Greenhouse Gases

In order to start measuring carbon footprints, it is important to understand the underlying principles behind greenhouse gases (GHGs) and the concepts associated with them, such as radiative forcing (RF), global warming potential (GWP) and carbon dioxide equivalent (CO2e). Dictionary.com defines a carbon footprint as, “the amount of carbon dioxide or other carbon compounds emitted into the atmosphere by the activities of an individual, company, country”, or more generally in another definition, “the total set of greenhouse gas emissions caused directly and indirectly by an individual, event, organization, product expressed as CO2e.” Thus, a carbon footprint is essentially the total combined GHGs emitted directly or indirectly as a result of a process or thing. GHGs are gases that insulate and warm the earth by absorbing energy from the sun, more specifically infrared radiation, trapping it in the Earth’s atmosphere. Different GHGs have different radiative efficiencies, their ability to absorb energy, and lifetimes, the time period that they will remain in the atmosphere. The impact of GHGs on the Earth can be described with RF.

Radiative forcing is defined as, “the change in the net vertical irradiance (expressed in Wm-2) at the tropopause due to an internal change or a change in the external forcing of the climate system, such as, for example, a change in the concentration of carbon dioxide or the output of the sun.”. It can be calculated with the formula: . In simpler terms, RF is the difference in amount of energy absorbed and lost by Earth. In the context of GHGs, RF refers to the amount of radiative energy absorbed by a gas, and hence its impact towards the Earth. RF can be positive, which happens when GHGs absorb infrared radiation, causing an increase in the Earth’s energy bucket, resulting in a warming effect. Conversely, negative RF occurs when aerosol particles reflect solar radiation, causing a decrease in the Earth’s energy bucket, leading to a cooling effect. In addition, the RF of a certain gas is determined by different four factors, one of which is atmospheric concentration, which refers to the quantity of the GHG emitted that remains in the atmosphere. The next factor is the warming/cooling capacity, defined as the strength of the gas in trapping or reflecting heat. Another factor is a gas’s residence time in the atmosphere, which describes its lifetime. The last factor is spatial distribution which refers to how far a GHG spreads geographically. However, RF is instantaneous and does not account for the impacts of GHGs in the long-term.

While radiative forcing is used to determine the additional net-difference of energy absorbed by the Earth as a result of GHGs, the global warming potential of a gas is an estimate of how much that given gas contributes to the Earth’s RF. GWP is defined:

An index, describing the radiative characteristics of well-mixed greenhouse gases, that represents the combined effect of the differing times these gases remain in the atmosphere and their relative effectiveness in absorbing outgoing infrared radiation. This index approximates the time-integrated warming effect of a unit mass of a given greenhouse gas in today’s atmosphere, relative to that of carbon dioxide.”

GWP is calculated with the formula: . Essentially, the GWP of various GHGs are ratios that compare the amount of infrared energy absorbed by 1 ton of a given gas over a period of time (usually 100 years) compared to 1 ton of CO2 (which has a GWP of 1 because it is used as a reference). For example, a GHG with a GWP of 100 would increase the RF by 100 times more than CO2 would. The key factors that account for GWP include the capacity of a gas to absorb infrared radiation, at what wavelengths does the gas absorbs radiation and how long the gas will remain in the atmosphere (all of which will not be discussed in detail). As a result, the GWP of gases may differ depending on how long the gas has been in the atmosphere. For instance, methane (CH4) has a GWP of 56 over 20 years, but drops to 21 when looking at a time span of a 100 years and then to 6.5 at 500 years. The shift in GWP over time is attributed to the lifetimes of different GHGs and how long they remain in the atmosphere. Overall, GWPs of numerous GHGs are critical to creating a fixed unit of measurement when measuring the carbon footprint of a process or item.

In connection to the GWP, the carbon dioxide equivalent is a standard unit of measuring GHGs based on the GWP. The concept behind CO2e is to express the RF all GHGs as a common unit in terms of CO2 so as to be able to effectively measure the carbon footprint of an item or process within a single number. The formula for finding the CO2e of a given gas is: . To summarize, GHGs result in positive RF, leading to an increase in the Earth’s temperature. The GWP of different GHGs are used to create a standard unit expressed in CO2e, which is used in measuring the carbon footprint of any item or process.