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State-of-the-art Report

10 years of carbon calculator use: what have we learned for the future?

10 ans d'utilisation des calculateurs carbone: qu'avons-nous appris pour l'avenir?

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ABSTRACT: Correct measurement of emissions from the geotechnical industry has been a challenge for the last 10 years and remains a key process to achieving the environmental transition objectives towards 2050. In this context, there have been multiple calculation tools developed in Europe, coming from different actors, such as contractors, consultants, federations, and associations. In view of their importance and multiplicity, it is essential to evaluate their use, reliability, and effectiveness for a correct orientation of future efforts. This study aims to analyse the use of European calculators in a practical way at the local and project level, as well as their reference position worldwide. The role of the calculators coming from geotechnical associations and federations as regulators and guarantors of transparency in the sector has been another important axis of evaluation. And finally, the complexity and the level of detail required in the indicators of the tools to achieve the highest possible utilization and support of the commercial departments in a project bidding phase were compared.

RÉSUMÉ: La mesure correcte des émissions de l'industrie géotechnique a été un défi au cours des dix dernières années et reste un processus clé pour atteindre les objectifs de la transition environnementale à l'horizon 2050. Dans ce contexte, de nombreux outils de calcul ont été développés en Europe, provenant de différents acteurs, tels que des entrepreneurs, des consultants, des fédérations et des associations. Compte tenu de leur importance et de leur multiplicité, il est essentiel d'évaluer leur utilisation, leur fiabilité et leur efficacité afin d'orienter correctement les efforts futurs. Cette étude vise à analyser l'utilisation des calculateurs européens de manière pratique au niveau local et au niveau des projets, ainsi que leur position de référence au niveau mondial. Le rôle des calculateurs provenant des associations et fédérations géotechniques en tant que régulateurs et garants de la transparence dans le secteur a été un autre axe d'évaluation important. Enfin, la complexité et le niveau de détail requis dans les indicateurs des outils pour obtenir la meilleure utilisation possible et le meilleur soutien des départements commerciaux dans la phase de soumission d'un projet ont été comparés.

Keywords: Life cycle assessment; carbon footprint; calculator; environmental product declaration.

1 INTRODUCTION

Over the past 10 years, it has become evident that the building and construction sector plays a crucial role in global energy consumption and carbon emissions. In 2021, the building and construction sector alone was responsible for 37% of global energy and process-related carbon dioxide (CO2) emissions, with carbon emissions from building operations reaching a unprecedented high of 10 GtCO2, and those related to materials production (e.g. concrete, steel, aluminium, glass and bricks) contributing an additional 3.6 GtCO2.

The European context of regulations and directives on sustainable development and energy efficiency of buildings (RE2020, CSRD, Tertiary Decree, European Taxonomy, etc.) is getting stronger and stronger and is pushing companies in the building sector to better measure the emissions released during the manufacturing, transport, construction, and end-of-life phases of all built infrastructures. But this momentum is even more driven by the expectations of clients and investors, who already at the project bidding stage are particularly interested in knowing the environmental impact of their future projects.

Geotechnical engineering projects play a large role in the civil infrastructure system, making substantial contributions to the construction sector in terms of energy and resource consumption. As such, practitioners can apply sustainability as a design criterion and to value that effort by presenting emission calculations and comparisons to clients. To accomplish this, several tools have been developed over the past decade that quantify embodied carbon through environmental product declarations (EPDs) or life cycle assessments (LCAs).

The European Federation of Foundation Contractors (EFFC) and the Deep Foundation Institute (DFI) developed one of the first tools to calculate the embodied carbon of geotechnical construction projects, the EFFC/DFI Carbon Calculator, a decade ago.

However, other tools have been used for some time in the market, such as (EC3, eTool, ECOM, SimaPro, e-CO2ncerned). A comparative review of these tools and their use over the last decade was conducted to understand the differences in scope, calculation methods and applicability to the industry. The market reaction to the use of the EFFC-DFI calculator by commercial teams has been analysed to understand the necessary improvements to be made to the tool.

2 ENVIRONMENTAL IMPACT QUANTIFICATION METHODS

Numerous methodologies are available for evaluating environmental impacts, each serving distinct purposes.

Among the most used approaches are life cycle assessment, carbon footprinting, and environmental product declarations. Although these methods share certain similarities, each has distinct characteristics and adheres to different standards.

2.1 Life cycle assessment

Life cycle assessment (LCA) is a systematic analytical framework to evaluate the environmental impacts of a product or system over its entire life cycle. Several organizations have created standards to define the perimeter, processes and principles of the calculations, however, the most recognized procedures are included in the ISO14000 standards. It is primarily concerned with the process-based methodology, which is usually defined in four phases: goal and scope definition, life cycle inventory (LCI), life cycle impact assessment (LCIA), and interpretation (ISO 2006).

The scoping phase of an LCA is often described as "cradle-to-grave" (A-C), which includes impacts from the raw material extraction phase to the end of the useful life of the product or system, or "cradle-to-gate", which only includes impacts up to the last stage of the manufacturing process before the product passes through the site (A1-A3).

The LCI quantifies the relevant environmental flows of inputs (e.g. raw materials, water and energy resources) and outputs (e.g. emissions to air, water and soil and waste generation) of the system. Then, in the LC phase, the environmental flows contained in the LCI are translated into environmental and human health impact indicators. A LCI and an LCIA can be compiled in a spreadsheet or in a specific computer program, as explained later in this document.

2.2 Carbon footprint

Carbon footprinting (CF) and LCA are related but distinct methods for assessing the environmental impact of a product or system. Although CF applies life cycle principles and accounting methods, it is based on a single impact category: GHG emissions related to climate change, often quantified as GWP. LCAs, on the other hand, evaluate other environmental impacts, such as energy use, water consumption and air pollution (Motta 2022).

As with LCA, several standards exist to standardize CF procedures for both corporate and product analysis. The Greenhouse Gas Protocol Corporate Standard (GHG Protocol) is the most widely used international emissions accounting standard and has served as the basis for most other standards, including those developed by ISO.

2.3 Environmental product declaration

An EPD is a verified and registered document that conveys information on the life-cycle environmental impact of a product adhering to standards like ISO 21930 and EN 15804 for the building and construction sector (EN 2012; ISO 2017). These provide a valuable open data source for comprehensive LCAs.

3 EXISTING TOOLS: PHASE 1

In the first stage of the study, five carbon calculation tools from organizations, associations and external suppliers were compared. A summary of these is presented in Table 1.

Table 1. Summary table of major characteristics of the carbon calculation tools.

Tool	**EC3**	**eTool**	**Embodied Carbon Estimator (ECOM)**	**SimaPro**	**EFFC DFI Carbon Calculator**
Organization	Building Transparency	Cerclos	Structural Engineering Institute	Pre Sustainability	EFFC-DFI
Activity Sector	Building	Building	Structural Engineering	Several	Geotechnical Engineering
Geographic Regions	Global	Global	North America	Global	Global*
Standard	ISO 21930 EN 15804	ISO 14040/44,27001, 21930 EN 15978, 15804 PAS 2080	EN15978	ISO 14040/44	ISO 14067 PAS 2050:2011
Impact Categories	GWP**	GWP **	GWP	GWP **	GWP
LCA Scope	A1-A3	A-C	A1-A3	A-C	A-B, C2
LCIA Method	Various***	CML	CML	Various***	Assigned Factors***
BIM Plug-In	✓	✓	×	×	×
Cost	Free	600-7,500 USD/yr (based on features)	Free	2,600-7,275 EUR/yr (based on features)	Free

3.1 Embodied carbon in construction calculator (EC3)

EC3 is a web-based tool developed by Building Transparency, a nonprofit organization, that allows users to determine the embodied carbon of building materials and structures based on third-party verified EPDs.

An important characteristic of this tool is the life cycle scope included in the GWP calculation, considering a 'cradle-to-gate' life cycle.

Two of the most notable advantages of this tool are that it is free and user-friendly. The interface makes it extremely easy for inexperienced users. It also takes into account uncertainties, providing more realistic ranges of GWP than if a single, deterministic value were given. However, the scope of the tool is more oriented to superstructures, which may limit its applicability to other types of projects.

3.2 ETool

ETool, a web-based application developed by Cerclos, serves as a tool for evaluating the environmental impacts of projects and identifying areas for improvement. eTool offers templates for building components, energy, and water use. Users have the flexibility to choose from these templates or create their own to determine GHG emissions. This tool provides a financial cost analysis, combining environmental impact assessment with financial analysis.

eTool offers robust functionality for the environmental and financial assessment of projects, but can be difficult to understand for users unfamiliar with sustainability assessment and life-cycle analysis.

eTool focuses on building and construction projects, which restricts its applicability and the quality of data related to other sectors.

3.3 ECOM - Embodied Carbon Order of Magnitude

Embodied Carbon Order of Magnitude (ECOM) is a web-based estimator developed by the Structural Engineering Institute (SEI) that allows users to determine approximate embodied carbon of material products, assembling of framing, or entire structural frame. This tool relies on data sourced from publicly available EPDs.

The interface is easy to comprehend and does not require significant research prior to use. However, users are limited to a small selection of material types and strengths and cannot model life cycle stages beyond material production. Consequently, results may not provide a comprehensive assessment of the total environmental impacts associated with structural projects.

3.4 SimaPro

SimaPro is a software and web-based tool developed by PRe-Sustainability widely used for sustainability reporting, carbon, environmental, social and water footprinting, biodiversity assessments, and sustainable product design.This tool allows users to model LCAs of products, processes, and systems, as well as auxiliary products within a life cycle chain.

SimaPro houses an extensive database of LCI data, which can be used in a wide range of industries and sectors.

SimaPro offers tools to generate comprehensive reports and visualizations of calculated impacts. While SimaPro is a powerful and multidisciplinary tool for performing LCA, it has some potential drawbacks, such as cost and complexity.

3.5 EFFC-DFI Carbon calculator

The EFFC-DFI Carbon Calculator is an Excel-based tool dedicated to calculating embodied carbon of foundations and other geotechnical systems. The calculator accounts for several emission sources within the embodied carbon calculation, including material manufacturing, material transportation, energy consumption, people’s transport, equipment transportation, equipment manufacturing, waster transportation, and waste management.

The EFFC-DFI calculator requires a series of inputs for each emission source category. For instance, in material manufacturing, users are prompted to specify material type, quantity, and additional information like cement type and steel shape.

These details enhance the accuracy of embodied carbon estimates, recognizing that emission factors differ based on these aspects.

It is important to highlight that this tool assigns recommended emission factors from different databases for each input, although users have the option to utilize country specific databases for materials (France, United Kingdom, and United States) and electricity grids, following ISO 14067 and PAS 2050:2011 standards.

Moreover, users can create subprojects, allowing them to compute the carbon footprint of specific project segments. These can be consolidated to model the embodied carbon of an entire project. Results can be generated for subprojects, projects, and comparisons between multiple projects. The calculator automatically creates pie and bar charts of results, providing a visual representation of the data.

5 EXISTING TOOLS: PHASE 2

In phase 2 of the study, we have incorporated a look at possible internal tools developed by construction companies, which are not accessible to the public, but are used in the bidding stage, and what impact they may have with those already studied.

The French global Group VINCI has been taken as an example, with implementation in more than 120 countries around the world, and with a specific business line of foundations. The Group has developed the e-CO2ncerned calculator, which includes a specific development for geotechnical activities.

E-CO2ncerned is a Carbon Footprint tool common to all VINCI entities that allows both to calculate the greenhouse gas (GHG) emissions of a project and to compare the GHG emissions of several variants. It is Carbon Footprint® certified by the Bilan Carbone Association and ADEME. The calculator started as an Excel file, which was later moved to a web development. The calculator counts emissions with a VCA approach, from “cradle-to-grave”.

The emission factors (EF) used in e-CO2ncerned come from different databases: ADEME (Environmental and Energy Maitrise Agency) carbon database, EcoInvent database, Environmental and Health Declaration Sheets (FDES) from INIES, and VINCI Group internal data.

The web interface used is one of the advantages of the tool, as well as the reports that are automatically obtained at the end of the project, which allow to compare a base solution with an alternative in a quick way and with appropriate graphics.

Likewise, the possibility of incorporating in the analysis other stages of the project that are not specific to geotechnical engineering, according to user comments, has allowed to analyze the integrity of the project and shows the client a general and wide vision of the project.

However, being an internal calculator, at a tender stage, it has been impossible for the client to compare the environmental impacts with those of other competitors' tenders.

Feedback from users has shown a lack of confidence on the part of clients in the emissions factors used, due to their internal origin.

6 COMPARISON BETWEEN TOOLS

To date, the EFFC-DFI Carbon Calculator is the only tool specifically designed to model environmental impacts of geotechnical projects. Other internal calculators for individual companies, such as the e-CO2ncerned calculator, have geotechnical modules.

In contrast, tools like EC3 and eTool primarily target the building sector, while SimaPro offers broader applicability across various industries.

While it is possible to adapt these tools for geotechnical projects, doing so requires extensive data manipulation to align inputs with the specific requirements of each calculator.

The EC3 calculator, on the other hand, allows users to specify certain material characteristics, but this is dependent on EPD availabilities. Other more comprehensive tools, such as SimaPro, allow users to incorporate specific elements, such as aggregates, based on available LCI datasets, leaving the practitioner to correctly manipulate inputs to model different concrete contributions.

The e-CO2ncerned calculator is limited to a list of materials, with specific strengths, which could be limiting in case of adding a new material.

Another point of comparison is ease of use. Although tools like SimaPro offer more flexibility in modeling processes and scopes, this introduces a further level of complexity. This could add a barrier for new users. In contrast, the EFFC-DFI Carbon Calculator streamlines much of the user activity required in other tools, making it more accessible and efficient to implement. However, this comes with some trade-offs, as users are limited to a predefined set of materials, energy, and transportation options based on the emission factor database.

A comparative study of a point project has been carried out with the EFFC and e-CO2ncerned calculators, presenting base solution and alternative solution data, and analyzing the feedback obtained by the client. A summary of these is presented in Table 2.

The base solution presented included: Sheet Piles Anchors; Soil improvement, RC, Earthworks, Dredging, Pavement, and utilities.

Alternative solution: Slurry wall, Starsol Piles, Anchors, Soil improvement, RC, Earthworks, Dredging, Pavement, and utilities.

Table 2. Total emissions expressed in (TCO2eq).

Tool	Emissions basic solution	Emissions alternative solution
EFFC-DFI	4518	2716
e-CO2ncerned	3700	2900

The differences in emissions are mainly based on the EFFC-DFI concept of ratios versus a detailed approach in the e-CO2ncerned calculator, based on power and equipment usage.

From an action analysis point of view, it was concluded that detailed energy consumption analyses can be useful to understand future actions to be implemented by the company on that topic, such as Scope 1 and 2 emission reduction trajectories. However, in the overall view of a project, and for the practical purposes of showing general data to a client, the ratios are sufficient, since in both cases it is noted that the impact due to materials accounts for about 70% of emissions, and at a tender stage, and when comparing with an alternative design, it is the overall data that is of commercial interest.

To further improve its usefulness, the EFFC-DFI Carbon Calculator could consider expanding its database to include additional input streams, which would allow more diverse processes and systems to be modeled.

7 CONCLUSIONS

Four tools were analyzed in phase 1, in addition to the EFFC-DFI carbon calculator, to understand their scopes of application, standards and characterization factors, calculation methodologies, etc.

Then in phase 2 the EFFC-DFI calculator has been compared with a company internal calculator to understand the commercial impact and customer requirements in Europe.

Based on this study, the following conclusions can be drawn:

- To date, the EFFC-DFI Carbon Calculator is the only tool specifically designed to model the environmental impacts of geotechnical projects, with a focus on deep foundations.

- eTool, and SimaPro stand out for their ability to perform comprehensive LCA, as opposed to other that are limited to CF assessments. These tools enable users to evaluate multiple environmental impact categories concurrently, allowing for a more holistic analysis that ensures design changes do not inadvertently shift environmental burdens from one category to another.
- From a commercial aspect, the automatic report produced by the e-CO2ncerned calculator makes it easier for commercial teams to sell and compare an alternative solution with a base solution. The EFFC-DFI carbon calculator could improve this aspect and provide a commercial report in Word format.
- The EFFC-DFI Carbon Calculator could be enhanced by expanding its database to encompass additional input flows. This would broaden the range of applications and adaptability to meet specific project needs.
- In most of the applied projects, the EFFC-DFI calculator generates more confidence in the customers than the internal calculators of the companies, because it comes from a neutral organization. One way to further improve the future positioning of the calculator in the market is to obtain new external certifications.

In the context of geotechnical engineering projects, the EFFC-DFI carbon calculator stands out as the most suitable and user-friendly option. By incorporating the recommendations made here, this tool could be further enhanced for improved applicability.

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