A COMPARISON OF CO2 CALCULATORS FOR BUILDING CONSTRUCTION

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ABSTRACT

Decisions made during the design and construction phases of a building affect its level of sustainability. The environmental impact of the built facility is a major element of sustainability that is often assessed in terms of the CO_2 emissions or carbon footprint of various activities such as material extraction, fabrication, transportation, and installation. Several tools have been developed to provide an estimate of the carbon footprint based on building characteristics such as type, location, and site attributes. Different tools such as the Build Carbon Neutral, Faithful-Gould Construction, yield different values of CO_2 for the same building project. Moreover, most calculators conceal information about interim calculation and methodology used, which hinders in-depth evaluation and validation of the estimates. This paper compares a set of carbon footprint calculators for construction buildings. The comparison relies on a set of criteria which includes input data requirements, level of detail, potential for customization, and comprehensiveness. Although carbon calculators are considered a welcome tool for assessing the environmental impact of construction; however, as this paper reveals, there is a need for better accuracy and transparency in the calculators. This would aid practitioners in making unbiased decisions, thus fulfilling their professional duties to the community at large.

Keywords: Carbon footprint, Environment, Construction, Buildings, Sustainability

1. INTRODUCTION

The growing concentration of carbon dioxide (CO_2) due to human induced release of green house gases (GHG) into the atmosphere is a long-term and large scale problem contributing to global warming. The imbalances caused in the ecosystem due to warming are already being signaled in the form of climate change and severe weather events (Rignot et al. 2006, IPCC 2007). These threats correlate 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. According to the world green building council, the building construction sector is responsible for a significant amount of this consumption. The commercial and residential buildings in the US alone 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 an effort to increase the understanding of the environmental impact of construction buildings, numerous tools have been developed to estimate the carbon footprint of buildings. This estimate is defined as the amount of CO_2 emissions that a building is directly and indirectly responsible for, over a given period of time (Wiedmann et al 2007). These calculators typically divide the building's profile into stages covering its entire lifecycle; and based on differing formulations of user input, they generate a quantified amount of CO_2 or CO_2 equivalents emitted, generally in units of mass of CO_2 per year. Some of these calculators are provided by private companies (e.g., Faithful-Gould Construction, Nzwood), while others are provided by non-governmental organizations (e.g., Build Carbon Neutral, Carbon Calculator V3.1.2). Other tools such as Gabi can be used to model the stages of a product from a life cycle perspective and to help users choose the raw or processed materials of a manufactured item. Although Gabi considers the impact of products on the environment, and therefore it captures the GHG emissions of construction products and raw materials, construction specific carbon footprint calculators are needed to calculate the carbon footprint of a building as a whole unit (PE-international 2012).

Carbon footprint calculators are not limited to construction buildings. Many calculators have been developed to estimate the carbon emissions associated with human behavior. For example, calculators such as American Forest (American Forest 2012), Green Mountain (Green Mountain 2012), and Terrapass (Terrapass 2012) estimate the carbon footprint (e.g., due to household activity or transportation) that an individual is directly or indirectly responsible for over a certain period of time.

Non-governmental organizations have been implementing several programs to promote sustainable technologies (e.g., investments in renewable energy technology) to mitigate or reduce the carbon footprint of buildings. Even when not coupled with policy measures, carbon footprint calculators play a fundamental role in promoting carbon emission reductions through efficient building material selection and design. In addition to policy matters, the corporate world has sensed a carbon constrained economy, where carbon footprint influences the way business is made. Consequently, a rush to calculate the carbon footprint has begun worldwide leading companies to start initiatives aimed at cutting down carbon emissions in an attempt to reap a competitive advantage (Kleiner 2007). However, most carbon footprint calculators have been accompanied by discrepancies in output values given the same inputs for a building, where values can vary by plus or minus 40 percent of the carbon footprint of a building. Discrepancies in carbon emission estimates could influence the decisions architects and engineers make to reduce CO_2 emissions during the pre-construction phase of the project (e.g., focus on changing the concrete mix versus adding more steel bars) as well as the level of effort required to offset the total amount of emissions once the building is constructed (Säynäjoki et al 2011). The variations in the calculators' results may be due to the conversion factors used that are country/region specific or to the different calculating methodologies employed in each calculator. In many cases, the reasons behind these variations are unexplained, due to the lack of details and transparency required to make a clear judgment.

The objective of this study is to describe the few existing tools that calculate the carbon footprint of construction buildings. These tools 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 carbon footprint calculation, there is a need for a tool that estimates the total carbon footprint of construction buildings while taking into consideration project characteristics (e.g., size, location, material choices).

2. METHODOLOGY

This paper provides a description of, and highlights differences among, a set of available construction carbon calculators with the aim to explain the output variations. To compare emissions outputs for the same input behavior across calculators, a typical residential building located in Beirut, Lebanon, was chosen to represent the baseline case for our study. A description of the project characteristics is summarized in Table 1.

The paper focused on two main elements. First, construction calculators often provide inputs for average behavior (i.e. landscape disturbed, ventilation system, construction material used) if practitioners are unsure of their input values. Therefore, when applicable, the paper compares what each calculator considered average behavior and whether or not the approximations made were justified. Second, CO_2 emissions per annum associated with the construction project characteristics shown in Table 1 were compared across calculators. The paper also examines the difference in results, if any, and evaluates the calculators based on criteria discussed in the following sections.

Table 1: Project Characteristi

Project description	
Project type	Residential
Project category	Luxurious Apartments
Structure type	Reinforced Concrete
Location	Beirut
Site area (in m^2)	1,200
Sub-structure Built-up Area (BUA) in m^2	5,532
Sup-structure BUA in m^2	10,686
Number of floors underground	3 basements
Number of floors above ground	10 floors and a Roof

3. SELECTION OF CALCULATORS

Building construction carbon calculators require several inputs of the building project in question, and in return, estimate the amount of CO_2 emitted. The estimate could apply either to the construction phase only, construction and operation, or to the total estimated service life. This paper examines five commonly used building construction-specific carbon footprint calculators (Table 2). All five calculators estimate the carbon footprint for the construction phase of a building project; however, each has a specific methodology and required input, with enough similarity for comparison purposes.

Table 2: Sources of the Construction Calculators Used in the Analysis.

Construction carbon footprint calculator	Internet Link
Build Carbon Neutral	http://buildcarbonneutral.org/
Faithful-Gould Construction	http://www.fgould.com/carbon-calculator/
Green footstep	http://www.greenfootstep.org/
Nzwood	http://www.nzwood.co.nz/carbon-calculator/
Carbon Calculator V3.1.2	http://www.environment-agency.gov.uk/static/documents/Business/Carbon_calculator_v3_1_2.xls

While going though the literature, two types of calculators were encountered. The first type of calculator (e.g. GaBi, Alcorn) requires inputting the units of CO_2 emissions per units of volume (or mass) of each material. The second type of calculator provides these CO_2 emissions coefficients and requires project related information only. In this paper the second type of calculator was chosen, since one of the goals of this paper is to create a benchmark for a tool that is being developed by the research team. Thus, materials specific coefficients and values for embodied CO_2 are embedded within the framework of the five calculators selected. The user can directly use them without having to perform surveys or research to obtain the CO_2 coefficients for the different materials incorporated in the building project. This way, each calculator could be regarded as self-contained, and only requires project-related information. The chosen calculators are described in further detail in the following section.

4. DESCRIPTION AND COMPARISON OF CALCULATORS

The selected calculators target different stakeholders of a building project. Some, such as the Green Footsteps, are intended primarily to help designers set carbon emission goals and design targets. Similarly, designers are the main target of the BuildCarbonNeutral calculator, which is developed by a cooperative effort led by Mithun architects, designers and planners, and the Lady Bird Johnson WildFlower Center at the University of Texas at Austin with assistance from the University of Washington Program on the Environment. On the other hand, the Faithful-Gould Construction calculator, which is developed by an international consultancy firm, provides project management as well as building surveying services for construction projects. The Nzwood and Aggrgain calculator highlights the effect of using wood and recycled aggregates on the carbon footprint of a building construction project.

Each calculator is divided into sub-categories where users are prompted to input the characteristics of the construction project. The BuildCarbonNeutral calculator is divided into three parts: building size, primary structural system above ground, and site. The calculator requires the total built-up area of the building as well as the number of stories above and below ground. The user chooses several parameters such as landscape disturbed and installed, type of existing and installed vegetation, and type of built structure: wood, concrete, steel, or mixed (Mithun and Wildflower center 2012).

The Faithful-Gould construction calculator uses four steps to calculate the carbon footprint of a project. The user starts by choosing the type of building: hotel, retail, school, warehouse, or flat, and then inputs the total built-up area. Then, the user specifies the nature of the ventilation system and the average depth between windows and the working area (i.e. narrow plan versus deep plan) (Faithful and Gould 2012).

Green footstep is more detailed than the aforementioned two calculators. It starts by asking the user to choose the unit system to be used (i.e. US versus SI) and project location, and displays the average emissions coefficient for this location in Kg CO_2e/KWh. The user can either accept this value or input another value. The second step asks for information on the site characteristics (e.g., size in square meter) and on the local ecosystem (e.g., ecological type, domain, zone, underdeveloped or previously developed). The last step is dedicated to determine the building characteristics (e.g., building type, average floor area, expected total building lifetime and project completion date). Unlike other calculators, green footstep allows users to account for another GHG emissions source by adding its emissions rate in tons of CO_2e/year (Rocky Mountain Institute 2012).

Nzwood is a simple calculator that provides a simplified carbon footprint for a range of building designs using only the building type and total built-up area. The user can compare the chosen option with a base case, which is referred to as “build-in-timber”. The carbon footprint calculation relies on Life Cycle Assessment (LCA) principles however focusing on two phases: production and manufacturing of building materials and components of the building designs (e.g., steel, concrete and timber structure), often referred to as ‘cradle to gate’ assessment. The assessment is not a full life-cycle assessment and does not include emissions during transportation (from the manufacturing plant to the construction site), construction, operation and maintenance, demolition, recycling, disposal and transportation to landfills at the end-of-life of the building (NZ Wood 2012).

Carbon Calculator v3.1.2 is an excel spreadsheet tool that measures the GHG impact of construction activities in terms of carbon dioxide equivalency (CO_2e). This tool, which was developed by Environmental Agency, calculates emissions of construction activities and helps contractors and consultants assess their projects. It calculates the embodied CO_2e of material and the CO_2e associated with their transportation, as well as personnel travel and site energy. The spreadsheet is divided into eleven sheets. The project information sheet records basic information about the project. The construction input sheet estimates the carbon footprint from construction materials and activities on site. The report sheet presents the results in standard form and includes reduction tips for carbon intensive materials. The remaining sheets provide further information as well as space for relevant background calculations (Environment Agency 2012). Table 3 provides a brief description of the selected calculators.

Table 3: Description of the Selected Calculators.

Calculators	Targeted stakeholders	Building LCA phases	Types of parameters	Level of input details
Build Carbon Neutral	Developers, Builders	Construction	Building size, type and site characteristics	Medium
Faithful-Gould Construction	Clients	Construction and operation	Area, building and ventilation type	Medium
Green footstep	Engineers, Developers	Construction	Quantitative and qualitative site and building characteristics	Medium
Nzwood	Clients	Construction	Floor area and building type	Low
Carbon Calculator V3.1.2	Researchers	Construction	Quantitative construction materials	High

5. CASE STUDY

Carbon footprint, being a quantitative expression of GHG emissions from an activity or a process helps in carbon emission management and evaluation of mitigation measures (Abanda et al 2010). Thus, having a calculator to assess the impact of construction on the environment is essential to alleviate the carbon footprint of a building. Once quantified, the important sources of emissions can be identified, highlighting areas of emission reductions and increasing efficiencies.

In order to study their strengths and weaknesses, each of the selected calculators is used to calculate the carbon footprint of the same building, which was previously described in Table 1. BuildCarbonNeutral states clearly on its website the assumptions taken to calculate the carbon emissions of a certain project. The calculator has an accuracy of plus or minus 25 percent, and takes into account site excavation, core and shell (structural systems, building envelope and building systems). However tenant improvements, interiors or furniture, fixtures or equipment are not included in this calculator. Table 4 below shows the input and results obtained while using the BuildCarbonNeutral when applied to the base case.

Table 4: BuildCarbonNeutral Calculator Applied To the Base Case.

Building characteristics	Case study results
Total square feet	174,569
Stories above ground	10 floors and a roof
Stories below ground	3
Primary structural system above ground	Concrete
Eco-region	Mediterranean
Predominant existing vegetation	Shrubland
Predominant installed vegetation	Short Grass
Landscape disturbed	21,528
Landscape installed	19,375
Net embodied CO_2	7,714 metric tons

The total obtained carbon footprint is 7,714 tons of embodied CO_2 emitted during the construction phase of the building. This result may vary from 5,785 to 9,642 tons of CO_2 depending on the assumptions made regarding landscape disturbed and landscape installed. This calculator does not account for operational carbon emissions generated once the building construction is completed and does not state whether the equivalent CO_2 is taken into account or only CO_2 emissions are calculated. It also provides a list of references and background information concerning carbon offset to help practitioners lower their construction emissions.

Unlike BuildingCarbonNeutral, Faithful-Gould Construction calculator estimates the embodied emissions in tons of CO_2e as well as the operational emissions in tons of CO_2e/year. However, this calculator specifies neither the assumptions, nor the methodology used to calculate the carbon emissions. Table 5 below summarizes the inputs and results obtained while applying the Faithful-Gould Construction Calculator on the base case.

Table 5: Faithful-Gould Construction Calculator Applied To the Base case.

Building characteristic	Case study results
Type of building	Residential
Total area	16,218
Type of ventilation	Air conditioned
Building depth	Narrow plan
Embodied CO_2e	9,062 metric tons
Operation CO_2e/year	1,179 metric tons

The total embodied CO_2 emissions obtained is 9,062 tons of CO_2e whereas the operational emissions are 1,179 tons of CO_2e/year. The embodied CO_2 emission from this calculator is within the range of CO_2 emission obtained from Build Carbon neutral calculator. In this calculator, the building expected lifetime is not specified, making the comparison with other calculators difficult.

Green Footstep calculator is a more detailed tool than the two previously mentioned calculators, taking into consideration the country emissions of the construction project. The results shown in Table 6 indicate embodied emissions of 6,554 tons CO_2e and operational emissions of 1,560 tons CO_2e/year over 60 years of facility life.

Table 6: Green Footprint Calculator Applied To the Base Case.

Building characteristic	Case study
Building type	Residential: multifamily
Size of construction site	1,200 m^2
Site characteristic	Previously developed
Approximate floors area	16,218 m^2
Expected building lifetime	60 years
Construction CO_2e	6,554 metric tons
Operation CO_2e/year	1,560 metric tons

Green Footstep also provides the ability to input a customized average emission coefficient for the location in Kg.CO_2e/KWh and provides the user the option of choosing the baseline for construction and operational emissions - the user can select the U.S. economic input-output LCA or enter directly a user value in tons of CO_2e. In contrast, Nzwood only require three criteria to calculate the construction emissions of a building. Table 7 lists these criteria along with the results of 5,767 tons of construction CO_2.

Table 7: Nzwood Calculator Applied to the Base Case.

Building characteristic	Case study
Type of building	Commercial multi-storey
Total floor area	16,218 m^2
Building structure	Concrete
Construction CO_2	5,767 metric tons

Unlike the previous calculators, Carbon Calculator V3.1.2 is a spreadsheet showing materials used in the construction of a building. This calculator provides a user guide, carbon reduction tips, a list of uncertainty and assumptions, and shows the sources of the data used. It is more detailed than the previously mentioned calculators and has the advantage of listing specific construction materials, where the user has to input the quantities for each material used in the construction process. The total carbon emissions generated is 9,115 tons CO_2e including the embodied and transportation CO_2e emissions with a plus or minus 25 percent of the true value. A summary of the carbon footprint obtained from the different calculators is shown in Figure 1 below. The following section explains the fluctuations among the results obtained from the five examined calculators.

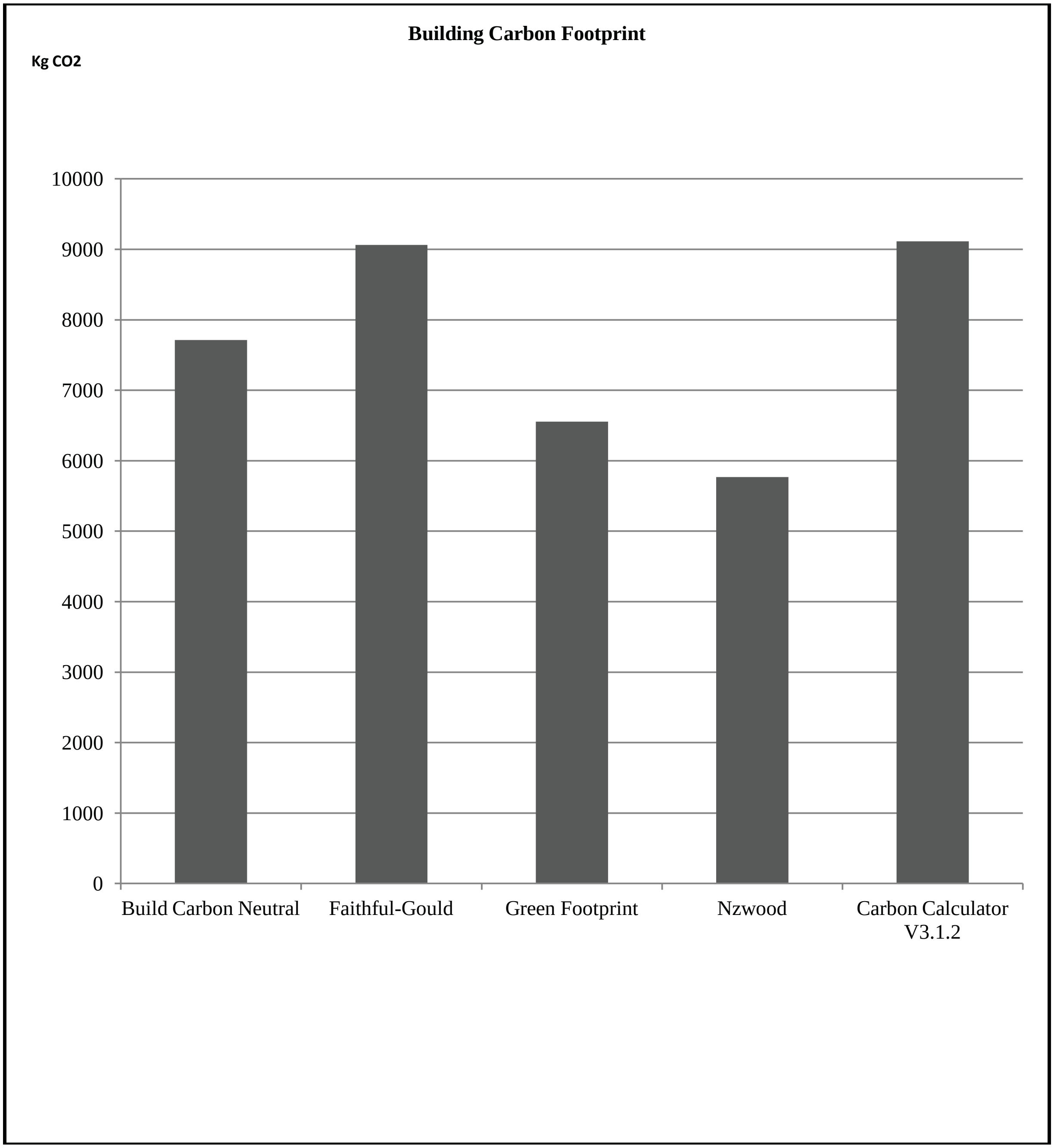

Figure 1: Histogram showing the carbon footprint from each calculator.

6. DISCUSSION

Although the selected calculators were used with uniform inputs (i.e. same case study), their results varied significantly. These variations may be due to differences in conversion factors, carbon equivalent coefficients, and differing methodologies and assumptions. However, it is difficult to pinpoint to the exact reasons for the variations and, therefore, assess the accuracy of the calculators without transparency in calculations. For the embodied carbon footprint emission, three calculators, Faithful-Gould, Green Footstep and Carbon Calculator V3.1.2 specified that all GHG emissions are taken into consideration and emissions are calculated in CO_2e, with a maximum difference of 2561 tons CO_2e. This difference is likely because Carbon Calculator V3.2.1 accounts for the transportation emissions in its calculations. The operation carbon footprint from Faithful-Gould and Green Footstep differs by 381 tons CO_2e/year. This difference might be due to the use of various methods for computing the operational emissions, (e.g. using a cradle to grave approach versus cradle to gate) thus resulting in different levels of CO_2e emissions per year. Only one calculator attempts to account for the geographic location by offering country dependent estimates for electricity related emissions. Two calculators, Green Footstep and Carbon Calculator V3.1.2 allow users to override the individual CO_2 coefficients. The remaining calculators use embedded coefficients, which makes it difficult to track the origin of these variations in results. Table 8 below summarizes some of the differences among calculators.

A scale of 1 to 5 was used to reflect the level of transparency of each calculator based on the following criteria:

Level 1- The source of the data is not mentioned.

Level 2-The source of data is mentioned but not clearly.

Level 3-The source of the data is stated but cannot be viewed.

Level 4-The source of data is stated and one can view some items.

Level 5-The source of data is stated and one can see any data/coefficient if needed.

Notably, Table 8 shows a lack of uniformity among calculators. These differences may be a result of distinct conversion factors used or various methodologies employed to estimate carbon emissions. These variations, even when negligible, can produce considerable variation in results when compounded in calculations. Furthermore, the reasons for using different methodologies are unclear. The lack of background information in some calculators emphasizes the need for greater transparency, which would allow practitioners to better understand the calculations and results. The variability observed here does not necessarily imply invalid results; however, the discrepancies in output do have potential effects. A difference of several tons of emissions in a building's carbon footprint calculation may induce different responses. For example, if a carbon calculator gives a lower value than the expected value, the owner may be induced to opt for less energy efficient equipments. Similarly, if the carbon footprint of a building is higher, the owner/consultant may put a greater effort into a range of reductions or offset purchases or both. These variations also may influence the extent to which policymakers support different types of building reduction measures.

In summary, practitioners should look for calculators that have as many of the criteria listed in Table 8 as possible. An ideal carbon footprint calculator should be transparent, include background information about the origin of the data, clearly state the approximation made during the calculation, include all the GHG emissions, provide country specific estimates, and allow the users to override the individual CO_2 figures.

Table 8: Comparison of Calculators.

Calculators	Include background information	Offers country specific estimates	Include GHG emissions	Transparent	Allow users to override the individual CO_2 figures
Build Carbon neutral	Yes	No	No	3	No
Faithful-Gould	No	No	Yes	1	No
Green footstep	Yes	Yes	Yes	4	Yes
Nzwood	Yes	No	No	2	No
Carbon Calculator V3.1.2	Yes	No	Yes	4	Yes

7. CONCLUSION AND FUTURE WORK

This study provides a description of construction carbon calculators, and highlights the differences in their methodologies and results. The dissimilarities found in this study reveal the need for further research and standardization in the field of construction carbon calculators. There is also a need for a methodology or a tool that will help practitioners understand and assess the impact of construction on the environment. Accurate and transparent results will allow users to make unbiased decisions and fulfill their professional duties to both their clients and to the wider community. Currently, the research team is building a carbon footprint calculator that will cover the gaps highlighted in this paper.

REFERENCES

Abanda, H., Tah, J.H.M., Cheung, F., and Zhou, W. (2010). "Measuring the embodied energy, waste, CO_2 emissions, time and cost for building design and construction." In Computing in Civil and Building Engineering, *Proc., Int. Conf.*, Jun. 30-Jul. 2, Nottingham, UK, Paper 181.

American Forest, "Carbon Calculator." http://www.americanforests.org/learn-more/carbon-calculator/. (accessed 29/07/12. 2012)

Environment Agency, "Carbon Calculator v3.1.2." http://www.environment-agency.gov.uk/static/documents/Business/Carbon_calculator_v3_1_2.xls. (accessed 16/04/12, 2012).

Faithful and Gould, "Construction carbon calculator." http://www.fgould.com/carbon-calculator. (16/04/12, 2012).

Green Mountain, "Green Mountain Energy" http://www.greenmountain.com/green-mountain-energy-company-store/carbon-calculator. (29/07/12, 2012).

IPCC. (2007). Climate Change, The Physical Science Basis, *Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge.

Kleiner, K. (2007). "The corporate race to cut carbon," Nature, vol. 3, pp. 40–43.

Mithun and Wildflower center, "Buildcarbonneutral." http://buildcarbonneutral.org. (16/04/2012, 2012)

NZ Wood, "Carbon calculator." http://www.nzwood.co.nz/carbon-calculator. (16/04/2012, 2012).

PE-international, GaBi Software. http://www.pe-international.com/international/index/. (16/04/2012, 2012).

Rignot, E., Kanagaratnam, P. (2006). "Changes in the velocity structure of the Greenland ice sheet," *Science*, 311(5763), pp. 986–990.

Rocky Mountain Institute, "Green footstep." http://www.greenfootstep.org. (16/04/2012, 2012)

Säynäjoki, A., Heinonen J., and Junnila, S. (2011). "Carbon footprint assessment of a residential development project," *Int. J. Environ. Sci. Dev*. vol. 2 pp. 116–123.

Terrapass, "Carbon Footprint Calculator." http://www.terrapass.com/individuals-families/carbon-footprint-calculator/. (29/07/12, 2012).
U.S. Department of Energy. (2008). "Energy efficiency trends in residential and commercial buildings." Energy Efficiency and Renewable Energy, October.
Wiedmann, T., and Minx, J. (2007). "A definition of 'carbon footprint." In: CC Pertsova, *Ecological Economics Research Trends,* Nova Science Publishers, Hauppauge NY, USA.