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Assessing Carbon Footprint Calculators for Evaluating the Embodied Carbon in a Single-Family Home: A Case Study

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Abstract

This paper provides an assessment of the utilization and effectiveness of four distinct carbon footprint calculators designed specifically for the construction industry: the Embodied Carbon in Construction Calculator (EC3), Building Emissions Accounting for Materials (BEAM), OneClick Life Cycle Assessment (LCA), and Athena Impact Estimator for Buildings. These tools were tested using a consistent data set derived from the construction estimates of a single-story, detached residential home located in Rancho Mirage, California. The estimates included detailed information on the quantities of materials used, serving as the primary inputs for each calculator. The study focused on evaluating the capabilities of these programs to generate outputs reflecting the embodied carbon emissions associated with construction activities. While some calculators offered advanced features, such as the ability to factor in utility consumption and material transportation emissions, this study concentrated on the core functionality of each tool, primarily assessing raw material impacts. Each program was evaluated for its technological framework, accuracy, user-friendliness, comprehensiveness, and versatility. The findings revealed variations in the performance and usability of the calculators, with each program exhibiting unique strengths and limitations. This paper provides a comparative analysis of these tools, offering insights into their practical application in construction projects and guiding users in selecting the most appropriate calculator based on their specific needs and project requirements.

Keywords

Carbon, Carbon Calculator, Emissions, Embodied Carbon, Construction.

1. Introduction

The construction industry is a significant contributor to global environmental impacts, accounting for approximately 25 to 40 percent of the world's total carbon emissions and 40 percent of worldwide energy usage (Afable, 2022; Sikra, 2020). As the demand for new infrastructure grows, particularly in response to a rising global population, the industry's environmental footprint is expected to expand. This presents an urgent need for sustainable building practices that can mitigate the industry's contribution to climate change. In response to these challenges, there has been a growing emphasis on the implementation of green building practices, supported by organizations such as the U.S. Green Building Council and the U.S. Environmental Protection Agency. Among the most influential tools in promoting sustainable construction is the Life Cycle Assessment (LCA), a methodology that evaluates the environmental performance of products or processes over their entire life cycle, from raw material extraction to end-of-life disposal and recycling (Cabeza, 2013). LCA is crucial in the construction industry as it allows for a comprehensive analysis of both embodied carbon, which refers to greenhouse gas emissions arising from the manufacturing, transportation, installation, maintenance, and disposal of building materials, and operational carbon, which pertains to emissions due to building energy consumption (Simonen, 2022). To facilitate the application of LCA in construction, various carbon calculators have been developed. These tools assess the carbon footprint of construction projects by analyzing material quantities and other inputs derived from construction estimates. However, the effectiveness and usability of these calculators can vary significantly depending on their technological framework, data comprehensiveness, and user interface. This study examines four prominent carbon calculators—Embodied Carbon in Construction Calculator (EC3), Building Emissions Accounting for Materials (BEAM), OneClick Life Cycle Assessment (LCA), and Athena Impact Estimator for Buildings. This paper aims to provide a thorough evaluation of these tools by applying each to a consistent data set derived from a single-story, detached residential home located in Rancho Mirage, California. By comparing the calculators' outputs, the study seeks to determine their accuracy, user-friendliness, and overall suitability for use in the construction industry. This analysis is framed within the broader context of Whole Building Life Cycle Analysis (WbLCA), which includes stages such as production, construction, use, and end-of-life, as well as the Carbon Footprint Scope categories defined by the Greenhouse Gas (GHG) Protocol: Scope 1 (direct GHG emissions), Scope 2 (indirect GHG emissions from electricity and heat), and Scope 3 (other indirect GHG emissions) (Carbon Footprint, 2016; The Carbon Leadership Forum, 2019). The findings of this study contribute to the ongoing discourse on sustainable construction by offering insights into the capabilities and limitations of current carbon calculator technologies. These insights can guide industry professionals in selecting appropriate tools for minimizing the environmental impact of building projects, ultimately supporting the construction industry's transition to a more sustainable future.

2. Literature Review

Carbon emissions are an important topic of discussion in today's world due to the adverse effects that they have on the environment. Carbon emissions are the release of carbon dioxide into the atmosphere due to human activities such as burning fossil fuels and deforestation. These emissions contribute to climate change, which has severe consequences such as rising sea levels, extreme weather patterns, and loss of biodiversity. The construction industry has many phases and thus many opportunities to create carbon emissions It is key to consider all phases of construction to ensure we attack the carbon footprint of the industry holistically. Understanding and reducing carbon emissions is crucial for preserving the planet's health and ensuring a sustainable future.

Carbon calculators are essential tools for measuring carbon footprints in various industries, including the construction sector. The tools are web-based applications that allow construction stakeholders to estimate their carbon emissions, understand their impact on the environment, and identify areas for improvement. The construction industry contributes to massive carbon footprints due to the use of fossil fuels, electricity, and the heavy waste burden created by construction activities (Simonson 2021). Carbon calculators use data such as energy consumption, transportation, and waste disposal resulting from construction activities to calculate the carbon footprint. Despite the significance of carbon calculators in measuring carbon footprints, there is still a lack of literature on how these programs work and produce their output. Previous studies on carbon calculators have mainly focused on their ability to teach individuals about their environmental impacts and spur action. Researchers are exploring the capabilities of carbon calculators in communicating the impacts of consumption at different levels. By understanding how these programs work, developers can adapt them to improve their accuracy, effectiveness, and user experience. With the research available concerning the capabilities of these programs, developers will also be able to improve upon any shortcomings that come up as results of prior research. As new technologies emerge in the construction industry, carbon calculators can help stakeholders make informed decisions and act towards reducing their carbon footprint. By using green building materials and practices, minimizing waste, and utilizing energy-efficient systems, construction companies can reduce their carbon emissions and contribute to a more sustainable future.

As previously stated, there have been numerous studies conducted that focus on carbon calculators' ability to spread awareness to the public about the environmental impacts they impose and are unaware of. One study in India conducted a study in which they analyzed the use of eight carbon footprint calculators (CFCs) available to the public. They determined that many of these were not specific to the environmental conditions in India and thus the development of 'Yo!Green', India's first certified CFC, underwent (Nahar 2018). Their ranking system placed this certified CFC at the peak performance in all categories while the other programs were not up to the standards of an effective calculator. Nahar conducted a case study on a single family using this new program and found that the program gave them clear results about what in their home is contributing to their carbon footprint and they were able to take actions to reduce their emissions (Nahar 2018). Nahar also cites that "using individual CFCs can be effective for engaging individuals and reducing their emissions because the public typically underestimates their contribution"

(Nahar 2018). Further, there have been empirical studies that found "positive effects in terms of learning about CO2 impacts, increased awareness, and enhanced efforts and guidance, as well as individual empowerment leading to slightly reduced CO2 emissions" (Nahar 2018). All this is to say that people are generally aware that they contribute to carbon emissions but don't exactly understand the extent and what areas of their life produce such impacts. With carbon calculators, they feel compelled to act even if it may be something small. It all serves to further the fight to decrease our carbon footprint as a society. However, these calculators are not without faults.

A significant portion of the literature available on carbon calculators examines the drawbacks and shortcomings of these programs. The general purpose of CFCs remains the same from program to program which is to provide the public with an understanding of the impacts they have on carbon emissions and encourage sustainable change. A study in the Journal of Cleaner Production conducted by Marja Salo and colleagues states that "detailed definitions on what to include and exclude from the footprint calculation vary from one calculator to another" (Salo 2018). Since the parameters of the programs vary, the output can vary which as well could lead to serious misconceptions about one's carbon footprint. A study by graduate students at Vanderbilt looked at the use of a carbon calculator from an individual's perspective and found that even with uniform inputs, results would vary without any transparency to be able to discern why the variations exist (Padgett 2007). Studies like these test the credibility and accuracy of CFCs and as said can lead to misconceptions. At the individual level, this would simply lead to a few people misunderstanding their impact while if businesses were to run into inaccuracies like this, there could be more severe consequences.

A paper written by Sarah West and colleagues refers to CFCs as a "complex yet imprecise science because of data limitations and use of different inputs" (West 2016). They also make a point to discuss the aspects of individual behavior and the likeliness of individuals to take action based on the results of a carbon footprint calculation. Specifically, West cites a paper that examined focus groups and found "household energy reduction measures to be acceptable, but compromising on hot water use and cooking were less acceptable" (West 2016). While the CFCs can produce output, there is still a human barrier that can prevent action. This explains much of the data we see in the literature regarding CFCs. As these programs continue to improve, usage should increase to constantly and consistently provide accurate data to the public. There is virtually no literature on the usage of these programs from a construction perspective and this paper seeks to change that.

3. Methodology

This study involved a student researcher working on their senior project to calculate the embodied carbon footprint of a single-family home. This study systematically assesses the utilization and effectiveness of four prominent carbon footprint calculators designed specifically for the construction industry: the Embodied Carbon in Construction Calculator (EC3), Building Emissions Accounting for Materials (BEAM), OneClick Life Cycle Assessment (LCA), and Athena Impact Estimator for Buildings. These tools are integral to the quantification of greenhouse gas emissions, particularly in relation to the embodied carbon associated with construction activities. The evaluation employed a standardized dataset derived from a comprehensive construction estimate for a single-story, detached residential home situated in Rancho Mirage, California. This estimate included detailed quantities of all construction materials used in the project. To ensure methodological rigor and comparability, the study focused exclusively on material-related emissions, thereby excluding additional variables such as utility consumption and transportation emissions, which some of the calculators are capable of analyzing. Each carbon calculator processes the input data through its distinct computational framework, resulting in the generation of outputs that quantify the carbon emissions associated with the specified materials. Despite the availability of advanced features in some calculators—such as the incorporation of emissions from material transportation and operational energy use—this study deliberately constrained the scope to material-based emissions to maintain consistency across the tools being evaluated. The assessment criteria encompassed several key dimensions, including accuracy, user interface and ease of use, comprehensiveness of data inputs and outputs, and the overall versatility of each tool. The outputs from each calculator were critically analyzed to identify their respective strengths and limitations, providing insights into their applicability to various types of construction projects. By employing a consistent and controlled dataset, this study offers a balanced and rigorous comparison of the capabilities and constraints of these carbon footprint calculators within the construction industry.

4. Results

This paper aims to assess the usage, advantages, and limitations of each individual carbon footprint calculator named above. It will provide a comprehensive comparison of all the calculators under consideration, considering factors such as accuracy, user-friendliness, comprehensiveness, and versatility.

4. 1 EC3

The Embodied Carbon in Construction Calculator was the top result upon searching for construction carbon calculator programs on Google and was thus the most popular program to use for this purpose. It was very easy to access this program as the researcher just needed to register an account and they were able to open and use the program to its full extent. There were no paywalls to lock them out and anyone could pick up and use this program directly in their browser of choice. This program had a very strong structure and was very professionally organized such that each tool was readily available. Available tools include finding materials, planning a building, bid sheets, and managing data. This study utilized the planning of a building tool that allowed the researcher to input building material quantities and the tool provided the environmental impact as a result. This program utilizes a database of materials with Environmental Product Declarations (EPDs) in order to accumulate the environmental impact of building materials. EPDs are documents that communicate the environmental impact and performance of a specific material (A simple guide to environmental product declarations). The EPDs are the key that makes this program click and allowed the researcher to see the carbon emissions of a wealth of materials. While this was very efficient, it was also a major drawback of this program. If there was no EPD information on a specific material used in the researcher's building, there was almost no way to input the necessary information. For example, the Rancho Mirage house utilizes a post-tensioned slab for its foundation and thus had a large quantity of post-tensioned cables in the material estimate. However, EC3 did not have any EPD information for PT cables and there was no way to input outside data on the environmental impact of the material. The researcher was forced to use only the EPD information contained in EC3's database. One workaround was to find a material that may have similar carbon emissions in the database and perhaps rework numbers to properly account for the emissions of the missing material. Additionally, the researcher was forced to use the units the program provided upon choosing an EPD which sometimes did not properly work with the material estimate. The program also requires a high degree of specificity when inputting material data to provide the researcher with output regarding that material's impact. This often held the researcher back from finding generalized information if they do not have exact specifications for a certain material. However, if they did have enough information, this program provided the researcher with a very effective graphic to communicate where their material stood compared to other similar materials. EC3 was a very well-structured program with a great user interface, however, requires an extremely detailed estimate in order to provide the most accurate data.

4.2 BEAM

The Building Emissions Accounting for Materials calculator was extremely useful for using construction estimates and calculating the material data from such estimates. Once again, this program was very easy to access and just requires a simple registration to start using. They only ask for donations, if possible, to ensure that the program could continue to run and be available to all. The program runs off of Google Sheets and was highly intuitive. The organization was very simple and works perfectly with the numbers obtained from a construction estimate. The researcher inputted all the major numbers on the first page to describe the entire building and the program translates all that information to the subsequent pages which allowed them to get detailed material information for the many aspects of your building. Those pages provide a wealth of options where they could pick the closest material to the one used on their project. Additionally, if they were unable to find their material in the space provided, they have a section where they could input additional materials by any measure they wanted such as length, area, or volume. Similar to the previous program, however, this program was still missing PT cables, and the program may be missing certain other materials found in a building estimate. This program defaults to using metric units for all measurements and while it did allow the researcher to change to imperial, they were required to run a script that Google deemed unsafe. Finally, the highlight of this program was the organization of their review and results screens. The review screen very clearly shows all the material inputs the researcher had provided through their usage so they could be sure they did not miss anything. The results screen provides graphics that are easily digestible and informed the researcher of the state of their building's carbon emission intensity.

4. 3 OneClick

OneClick LCA was much more difficult to access than the previous two programs. The researcher was not able to access the program directly off the website and acquisition of the program generally required a hefty sum of money depending on the organization accessing the program. They do offer a student license that stays active for one year, which allows usage of the program for this particular study. Upon accessing the program, it could be more efficiently structured and there was some difficulty starting a project for the first time. Upon opening a project, the interface for inputting material data was quite well structured and lays out the general portions of a building well. However, regarding each input, they show a list of every material they have available in categories which sometimes made it difficult to find the actual material the researcher was looking for and even harder to tell if that material was missing altogether. Where this program shined was in the automatic calculations it did to provide extra data regarding the replacement of materials, material trucking, and waste. It also had the capacity for a high degree of specificity where the researcher could input the numbers for those extra sections themself. There was also room for more calculations regarding the operation and usage of utilities during the life cycle of the building. While these were not utilized in this study, it shows the extent of this program's capabilities. This program also offers a wealth of graphics that clearly and effectively demonstrate the carbon impact of a building.

4.4 Athena Impact Estimator for Buildings

Athena Impact Estimator for Buildings was the only program that was external and could not be utilized within a browser. This was also a difficult-to-obtain program, due to a poorly organized website. The website mostly discusses the uses and opportunities that come with their many available programs but did not make it clear how to download each. It was free to use however and requires a few steps to run the application. This was the only external application and the only program that had a problem with buffering. The software would need time after almost every input. The structure was not as intuitive as the previous programs. The researcher opened the program to see a completely blank screen and there was little guidance to help them start their project and begin inputting data. There are significantly fewer options than the previous programs for each individual material. However, the lack of options simplified the process and made it easier to get numbers for each material quickly. As with each program, there are materials missing. Finally, the results shown in reports from this program are much more difficult to digest than the previous applications. The main reports are very number-heavy, and it was difficult to understand the importance of each number. There are graphs for different environmental aspects, however, even these are tough to read as there aren't any parameters to compare to.

5. Conclusions

In conclusion, the construction industry is a significant contributor to global energy consumption and carbon emissions, presenting a critical challenge to environmental sustainability. However, with the growing emphasis on sustainable practices and the development of tools such as carbon calculators, the industry is increasingly equipped to mitigate its environmental impact. Organizations like the U.S. Green Building Council and the U.S. Environmental Protection Agency continue to promote green building standards such as LEED certification, further driving the industry's shift towards sustainability. This study has evaluated and compared four prominent carbon calculators: EC3, BEAM, OneClick LCA, and Athena Impact Estimator for Buildings. Each of these calculators offers distinct strengths and challenges, making them suitable for different aspects of construction project analysis.

The EC3 calculator is noted for its extensive database of Environmental Product Declarations (EPDs) and its user-friendly interface, making it a strong choice for projects where material data is readily available. However, its dependence on EPDs can be a limitation when specific materials lack data. The BEAM calculator integrates seamlessly with construction estimates and is highly accessible due to its Google Sheets-based interface. While it is easy to use, it shares a similar limitation with EC3 regarding gaps in material data. OneClick LCA provides a comprehensive suite of tools for lifecycle analysis, including capabilities for material replacement, trucking, and waste calculations. Although it offers deep analytical insights, its complexity and less intuitive interface may pose challenges for some users. The Athena Impact Estimator for Buildings prioritizes simplicity and speed in material selection and data input, but it falls short in delivering easily interpretable results and is hindered by performance issues.

The choice of the most suitable calculator depends heavily on the specific needs of the project. For those requiring detailed analysis with access to a wide range of materials, EC3 and OneClick LCA offer substantial benefits but require careful attention to material data. BEAM provides a more streamlined and accessible option for those working directly from construction estimates, while Athena may be more appropriate for users who prioritize speed and simplicity over detailed output. Ultimately, the selection of the most appropriate tool should consider the balance between ease of use, the availability of material data, and the depth of analysis required for the project at hand. This study contributes to the understanding of carbon calculators in the construction industry, offering insights into their applicability and limitations. Future research should explore using more detailed construction estimates that encompass all phases of a building's life cycle and evaluate a broader range of calculators and users to further refine these tools and enhance their impact on sustainable construction practices.

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