\)”, expressed in tonnes as measured in accordance with ON.25(b).
- \(CC_i\) = Carbon content of the solid fuel, from the fuel analysis results for measurement period “\(i\)” calculated in accordance with ON.25(j), expressed in tonnes of C per tonne of fuel.
- 3.664 = Ratio of molecular weights, CO\textsubscript{2} to carbon.

For a liquid fuel:

\[ CO_2 = \sum_{i=1}^{n} 3.664 \times \text{Fuel}_i \times CC_i \]

where,
- \(CO_2\) = Annual CO\textsubscript{2} emissions from the combustion of the specific liquid fuel, expressed in tonnes.
- \(n\) = Number of required carbon content determinations for the calendar year, as specified in ON.25(a).
- \(\text{Fuel}_i\) = Volume of the liquid fuel combusted in measurement period “\(i\)” as specified in ON.25(b), expressed in kilolitres.
- \(CC_i\) = Carbon content of the liquid fuel, from the fuel analysis results for measurement period “\(i\)” calculated in accordance with ON.25(j), expressed in tonnes of C per kilolitre of fuel.
- 3.664 = Ratio of molecular weights, CO\textsubscript{2} to carbon.

For a gaseous fuel:

\[ CO_2 = \sum_{i=1}^{n} 3.664 \times \text{Fuel}_i \times CC_i \times 0.001 \]
where,

\[ \text{CO}_2 = \text{Annual CO}_2 \text{ mass emissions from combustion of the specific gaseous fuel, expressed in tonnes.} \]

\[ n = \text{Number of carbon content determinations for the calendar year, as specified in ON.25(a).} \]

\[ \text{Fuel}_i = \text{Volume of fuel combusted in period “}i\text{”, expressed in Rm}^3 \text{ at a reference temperature and pressure conditions as used by the facility, or expressed in kg if a mass flow meter is used as measured in accordance} \]

\[ \text{CC}_i = \text{Carbon content of the gaseous fuel, from the fuel analysis results for the period “}i\text{” calculated in accordance} \]

\[ 3.664 = \text{Ratio of molecular weights, CO}_2 \text{ to carbon}. \]

\[ 0.001 = \text{Conversion factor from kg to tonnes}. \]

**Calculation of CH}_4\text{ and N}_2\text{O Emissions:**}

_Calculation Methodology 1_ uses any of the following equations (as applicable) to calculate the annual CH}_4\text{ and N}_2\text{O emissions from the combustion of each fuel.}

For non-coal fuel,

\[ E = \sum_{i=1}^{n} \text{Fuel}_i \times \text{HHV} \times \text{EF} \times 0.000001 \]

For coal,

\[ E = \sum_{i=1}^{n} \text{Fuel}_i \times \text{EF}_c \times 0.001 \]

where,

\[ E = \text{Annual CH}_4\text{ or N}_2\text{O emissions from a specific fuel type, expressed in tonnes.} \]

\[ \text{Fuel}_i = \text{Quantity of the fuel combusted during measurement period “}i\text{”, expressed in tonnes for solid fuels, standard cubic meters for gaseous fuels, and kilolitres for liquid fuels.} \]

\[ \text{HHV} = \text{Default high heat value for fuel type “}i\text{” contained in Table 20-1 or 20-1a expressed in GJ per tonne of solid fuel, GJ per kilolitre of liquid fuel, or GJ per cubic meter of gaseous fuel.} \]

\[ \text{EF} = \text{Default CH}_4\text{ or N}_2\text{O emission factor for fuel type contained in Tables 20-2 or 20-4, as applicable, expressed in grams CH}_4\text{ or N}_2\text{O per GJ or an equipment-specific emission factor contained in US EPA AP-42 as appropriate.} \]

\[ \text{EF}_c = \text{Default CH}_4\text{ or N}_2\text{O emission factor for each coal type contained in Table 20-6, expressed in grams CH}_4\text{ or N}_2\text{O per kg of coal or an equipment-specific emission factor.} \]

\[ 0.000001 = \text{Conversion factor from grams to tonnes.} \]

\[ 0.001 = \text{Conversion factor from g/kg to tonnes/tonne.} \]

Similarly, both above formulas can be recalculated using the HHV values provided by the fuel supplier or material vendor.

**2.1.2 Choice of Emission Factors**

Since the tables providing emission factors are large, we put only their references here. The CO}_2\text{ emission factors are available in the IPCC guidelines (Chapter 1, Table 1.4). Default emission factors for CH}_4\text{ and N}_2\text{O emissions from stationary combustion are also available in the same guideline (Chapter 2, Table 2.2 to Table 2.5) based on the type of industry.}

In its concluding remarks, the ECCC guideline also states “Currently, there are no specific protocols to define how reporters must calculate their GHG emissions. However, reporters must use methods that are consistent with the methodologies approved by the UNFCCC and developed by the IPCC.”

**2.1.3 Example of Calculation Method**
We will use the example property from Section 1.4 – located at 21, Panorama Crt, Toronto, M9V 4E3 – for which we have the energy use data for the year 2011 located in Ontario, Canada. Following the Equation 2.1, we can calculate the CO$_2$ emissions. The GWPs listed in Table 2 are updated values suggested by the Intergovernmental Panel on Climate Change (IPCC). All the thermal conversion factors are available and considered as described by EPA here. Please note that if we do not have any of the fuels and factor values, we consider and set their values as ‘zero’ (0).

Total Emissions = ($E_{CO2}$ X GWP$_{CO2}$ for Electricity) + ($E_{CO2}$ X GWP$_{CO2}$ for Gas)

= (334,525.1786 kWh X 1) + (62,129.76002 m$^3$ X 1)

= (334,525.1786 X 0.003412 X 11.72) kg + (62,129.76002 X 0.036425 X 52.14) kg

= 13,377.207 kg + 117,996.809 kg

= 131,374.016 kg

= 131.374016 tonnes of CO$_2$

Therefore, the total CO$_2$ emissions using the ECCC (with the IPCC global warming potentials and emissions factors) are 131.374 tonnes of CO$_2$.

2.1.4 Online Tool/Data

The ECCC provides publicly available searchable open GHG emissions data in raw Excel format but does not provide any online tool or API to access or get standardized updates on this GHG data. The GHG emissions data is searchable by reporting year, company or facility name, province or territory, city, and so on. The GHG reporting works under the Greenhouse Gas Emissions Reporting Program (GHGRP).

Access the reported facility data in various formats:

- **Online Data Search** starting from 2004 with personalized queries of the reported facility data
- Key tables of facility-reported GHG emissions for the most recent year:
- **Downloadable Emissions Data** (Excel and CSV) with complete set of emissions data by facility from 2004-2015 available on the Open Data Portal
- **Interactive indicator maps** for GHG emissions from facilities

The **Online Data Search** provides the ability to create personalized queries of the reported facility data. The search will return dynamic tables. One can select just one, or a combination of multiple search criteria.

2.2. The Greenhouse Gas (GHG) Emission Reduction Analysis Model by Natural Resources Canada (NRCan) [6]

The RETScreen Greenhouse Gas (GHG) Emission Reduction Analysis Model found in the GHG Analysis worksheet of the RETScreen Software, helps the user estimate the greenhouse gas emission reduction (mitigation) potential of a proposed clean energy project. It calculates the GHG emission profile for a Base Case System (Baseline), and for the Proposed Case System (clean energy project).

The methodology implemented in the RETScreen Software to calculate the GHG emission reductions associated with a clean energy project, has been developed by Natural Resources Canada in collaboration with the United Nations Environment Programme (UNEP), the UNEP Collaborating Centre on Energy and Environment at the RISØ National Laboratory, and the World Bank’s Prototype Carbon Fund (PCF).

The following hypotheses are considered by the RETScreen in addition to the Base Case/Proposed Case comparison:
Combustion produces not just carbon dioxide, but also methane and nitrous oxide. The RETScreen Software uses carbon dioxide, the most common GHG, as a common currency: methane and nitrous oxide emissions are converted into their equivalent carbon dioxide emissions according to their GWP. International scientific committees such as the International Panel on Climate Change [IPCC, 1996] have proposed GWP factors for these gases.

The transmission and distribution (T&D) losses in electrical systems that feed into a grid must be considered. When electricity is generated in one place but consumed in another, a certain fraction of the electricity is lost as heat from the transmission and distribution lines connecting the two. Modern, industrialized grids tend to have losses of around 8% to 10%. Thus, electricity destined for a grid (i.e. not consumed directly on-site) produced by either the base case system or the proposed case system must include these losses when calculating the energy delivered to the end user.

The number of credits that accrue to the project may be reduced if a percentage has to be paid annually as a transaction fee to a crediting agency (e.g. the United Nations Framework Convention on Climate Change - UNFCCC) or the country hosting the project, or both.

### 2.2.1 GHG for electricity generating technology models – base case electricity system

For a single fuel type or source, the following Equation 7.1 is used to calculate the base case electricity system GHG emission factor, $e_{\text{base}}$:

$$e_{\text{base}} = \left( e_{\text{CO}_2} \frac{\text{GWP}_{\text{CO}_2}}{\eta} + e_{\text{CH}_4} \frac{\text{GWP}_{\text{CH}_4}}{\eta} + e_{\text{N}_2\text{O}} \frac{\text{GWP}_{\text{N}_2\text{O}}}{\eta} \right) \frac{1}{1 - \lambda}$$

where,

- $e_{\text{CO}_2}$, $e_{\text{CH}_4}$, and $e_{\text{N}_2\text{O}}$ are respectively the CO$_2$, CH$_4$ and N$_2$O emission factors for the fuel/source considered,
- GWP$_{\text{CO}_2}$, GWP$_{\text{CH}_4}$, and GWP$_{\text{N}_2\text{O}}$ are the GWPs for CO$_2$, CH$_4$ and N$_2$O,
- $\eta$ is the fuel conversion efficiency, and $\lambda$ is the fraction of electricity lost in transmission and distribution. The default emission factors used in RETScreen are the one provided by UNEP.

The GWP of a gas, or “GWP,” describes the potency of a GHG in comparison to carbon dioxide, which is assigned a GWP of 1. For example, a GWP of 310 for N$_2$O indicates that a tonne of nitrous oxide is considered to cause 310 times more global warming than a tonne of carbon dioxide. The GWP for methane and nitrous oxide can be defined by the user (in the case of a “custom” analysis) or by the software (in the case of a “standard” analysis). The default values used by RETScreen can be found in the Revised Intergovernmental Panel on Climate Change (IPCC) Guidelines for Greenhouse Gas Inventories, 1996. Effective from 2016 new measures have been taken. Accordingly, the GWP of CH$_4$ and N$_2$O have been changed as shown in the following table.

<table>
<thead>
<tr>
<th>Greenhouse Gas</th>
<th>GWP (until 2015)</th>
<th>GWP (from 2016)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO$_2$</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>CH$_4$</td>
<td>21</td>
<td>25</td>
</tr>
<tr>
<td>N$_2$O</td>
<td>310</td>
<td>298</td>
</tr>
</tbody>
</table>

In cases for which there are a number of fuel types or sources, the GHG emission factor $e_{\text{base}}$ for the electricity mix is calculated as the weighted sum of emission factors calculated for each individual fuel source:

$$e_{\text{base}} = \sum_{i=1}^{n} f_i e_{\text{base},i}$$

where, $n$ is the number of fuels/sources in the mix, $f_i$ is the fraction of end-use electricity coming from fuel/source $i$, and $e_{\text{base},i}$ is the emission factor for fuel $i$, calculated through a formula similar to the equation for $e_{\text{base}}$. 
where, \( e_{CO_2,i} \), \( e_{CH_4,i} \), and \( e_{N_2O,i} \) are respectively the CO\(_2\), CH\(_4\) and N\(_2\)O emission factors for fuel/source \( i \), \( \eta_i \) is the fuel conversion efficiency for fuel \( i \), and \( \lambda_i \) is the fraction of electricity lost in transmission and distribution for fuel \( i \).

### 2.2.2 An Example Calculation

We will use the example property from Section 1.4 – located at 21, Panorama Crt, Toronto, M9V 4E3 – for which we have the energy use data for the year 2011 located in Ontario, Canada. Following the Equation 7.1, we can calculate the CO\(_2\) emission for electricity and natural gas. The GWP\(_s\) listed in Table 2 are updated values suggested by the Intergovernmental Panel on Climate Change (IPCC). All the thermal conversion factors are available and considered as described by EPA [here](#). Please note that if we do not have any of the fuels and factor values, we consider and set their values as ‘zero’ (0). Emission factors are considered from NRCan [website](#).

\[
e_{\text{gas}} = \left( e_{CO_2} \times GWP_{CO_2} \right) + \left( e_{CH_4} \times GWP_{CH_4} \right) + \left( e_{N_2O} \times GWP_{N_2O} \right)
\]

\[
= (62,129.76002 \text{ m}^3 \times 1) + 0 + 0
\]

\[
= (62,129.76002 \times 0.03724) \text{ GJ} \times 1 + 0 + 0
\]

\[
= 2313.7123 \text{ GJ}
\]

\[
= 2313.7123 \times 56.1 \text{ kg}
\]

\[
= 129,799.26003 \text{ kg}
\]

\[
= 129.79926 \text{ tonnes of CO}_2
\]

\[
e_{\text{electricity}} = \left( e_{CO_2} \times GWP_{CO_2} \right) + \left( e_{CH_4} \times GWP_{CH_4} \right) + \left( e_{CH_4} \times GWP_{CH_4} \right)
\]

\[
= (334,525.1786 \text{ KWh} \times 1) + 0 + 0
\]

\[
= (334,525.1786 \times 0.0036) \text{ GJ} \times 1 + 0 + 0
\]

\[
= 1204.291 \text{ GJ}
\]

\[
= 1204.291 \times 11.72 \text{ kg}
\]

\[
= 14,114.29052 \text{ kg}
\]

\[
= 14.1143 \text{ tonnes of CO}_2
\]

\[
e_{\text{base}} = e_{\text{gas}} + e_{\text{electricity}}
\]

\[
= 129.79926 \text{ tonnes of CO}_2 + 14.1143 \text{ tonnes of CO}_2
\]

\[
= 143.91356 \text{ tonnes of CO}_2
\]

Therefore, the total CO\(_2\) emissions using the NRCan method (with the UNEP emission factors) are 143.914 tonnes of CO\(_2\).

### 2.2.3 Online Tool and Open Data

In Canada, the ultimate responsibility for GHG inventory lies on the Greenhouse Gas Division of Environment and Climate Change Canada (ECCC). NRCan also takes part (in collaboration with Canadian Forest Service) in reporting GHG emissions that it is responsible for. Therefore, NRCan does not hold a separate data/inventory of national GHG emissions. NRCan relies on ECCC for annual national GHG reporting to UNFCCC.

NRCan has a comprehensive energy use database available [here](#), from the sectors including Residential, Commercial/Institutional, Industrial, Transportation, and Agriculture. All the data sources rely on third-party or other governmental bodies, the list of which is available [online](#).
Although NRCan does not provide any of their own tools for GHG emissions from energy use, it provides a Bioenergy GHG calculator that evaluates the GHG mitigation potential and timing of GHG emission reductions when forest bioenergy is used as a substitute for fossil energy. The online version of the Bioenergy GHG calculator tool is freely available.

2.3 Greenhouse Gas Emissions Reporting by Government of Ontario (ONgov) [8]

The Government of Ontario follows the guidelines from Environment and Climate Change Canada (ECCC) [1] and the emission factor (EF) and GWP for each fuel are decided from the IPCC guidelines. However, ECCC also focuses more on various other sources of GHG emission including manufacturing, production, and–or generation. Some of these sources and their GHG quantification methods include General stationary combustion (ON.20), Primary manufacturing aluminum (ON.70), Cement manufacturing (ON.90), Electricity generation and cogeneration (ON.40), Glass production (ON.140), Iron and steel manufacturing (ON.150), Petroleum refining (ON.200). We are more interested in General stationary combustion (ON.20) which we discussed in detail in Section 2.

Entire calculations of GHG emissions is symmetrical to the ECCC. For the example calculation please refer to Section 2.1.3.

2.3.1 Online Tool and Open Data

The government of Ontario itself does not provide any GHG emissions calculation tool neither Web APIs for developers to get GHG emissions data. However, currently, only a few open data are available publicly. In particular,

- Greenhouse gas emissions reporting by facility (2010-2014)
- Energy use and greenhouse gas emissions for the Broader Public Sector showing the amount of energy used and greenhouse gases (GHG) emitted for the Broader Public Sector, i.e., municipalities, municipal service boards, school boards, universities, colleges and hospitals (2011-2014)
- Data catalog for searching the catalog to find government data where the data is either open, restricted, under review or in the process of being made open, depending on the sensitivity of the information.


Climate change from human activities is one of the key environmental issues. Controlling the emission of greenhouse gas (GHG) emissions would play a key role in limiting global warming according to the Kyoto Protocol signed in 1997. The United Nations Environment Programme (UNEP) provided a guideline for GHG emissions calculation that enables countries or companies with little or no experience to engage in the GHG estimation process, creating a common reporting platform.

3.1 The Overall Process

The Overall Emission = Energy\text{related}CO_2\text{-emission} + Transport\text{related}CO_2\text{-emission} + Process\text{related}CO_2\text{-emission}... \ (Eq. 3.1)
3.2 Detailed Estimation Method

Two frequent categories that contribute to the GHG emissions are energy-related and process-related emissions. Therefore, to derive the GHG emission, they need to be assessed and calculated separately and then aggregated. The aggregated GHG value is then normalized using a measure of business activity. Here, the normalization is essential, which allows inter- and intra-organization comparison. The methodology used to estimate the GHG emissions is based on fundamental research by the Intergovernmental Panel on Climate Change (IPCC) for calculating the GWP of chemical species. The key to the estimation model is the conversion of all relevant emissions to the IPCC reference gas, i.e., Carbon Dioxide (CO₂).

3.2.1 Conversion Factors
The conversion factors used in the UNEP GHG estimation method for various fuel types are presented in Appendix.

3.2.2 Energy-related Greenhouse Gas Emission
The combustion of fossil fuels is the most common source of GHG emissions.

\[
\text{Direct Combustion of Fuels} = \text{Primary Fuels} + \text{Secondary Fuels} \ldots \quad (\text{Eq. 3.2})
\]

Primary fuels include coal and natural gas whereas secondary fuels include refined petroleum products. The sources of the data can be a utility provider, the electricity bills, the invoices for fuel deliveries, various meter readings (estimated from invoices if meter readings are not available), the gas bills, the pipeline measurements, and various energy management software.

To calculate GHG emissions from the combustion of fuels, UNEP guideline relies on an activity statistic (i.e., annual fuel consumption in tonnes) and an emission factor (i.e., tonnes of CO₂ per tonne of fuel combusted). The calculation of the GHG emissions from coal depends on the net calorific value (NCV) of the fuel, which varies across the coal types, country, and region. Table 9 in [2] presents emission factors for different countries and missing countries rely on the default value for coal as shown at the bottom of the table.

Carbon dioxide emissions from the most frequently used fuels can be calculated by finding the appropriate fuel consumption data in one of the units and then multiplying the fuel consumption by the appropriate factor from Table 3 in [2]. Carbon dioxide emissions derived from the consumption of electricity are one of the single highest sources of emissions.

Based on and the formula of direct combustion of fuels above, the general GHG emission calculation can be expressed as,
GHG_Emission_{Energy} = (\text{Coal} \times EmissionFactor_{NCV}) + \Sigma (\text{Refined Petroleum Products} \times EmissionFactor) 
... (Eq. 3.3)

3.2.3 Transport-related Greenhouse Gas Emission

Emissions from transport are broken down into two categories: Road Vehicle transport and Non-Road transport as shown in the equation below. The CO₂ emission factors are presented in Table 3 and Table 4 in [2]. Table 5 in [2] can be used for calculating GHG emission on driving mileage, which is useful when companies are renting transport for employees. Table 6 [2] shows the CO₂ emission factor for each person-kilometer for non-road passenger transports.

GHG_{Emission_{Transport}} = RoadVehicle_{Transport \, CO2EF} + NonRoad_{Vehicle \, Transport \, CO2EF} 
... (Eq. 3.4)

NonRoad_{Vehicle \, Transport \, CO2EF} = NonRoad_{Passenger \, Transport \, CO2EF} + Freight_{Transport \, CO2EF} 
... (Eq. 3.5)

3.2.3 Process-related Greenhouse Gas Emission

Process-related emissions are from non-energy-related sources, i.e., industrial production processes, that transform materials chemically or physically. Process-related greenhouse gas emission is reported in tonnes and converted to carbon dioxide equivalents using the GWP as presented in Table 8 in [2].

3.3 Summary

Once the data is gathered, one requires to aggregate the energy- and transport-related carbon dioxide emissions with the process-related CO₂ equivalent emissions (as shown in Equation 3.1). And, for the normalization, four denominators can be considered for measuring company activity regarding GHG emissions: turnover, added value, employees, and unit of production.

Turnover (also referred to as sales) represents the total value of goods and services sold by the company to third parties in the normal course of trade. Added Value shows how much of the added value was distributed to employees as salaries etc., how much to the community via taxes, how much to the providers of capital, and how much was needed to be retained in the business for maintenance or expansion. An Employee denominator is quite simply the number of employees under contract and directly employed by a company. Unit of Production denominator can be used for manufacturing companies as the ability to relate GHG emissions to product output can aid comparison between similar sectors of manufacturing.

3.4 Translating Equations into Calculation Methodology

For each petroleum fuel,

\[ \text{CO}_2-\text{Emission-from-Fuel-Use} = \text{Basic-Unit} \times \text{Emission Factor} \]

For electricity use,

\[ \text{CO}_2-\text{Emission-from-Electricity} = \text{Basic-Unit-KWh} \times \text{CO}_2-\text{Emission-Factor (country-specific)} \]

For road transport, for each fuel,

\[ \text{CO}_2-\text{Emission-from-Road-Transport} = \text{Basic-Unit} \times \text{CO}_2-\text{Emission-for-each-Fuel} \]

For non-road transport, for each transport type,

\[ \text{CO}_2-\text{Emission-from-Non-Road-Transport} = \text{Basic-Unit} \times \text{CO}_2-\text{Emission-Factor-for-Transport-Type} \]

\[ \text{CO}_2-\text{Emission-from-Transport} = \text{CO}_2-\text{Emission-from-Road-Transport} + \text{CO}_2-\text{Emission-from-Non-Road-Transport} \]
For process related emission, for each type of trace gas,
\[
\text{CO}_2\text{-Emission-for-Process} = \text{Basic-Unit-Tonne} \times \text{GWP}
\]

\[
\text{Total-GHG} = \text{CO}_2\text{-Emission-from-Fuel-Use} + \text{CO}_2\text{-Emission-from-Electricity} + \text{CO}_2\text{-Emission-from-Transport} + \text{CO}_2\text{-Emission-from-Non-Transport} + \text{CO}_2\text{-Emission-for-Process}
\]

Normalized GHG,
\[
\text{CO}_2 \text{ produced for each value ($)} \text{ of good/service} = \frac{\text{Total-GHG}}{\text{Turnover}}
\]
\[
\text{CO}_2 \text{ produced for each added value ($)} = \frac{\text{Total-GHG}}{\text{Added-Value}}
\]
\[
\text{CO}_2 \text{ produced for each employee} = \frac{\text{Total-GHG}}{\text{Employees}}
\]
\[
\text{CO}_2 \text{ produced for each unit of production} = \frac{\text{Total-GHG}}{\text{Unit-Production}}
\]

### 3.5 An Example of Calculation Method

We will use the example property from Section 1.2 from Section 1.4 – located at **21, Panorama Crt, Toronto, M9V 4E3** – for which we have the energy use data for the year 2011 located in Ontario, Canada. Following the Equations 3.1 to 3.5, we can calculate the CO\(_2\) emissions. The GWPs listed in Table 2 are updated values suggested by the Intergovernmental Panel on Climate Change (IPCC). All the thermal conversion factors are available and considered as described by EPA here. Please note that if we do not have any of the fuels and factor values, we consider and set their values as ‘zero’ (0).

For electricity use (using the emission factor of 1996 – Canada),
\[
\text{CO}_2\text{-Emission-from-Electricity} = \text{Basic-Unit-KWh} \times \text{CO}_2\text{-Emission-Factor (country-specific)}
\]
\[
= 334,525.1786 \text{ KWh} \times 0.000163 \text{ tCO}_2/\text{kWh}
\]
\[
= 54.528 \text{ tonnes CO}_2
\]

For natural gas (using the emissions factors from Table 3 in [2]),
\[
\text{CO}_2\text{-Emission-from-Natural-Gas} = \text{Basic-Unit-KWh} \times \text{CO}_2\text{-Emission-Factor}
\]
\[
= 62,129.76002 \text{ m}^3 \times 0.0002020 \text{ tCO}_2/\text{kWh}
\]
\[
= (62,129.76002 \times 10.32) \text{ ekWh} \times 0.0002020 \text{ tCO}_2/\text{ekWh}
\]
\[
= 641,179.123 \text{ ekWh} \times 0.0002020 \text{ tCO}_2/\text{ekWh}
\]
\[
= 129.518 \text{ tonnes CO}_2
\]

For road transport, for each fuel,
\[
\text{CO}_2\text{-Emission-from-Road-Transport} = \text{n/a (set as 0)}
\]

For non-road transport, for each transport type,
\[
\text{CO}_2\text{-Emission-from-Non-Road-Transport} = \text{n/a (set as 0)}
\]
\[
\text{CO}_2\text{-Emission-from-Transport} = \text{n/a (set as 0)}
\]

For process related emission, for each type of trace gas,
\[
\text{CO}_2\text{-Emission-for-Process} = \text{n/a (set as 0)}
\]

\[
\text{Total-GHG} = \text{CO}_2\text{-Emission-from-Fuel-Use} + \text{CO}_2\text{-Emission-from-Electricity} + \text{CO}_2\text{-Emission-from-Transport} + \text{CO}_2\text{-Emission-from-Non-Transport} + \text{CO}_2\text{-Emission-for-Process}
\]
Total-GHG = 129.518 tonnes CO\(_2\) + 54.528 tonnes CO\(_2\) + 0 tonnes CO\(_2\) + 0 tonnes CO\(_2\) + 0 tonnes CO\(_2\)

Total-GHG = 184.046 tonnes CO\(_2\)

Therefore, the total CO\(_2\) emissions using the UNEP (with the UNEP provided emission factors) are 184.046 tonnes of CO\(_2\).

3.6 Online Tool and Open Data

UNEP does not provide an online tool for the calculation of GHG emissions. However, it provides Open Data and REST Web services to access those data in the JSON format.

The online portal provided by UNEP for open data access is known as Environmental Data Explorer. Using the Environmental Data Explorer (EDE) Web services, if the developers want to use one of EDE services, they need to contact the Environmental Data Explorer team (Stefan Schwarzer - stefan.schwarzer@unep.org) to request permission. The list of all REST-based HTTP methods/operations is available here: http://ede.grid.unep.ch/api/.

In summary, the Environmental Data Explorer is the authoritative source for data sets used by UNEP and its partners in the Global Environment Outlook (GEO) report and other integrated environment assessments. Its online database holds more than 500 different variables, as national, sub-regional, regional and global statistics or as geospatial data sets (maps), covering themes like Freshwater, Population, Forests, Emissions, Climate, Disasters, Health, and GDP. Display them on-the-fly as maps, graphs, data tables or download the data in different formats.

4. Greenhouse Gas Emissions Estimation by the US Environmental Protection Agency (EPA) [3]

The methodology for calculating GHG emissions in Portfolio Manager is based on the Greenhouse Gas Protocol Corporate Accounting and Reporting Standard developed by the World Resources Institute (WRI) and World Business Council for Sustainable Development.

Most of the GHG calculation methods use “default fuel analysis approach” (DFAA), which considers primarily the type and quantity of the fuel. The DFAA is simple and straightforward in the calculation. However, the DFAA considers only direct estimated CO\(_2\) because the calculation with CH\(_4\) and N\(_2\)O is complicated, as they not only depend on fuel characteristics but also on the combustion technology. In general, the amount of total GHG emission is calculated as the summation of direct and indirect emissions as shown in Equation 1. Also, for counting each energy emissions of a site, we need to convert the total site energy value (for any fuel type) to its CO\(_2\) equivalent factor as shown in Equation 2.

\[
\text{Total GHG Emission} = \text{Direct GHG Emission} + \text{Indirect GHG Emission} \quad \cdots \cdots \text{(Eq. 4.1)}
\]

\[
\text{Total Biomass Emission} = \text{Emission from Biogenic Fuel} \quad \cdots \cdots \text{(Eq. 4.1.1)}
\]

\[
\text{Net GHG Emission} = \text{Total GHG Emission} – \text{Avoided Emission} \quad \cdots \cdots \text{(Eq. 4.1.2)}
\]

\[
\text{Total Emission from an Energy Source} = \text{Site Energy Value X Emission Factor} \quad \cdots \cdots \text{(Eq. 4.2)}
\]

where, the Emission Factor is the single CO\(_2\) equivalent number for Carbon Dioxide (CO\(_2\)), Methane (CH\(_4\)), Nitrous Oxide (N\(_2\)O), and Sulfur Hexafluoride (SF\(_6\)).
4.1 Calculation of Direct GHG Emission
For Natural Gas and Oil:
1. Any energy consumption (for each fuel type) needs to be converted to MBtu (Mega British Thermal Unit) energy. This is known as the site energy. MBtu is a standard unit of measurement used to denote the amount of heat energy in fuel plus the ability of appliances to produce heating/cooling. For example, fuels in mass or volume are converted to energy using standard heat content factor.
2. Multiply the total site energy by the single CO₂ equivalent factor, which incorporates the reference GWP of each gas. As a note, the GWP of CO₂ is 1, CH₄ is 25, is N₂O 298. This means that latter two gases have 25 and 298 times more effect on the global warming, respectively than the CO₂. In the USA, each fuel has one unique factor computer nationwide. In Canada, factors for fuel oil are applied national-level but factors for gas vary by province. The emissions factors for other fuel types other than natural gas are presented in Figure 1 in [3] and the emissions factors for natural gas is presented in Figure 2 in [3].
3. Add the values from Step 2 for each fuel type to total Direct GHG Emission.
4. Add the value from Step 3 to the Total GHG Emission.

Therefore, the calculation of total direct GHG emission can be expressed as:

\[
Direct \ GHG \ Emission = \text{Natural Gas } m^3 \times CO_2\text{-eqv-factor (province-specific)} + \text{Propane } m^3 \times CO_2\text{-eqv-factor (province-specific)} + \text{Oil } m^3 \times CO_2\text{-eqv-factor (national)} \ldots \ldots \text{(Eq. 4.3)}
\]

After the conversion from m³ to MBtu,

\[
Direct \ GHG \ Emission = \text{Natural Gas } MBtu \times CO_2\text{-eqv-factor (province-specific)} + \text{Propane } MBtu \times CO_2\text{-eqv-factor (province-specific)} + \text{Oil } MBtu \times CO_2\text{-eqv-factor (national)} \ldots \ldots \text{(Eq. 4.3.1)}
\]

The national CO₂-equivalent emissions factor for different types of oil and propane are presented in Figure 1 in [3]. The province-specific CO₂-equivalent emissions factor for natural gas is shown in Figure 2 in [3].

4.2 Calculation of Indirect GHG Emission
For Electricity:
1. Convert the billed energy consumption to the MBtu unit, name as site energy.
2. Multiply the site energy by the CO₂-equivalent emission factor for the electricity in Canada (unique value for each province) as shown in Figure 6 in [3].
3. Add the electric consumption to the total Indirect GHG Emission.

For District Heating/Cooling/Steam:
1. Convert the billed energy consumption (for each fuel) to the MBtu unit, name as site energy.
2. Multiply the site energy by the CO₂-equivalent emission factor for the district heating/cooling in Canada (unique value for each province) as shown in Figure 3 in [3].
3. Add the district heating/cooling consumption to the total Indirect GHG Emission.

Therefore, the calculation of total indirect GHG emission can be expressed as:

\[
Indirect \ GHG \ Emission = \text{Electricity kWh} \times CO_2\text{-eqv-factor (province-specific)} + \text{District Heating GJ} \times CO_2\text{-eqv-factor} + \text{District Cooling GJ} \times CO_2\text{-eqv-factor} + \text{District Steam GJ} \times CO_2\text{-eqv-factor} \ldots \ldots \text{(Eq. 4.4)}
\]
After the conversion from kWh and m³ to MBtu,

\[
\text{Indirect GHG Emission} = \text{Electricity MBtu} \times \text{CO}_2\text{-eqv-factor (province-specific)} + \text{District Heating MBtu} \times \text{CO}_2\text{-eqv-factor} + \text{District Cooling MBtu} \times \text{CO}_2\text{-eqv-factor} + \text{District Steam MBtu} \times \text{CO}_2\text{-eqv-factor} \ldots \ldots \text{(Eq. 4.4.1)}
\]

The provincial CO₂-equivalent emission factors for electricity in Canada are presented in Figure 6 in [3]. The national CO₂-equivalent emission factors for district heating, cooling, and steam are shown in Figure 3 in [3].

4.3 Calculation of Total GHG Emission

If we combine the Equations 3.1 and 4.1, the Equation 1 can be rewritten as the following:

\[
\text{Total GHG Emission} = (\text{Natural Gas MBtu} \times \text{CO}_2\text{-eqv-factor (province-specific)} + \text{Propane MBtu} \times \text{CO}_2\text{-eqv-factor (province-specific)} + \text{Oil MBtu} \times \text{CO}_2\text{-eqv-factor (national)}) + (\text{Electricity MBtu} \times \text{CO}_2\text{-eqv-factor (province-specific)} + \text{District Heating MBtu} \times \text{CO}_2\text{-eqv-factor} + \text{District Cooling MBtu} \times \text{CO}_2\text{-eqv-factor} + \text{District Steam MBtu} \times \text{CO}_2\text{-eqv-factor}) \ldots \ldots \text{(Eq. 4.5)}
\]

4.4 Calculation of Biomass Emission

Biomass emissions from buildings are similar to other direct emissions since they reflect emissions from onsite fuel combustion. Currently, ENERGY STAR Portfolio Manager only track emissions from wood as the biogenic fuel. There is only one national factor for emissions from wood that is applied to the US, i.e., 94.22 kg of CO₂eq Emissions per MBtu, which is 100.95 for Canada. The calculation process involves:

1. All meters for wood are converted from native units to MBtu.
2. Total site energy for wood is multiplied by a single CO₂ equivalent factor that incorporates the contribution of CO₂, CH₄, and N₂O.
   a. In the US and Canada, there is one national factor applied.
3. Emissions resulting from wood are reported as biomass emissions.

However, the biomass emissions are not included in the total GHG emissions and are tracked down separately.

4.5 Calculation of Energy Use/Usage Intensity (EUI)

The EUI refers to a building’s energy use as a function of its size or other characteristics and can be expressed as energy per square foot (per year). It is calculated by dividing the total energy consumption of the building in one year by the total floor space of the building.

\[
\text{EUI} = (\text{Total Electricity kWh} + (\text{Total Gas m}^3 \times \text{Conversion Factor})) / (\text{Total Space ft}^2) \ldots \ldots \text{(Eq. 4.6)}
\]

where, the conversion factor used by the Ministry of Energy is a constant value of 10.6277. The standard value used as the conversion factor is 10.32 as mentioned in the next section.

4.6 Important Conversion Formulas

Some conversions are required for the Equations 3 and 4. For example, natural gas is measured and billed in the unit of Cubic Meter (m³), the electricity is measured and billed in the unit of kilo-Watt-hour (kWh), and district heating/cooling/steams are measured in GJ. However, all the CO₂-equivalent emission factors are calculated in the unit of MBtu, i.e., Mega British Thermal Unit. Therefore, some conversions are an essential for the direct, indirect, and total GHG calculations. The following generic conversions will serve our purpose:

\[1 \text{ m}^3 \text{ gas} = 10.32 \text{ ekWh}\]
1 m³ gas = 0.036425 MBtu = 36.425 kBtu
1 m³ gas = 0.03724 GJ gas
1 kBtu = 1/36.425 m³ = 0.027454 m³
1 kWh electricity = 1 ekWh
1 MCF (thousand cubic feet) gas = 292.2 ekWh
1 litre diesel = 10.83 ekWh
1 GJ gas = 277.8 ekWh = 0.947854 MBtu
1 GJ gas = 26.853 m³ gas = 947.8171 cf. (cubic feet) gas
1 kWh = 3.6 MJ = 0.0036 GJ
1 MJ = 0.27778 kWh
1 kWh = 3.412 kBtu
1 kWh = 0.003412 MBtu
1 kBtu = 0.293083 kWh

A detailed list of conversion formulas is also available on EPA’s Website on thermal conversion reference guide.

In summary, two key metrics in ENERGY STAR Portfolio Manager measuring greenhouse gas emissions are (1) Total Emissions that measures the majority of GHGs associated with commercial buildings, which can further be split into component metrics like Direct Emissions (energy directly burned at a building -- natural gas) and Indirect Emissions (energy burned after purchased from a utility -- electricity) and (2) Biomass Emissions that are from biogenic fuels that are burned onsite, e.g., wood. Emissions are calculated by multiplying one’s site energy values by emissions factors.

4.7 The Illustrative Examples

In the following, we show with an illustrative example the calculation of EUI and GHG. For example, 21 Panorama (located at 21 Panorama Crt, Toronto, M9V 4E3), a type of administrative offices and related facilities including municipal council chambers, consumed a total electricity of 334,525.178571429 kWh and total natural gas of 62,129,7600193961 m³ for the year 2011. If the location has the 96,369,1967 ft² of total floor area of the indoor space in which operation is conducted. Then, using the Equation 4.6, the EUI value for 21 Panorama would be,

\[
EUI = \frac{(334,525.178571 \text{ kWh} + (62,129.760019 m^3 \times 10.6277))}{96,369.1967 \text{ ft}^2}
\]

\[
EUI = 10.323025 \text{ ekWh/ft}^2
\]

Or, \( EUI = 35.222161 \text{ kBtu/ft}^2 \)

Or, \( EUI = 0.035222 \text{ MBtu/ft}^2 \)

In general, the higher the EUI value is, the more operating expenses are required or being spent for a given property or location.

GHG Calculation Example: We will use the example property from Section 1.2 from Section 1.4 — located at 21, Panorama Crt, Toronto, M9V 4E3 — for which we have the energy use data for the year 2011 located in Ontario, Canada. Following the Equations 4.1 to 4.5, we can calculate the CO₂ emissions. The GWPs listed in Table 2 are updated values suggested by the Intergovernmental Panel on Climate Change (IPCC). All the thermal conversion factors are available and considered as described by EPA here. Then, according to Equations 4.1 to 4.5, the total GHG for the property would be,

\[ Total \ GHG \ Emission = Direct \ GHG \ Emission + Indirect \ GHG \ Emission \]

\[ Direct \ GHG \ Emission = Natural \ Gas \ m^3 \times CO_2-eqv-factor \ (province-specific) + \]

\[ Indirect \ GHG \ Emission = Electric \ energy \ kWh \times CO_2-eqv-factor \ (utility) \]
Propane \( m^3 \times CO_2\text{-eqv-factor (province-specific)} \) + 
Oil \( m^3 \times CO_2\text{-eqv-factor (national)} \)
\[ = 62,129.76002 \times 52.14 \text{ kg/MBtu (for Ontario)} \]
\[ + 0 \text{ (Propane)} \]
\[ + 0 \text{ (Oil)} \]
\[ = 62,129.76002 \times 0.036425 \times 52.14 \text{ kg/MBtu (for Ontario)} \]
\[ + 0 \text{ (Propane)} \]
\[ + 0 \text{ (Oil)} \]
\[ = 2,263.0765 \text{ MBtu} \times 52.14 \text{ kg/MBtu (for Ontario)} \]
\[ + 0 \text{ (Propane)} \]
\[ + 0 \text{ (Oil)} \]
\[ = 117,996.809 \text{ kg} \]
\[ = 117.997 \text{ tonnes} \]

**Indirect GHG Emission**
\[ = \text{Electricity kWh} \times CO_2\text{-eqv-factor (province-specific)} + \]
District Heating GJ \( \times CO_2\text{-eqv-factor} \) + 
District Cooling GJ \( \times CO_2\text{-eqv-factor} \) + 
District Steam GJ \( \times CO_2\text{-eqv-factor} \)
\[ = 334,525.1786 \text{ kWh} \times 11.72 \text{ kg/MBtu} + \]
\[ 0 \text{ GJ} \]
\[ 0 \text{ GJ} \]
\[ 0 \text{ GJ} \]
\[ = 1141.4 \text{ MBtu} \times 11.72 \text{ kg/MBtu} + \]
\[ 0 + \]
\[ 0 + \]
\[ 0 \]
\[ = 13,377.208 \text{ kg} + \]
\[ 0 + \]
\[ 0 + \]
\[ 0 \]
\[ = 13.377 \text{ tonnes} \]

Therefore, from the equation,

**Total GHG Emission**
\[ = \text{Direct GHG Emission} + \text{Indirect GHG Emission} \]
\[ = 117.997 \text{ tonnes} + 13.377 \text{ tonnes} \]
\[ = 131.374 \text{ tonnes} \]

Therefore, the total \( CO_2 \) emissions using the EPA (with the WRI methodology) are 131.374 tonnes of \( CO_2 \).

The ENERGY STAR Portfolio Manager® specifically focuses on US and Canada GHG emissions. Figure 1, Figure 2, Figure 3, and Figure 6 in [3] can be used to calculate direct and indirect GHG emissions for the US and Canada due to biomass burning and various energy use. However, using the IPCC emission factors similar estimation methodologies as shown in Equations 4.1 to 4.5 can be applied for calculating indirect emission, e.g., emissions from electricity use.

### 4.8 Online Tool and Open Data

EPA's online energy management and tracking tool Portfolio Manager® enables one to measure and track the energy and water performance of any building over time as well as greenhouse gas emissions. One can also use
Portfolio Manager to set his energy use target and see how the estimated design energy stacks up against similar existing buildings nationwide.

Target Finder is EPA’s online calculator that helps architects, engineers, and property owners and managers assess the energy performance of commercial building designs and existing buildings. The two basic uses of Target Finder include: (1) to see what annual energy usage one needs to achieve to meet a target and (2) to evaluate estimated energy use. In addition, one can see the projected costs and greenhouse gas emissions.

Like Portfolio Manager®, Target Finder also accounts for building and operating characteristics, such as operating hours and number of PCs, as well as 30-year weather data for the project site. It then compares this data to the actual energy consumption of real buildings, as collected by nationally representative surveys, such as DOE’s Commercial Buildings Energy Consumption Survey (CBECS). The data from these surveys are built into Target Finder, meaning that, with a couple mouse clicks, one can assess his designs against the best-available data sample in the nation, plus he can normalize the values against size, operating characteristics, and weather.

EPA provides a simplified GHG emissions calculator (that can be downloaded from here) to help small business and low emitter organizations estimate and inventory their annual greenhouse gas (GHG) emissions. The calculator will determine the direct and indirect emissions from all sources at a company when activity data are entered into the workbook for one year.

EPA also provides a Household Carbon Footprint Calculator to quantify (1) the greenhouse gas emissions from home electricity use, (2) the greenhouse gases emitted from one’s furnace and boiler, (3) the emissions from one’s car or truck depends on how much one drives, what the vehicle’s fuel efficiency is, and how one drives (e.g., the amount of time spent idling in traffic), and so on.

EPA provides two open data sets: (1) the first, through the Greenhouse Gas Reporting Program (GHGRP) that collects Greenhouse Gas (GHG) data from large emitting facilities, suppliers of fossil fuels and industrial gases that result in GHG emissions when used, and facilities that inject carbon dioxide underground and (2) the second one through an interactive Flight tool that includes greenhouse gas emissions from large facilities.

EPA offers a complete application programming interface (API) to facilitate data exchange with Portfolio Manager. One can use this suite of REST-based Web services to enter data into Portfolio Manager on behalf of his customers and receive ENERGY STAR® metrics to incorporate into his own energy information software and services. Software providers, utilities, and property management companies can use Portfolio Manager’s flexible Web services to meet their clients’ specific needs, e.g., import customer data into Portfolio Manager and export metrics out of Portfolio Manager.

EPA offers a suite of RESTful Web services that allow one to exchange data with the Portfolio Manager. One can use these services to benchmark his own buildings, enter data on behalf of his customers, and receive ENERGY STAR metrics to incorporate in his own energy information software and services. The Application Programming Interface (API) includes both the test environment and live environment. A brief introduction to Exchanging Data, Connection and Sharing guidance for providers, and Testing Web services are available on ENERGY STAR Web site.

5. GHG Emissions Calculation Methodology and GHG Audit by International Sustainability and Carbon Certification (ISCC) \[^{4}\]

ISCC recommends the segments that must report their GHG emission values include: (i) biomass producers; (ii) conversion units (e.g., conversion of solid biomass into liquid biomass or processing of liquid biomass); (iii) transport and distribution.

5.1 GHG Emissions Calculation Methodology

ISCC suggests three options for reporting GHG information: (i) Use of default value as defined in the Directive 2009/28/EC and to apply these values they must be converted to CO₂ Eq emissions per Kg of the main product
produced; (ii) Use of individually calculated values ("actual values") calculated based on the calculation methodology from the Directive 2009/28/EC; and (iii) the combination of default value and individually calculated value. However, the calculation based on the actual values is the most common one and we will only discuss this in the below.

Overall GHG emissions of a bioenergy supply chain are calculated based on the following formula, comprised of emissions and emissions savings:

\[
E = \text{Total Emission} - \text{Emission Savings}
\]

\[
\text{Total Emission} = e_{ec} + e_i + e_p + e_{td} + e_u
\]

\[
\text{Emission Savings} = e_{sca} - e_{ccs} - e_{ccr} - e_{ee}
\]

where,

- \( E \) = total emissions from the use of the fuel
- \( e_{ec} \) = emissions from the extraction or cultivation of raw materials
- \( e_i \) = annualized emissions from carbon stock changes caused by land-use change
- \( e_p \) = emissions from processing
- \( e_{td} \) = emissions from transport and distribution
- \( e_u \) = emissions from the fuel in use
- \( e_{sca} \) = emission saving from soil carbon accumulation via improved agricultural practices
- \( e_{ccs} \) = emission saving from carbon capture and geological storage
- \( e_{ccr} \) = emission saving from carbon capture and replacement
- \( e_{ee} \) = emission saving from excess electricity from cogeneration

Please note that the emissions from the manufacture of machinery and equipment are not to be considered for the calculation of total emission. The unity of the different variables is g CO\(_2\)/MJ final product.

GHG emissions (EM) from cultivation \( e_{ec} \), including the GHG emissions from cultivation itself and harvest as well as the emissions from the production of the inputs necessary for cultivation, must be calculated according to the following formula (EM = emissions; EF = emission factor):

\[
e_{ec} = \frac{EM_f \text{ fertility}}{\text{crop yield}_{\text{main product}}} \times \frac{kg \ CO_2}{ha \cdot yr} + EM_{\text{diesel}} \times \frac{kg \ CO_2}{ha \cdot yr} + EM_{\text{electricity}} \times \frac{kg \ CO_2}{ha \cdot yr} + EM_{\text{input}} \times \frac{kg \ CO_2}{ha \cdot yr}
\]

\[
EM_{\text{fertility}} = f \text{ utilize} \left( \frac{kg \ CO_2}{ha \cdot yr} \right) \times \left( \frac{EF_{\text{production}} \times kg \ CO_2}{kg} + EF_{\text{crop yield}} \times \frac{kg \ CO_2}{ha \cdot yr} \right)
\]

\[
EM_{\text{diesel}} = \text{diesel} \left( \frac{L}{ha \cdot yr} \right) \times EF_{\text{diesel}} \times \frac{kg \ CO_2}{l}
\]

\[
EM_{\text{electricity}} = \text{electricity} \left( \frac{kWh}{ha \cdot yr} \right) \times EF_{\text{regional electricity mix}} \times \frac{kg \ CO_2}{kWh}
\]

\[
EM_{\text{input}} = \text{input} \left( \frac{kg}{ha \cdot yr} \right) \times EF_{\text{input}} \times \frac{kg \ CO_2}{kg}
\]
For the calculation of $e_{ec}$ as a minimum, the following data needs to be collected on-site, i.e. the respective quantities must be extracted from respective operating documents and must be verified by the auditors. Annual averages of the previous year must be used:

- Fertilizers (mineral and organic) [kg/(ha*yr)] – total yearly amount of applied fertilizers in the cultivation period (N, P$_2$O$_5$, K$_2$O, CaO-fertilizer) and pesticides, herbicides, rodenticides
- Diesel [l/(ha*yr)] – total yearly amount of diesel used on farm per hectare
- Electricity consumption – total yearly electricity consumption per hectare
- Crop yield main product [kg crop yield/(ha*yr)] – Yearly crop yield of the main product in kg per hectare. In case of drying the mass of dried product is necessary
- Yield of co-products

For the calculation of $e_{ec}$ the following emission factors must come from the ISCC provided list of emission factors:

- Emission factor diesel [kg CO$_2$/l diesel]
- Emission factor fertilizer production [kg CO$_2$/kg fertilizer]
- Emission factor for fertilizer emissions from the field [kg CO$_2$/kg fertilizer]. An appropriate way to consider N$_2$O emissions from soils is the IPCC methodology, including what is described there as both “direct” and “indirect” N$_2$O emissions.
- Emission factor regional electricity mix [kg CO$_2$/kWh]

The annual emissions from carbon stock changes caused by land use change $e_l$ are calculated by dividing total emissions equally over 20 years based on the following formula:

$$e_l = \frac{CS_R [kgC/ha] - CS_A [kgC/ha]}{crop \ yield_{main \ product} [kg/ha \* yr] \times 20 [yr]} \times 3.664$$

where,

- $CS_R$ = the carbon stock associated with the reference land per unit of land (measured as mass of carbon per unit of land including both soil and vegetation)
- $CS_A$ = the carbon stock per unit area associated with the actual land use (measured as mass of carbon per unit of land, including both soil and vegetation)

If no land use change took place after the reference year, i.e. if the land was classified as agricultural land or falls within one of the exceptions as described in ISCC Document 202, $e_l$ is set to zero.

Every processing unit in the supply chain must guarantee that all GHG emissions from processing, $e_p$, GHG emissions from wastes (wastewater) and from the production of all inputs are included in the emissions calculation. The basis for the calculation should always be the previous year.

$$e_p = EM_{electricity \ consumption} [kgCO_2/yr] + EM_{heat \ production} [kgCO_2/yr] + EM_{inputs} [kgCO_2/yr] + EM_{waste \ water} [kgCO_2/yr]$$

where,

$$EM_{electricity \ consumption} = electricity [kWh/yr] \times EF_{regional \ electricity \ mix} [kgCO_2/kWh]$$
For the calculation of GHG emissions from processing (\(e_p\)), the following data needs to be collected on-site and must be verified by the auditors:

- Electricity consumption [kWh/yr] – annual total electricity consumption from external sources, i.e. not produced in an internal combined heat and power production (CHP) plant
- Heat production – Type of fuel used for steam production, e.g. heating oil, natural gas, crop residues
- Fuel consumption [kg/yr] – annual total fuel consumption for heat production, e.g. heating oil [kg], natural gas [kg], bagasse [kg]
- Further inputs (operating supplies)
- Yield main product [kg main product/yr] – Annual yield of the main product
- Yield of co-products
- Amount of wastewater [l/yr] – Annual amount of wastewater and wastes
- Feedstock inputs (Amounts, conversion rates, and GHG value of feedstock inputs)

GHG emissions from wastes are included in the calculation of \(e_p\). For the calculation of \(e_p\), the following emission factors must come from the ISCC list of emission factors:

- Emission factor fuel [kg CO\(_2\)/kg]
- Emission factor wastewater [kg CO\(_2\)/l] and wastes [kg CO\(_2\)/l]
- Emission factor regional electricity mix [kg CO\(_2\)/kWh]
- Emission factors for operating supplies

The GHG emissions are calculated per unit mass of the main product (e.g. \(\text{CO}_2\)-emissions [kg]/rape oil [kg]). All respective elements in the supply chain calculate the GHG emissions from transport \(e_{td}\) of biomass taking account of all transport steps based on the following formula:

\[
e_{td} = \frac{d_{\text{loaded}}[\text{km}] \cdot K_{\text{loaded}} [\text{lit}]/\text{km} + d_{\text{empty}}[\text{km}] \cdot K_{\text{empty}} [\text{lit}]/\text{km}}{m_{\text{intermediate product}}[\text{kg}]} \times EF_{\text{fuel}} \left[ \frac{\text{kg CO}_2}{\text{l}} \right]
\]

For the calculation of \(e_{td}\) the following information needs to be provided:

- Transport distance (d) [in km] loaded/ respectively empty – Distance the biomass is transported to the next element in the supply chain
- Mode of transport (e.g. diesel truck, 40 t)
- Amount of biomass transported.

The following impact factors are to be taken from the ISCC proposed emission factors:

- Emission factor fuel (\(EF_{\text{fuel}}\))
- \(K_{\text{loaded}} [\text{lit}/\text{km}]\) – Fuel consumption of the respective mode of transport per km when loaded
The reference unit (m) for transport is always kg of the product transported.

The GHG emissions from transport always need to be documented and included in the GHG calculations by the element in the supply chain that is receiving the product. Emissions from the distribution of the final product must also be considered and can be calculated according to the above formula.

The emissions from the fuel in use $e_u$ can be directly calculated based on the emission factors suggested by the ISCC 205 document (see Section 6, page 26). The fuel amount is to be multiplied by their corresponding factors to get the amount of GHG emissions. For example, natural gas is used as the process energy, per kgCO2eq/MJth an emission factor of 0.07 is applied for an industrial furnace. This $e_u$ is also calculated and used as the part of the GHG emission calculation in $e_p$.

Emission savings from surplus electricity from CHP production ($e_{ee}$) are calculated based on the following formula when the CHP runs on fossil fuels, bioenergy, where this is not a coproduct from the same process, or agricultural crop residues, even if they are a co-product from the same process:

$$
\frac{\text{excess electricity [kWh]} \times \text{EF}_f}{\text{yield}_{\text{main product}} [\text{kg}]} = \frac{\text{excess electricity [kWh]} \times \text{EF}_f}{\text{yield}_{\text{main product}} [\text{kg}]} 
$$

The amount of GHG emission savings from excess electricity equals the amount of GHG emissions from the production of an equal amount of electricity in a power plant using the same type of fuel as the CHP plant. For the calculation of $e_{ee}$ the following data is collected on-site:

- Excess electricity [kWh/yr] – Annual amount of electricity produced in an internal CHP plant (after notional reduction) but fed into an external grid,
- Type of fuel for CHP plant – Type of fuel used within the CHP plant and
- Yield_{main product} [kg/yr] – Annual yield of the main product
- Type of CHP plant (CHP, steam cogeneration plant, gas-steam power plant).

5.2 ISCC Defined Emission Factors

The choice of emission factors has a direct and definite impact on the results of the GHG emissions calculation. However, in the framework of the Directive 2009/28/EC, there is no official list of emission factors available which must be used. This is mainly because of the inconsistent literature on emission factors, the large variance of individual factors, and unavailability of emission factors for some inputs where an approximation is used. To avoid cherry picking and to assure that GHG emissions calculation is done based on transparent and verifiable emission factors, ISCC has developed a list of most relevant emission factors which should be used for all GHG emissions calculation and audits within the ISCC System. The complete list of various emission factors is available on ISCC website.

5.3 Example of Calculation: Summary

The intended audiences of ISCC standard are biomass producers, conversion units (i.e., conversion of solid biomass into liquid biomass or processing of liquid biomass), and the transport and distribution sector. For most of the calculations, one needs the information on the yielded crop for the current year and the previous years average. Therefore, it is highly possible that the calculation methodologies proposed by ISCC are not applicable to household and commercial energy consumers including electricity and natural. These calculations well fit for GHG emissions for (1) land use for various purposes, (2) raw materials production, and (3) various processing related to agricultural activities.
ISCC is an international certification system for Biomass and Biofuels, e.g., fuels and electricity. The choice of emission factors has an impact on the results of the GHG emissions calculation. In the framework of the Directive 2009/28/EC, there is no official list of emission factors available which must be used. The consistent literature on emission factors is limited, the variance of individual factors may be large and for some inputs emission factors might not be available at all or just an approximation can be used. However, to avoid cherry-picking and to assure that GHG emissions calculation and audit takes place on an objective, transparent and verifiable basis, ISCC has developed a list of emission factors. This list covers the most relevant emission factors. It should be used for all GHG emissions calculation and audits within the ISCC System. The list was developed based on experience from a two-year ISCC pilot phase and from the operational phase in 2010. The ISCC list of emission factors can be supplemented and/or amended. ISCC emission factors can be applied in a common way regardless of member countries. Any ISCC member, client or certification body can submit a new value or an update for an existing value.

5.4 Online Tool and Open Data

The BioGrace greenhouse gas (GHG) calculation tool has been recognized as a voluntary scheme by the European Commission. The BioGrace voluntary scheme is a comprehensive, user-friendly GHG calculator based on Excel, featuring unanimously defined standard values, detailed calculation rules, and a user manual. An Excel-based GHG calculation tool has been build which shows, for the 22 biofuel production pathways. It is available as a ZIP-package.

BioGrace also provides a tool for calculating GHG emissions from electricity, heating, and cooling. The BioGrace GHG calculation tool for electricity, heating, and cooling follows the methodology laid down in the European Commission reports of 2011 and 2014.

However, ISCC does not provide access to its data, neither provides any Web services or APIs to access to their data.


This GHG Protocol Corporate Standard covers the accounting and reporting of the six greenhouse gases covered by the Kyoto Protocol—carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF₆). As this guideline suggests, the proposed GHG Protocol Corporate Standard focuses only on the accounting and reporting of emissions and does not require emissions information to be reported to WRI, WBCSD, or other bodies. In addition, while this standard is designed to develop a verifiable inventory, it does not provide a standard for how the verification process should be conducted.

The WRI guideline categories the emission types in Direct GHG emission (from sources that are owned/controlled by the company) and Indirect GHG emission (a consequence of the activities of the company but occur at sources owned/controlled by another company). However, the terms ‘direct’ and ‘indirect’ as used in this document should not be confused with their use in national GHG inventories where ‘direct’ refers to the six Kyoto gases mentioned above and ‘indirect’ refers to the precursors NOx, NMVOC, and CO.

To help delineate direct and indirect emission sources, improve transparency, and provide utility for different types of organizations and different types of climate policies and business goals, three 'scopes' (scope 1, scope 2, and scope 3) are defined for GHG accounting and reporting purposes. Companies shall separately account for and report on scopes 1 and 2 at a minimum. The defined scopes are:

- **Scope 1**: Direct GHG emissions -- Occur from sources that are owned or controlled by the company, for example, emissions from combustion in owned/controlled boilers, furnaces, vehicles, etc.; emissions from chemical production in owned or controlled process equipment. Direct CO₂ emissions from the
combustion of biomass shall not be included in scope 1 but reported separately. GHG emissions not covered by the Kyoto Protocol, e.g. CFCs, NOx, etc. shall not be included in scope 1 but may be reported separately.

- Scope 2: Electricity indirect GHG emissions -- Accounts for GHG emissions from the generation of purchased electricity consumed by the company. Emissions in Scope 2 occur at the facility where electricity is generated.
- Scope 3: Other indirect GHG emissions -- An optional reporting category that allows for the treatment of all other indirect emissions. Scope 3 emissions are a consequence of the activities of the company, but occur from sources not owned/controlled by the company, e.g., extraction and production of purchased materials or transportation of purchased fuels.

6.1 Identification of Activities for the Calculation of GHG Emission for different Scopes

Direct GHG Emissions (Scope 1):
Direct GHG Emissions aggregate the emissions from the following activities:

- Emissions from the generation of electricity, heat, or steam from fuels in stationary sources, e.g., boilers, furnaces, turbines
- Emissions from physical or chemical processing, e.g., cement, aluminum, adipic acid, ammonia manufacture, and waste processing
- Emissions from the transportation of materials, products, waste, and employees using for example trucks, trains, ships, airplanes, buses, and cars
- Emissions result from (un)intentional releases a.k.a. fugitive emissions from for example equipment leaks from joints, seals, packing, and gaskets; methane emissions from coal mines and venting; hydrofluorocarbon (HFC) emissions during the use of refrigeration and air conditioning equipment; and methane leakage from gas transport, etc.

It is important to note that emissions associated with the sale of own-generated electricity to another company are not deducted/netted from scope 1. However, emissions associated with the sale/transfer of own-generated electricity may be reported as an optional information separate from the main reporting.

Electricity Indirect GHG Emissions (Scope 2):
Indirect GHG Emissions related to transmission and distribution (T&D) aggregate the following:

- Purchased electricity consumed by the utility company during T&D
- Purchased electricity consumed by end consumers

Other Indirect GHG Emissions (Scope 3):
Some of these activities under Scope 3 might be included under scope 1 if the pertinent emission sources are owned or controlled by the company, for example, if the transportation of products is done in vehicles owned or controlled by the company. Activities include:

- Extraction and production of purchased materials and fuels
- Transport-related activities
  - Transportation of purchased materials or goods
  - Transportation of purchased fuels
  - Employee business travel
  - Employees commuting to and from work
  - Transportation of sold products
  - Transportation of waste
- Electricity-related activities not included in scope 2
Extraction, production, and transportation of fuels consumed in the generation of electricity (either purchased or own generated by the reporting company)
- Purchase of electricity that is sold to an end user (reported by utility company)
- Generation of electricity that is consumed in a T&D system (reported by end-user)

- Leased assets, franchises, and outsourced activities — emissions from such contractual arrangements are only classified as scope 3 if the selected consolidation approach (equity or control) does not apply to them
- Use of sold products and services
- Waste disposal
  - Disposal of waste generated in operations
  - Disposal of waste generated in the production of purchased materials and fuels
  - Disposal of sold products at the end of their life

6.2 Calculation of GHG Emission

As the guideline suggested, the most common approach for calculating GHG emissions is through the application of documented emission factors. The emission factors are the calculated ratios relating GHG emissions to a proxy measure of activity at an emissions source.

For most small to medium-sized companies and for many larger companies, scope 1 GHG emissions will be calculated based on the purchased quantities of commercial fuels (such as natural gas and heating oil) using published emission factors. Scope 2 GHG emissions will primarily be calculated from metered electricity consumption and supplier-specific, local grid, or other published emission factors. Scope 3 GHG emissions will primarily be calculated from activity data such as fuel use or passenger miles and published or third-party emission factors.

There are two basic approaches for gathering data on GHG emissions from a corporation’s facilities as shown in the table below:

- **Centralized**: individual facilities report activity/fuel use data (such as quantity of fuel used) to the corporate level, where GHG emissions are calculated.
- **Decentralized**: individual facilities collect activity/fuel use data, directly calculate their GHG emissions using approved methods, and report this data to the corporate level.

<table>
<thead>
<tr>
<th>SITE LEVEL</th>
<th>CORPORATE LEVEL</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CENTRALIZED</strong></td>
<td></td>
</tr>
<tr>
<td>Activity Data</td>
<td>Sites Report Activity Data (GHG Emissions Calculated at Corporate Level: Activity Data X Emissions Factor = GHG Emissions)</td>
</tr>
<tr>
<td><strong>DECENTRALIZED</strong></td>
<td></td>
</tr>
<tr>
<td>Activity data X Emission Factor = GHG Emissions</td>
<td>Sites Report GHG Emissions</td>
</tr>
</tbody>
</table>

Therefore, the global formula to calculate the GHG emissions:

\[
\text{Total GHG Emission} = \text{Direct GHG Emission (from scope 1)} + \text{Indirect GHG Emission (from Scope 2 & 3)} \quad \text{(Eq. 6.1)}
\]
In general, it is calculated that the produced or transmitted electricity has the emission factor of 0.2 t/MWh, e.g., a generation of 100 MWh electricity would do the emission of 20t of GHG. All the emission factors are considered from the IPCC guidelines.

6.3 Managing Data and Emission Reporting Quality

WRI defined some quantification quality strategy from data gathering to the calculation of GHG emissions:

Data Gathering, Input, and Handling Activities:
- Check a sample of input data for transcription errors
- Identify spreadsheet modifications that could provide additional controls or checks on quality
- Ensure that adequate version control procedures for electronic files have been implemented

Data Documentation:
- Confirm that bibliographical data references are included in spreadsheets for all primary data
- Check that copies of cited references have been archived
- Check that assumptions and criteria for selection of boundaries, base years, methods, activity data, emission factors, and other parameters are documented
- Check that changes in data or methodology are documented

Calculating Emissions and Checking Calculations:
- Check whether emission units, parameters, and conversion factors are appropriately labeled
- Check if units are properly labeled and correctly carried through from beginning to end of calculations
- Check that conversion factors are correct
- Check the data processing steps (e.g., equations) in the spreadsheets
- Check that spreadsheet input data and calculated data are differentiated Check a representative sample of calculations, by hand or electronically
- Check some calculations with abbreviated calculations (i.e., back of the envelope calculations)
- Check the aggregation of data across source categories, business units, etc.
- Check consistency of time series inputs and calculations

6.4 Required Information on GHG Emission Reporting

A public GHG emissions report that is in accordance with the GHG Protocol Corporate Standard shall include the following information:

Description of the company and inventory boundary:
- An outline of the organizational boundaries chosen, including the chosen consolidation approach.
- An outline of the operational boundaries chosen, and if scope 3 is included, a list specifying which types of activities are covered.
- The reporting period covered.

Information on emissions:
- Total scope 1 and 2 emissions independent of any GHG trades such as sales, purchases, transfers, or banking of allowances.
- Emissions data separately for each scope.
- Emissions data for all six GHGs separately (CO\textsubscript{2}, CH\textsubscript{4}, N\textsubscript{2}O, HFCs, PFCs, SF\textsubscript{6}) in metric tonnes and in tonnes of CO\textsubscript{2} equivalent.
• Year chosen as the base year, and an emissions profile over time that is consistent with and clarifies the chosen policy for making base year emissions recalculations.

• Appropriate context for any significant emissions changes that trigger base year emissions recalculations (acquisitions/divestitures, outsourcing/insourcing, changes in reporting boundaries or calculation methodologies, etc.).

• Emissions data for direct CO₂ emissions from biologically sequestered carbon (e.g., CO₂ from burning biomass/biofuels), reported separately from the scopes.

• Methodologies used to calculate or measure emissions, providing a reference or link to any calculation tools used.

• Any specific exclusions of sources, facilities, and/or operations.

6.5 An Example Calculation

We will use the example property from Section 1.2 – located at 21, Panorama Crt, Toronto, M9V 4E3 – for which we have the energy use data for the year 2011 located in Ontario, Canada. Following the Equation 6.1, we can calculate the CO₂ emission from different Scopes. The emission factors applied for fuels are taken from the IPCC 1996 guidelines.

\[
\text{Total GHG Emission} = \text{Direct GHG Emission (from scope 1)} + \text{Indirect GHG Emission (from Scope 2 & 3)}
\]

\[
= \text{Natural Gas (from scope 1)} + \text{Electricity Consumed (from Scope 2)}
\]

\[
= 62,129.7602 \text{ m}^3 + 334,525.1786 \text{ kWh}
\]

\[
= 62,129.7602 \text{ m}^3 + 334,525.1786 \text{ kWh}
\]

\[
= 62,129.7602 \times 10.32 \text{ eKWh} + 334,525.1786 \text{ kWh}
\]

\[
= 641.179 \text{ MWh} + 334.5252 \text{ MWh}
\]

\[
= 975.7043 \text{ MWh}
\]

\[
= 975.7043 \text{ MWh} \times 0.2 \text{ tonnes of CO}_2/\text{MWh}
\]

\[
= 195.141 \text{ tonnes of CO}_2
\]

**Therefore, the total CO₂ emissions using the WRI method (with the IPCC emission factors) are 195.14 tonnes of CO₂.**

6.6 Online Tool and Open Data

This section provides an overview of the GHG calculation tools and guidance available on the GHG Protocol Initiative website (www.ghgprotocol.org).

There are two main categories of calculation tools:

• Cross-sector tools that can be applied to different sectors. These include stationary combustion, mobile combustion, HFC use in refrigeration and air conditioning, and measurement and estimation uncertainty.

• Sector-specific tools that are designed to calculate emissions in specific sectors such as aluminum, iron and steel, cement, oil and gas, pulp and paper, office-based organizations.

Stationary Combustion tool:

• Calculates direct and indirect CO₂ emissions from fuel combustion in stationary equipment.
• Provides two options for allocating GHG emissions from a co-generation facility
• Provides default fuel and national average electricity emission factors

Mobile Combustion tool:
• Calculates direct and indirect CO₂ emissions from fuel combustion in mobile sources
• Provides calculations and emission factors for road, air, water, and rail transport

All the above tools are freely available on http://www.ghgprotocol.org/calculation-tools in the form of Excel templates. WRI is a global research organization that spans more than 50 countries, with offices in the United States, China, India, Brazil, Indonesia and more. More than 700 experts and staff work closely with leaders to turn big ideas into action to sustain natural resources—the foundation of economic opportunity and human well-being. WRI work focuses on six critical issues at the intersection of environment and development: climate, energy, food, forests, water, and cities and transport.

The collection of WRI open data is available on http://datasets.wri.org. WRI produces and manages datasets as part of their commitment to providing quality and open data to researchers and partners. All WRI data are based on their research, which is held to traditional academic standards of excellence, including objectivity and rigor. The WRI GHG emission datasets include, for example, UNFCCC Annex I GHG Emissions Data, U.S. States Greenhouse Gas Emissions, Paris Contributions Data, Country Greenhouse Gas Emissions Data, Emissions Projections.

The WRI also has a forthcoming guide for quantifying reductions from GHG mitigation projects titled "GHG Protocol Project Quantification Standard".


Carbon dioxide is by far the most common greenhouse gas. The main greenhouse gases include: carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), sulphur hexafluoride (SF₆), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), as well as ozone-depleting chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs) – these latter two groups of gases are not covered by the Kyoto Protocol.

7.1 Calculation of GHG

Each greenhouse gas has a different capacity to cause global warming, depending on its radiative properties, molecular weight and the length of time it remains in the atmosphere. The GWP of each greenhouse gas is defined in relation to a given weight of carbon dioxide and for a set time period (for the purpose of the Kyoto Protocol a period of 100 years). GWPs are used to convert emissions of other greenhouse gases into CO₂ equivalents – making it possible to compare the potential effects of different gases.

<table>
<thead>
<tr>
<th>GHG</th>
<th>Full Names</th>
<th>GWPs</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂</td>
<td>Carbon dioxide</td>
<td>1</td>
</tr>
<tr>
<td>CH₄</td>
<td>Methane</td>
<td>21</td>
</tr>
<tr>
<td>N₂O</td>
<td>Nitrous oxide</td>
<td>310</td>
</tr>
<tr>
<td>HFCs</td>
<td>Hydrofluorocarbons</td>
<td>149 (C₂H₆F₂) to 11700 (CHF₃)</td>
</tr>
<tr>
<td>PFCs</td>
<td>Perfluorocarbons</td>
<td>5700 (CF₄) to 11900 (C₂F₆)</td>
</tr>
<tr>
<td>SF₆</td>
<td>Sulphur hexafluoride</td>
<td>23900</td>
</tr>
</tbody>
</table>

Categories defined in Kyoto Protocol:

Within the inventory reporting requirements of the UNFCCC and the Kyoto Protocol, estimates of greenhouse gas emissions are produced for a number of sectors delineated according to process-technological characteristics.
Amongst these are four main sectors: energy (fuel combustion); industrial processes, solvent and other product use; agriculture; and waste. Each of these sectors (for example, fuel combustion) may be comprised of individual categories (fuel combustion in transport) and sub-categories (fuel combustion in road transportation).

Land use, land-use change, and forestry (LULUCF) activities also have the potential to help reduce emissions, as they seek to protect existing carbon stocks (for example, by reducing deforestation and land degradation), or to encourage new carbon stocks (afforestation/reforestation). The Kyoto Protocol restricts the accounting of the LULUCF sector, with net emissions relating to forest land management, cropland management, grazing land management and/or revegetation considered as optional in relation to inventory reporting requirements. As such, net emissions from LULUCF are treated as a memo item in greenhouse gas inventories and are excluded from the total emissions as used in relation to Kyoto targets.

Data collection forms an integral part of any greenhouse gas inventory and is reliant on existing statistical sources. Emissions inventories do not ‘measure’ greenhouse gas emissions per se; rather, they ‘estimate’ emissions through the application of the 1996 IPCC guidelines which offer a range of methods. The simplest approach involves combining information on the extent of a human activity with a coefficient quantifying the emissions from that activity. Such coefficients are called ‘emission factors’. The general formula to calculate GHG emissions is as follows:

\[ \text{Emissions} = \text{Activity Data} \times \text{Emissions Factor} \]

### 7.2 An Example of Calculation

We will use the example property from Section 1.2 from Section 1.4 – located at 21, Panorama Crt, Toronto, M9V 4E3 – for which we have the energy use data for the year 2011 located in Ontario, Canada. Following the Equation 8.1, we can calculate the \( \text{CO}_2 \) emissions. The GWPs listed in Table 2 are updated values suggested by the Intergovernmental Panel on Climate Change (IPCC). The emission factors are also considered from IPCC suggested values. All the thermal conversion factors are available and considered as described by EPA here.

\[
\text{Total Emissions} = (E_{\text{CO}_2} \times \text{GWP}_{\text{CO}_2 \text{ for Electricity}}) + (E_{\text{CO}_2} \times \text{GWP}_{\text{CO}_2 \text{ for Gas}})
\]
\[
= (334,525.1786 \text{ kWh} \times 1) + (62,129.76002 \text{ m}^3 \times 1)
\]
\[
= (334,525.1786 \times 0.003412 \times 11.72) \text{ kg} + (62,129.76002 \times 0.036425 \times 52.14) \text{ kg}
\]
\[
= 13,377.207 \text{ kg} + 117,996.809 \text{ kg}
\]
\[
= 131374.016 \text{ kg}
\]
\[
= 131.374 \text{ tonnes of CO}_2
\]

Therefore, the total \( \text{CO}_2 \) emissions using the EEA (with the IPCC provided default GWP values and emission factors) are 131.374 tonnes of \( \text{CO}_2 \).

### 7.3 Online Tool and Open Data

EEA does not provide an online tool for the calculation of GHG emissions. However, it has a large collection of emissions, pollution, and other environmental data publicly available online. EEA also provides Semantic Data Service that enables users to search for the content of data in Eionet (European Environment Information and Observation Network). Eionet provides GEMET to use the semantic services as REST services. Nevertheless, GEMET REST services do not result in GHG emissions data.

The Department for Environment, Food and Rural Affairs of the Government of UK also has its own GHG emissions inventory guidelines and reporting templates. The guideline “Guidance on how to measure and report your greenhouse gas emissions” was published September 2009 and still being followed unchanged.
8. Estimating Greenhouse Gas Emissions in Agriculture by Food and Agriculture Organization of the United Nations (FAO)\(^9\)

FAO follows the 2006 IPCC guidelines to estimate the GHG emissions. The 2006 IPCC Guidelines for National Greenhouse Gas Inventories (2006 IPCC Guidelines) were prepared upon the invitation of the UNFCCC, to provide good practice methodologies for countries to use in preparing GHG inventories when reporting to the UNFCCC. As shown in the picture below, the GHG inventory sectors are Energy, Industrial Processes & Product Uses (IPPU), Agriculture, Forestry & Other Land Use (AFOLU) and Waste.

The 2006 IPCC Guidelines are an evolutionary development with respect to the 1996 IPCC Guidelines, the GPG 2000 and the GPG-LULUCF 2003. The 2006 approach ensures continuity and enables experiences with the existing guidelines, new scientific information, and the results of the UNFCCC review process to be incorporated.

One of the most significant changes between the 1996 and 2006 versions of the Guidelines is the assembly of Land Use, Land Use Change and Forestry (LULUCF) and the Agriculture sectors into a single AFOLU sector.

8.1 The GHG Emission Reporting Method

The fundamental formula for estimating the quantity of GHG emissions can always be expressed as the multiplication of the activity data (AD) by the emission factor (EF) as shown in the following equation:

\[
\text{Activity Data (AD)} \times \text{Emission Factor (EF)} = \text{Emissions/Removals}
\]

where,

\( \text{EF} \) = Emission factor. Emission factors are coefficients that quantify the emissions or removals of a gas per unit activity data. Emission factors are based on samples of measurements, averaged at various levels of detail depending upon the Tier methodology used, to develop a representative rate of emission for a given activity level under a given set of operating conditions.

\( \text{AD} \) = Activity data. Activity data describe the magnitude of a human activity resulting in emissions or removals of greenhouse gases, taking place during a given period of time and over a specified area.

In general, FAO’s GHG emission estimation is more agricultural domain centric. In this document, however, we are more interested in the emissions from commercial and residential buildings and human fuel consumption. Therefore, the detailed calculations proposed by FAO on the GHG emissions related to AFOLU (Agriculture, Forestry and Other Land Use) – Land use, Forest land, Cropland, Grassland, Burning Biomass – are out of the scope of this document and are not discussed here. Interested readers are encouraged to go through [9].

As the principal focus of GHG emissions calculation by FAO is on the land use, land use change and forestry, and the agriculture sectors, we do not detail the GHG emission calculation in this document. This is because our scope of GHG emission calculation is from household energy and commercial consumption. However, FAO provides a good collection of open data sets that can be explored and analyzed further, which we highlight in the following section.
8.2 Online Tool and Open Data

FAOSTAT – www.fao.org/faostat/en/ – provides free access to food and agricultural emissions data for over 245 countries and territories and covers all FAO regional groupings from 1961 to the most recent year available.

The data – www.fao.org/faostat/en/#data – in the FAOSTAT database are derived from national questionnaires and pertain to various agricultural sectors. These are compiled by National Statistics Offices (NSOs) or Ministers of Agriculture and sent to FAO Statistics Division on an annual basis. The questionnaire data are checked with countries and validated, so that coherent and consistent time series may be obtained. In case of gaps or missing official data, time series are completed with other international data sources and calculated through estimation methods. Besides the data on food, FAOSTAT also gather and freely provide data from Emissions - Agriculture including emission data related to Enteric Fermentation, Manure Management, Rice Cultivation, Synthetic Fertilizers, Manure applied to Soils, Manure left on Pasture, Crop Residues, Cultivation of Organic Soils, Burning - Savanna, Burning - Crop Residues, and Energy Use.

In addition, FAO provides data on Emissions - Land Use including Forest Land, Cropland, Grassland, Burning - Biomass, and so on. All these data are country-wise and yearly, and reports can be generated based on fuel types.

There is an initiative called FAOdata -- http://api.data.fao.org/1.0/ through which authorized developers are allowed to add, retrieve, update, delete, browse and search resources in the data.fao.org catalog through Web services in the RESTful and SOAP style. More details on the REST APIs are available on http://api.data.fao.org/1.0/esb-rest/groups.html.

In addition to all the above open datasets, UFCCC provides several links to a large collection of emissions, environmental, and agricultural external datasets on its Web site.

9. Summary of Comparison

In the following, we make a high-level comparison among the GHG standards on different criteria.

<table>
<thead>
<tr>
<th>Criteria/Organizations</th>
<th>ECCC</th>
<th>UNEP</th>
<th>EPA</th>
<th>ISCC</th>
<th>WRI</th>
<th>NRCan</th>
<th>EEA</th>
<th>ONGov</th>
<th>FAO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emissions from Biomass Materials Included in The Main Emissions Calculation?</td>
<td>No, Reported separately</td>
<td>Yes</td>
<td>No, Reported separately</td>
<td>Yes</td>
<td>No, Reported separately</td>
<td>No</td>
<td>Yes</td>
<td>No, Reported separately</td>
<td>Yes</td>
</tr>
<tr>
<td>Methane and Nitrous Oxide from Biomass Included in The Reporting Threshold?</td>
<td>Yes</td>
<td>Yes</td>
<td>No, Reported separately</td>
<td>Yes</td>
<td>No, Reported separately</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Transport and Distribution</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Mandatory GHGs Subject to Mandatory Reporting</td>
<td>CO₂, CH₄, N₂O, SF₆, C₂H₆F₂, CSF₃</td>
<td>CO₂, CH₄, N₂O, SF₆, C₂H₆F₂, CSF₃</td>
<td>CO₂, CH₄, N₂O, SF₆, C₂H₆F₂, CSF₃</td>
<td>CO₂, CH₄, N₂O, SF₆, C₂H₆F₂, CSF₃</td>
<td>CO₂, CH₄, N₂O, SF₆, C₂H₆F₂, CSF₃</td>
<td>CO₂, CH₄, N₂O, SF₆, C₂H₆F₂, CSF₃</td>
<td>CO₂, CH₄, N₂O, SF₆, C₂H₆F₂, CSF₃</td>
<td>CO₂, CH₄, N₂O, SF₆, C₂H₆F₂, CSF₃</td>
<td></td>
</tr>
<tr>
<td>Global Warming Potentials</td>
<td>IPCC suggested</td>
<td>IPCC suggested</td>
<td>IPCC suggested</td>
<td>IPCC suggested</td>
<td>IPCC suggested</td>
<td>IPCC suggested</td>
<td>IPCC suggested</td>
<td>IPCC suggested</td>
<td></td>
</tr>
</tbody>
</table>

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**Methods of Estimations**

<table>
<thead>
<tr>
<th>Methods of Estimations</th>
<th>Monitoring or Direct Measurement; Mass Balance; Emission Factors; Engineering Estimates</th>
<th>Emission Factors</th>
<th>Emission Factors</th>
<th>Emission Factors</th>
<th>Emission Factors</th>
<th>Emission Factors; Engineering Estimates</th>
<th>Emission Factors; Engineering Estimates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Appropriate for Generation Sites?</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Suitable for Residential and Commercial Buildings?</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Choice of Emission Factors (EF)</td>
<td>IPCC suggested</td>
<td>IPCC suggested</td>
<td>IPCC suggested</td>
<td>IPCC suggested</td>
<td>IPCC suggested</td>
<td>IPCC suggested</td>
<td>IPCC suggested</td>
</tr>
<tr>
<td>Specific to Countries</td>
<td>Canada</td>
<td>Worldwide</td>
<td>Canada, USA</td>
<td>EU countries</td>
<td>Worldwide</td>
<td>Canada</td>
<td>EU countries</td>
</tr>
<tr>
<td>Online Tool for Calculations?</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Provides Open Data?</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Reference Gas Used</td>
<td>Carbon Dioxide</td>
<td>Carbon Dioxide</td>
<td>Carbon Dioxide</td>
<td>Carbon Dioxide</td>
<td>Carbon Dioxide</td>
<td>Carbon Dioxide</td>
<td>Carbon Dioxide</td>
</tr>
<tr>
<td>Applicable to Agricultural Sector</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Provide APIs/Web Services</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Reference Property Calculation CO₂ emission value</td>
<td>131.374 tonnes of CO₂</td>
<td>184.046 tonnes CO₂</td>
<td>131.374 tonnes CO₂</td>
<td>-</td>
<td>195.141 tonnes of CO₂</td>
<td>143.914 tonnes of CO₂</td>
<td>131.374 tonnes of CO₂</td>
</tr>
</tbody>
</table>

**9.1 Discussions: Similarities and Differences among the Standards**

In this section, we assess each GHG standard, its estimation method, and the estimated value where applicable.

**9.1.1 ECCC (Environment and Climate Change Canada):**

The ECCC (Environment and Climate Change Canada) relies on IPCC (Intergovernmental Panel on Climate Change) guidelines for GHG inventory, thus ECCC uses the default GWP as suggested in the IPCC guidelines. The ECCC method could be applicable to residential and commercial buildings but it is more suitable for the generation sites that use hard fuels like coal. For the reference facility in Section 1.4, we have estimated GHG emissions using the ECCC method of **131.374 tonnes of CO₂** for the year 2011. The ECCC estimation method not only measures CO₂ emission, it also measures other GHGs like CH₄, H₂O, PFCs, HFC, and SF₆ with equal importance. Also, while calculating GHG emissions, the ECCC method calculated emissions separately for solid fuel, liquid fuel, and gaseous fuel and then add them up. One particular parameter in ECCC method is HHV (high heat value) which is the amount of heat produced by a complete combustion of fuel and it is measured as a unit of energy per unit mass or volume of a substance, e.g., measured as kcal/kg, kJ/kg, or Btu/m³. The ECCC provides several alternatives for estimating GHG emissions some of which relies on engineering measurements like Ratio of Molecular Weights (RMW). The ECCC does not provide any online tool or APIs for GHG emissions calculations. However, it provides open dataset which can only be achieved through search and browse. ECCC does not provide any APIs to access its provided open data either.
9.1.2 NRCan (Natural Resources Canada):

The NRCan instead relies on the default GWP as suggested in the UNEP guidelines. The NRCan method could be applicable to residential and commercial buildings but it is more suitable for the natural sources of GHG emissions like land, forest, agriculture, and so on. For the reference facility in Section 1.4, we have estimated GHG emissions using the NRCan method of 143.914 tonnes of CO₂ for the year 2011. The NRCan estimation method mainly focuses on CO₂, CH₄, and N₂O in its calculation. NRCan (Natural Resources Canada) provides a comprehensive tool – RETScreen – as a clean energy management software system for energy efficiency, renewable energy, and project feasibility analysis as well as ongoing energy performance analysis. The RETScreen Expert is capable of GHG emissions estimation and weather normalization of energy data. However, the RETScreen Expert is currently available in viewer mode only. In RETScreen, the default GWP and emission factors are used as suggested by IPCC guidelines. NRCan provides a comprehensive energy use database but it does not provide any APIs or Web services to access these open datasets.

9.1.3 Government of Ontario (ONgov):

The guidelines followed by the Government of Ontario (ONgov) is entirely same as ECCC. Therefore, we did not duplicate the discussion, neither the estimation method for GHG emissions.

9.1.4 UNEP (United Nations Environment Programme):

UNEP (United Nations Environment Programme) provides an all-encompassing GHG emissions computation method. All-encompassing in the sense that it considers not only individual fuel and electricity consumption, but it also includes transport and process-related emission figures in its GHG inventory. UNEP classifies the GHG emission into two broad categories: energy-related and process-related. UNEP relies upon its own emission factors for GHG calculation, for example, for natural gas it uses 0.0002020 tCO₂/kWh (thus GJ or m³ units should be converted to e kWh or kWh) and for electricity, it uses 0.000163 tCO₂/kWh. Based on the UNEP methodology for the reference facility in Section 1.4, we have estimated GHG emissions of 184.046 tonnes of CO₂ for the year 2011. The UNEP is one of the highest bodies in GHG monitoring and controlling. Being a prominent international body for GHG, it provides rich sets of GHG and environmental data and RESTful Web services to access these data. However, UNEP does not provide its own GHG emission calculation tool since it focuses more on providing guidelines and mentoring other national and international public and private bodies. Since UNEP is an international body, calculations can be varied based on country-specific CO₂ emissions factors for coal and electricity, through which same formula can be applied in different countries by varying emission factors.

9.1.5 EPA (The United States Environmental Protection Agency):

The EPA provided a methodology for GHG emissions estimation follows the WRI suggested approach. For the emission factors and US/Canada specific calculations, EPA relies on their proprietary algorithm called “Default Fuel Analysis Approach” (DFAA). The EPA provided estimation approach is one of the approaches that do not include biomass in the GHG calculations. Based on the EPA methodology for the reference facility in Section 1.4, we have estimated GHG emissions of 131.374 tonnes of CO₂ for the year 2011 using the latest emission factors for Canada released in August 2017. However, using the previous emission factors this results in slightly higher GHG emissions of 157 tonnes of CO₂ for the same facility and year. This suggests that energy production and consumption style might become greener in recent days. The complimentary Web-based tool, called ENERGY STAR Portfolio Manager®, is mostly applicable to residential and commercial building energy uses. The main advantage of ENERGY STAR Portfolio Manager® is it provides a rich set of APIs to allow authenticated parties accessing their clients’ energy and property data.

9.1.6 ISCC (International Sustainability and Carbon Certification):

The guidelines provided by ISCC (International Sustainability and Carbon Certification, a European-centric organization) are mostly applicable to environmental and agricultural related emissions that require up to 20 years
of yielded crops. Overall, it finds emissions from fertilizer production and fuel consumption in agricultural activities including emissions from waste water. ISCC also uses IPCC suggested emission factors. However, we did not provide the emissions calculations as the methodology is not related residential or commercial energy use. ISCC provides an Excel-based GHG emissions calculation tool, but no open data, neither any APIs to access their data. Since ISCC is more focused towards agricultural and biomass emissions and requires information on yielded crops, we do not calculate GHG emissions for the reference facility.

9.1.7 WRI (World Resources Institute):

The guidelines suggested by WRI (World Resources Institute) combine the emissions from residential/commercial properties with the emissions from land, agriculture, and process/transportation-related activities. WRI supports both the centralized (top-down) and decentralized (bottom-up) approach for the calculation of GHG emissions. WRI categories GHG emissions into three categories: direct GHG emissions (Scope 1), electricity indirect GHG emissions (Scope 2), and other indirect GHG emissions (Scope 3). For the reference facility in Section 1.4, we have estimated GHG emissions using the NRCan method of 195.141 tonnes of CO\textsubscript{2} for the year 2011. The calculated value is highest among all other standards because it uses a very high emission factor of 0.2 tonnes of CO\textsubscript{2} per MWh of fuel consumption. WRI provides open dataset on GHG emissions and multiple tools for GHG emissions calculations. WRI provides both cross-sector and sector-specific GHG emissions calculations tools. However, it does not provide any APIs or services to access their open data, i.e., users need to manually download the emissions data.

9.1.8 EEA (European Environment Agency):

The EEA is the European counterpart of EPA in the USA. EEA adheres to the UNFCCC and Kyoto Protocols for limiting and reducing GHG emissions. The calculations and emission factors EEA uses are from IPCC guidelines. For the reference facility in Section 1.4, we have estimated GHG emissions using the NRCan method of 131.374 tonnes of CO\textsubscript{2} for the year 2011, which is equivalent to WRI and EPCC. Because all these three parties follow emission factors provided by IPCC. EEA does not provide any online tool, but a semantic search engine to search for energy use data. A Web service called GEMET exists to access the European energy use data. However, the service does not retrieve in any GHG emissions data.

9.1.9 FAO (Food and Agriculture Organization):

Lastly, FAO (Food and Agriculture Organization) is essentially focused on the GHG emissions from the agricultural, land use, and forest activities. Therefore, the residential and commercial buildings being our focus, the guidelines suggested by FAO is directly related to our purpose. Although FAO provides a rich set of food and agricultural emissions data for over 245 countries and territories. Interestingly, FAO provides services called FAOdata through which authorized developers are allowed to add, retrieve, update, delete, browse and search resources in the data.fao.org catalog through Web services in the RESTful and SOAP style. Again, likewise the ISCC, since FAO more focused towards agricultural and biomass emissions and we are more interested in GHG emissions from residential and commercial energy use, we do not calculate GHG emissions for the reference facility.

9.2 Third-party Tools for GHG Emission Calculation

Below are some third party GHG emissions calculators available online:

<table>
<thead>
<tr>
<th>Name of the Program</th>
<th>Tools Path / Name</th>
<th>Source/Type/Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>India GHG Program</td>
<td><a href="http://indiaghgp.org/calculation-tools">http://indiaghgp.org/calculation-tools</a></td>
<td>Individual/Business Energy Use</td>
</tr>
<tr>
<td>ROBERT</td>
<td><a href="https://www.robert.ca/en/ghg-calculator/">https://www.robert.ca/en/ghg-calculator/</a></td>
<td>Transport</td>
</tr>
</tbody>
</table>
10. Concluding Remarks

In this case study, we are more interested in GHG emissions due to energy use in residential and commercial buildings. In a residential/commercial property, one’s carbon footprint is the total amount of Carbon Dioxide (or any other GHG) that individual human activity generated and then released into the atmosphere through energy use of any kind within a given timeframe. The carbon footprint is usually calculated on a yearly basis and is measured in equivalent tonnes of CO₂. Typical examples of Carbon Dioxide emission sources from our daily life are the automobile (engine exhaust), home appliances that burn fossil fuels or use electricity, etc. But the estimation of CO₂ is not as simple as the idea is. One needs to have a thorough knowledge of emission factors, the units of fuel being used, and various conversion factors to approximate the GHG emissions.

The methods greenhouse gas (GHG) emissions estimations may vary depending on the sectors of emissions and even regions. The consumption-based measurement (also known as bottom-up and more related to imports) approach is the most common to use while there is also production-based measurement known as a top-down approach (more related to exports). In the production-based measurement, emissions are calculated not directly but indirectly from fossil fuel usage and other relevant processes such as industry and agriculture according to 2006 guidelines issued by the IPCC for GHG reporting.

This case study highlighted nine GHG emissions estimation standards (with several top international GHG/environmental bodies: WRI, UNFCCC, IPCC, FAO, etc.) to show their similarities and dissimilarities. We also show with example calculations where feasible the total GHG emissions from a reference facility located in Toronto. The two major GHG emissions estimation approaches are Emission Factor-based and Monitoring/Direct Measurement. In fact, estimation methods based on emission factors are more common than the monitoring or direct measurement, since it quite hard to directly measure them and very often they do not produce accurate results. Therefore, an exact measure depends on 'more precise' emission factors. Over time they may change.
depending on the type of energy/fuel, i.e., how greener they are in the production and transportation & distribution (T&D). For example, recently ENERGY STAR Portfolio Manager® changed some of their emission factors for some regions in USA and Canada, e.g., for Toronto, for electricity and natural gas. This is due to electricity in Ontario now being greener than a few years ago. All the calculations in this case study are done with latest available emission factors and GWP.

As discussed in this case study, there are a number of standards and estimation methods/tools available. All these standards and estimation methods/tools came up from diverse sources of research. However, obtaining a uniform methodology for GHG emissions estimation is challenging and impractical. There are many factors involved including the regional average temperature, regional weather diversity, land use policies, agricultural production capability, fuel availability and usage pattern including the types of fuel people rely on, and last but not least the adoption of technology. In general, a developed and exporting country with higher population emits more GHG into the atmosphere due to its manufacturing industries. On the other hand, less/least developed countries in the rural area depend more on biomass which is a significant source of methane (CH₄). Countries with livestock production face similar GHG emissions challenges. Overall, it's hard if not impossible to obtain a globally accepted/applicable GHG emissions estimation methodology. It is difficult to find the right balance between emissions and development, to save the atmosphere and to prevent climate change. That is the main concern of many international bodies like IPCC, UNFCCC, UNEP, etc. These bodies are still disputing which countries are major players in GHG emissions.

With the scarcity problem of a uniform and parameterized GHG estimation method, another fundamental obstruction exists with the lack of GHG data standardization for data sharing. Standards and international bodies hardly provide open APIs for sharing GHG data which could be very useful for educating individuals and businesses. This would also help in energy conservation and thus reducing GHG emissions. The ultimate success of this GHG reduction program largely lies on reducing the impact of climate change.

Although standards and international bodies do not always provide open APIs for GHG data acquisition and sharing, they provide their own GHG emissions estimation methodologies, the calculation of which might vary. This variation comes from different emission factors for the same fuel type and—or due to the fact that internal mass or material types of the same fuel vary that are found and burnt in different regions. For example, the net calorific value (NCV) for coal varies according to the region it is found. The scientists found that China uses poor quality brown coal (found from its underground mining is the lowest grade of coal and its heating value is around one-quarter of black coal) which contains less carbon than higher grade bituminous coal and has more potential of emitting GHG to the atmosphere.

It is important to have easily understandable and usable GHG estimation calculations. Major national and international bodies should provide online tools or Web APIs for easy estimation and efficient sharing of GHG data. Unfortunately, this is not the case and individuals and businesses are implementing their proprietary tools and methods which are not properly verified and validated. Governments and international bodies need to come forward with simplified yet advanced measurement methods and tools for GHG emission estimation. In the below we summarize the findings of this case study:

- All the studied standards in this case study are bound to report all the GHGs in Kyoto Protocol (1997) that include CO₂, CH₄, N₂O, SF₆, C₂H₆Fₓ, and CₓFₓ;
- Known methods for GHG estimation are: (i) Monitoring/Direct Measurement, (ii) Mass Balance (iii) Emission Factors, and (iv) Engineering Estimates. The Monitoring/Direct Measurement and Emission Factors-based methods are the most commonly used for GHG emissions estimation;
- The GHG emission estimation methods aggregate all the gases into one category of CO₂, however, it is widely acknowledged that this faces many difficulties and challenges with accuracy, introducing some margin of error. The IPCC guidelines suggest that uncertainties for CO₂ are up to 10% for electricity generation and industrial processes and up to 60% for land use change and forestry;
- Our findings on GHG emissions estimation standards suggest that GHG calculations may vary based on the estimation methodology one follows for a specific sector and the default CO₂-equivalent emission factors one applies that is country-specific;
• In Canada, the ultimate responsibility for GHG inventory lies on the Greenhouse Gas Division of ECCC. NRCan also takes part in collaboration with Canadian Forest Service in reporting GHG emissions that it is responsible for;
• As recommended by the ECCC, all individuals and businesses who operate a facility that emits 50 kilo-tonnes of CO₂-equivalent (a.k.a., the reporting threshold) or more of GHGs in a calendar year must report their emissions information to ECCC;
• The ECCC calculations cover the GHG emissions from general stationary combustion for example from fossil fuels, biomass, and other fuels. However, ECCC calculations are appropriate for generation sites and may not suitable for energy use at the residential and commercial buildings;
• The GWP (Global Warming Potentials) values for a fuel might change over the period, i.e., it might be upgraded or downgraded depending on the generation process. For example, IPCC recently downgraded the GWP of Methane (CH₄) by 4 and upgraded the GWP of Nitrous Oxide (N₂O) by 12;
• Standards differ in the inclusion of CO₂ emissions from biomass materials. For example, ECCC, WRI, and EPA recommended not to include CO₂ emissions from biomass to the threshold calculation. If party’s reporting requirements are met, the CO₂ emissions from biomass combustion must be calculated and reported separately as part of its GHG information. Exceptionally, WRI standard recommends for Methane (CH₄) and Nitrous Oxide (N₂O) emissions from biomass-related sources to be included in the reporting threshold calculation and reported as part of the GHG emissions;
• The RETScreen helps the user to estimate the greenhouse gas emission reduction (mitigation) potential of a proposed clean energy project. RETScreen calculates the GHG emission profile for a Base Case System (Baseline) and for the Proposed Case System (clean energy project). The methodology implemented in the RETScreen Software to calculate the GHG emission reductions associated with a clean energy project has been developed by NRCan in collaboration with the UNEP;
• NRCan considers the transmission and distribution (T&D) losses in electrical systems while calculating GHG emissions;
• The Government of Ontario follows the guidelines from ECCC, and the emission factors and GWP for each fuel are decided from the IPCC guidelines;
• According to the UNEP, the two frequent categories that contribute to the GHG emissions are energy and process-related emissions. They need to be assessed and calculated separately and then aggregated. The methodology UNEP proposes to estimate the GHG emissions is based on fundamental research by the IPCC;
• In UNEP calculations, the primary fuels include coal and natural gas whereas secondary fuels include refined petroleum products;
• The methodology for calculating GHG emissions in ENERGY STAR Portfolio Manager® (by EPA) is based on the Greenhouse Gas Protocol Corporate Accounting and Reporting Standard developed by the World Resources Institute (WRI) and World Business Council for Sustainable Development. The methodology uses the “default fuel analysis approach” (DFAA), which uses fuel’s type and quantity. The DFAA considers only direct estimated CO₂ because the calculation with CH₄ and N₂O is complicated, as they not only depend on fuel characteristics but also on the combustion technology;
• Two key metrics in ENERGY STAR Portfolio Manager® measuring greenhouse gas emissions are (1) Total Emissions that measures the majority of GHGs associated with commercial buildings, which can further be split into component metrics like Direct Emissions (energy directly burned at a building -- natural gas) and Indirect Emissions (energy burned after purchased from a utility -- electricity) and (2) Biomass Emissions that are from biogenic fuels that are burned onsite, e.g., wood. Emissions are calculated by multiplying site energy values by emissions factors;
• The ISCC recommends the segments that must report their GHG emission values include: (i) biomass producers; (ii) conversion units (e.g., conversion of solid biomass into liquid biomass or processing of liquid biomass); (iii) transport and distribution;
The ISCC calculations are more focused on agricultural and land requiring total yearly amount of applied fertilizers, yearly crop yield of the main product in kg/hectare, and so on. Thus, the ISCC method is not suitable for household or residential GHG emissions calculations;

The ISCC requires that the GHG emissions from transport always need to be documented and included in the GHG calculations by the end users in the supply chain that is receiving the product;

The ISCC calculations follow no official list of emission factors mainly because of the inconsistent literature on emission factors, the large variance of individual factors, and unavailability of emission factors for some inputs where an approximation is used. Therefore, to avoid cherry-picking, ISCC has developed a list of most relevant emission factors which should be used for all GHG emissions calculation and audits within the ISCC System;

The WRI guideline categories (and so the EPA’s Portfolio Manager) the emission types indirect GHG emissions (from sources that are owned/controlled by the company) and indirect GHG emissions (a consequence of the activities of the company/party but occur at sources owned/controlled by another company/party);

It is common for reporting parties to misreport the GHG emissions associated with T&D losses. There are issues in GHG emissions calculations at the national and international levels. Several GHGs are being emitted into the atmosphere but are not being recorded into official inventories. Levels of some emissions from India and China are so uncertain that experts say their records might vary 100%;
References


## Appendix

Table 2: Greenhouse Gases and Gas Species Subject to Mandatory Reporting.

<table>
<thead>
<tr>
<th>Greenhouse Gas</th>
<th>Formula</th>
<th>CAS Number</th>
<th>100-year GWP*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon dioxide</td>
<td>CO₂</td>
<td>124-38-9</td>
<td>1</td>
</tr>
<tr>
<td>Methane</td>
<td>CH₄</td>
<td>74-82-8</td>
<td>25</td>
</tr>
<tr>
<td>Nitrous oxide</td>
<td>N₂O</td>
<td>10024-97-2</td>
<td>298</td>
</tr>
<tr>
<td>Sulphur hexafluoride</td>
<td>SF₆</td>
<td>2551-62-4</td>
<td>22 800</td>
</tr>
</tbody>
</table>

**Hydrofluorocarbons (HFCs):**

| HFC-23 (trifluoromethane)            | CH₃F    | 75-46-7    | 14 800        |
| HFC-32 (difluoromethane)             | CH₂F₂   | 75-10-5    | 675           |
| HFC-41 (fluoromethane)               | CH₂F    | 593-53-3   | 92            |
| HFC-43-10mee (1,1,2,2,3,4,5,5,5-decafluoropentane) | C₆H₁₆F₁₀ | 138495-42-8 | 1 640        |
| HFC-125 (pentfluoroethane)           | C₅HF₅   | 354-33-6   | 3 500         |
| HFC-134 (1,1,2,2-tetrafluoroethane)  | C₅H₆F₄  (Structure: CH₂F₂CHF₂) | 359-35-3 | 1 100         |
| HFC-134a (1,1,2-tetrafluoroethane)   | C₅H₆F₄  (Structure: CH₂FCF₂)   | 811-97-2   | 1 430         |
| HFC-143 (1,1,2-trifluoroethane)      | C₅H₆F₃  (Structure: CH₂F₂CHF)  | 430-66-0   | 353           |
| HFC-143a (1,1,1-trifluoroethane)     | C₅H₆F₃  (Structure: CF₂CH₂)    | 420-46-2   | 4 470         |
| HFC-152a (1,1-difluoroethane)        | C₅H₆F₂  (Structure: CH₂CHF₂)   | 75-37-6    | 124           |
| HFC-227ea (1,1,1,2,3,3,3-heptafluoro-propane) | C₅H₆F₃   | 431-89-0   | 3 220         |
| HFC-236fa (1,1,1,3,3,3-hexafluoro-propane) | C₅H₆F₆   | 600-30-1   | 9 810         |
| HFC-245ca (1,1,2,2,3-pentafluoro-propane) | C₅H₆F₅ | 679-86-7   | 693           |

**Perfluorocarbons (PFCs):**

| Perfluoromethane (tetrafluoromethane) | CF₄     | 75-73-0    | 7 390         |
| Perfluoroethane (hexafluoroethane)    | C₂F₆    | 76-16-4    | 12 200        |
| Perfluoropropane (octafluoropropane)  | C₃F₈    | 76-19-7    | 8 830         |
| Perfluorobutane (decafluorobutane)    | C₄F₁₀   | 355-25-9   | 8 860         |
| Perfluorocyclobutane (octafluoro-cyclo-butane) | C₄F₁₄ | 115-25-3   | 10 300        |
| Perfluoropentane (dodecafluoro-pentane) | C₅F₁₂ | 678-26-2   | 9 160         |
| Perfluorohexane (tetradecafluoro-hexane) | C₆F₁₄ | 355-42-0   | 9 300         |