Measuring Methodologies

The carbon footprint of an item or process constitutes the total amount of greenhouse gas (GHG) emissions embodied in its life cycle added together. The life cycle of an item or process refers to all its stages of life from its birth including, “raw material extraction, material production, part production, and assembly, through its use, and final disposal (The Environmental Literacy Council 2017).” Therefore, a life cycle analysis (LCA) would refer to the environmental inputs and outputs of the given item or process at each stage, such as waste, pollutants, etc. In the context of carbon footprints, the LCA of a product would collect and quantify the GHG emissions of an item or process at each given stage, known as GHG accounting (Pandey 2011). There are several different standards available for GHG accounting, which include the GHG protocol, ISO 14064, 2006 IPCC Guidelines for National Greenhouse Gas Inventories and ISO 14025 (Pandey 2011). These standards help governments or companies walk through the process of conducting a LCA and collecting GHG data. There are two methods to perform a LCA and calculate the carbon footprint of an item or process: process analysis method (PA) or Economic Input-Output approach (EIO). Both methods have their weaknesses and strengths and despite their strengths, still do not manage to be entirely precise.

The most popular method for determining the carbon footprint of a product is the process analysis or “bottom-up” method. Given an item or process, its life cycle stages (inputs), such as manufacturing, transport, etc. are first categorized. The carbon emissions of each stage are then added up together to form the carbon footprint of that given item or process (Berners-Lee 2011, 199). This method starts from the bottom and builds up (hence, bottom-up approach) and it employs a straightforward and brute-force like approach. Because it considers all the factors involved within the given item or process, the result generated from this method will be very precise. It also allows for specific product comparison due to the categorization of the different process involved in the given items or processes (Carnegie Mellon University 2017). However, the PA method is extremely inefficient, time-consuming and costly (Berners-Lee 2011), due to the infinite number of stages involved in an item’s or processes’ life cycle. For example, if the carbon footprint of a piece of paper were to be calculated, first the GHG emissions of direct processes such as deforestation, production and transport would have to be taken into account. Next, the indirect GHG emissions of such as the production of energy required for machines for paper production and the materials and fuel required for transport would also have to be considered. From there, even more processes involved can be calculated and as a result, the number of stages involved in making paper can become overwhelming, highlighting the inconsistency of this method for larger products. In addition, the PA method has circulatory effects where the carbon path of an item or process can go in an infinite loop, resulting in an unlimited number of processes that must be assessed (Carnegie Mellon University 2017). For instance, to create paper, steel machinery is required, for which steel is required and for which steel machinery is required to make and so on. Because of these limitations, PA is only practically applicable to smaller and less complex items or processes.

The other method is known as the “top-down” approach, or economic input-output analysis (EIO). This approach is based off the input-output model designed by Wassily Leontief, where the interdependencies and monetary transactions between different industries are represented mathematically in a matrix (Carnegie Mellon University 2017). The EIO approach takes the economy as a whole (hence, top-down approach) and completely captures its rippling effects, allowing one to calculate a carbon footprint of an item or process just by knowing its cost (Berners-Lee 2011, 200). The EIO model is represented with a matrix, where each column and rows are the industries involved, and the intersection of a row and column refers to the value of which the row industry input is required for the column industry to produce $1 of output (McConnell 2017). Another matrix, known as the demand matrix, represents the demand of output from each industry (usually in money). An additional matrix, the production matrix, describes the amount of output produced by each industry (usually in money). The total output can be represented with the equation: , where A is the model, D is the demand matrix and X is the output matrix (McConnell 2017). For example:



The amount of output can be expressed as: (McConnell 2017)

In the context of carbon footprints, the EIO model is modified and an additional “environment” sector is created. Values in the row then represent the GHG output from an industry where it is represented as the input to the “environment” sector. This allows the model to depict how the interdependencies and changes in the economy would affect the GHG emissions to the environment (Carnegie Mellon University 2017).

Because the EIO approach encapsulates the entire economy, having a very broad boundary, it eliminates the inconsistencies of the PA approach of an overwhelming number of processes and its circulatory effects (Carnegie Mellon University 2017). Furthermore, since it is a developed model, it requires very little input and is very quick and efficient in return a carbon footprint estimate (Berners-Lee 2011, 200). However, the industries represented by the EIO model are an aggregated collection of types, results acquired may be very generic (Carnegie Mellon University 2017). In addition, the model views imports as products created within the economic boundary, leading to an overestimate of the carbon footprint of an item or process.

Many carbon footprint calculations employ the use of both PA-LCA and EIO-LCA models, creating a hybrid method. Small emissions would be covered with PA while the rest is left to EIO which allows for an increase in precision while maintaining the efficiency and speed of the EIO (Pandey 2011).

The process of GHG accounting involves three steps: selection of GHGs, setting boundaries and collection of GHG data (Pandey 2011). In the first step, the GHGs selected is dependent on the given item or process, whether to just include a specific GHG such as CO2 or to include a whole range such as the six Kyoto gases which include carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and Sulphur hexafluoride (SF­6) (UNFCCC 2010). For instance, in farming, CO2 and CH4 are significant GHG emissions while the significant GHG emission in other items or processes may differ. Therefore, it would be important to identify which GHG would be assessed.

The second step is to define a boundary, which refers to, “an imaginary line drawn around the activities that will be used for calculating carbon footprint” (Pandey 2011). This step is especially relevant for PA-LCA where a clear boundary must be defined so as to not go on calculating the emissions for infinity. This step is yet again dependent on the characteristics and properties of the given item or process. After the boundary has been defined, an operational boundary will be initialized next, which refers to, “the selection of the direct and indirect emissions, which will be accounted for” (Pandey 2011). Three different scopes categorizing emissions have been standardized, which help to avoid redundant accounting and to provide a sense of organization (Boles 2017). Scope 1 refers to “emissions from sources that are owned or controlled by the organization”, which include stationary combustion, mobile combustion, process emissions and fugitive emissions (Boles 2017). Scope 2 emissions are indirect emissions which are defined as “emissions from the consumption of purchased electricity, steam or other sources of energy generated upstream from the organization (Boles 2017). Finally, scope 3 is known as other indirect emissions and is defined as “emissions that are a consequence of operations of an organization, but are not directly owned or controlled by the organization” (Boles 2017). Most carbon footprints only account for scope 1 and 2 as the complexity and number of processes found in scope 3 is too high.

Finally, GHG data is collected, which can be done with models such as the EIO-LCA discussed earlier or directly through real-time measurements. The GHG data is then converted into units of CO2 using conversion ratios (GWP).

The process of measuring the carbon footprint of a select item or process is not simple. A LCA has to be first performed, where the inputs and outputs of the item or process is quantified. From there, there are three different methods that can be used to perform a LCA and calculate the carbon footprint of the item or process: the process analysis approach or economic input-output approach. The PA approach is mainly used for smaller products that do not have a complex carbon path while the EIO approach is used for more complex products. Both methodologies have their respective strengths and weaknesses. The third approach is combining the two methods to get the benefits from both. Furthermore, the process of GHG accounting involves three steps, which are identifying the important GHGs, defining a boundary and collecting GHG data. In order to calculate the carbon footprint of a region, the approach should be to take the prominent carbon emitting aspects and perform a combination of PA-LCA and EIO-LCA to yield the best results. Given the time frame for this project, it would be impractical to create a whole new approach that relies on the intricacies and in-depth study of cities to create the most precise results. Rather, it would be better to rely on the current methods and implement it in a reusable computer program.

References

"Life Cycle Analysis." The Environmental Literacy Council. Accessed April 22, 2017. https://enviroliteracy.org/environment-society/life-cycle-analysis/.

Berners-Lee, Mike. How bad are bananas?: the carbon footprint of everything. Vancouver: D & M Publishers, 2011.

Boles, Steve. "What are the differences between Scope 1, 2 and 3 Greenhouse Gas emissions?" ICompli Sustainability. Accessed April 23, 2017. <http://www.icomplisustainability.com/index.php/ask-the-expert/ghg> management/item/63-what-are-the-differences-between-scope-1-2-and-3-greenhouse gas-emissions/63-what-are-the-differences-between-scope-1-2-and-3-greenhouse-gas emissions.

Pandey, Divya, Madhoolika Agrawal, and Jai Shanker Pandey. "Carbon Footprint: Current Methods of Estimation." ResearchGate. July 2011. Accessed April 21, 2017. https://www.researchgate.net/publication/46289480\_Carbon\_Footprint\_Current\_Methods  
 \_of\_Estimation.

McConnell, Terry. Lecture 32. Accessed April 23, 2017. http://barnyard.syr.edu/mat183/l32/.

United Nations Framework Convention on Climate Change. "Kyoto Protocol." Kyoto Protocol. November 18, 2010. Accessed April 23, 2017. http://unfccc.int/kyoto\_protocol/items/3145.php.

University, Carnegie Mellon. Economic Input-Output Life Cycle Assessment - Carnegie Mellon University. Accessed April 22, 2017. http://www.eiolca.net/index.html.