Developing a Carbon Footprint Calculator for Construction Buildings

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ABSTRACT

Carbon footprint is commonly defined as the total amount of greenhouse gases produced directly or indirectly as a result of an activity. The term carbon footprint has become the standard for measuring the environmental impact of activities in several sectors (e.g., transportation, energy, construction). While there have been several studies documenting calculators that estimate the carbon footprint of individual activities (e.g., driving a car, riding an airplane), the literature describing the process of carbon footprint calculations for construction activities remains limited. The few existing tools that calculate the carbon footprint of construction buildings do not take into account some of the major variables in the design and construction process (e.g., properties of selected materials, location of suppliers). In an effort to improve the accuracy of carbon footprint calculations, this paper presents a tool that estimates the total carbon footprint of construction buildings while taking into consideration project characteristics (e.g., size, location, material choices). The calculator relies on data collected from construction material suppliers and covers the various phases of a construction project. Through a case study, the research team illustrates the use of the tool to identify the activities with high carbon emissions.

INTRODUCTION

Human-induced climate change is perhaps the greatest environmental threat of the 21st century (ECCM 2008). This threat correlates with the increased rates of depletion of natural resources, which are, in turn, the result of increased rates of consumption of raw materials in various industrial processes. The building construction sector is responsible for a significant amount of this consumption. For example, in the US commercial and residential buildings consume more energy than the transportation and industrial sectors, accounting for nearly 40 percent of the total national demand (U.S. Department of Energy 2008). The building construction sector is also a major source of CO_2 emissions, and is responsible, in the US and the

European Union, for about 40 percent of the environmental burden (Abanda et. al 2010). In the UK, construction is responsible for 50 percent of the total national carbon emissions and energy consumption (Brown et al. 2006 and Hammond and Jones 2010). Overall, the construction industry uses 40 percent of the total gravel, sand, and raw stone consumed worldwide. It also utilizes 25 percent of the unprocessed wood and 16 percent of the water consumed worldwide (Dixit et al. 2010).

These figures have encouraged researchers to look for ways to reduce the environmental impact of construction projects. Developed countries are starting to take actions to reduce greenhouse gas (GHG) emissions to stabilize global warming. Commitments have been carried out by various governments through the Kyoto Protocol, as well as the G5 and G8 summits to address the adverse effects of climate change. For instance, in the UK, the government has been proactive and has committed to implementing the Kyoto protocol by decreasing its CO_2 emissions below the 1990 levels by a minimum of 12.5 percent. To accomplish these goals, mitigation strategies for carbon emissions must be set up and executed strictly across various industrial sectors including construction (Galatowitsch 2009)

Construction researchers and practitioners did not take long to start investigating ways to reduce the carbon footprint of their projects. For this purpose, the concept of sustainable design was introduced via a set of eco-friendly design standards. These include the Leadership in Energy and Environmental Design (LEED) and Building Research Establishment Environmental Assessment Method (BREEAM) standards. Nonetheless, the success of these standards in reducing carbon footprint and minimizing the environmental impact of construction projects is yet to be proven. This is contingent on having tools that accurately measure the environmental impact of construction projects. This paper addresses this issue by presenting a carbon footprint calculator that is capable of estimating the total carbon emissions of a construction project while taking into consideration various building design characteristics (e.g., size, location, construction materials).

LITTERATURE REVIEW

The emergence of carbon footprint calculations coincides with the increased awareness of the contribution of industrial activities to global warming. Since the industrial revolution, human activities have increased the amount of GHG emitted into the atmosphere, leading to increased radiative forcing from CO_2 (rate of energy change per unit area of the globe), tropospheric ozone, methane, nitrous oxide, and chlorofluorocarbons (CFCs). The concentration of CO_2 has increased by 36 percent since 1750 whereas the concentration of methane has increased by 148 percent (EPA 2007).

Global warming caused by the absorption of thermal radiation by GHG, and re-radiated in all directions, is commonly known as the "greenhouse effect". This term was first proposed by Joseph Fourier in the early 19^{th} century and then investigated quantitatively by Svante Arrhenius in the late 19^{th} century (Ramanathan and Feng 2009). However, it was not until the late 1980s that the community started to recognize the seriousness of the problem. In 1988, the United Nations Environmental Program and the World Meteorological Organization founded the

Inter-governmental Panel on Climate Change (IPCC) in an effort to regulate and reduce carbon footprint of human activities. For this reason, global warming potentials (GWP) have been formed to broaden the evaluation of the different GHG (IPCC 2007). As shown in Table 1, GWP is a quantitative estimate of the environmental impact of various species of gases including carbon dioxide, methane, and HFCs.

Table 1. Global Warming Potentials of GHGs (adopted from IPCC 2007)

Species	**Chemical formula**	**GWP**
Carbon dioxide	CO_2	1
Methane	CH_2	25
Nitrous oxide	N_2O	298
HFCs	-	124 – 14800
Sulphure hexafluoride	SF_6	22800
PFCs	-	7390 – 12200

According to the European Commission, carbon footprint is a measure of the impact of activities on the climate change and on the environment in general. It relates to the amount of GHG produced through heating, burning fossil fuels for electricity, transportation etc. Carbon footprint is a measurement of all GHG that each individual produces and has a unit of tons (T), or kilogram, of carbon dioxide equivalent (European Commission 2007).

Carbon footprint is often classified as direct versus indirect. Direct carbon footprint, also known as the primary footprint, is a measure of direct emissions of CO_2 from the combustion of fossil fuels including transportation and domestic energy consumption. In the context of industrial activities, this footprint is the result of direct GHG emissions which the company releases during the manufacturing, assembly, and transportation of the finished goods. The indirect carbon footprint, also known as the secondary footprint, is a measure of the indirect carbon dioxide emissions from the entire lifecycle of the used product, starting with manufacturing and ending with the eventual breakdown. Indirect emissions typically develop outside the actual company through the use of raw materials, energy or services (Wiedmann and Minx 2007). Calculating the carbon footprint requires accurate estimation of both direct and indirect carbon footprint.

Another classification of carbon footprint is embodied versus operational. Embodied carbon is the carbon released when a product is manufactured, shipped to a project site and installed (Hammond and Jones 2008). For example, embodied carbon for building is the amount of CO_2 emitted during the construction process. In addition to embodied carbon, buildings are responsible for operational carbon, which is defined as the CO_2 emitted during the operation phase of the building facility.

The first step in the process of reducing the environmental impact of construction projects is to develop a framework that accurately measures the carbon footprint (direct and indirect, embodied and operational) of construction projects.

This requires a close examination of the entire project lifecycle, starting with planning and ending with demolition and disposal of ensuing material (Hammond and Jones 2010).

Several tools have been proposed to estimate the carbon footprint of construction projects. The National Institute of Standards and Technology (NIST) developed a tool called BEES (Building for Environmental and Economic Sustainability), which is based on consensus standards. The tool helps designers, builders, and manufacturers choose products from a list of 230 building products (NIST 2012). Other examples include the "carbon-footprint-calculator" (Conlon Construction 2011) and the "Build Carbon Neutral" (Build Carbon Neutral 2011) which target construction buildings. The former is designed to take into consideration the operating activities emissions of a household (e.g., electricity, natural gas, heating oil, coal, etc.). The latter is a web-based calculator which calculates the carbon emissions that are generated by a building based on the total building surface area, the number of stories and the primary structural system above ground (e.g., wood, concrete, steel). Site information is also required. This information includes the eco-region type, the predominant existing vegetation type, the predominant installed vegetation type, the landscape disturbed, and landscape installed. Other web-based calculators (e.g., greenfootstep) have similar inputs which include the type of building (e.g., hotel, retail, school, warehouse, flat), the built-up area, the type of ventilation (naturally ventilated versus air conditioned) and the distance between the windows and the location of occupant activities. Using these basic characteristics of buildings (e.g., number of floors, surface area), these calculators generate an estimate of carbon footprint with a level of accuracy of ±25 percent.

Despite giving an estimate of the carbon footprint of construction buildings, these tools do not take into account the distance between the different suppliers of products/construction materials and the location of the construction site. For example, glass manufactured and used in China, has a different carbon footprint than the same glass used in a construction project in Lebanon. Also, they do not differentiate among various products which serve the same purpose but have different manufacturing properties. For example, using concrete with or without fly ash has a different impact on the environment, which explains more explicitly why the existing construction calculators have limited accuracy.

METHODOLOGY AND FRAMEWORK

The objective of the paper is to present a carbon footprint calculator that is specific to construction buildings. By taking into consideration the building design features, the calculator is expected to have a higher accuracy than existing calculators. The methodology followed to achieve the objective of the study is comprised of three steps.

First, the paper presents a generic calculator which estimates the environmental impact of the process of constructing residential and commercial buildings. It focuses on the role of designers and contractors in material and supplier selection while taking into consideration carbon emissions. The calculator, which is built using National Instruments' Labview Virtual Programming software, estimates the carbon emissions associated with the major steps associated with the construction process. These include manufacturing, transportation, and installation of building materials.

Second, the paper discusses the process of creating a database of suppliers of construction materials who are active in the construction industry in Lebanon. Data is being collected from several manufacturers and suppliers of cement, aggregates, concrete, steel, wood, aluminum, and electrical and mechanical systems. Creating the database requires collecting information from three major types of companies:

1. Retailers and distributors that base their business on importing products and selling them in Lebanon (e.g., sanitary facilities). These companies do not carry out any manufacturing or processing step on the imported materials. In these cases, documenting the carbon footprint associated with manufacturing materials requires tracking the product back to its country of origin.
2. Suppliers that manufacture their products in Lebanon (e.g., concrete providers). In these cases, documenting the carbon footprint associated with manufacturing materials requires having access to production information. Tracking some of the raw materials to their country of origin might also be required (e.g., imported aggregates for making concrete).
3. Suppliers that import material and perform value-added operations (e.g., welding, assembling, cutting, wood work). In these cases too, documenting the carbon footprint associated with manufacturing requires having access to production information and tracking the raw materials to their country of origin.

To collect data from suppliers, the research team developed a survey questionnaire covering the following four areas:

- *Product information* such as product and company name, and geographic location (longitude and latitude).
- *Production information* such as production unit, yearly quantities, and number of employees.
- *Energy consumption* including diesel, petrol, gas, and oil.
- *Raw materials information* such as distance from source or country of origin, transportation method, quantities, and volumes.

Table 2 shows a sample of the data collected from a local pipe manufacturer.

Table 2. Sample Data Collected from a Pipe Manufacturing Company

Product information	
Product name	Pipe (PPR & PE)
Site location of company/supplier (Latitude)	33.956537
Site location of company/supplier (Longitude)	35.625848
Production Information	
Production unit (Ton, piece, m^2, m^3 etc)	Ton
Yearly production quantity	1400
Number of company employees	140
Energy Consumption	
Yearly oil consumption in L	250 L
Yearly electricity consumption in KWh	1340000 (generator meter)
Raw Material	
Transportation method: land	1000 tons
Quantity of raw material per unit produced	Variable
Transportation volume (units/shipment)	25 tons/truck
Source distance	Beirut port to the plant
Transportation method: land	400 tons
Quantity of raw material per unit produced	Variable
Transportation volume (units/shipment)	25 tons/truck
Source distance	Abu Dhabi to the plant
Transportation method: sea	1000 tons
Quantity of raw material per unit produced	Variable
Transportation volume (units/shipment)	150tons/shipment
Source distance	Finland to the plant

Third, the paper illustrates the implementation of the built calculator on a case study. At the first stage, the calculator is tested on a small-scale construction project which is described in greater detail in subsequent sections of this paper. The research team is in the process of investigating the feasibility of implementing the calculator on a real-world scale multi-storey construction project. To help designers and contractors make decisions on material and supplier selection, the research team is investigating several scenarios. These include suppliers in and out of the country and materials with various compositions (e.g. wood from china versus Lebanon, cement with various less carbon emitting mixes, local versus imported tiles, etc.).

CALCULATOR ARCHITECTURE

a. Data Input

After collecting the required data from suppliers, a tool named "CarbonAnalyzer" was developed to facilitate the database creation process. As shown in Figure 1, the tool has five main tabs.

In the product information tab, the user inputs the product name, company name, company location (latitude and longitude), and category (e.g., concrete, metal, wood, electrical, mechanical, etc.).

In the production information tab, the user chooses the production unit, the yearly production quantity, and the number of staff working in the plant.

In the energy consumption tab, all the data related to the energy used for the manufacturing of the product is added. This includes the yearly diesel, gas, petrol and oil consumption in liters, as well as the yearly electricity consumption in Kilowatt-hour.

In the raw material tab, the transportation method is chosen from a drop down box where the user can choose between land, air and sea. The quantity, volume, distance, and embodied CO_2 per unit can also be entered at this stage.

Finally, in the results tab, upon pressing the button "Calculate", the total embodied Kg of CO_2 per production unit will be displayed. To save the introduced data, the user can click on the "Save" button on the right bottom of the window and the result will be saved in a database file according to the path specified in the "Database Path" input space.

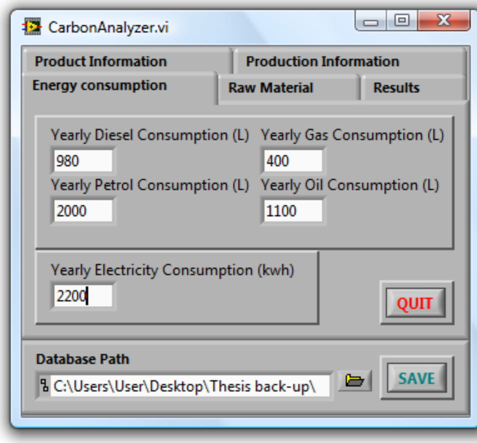

Figure 1: CarbonAnalyzer snapshot.

Once the "Calculate" button is pressed, the CarbonAnalyzer tool performs the following activities:

1. Convert a company's yearly energy consumption to carbon-equivalent emissions, and then divide it by the yearly production to get the carbon emission per product.
2. Add the obtained result to the embodied carbon of raw material per unit, along with its transportation emissions.
3. Save the result as the total carbon emissions per unit of product.

The same process is repeated with every product involved in the construction process. The saved file will be used along with the calculator to generate the total carbon footprint of a construction project. It should be noted that different countries have different material life cycles, leading to a higher or lower total carbon footprint. To ensure the accuracy of the carbon footprint calculations, the local energy sources should be taken into consideration. For example, the fuel energy footprint is different from the nuclear or hydraulic carbon footprints, which differ from countries to countries.

b. Calculator Programming

The carbon footprint calculator builds on an earlier study by the research team (Ammouri et al. 2011). Figure 2 shows a snapshot of the updated calculator which is divided into 10 categories: general project information, site works, concrete works, metal works, wood works, windows and doors, finishes, mechanical works, electrical works and results.

The calculator uses the created material supplier, retailer, distributor and manufacturer, database along with project input data to calculate the carbon footprint of the project. Project input data includes quantities of materials purchased, selected suppliers, location of project site, equipment used on-site, duration of site activities, and labor force requirements. In addition to displaying the total carbon emissions, the calculator displays the embodied carbon footprint of raw materials, transportation carbon footprint, and site work carbon footprint. Information can be saved in a text file for future reference or for evaluating various scenarios (e.g., local versus foreign suppliers). The following case study illustrates in more details the architecture of the carbon footprint calculator.

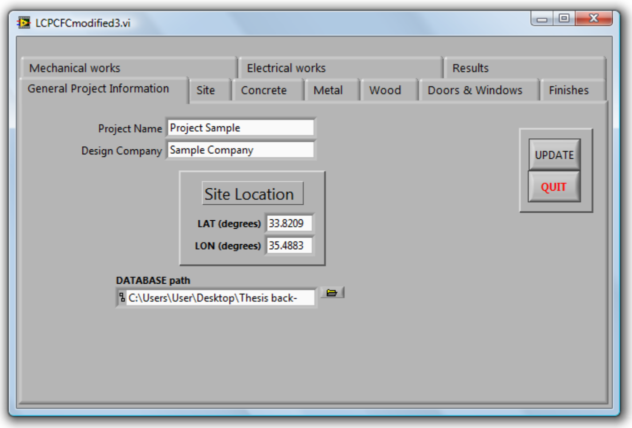

Figure 2: Carbon footprint calculator-general project information window

c. Case Example

The calculator was applied on a small-size case study which consists of a 500m^2 single-storey building. According to JK Lakshmi Cement Ltd, the approximate quantities of construction materials required for this building are: 1,755 bags of cement (50-kg each), 179 m^3 of sand, 27 m^3 of 0.01 m aggregates, 50 m^3 of 0.02 m aggregates, 155,217 bricks, and 4,306 kg of reinforcement steel. These numbers are based on the assumption of a load-bearing brick wall which has a thickness of 0.23 m in cement mortar 1:6.

Further information is needed to calculate the footprint of the buildings. For example, for the case of cement, the following data is needed:

- Amount of embodied carbon emissions, which is 0.83 kg of CO_2 per kg of cement using the EPA inventory, and 1.01 Kg of CO_2 per Kg of cement, using the collected data from the cement factory in Chekka, Lebanon.
- Transportation related data such as the distance from the supplier location to the construction site. For example, cement bought from a major Lebanese supplier travels 67 km to a construction site in Beirut. Despite the relatively short distance, the time spent especially during peak travel periods is at least

two hours. Other data include the carbon footprint of the trucks that are used to transport the cement. In this case, trucks with loads of 20t to 50t have an average of 536 CO_2 g/hp-hr (EPA 2011).

- Construction activity carbon emissions data such as the CO_2 of diesel cement and mortar mixers. This is assumed to be 530 CO_2 g/hp-hr for a 300-hp unit (EPA 2011). Other data include human-induced CO_2. Lebanon generates 4.077 tons of CO_2 per capital, which is equivalent to 4.186 kg of CO_2 per person per day (9 hours of work) (United Nations Statistics Division 2011).

Based on these assumptions and data, the raw material (embodied) CO_2 for cement is calculated using Equation (1), which illustrates EPA data, and Equation (2) which is based on the survey data:

$$Cement\ Embodied\ CO2 = 0.83 * 1755 * 50 = 72832.5\ Kg\ of\ CO2 \quad (1)$$
$$Cement\ Embodied\ CO2 = 1.01 * 1755 * 50 = 88627.5\ Kg\ of\ CO2 \quad (2)$$

The transportation CO_2 becomes (Time while engine is on) x (CO_2 /hp-hour) x (hp of truck) x (number of trucks) or:

$$Cement\ transp.CO2 = 2.2166 * 0.536 * 300 * 3 = 1069.28\ Kg\ of\ CO2 \quad (2)$$

Finally, the construction activity CO_2 becomes: (Diesel cement mixer kg of CO_2 / hp.hour) x (hp of diesel cement mixer) x (number of operation hours) x (number of days of activity) + (number of working days) x (number of worker) x (average kg of CO_2 per worker)

$$Cement\ Constr.Activity\ CO2 = 0.5297 * 300 * 2hours * 1day + 2days * 5 * 4.186 = 656.57\ Kg\ of\ CO2 \quad (3)$$

The total amount of CO_2 emissions for cement related activities is 74.558 tons (using EPA data) and 90.353 tons (using the survey data). The results indicate that the amount of CO_2 emitted during construction is negligible compared to the embodied CO_2. Nonetheless, there is little that designers or contractors can do to reduce embodied CO_2. They can, however, use the calculator to choose alternative suppliers and products (e.g., cement products mixed with fly ash or other less polluting substances). Users of this calculator can also address transportation CO_2 by either choosing fuel efficient trucks or choosing suppliers who are within a shorter distance to the construction site.

CONCLUSION

As illustrated by the case study, the built calculator can be used to estimate and evaluate the environmental impact of construction projects. The calculator provides a benchmarking tool for measuring carbon footprint of construction buildings and is a major first step in the process of minimizing the environmental impact of construction activities.

The process of building the database with suppliers who are active in the construction industry in Lebanon is on-going. Subsequently, the calculator will be tested on a real-world scale project. The carbon footprint of a typical multi-story commercial building will be computed using the calculator and the building's bill-of-quantities. Results will, then, be benchmarked against the carbon footprint reported using other existing calculators.

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