How to pursue the Whole Life Carbon vision: a method to assess buildings' Embodied Carbon

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Abstract

The design and construction of CO_2-neutral buildings by 2050 will be possible through many actions and strategies, including new metrics and indicators that would contribute to the accounting process for greenhouse gas emissions over the building's life cycle. Among the range of helpful indicators is Embodied Carbon (EC). Standards and references describe EC characteristics and possible uses both in the design stage and in other building life cycle stages, at the same time, they point out a need for methods of building CO_2-equivalent emissions calculation.
The paper deals with research titled "decarbonisation tools" aimed at providing common definitions and at developing an EC accounting method. The main phases of the investigation work are reported. Further, the paper describes some future developments and outlooks for making EC an indicator understandable to several stakeholders of the construction sector as well as user-friendly from the early stage of the design process.

Keywords (5)

Whole Life Carbon vision, Embodied Carbon, Carbon emissions, Global Warming Potential, Buildings' materials

1. Introduction

Global warming, due to the anthropogenic Green House Gas emissions (GHGs), has caused a mutation of the environment with huge consequences on ecosystems. Extreme natural phenomena such as heatwaves, flooding, rising sea level and more frequent storms have become commonplace and many of them are irreversible (IPCC, 2021).
For this reason - to avoid long-lasting effects - the global temperature rise must be limited to 1.5 degrees Celsius (°C) above pre-industrial levels (IPCC, 2018). Albeit world governments have signed an agreement (UNFCCC, 2016) and a climate pact (UNFCCC, 2021) to not exceed this threshold and to reduce GHGs, studies on climate trends show an increase of 2.4 °C by the end of the century (WMO, 2021; Climate Council, 2021).
In this context, the Building and Construction (B&C) sector plays a key role in GHGs. It is responsible for 38% of global carbon dioxide (CO_2) emissions, 10% of which result from manufacturing building materials and the other 28% is due to building's operational stage (UNEP, 2020).
From the Paris Agreement's actions (UNFCCC, 2016), several strategic initiatives have been launched to support the sustainable transformation of the built environment. With regards to the B&C sector, it is worth mentioning the Global Alliance for Buildings and Construction that advocates mitigation and adaptation strategies for the buildings as well as provide every year reports on progress toward a zero-emission, efficient, and resilient sector (UNEP, 2021).
Furthermore, in the framework of the Paris Agreement, it should be remarked on the encouragement participatory approach by several stakeholders, who acting in the B&C sector. The Built Environment Declares - signed by international architectural studios - can be considered one of the most interesting. It sets up strategic actions to be taken in the next years. Some other local proposals deserve to be highlighted, such as the London Energy Transformation Initiative (LETI, 2020) and the Built for the environment report (RIBA, 2021). Both provide actions for a transition to a fair and sustainable built environment.

The common denominator of the several examples described is the necessity to have net-zero CO_2 emissions by 2050. In order to achieve such an ambitious goal, each of the mentioned references highlights the importance of the design stage as a key process to assessing the anthropogenic and biogenic impacts related to materials selection; to get at a Whole Life Carbon (WLC) vision.
WLC can be taken as a program in which operational impact, related to the building use, as well as embodied impact, from materials and construction stages, must be net-zero.
The importance given to embodied impact is twofold. On the one hand, there is a gradual decrease of CO_2 emissions due to lower energy needs for thermal and electrical uses, with a consequent redefinition of the ratio between operational and embodied impacts (Benjamin, 2017). On the other hand, in order to achieve high-performance buildings, the use stage requires more materials, components and services, which means that the embodied impact is higher than it used to be, as shown by some studies (IEA, 2019 and 2020; Zimmermann, 2020).

2. Embodied Carbon: reference standards, definition, and ongoing development

The assessment of anthropogenic and biogenic impacts of materials can be performed with Embodied Carbon (EC) (Pomponi, 2018). EC is an indicator able to assess emissions and removals of carbon dioxide equivalent (CO_2eq) by building materials and its extension by the whole building (Marsh, 2018).
The CO_2eq is a unit of measurement that expresses the impact on global warming by a given quantity of GHGs (CO_2, methane, nitrous oxide, etc.) compared to an equivalent amount of CO_2; the conversion factors have been described by the Intergovernmental Panel on Climate Change (IPCC, 2013).
The determination of potential material's CO_2eq emissions can be traced back to the following references: the methodological framework of the Life Cycle Assessment study (UNI EN ISO 14040-14044:2021); the regulation on Environmental Product Declarations (EPD) (UNI EN ISO 14025:2010; UNI EN 15804:2021); the calculation method provided for assessing the environmental performance of buildings (UNI EN 15978:2011).
Each of the mentioned references does not exactly define the EC indicator, although the methodological approach proposed allows the calculation of Global Warming Potential (GWP), which is a key component of the EC. GWP is - in fact - an impact category able to measure the CO_2eq by GHGs, generally calculated on a time reference established over 100 years (IPCC, 2013).

A more detailed definition of EC has been described by the International Energy Agency, within the technical report: Evaluation of Embodied Energy and CO_2eq for Building Constructions - Annex 57.
Concerning the CO_2eq emitted and removed by building materials, it has provided the following definition: EC is a widely-used term that usually describes a greenhouse gases accounting method over one or more life cycle stages of a product, other than the ones related to the use phase of the building (IEA, 2016).
Although it proposes this general establishment, it also specifies that there are still no clear and commonly accepted definitions or a calculation methodology. Furthermore, the report highlights that no method has been identified to account for CO_2 removals from mitigation strategies acting on the building's design.

3. The project "decarbonization tools"

Within the international framework – before mentioned – still featured by some uncertainties, Green Building Council Italia has taken part in a European-scale project called #BuildingLife (WGBC, 2021) and it has set up some working teams. The Department of Architecture and Design (DAD) of the Politecnico di Torino has been selected to lead one of them with the main objective to develop a framework for EC accounting in the B&C sector.
Particularly, the *Decarbonization tools* project is aimed at identifying: references, methods, and potential tools to assess the EC in the design stage. The research has been carried out through phases, hereafter described.

First, in agreement with the references, a specific EC definition has been defined. It has been established that EC is an indicator able to assess the amount of CO_2eq that can be emitted, stored, removed, offset, and uptake by a certain good (product or whole building) in one or more life cycle stages. It means that the accounting identifies a given amount of GHGs and assesses its contribution as CO_2eq over the building life cycle.

The second phase has devoted to setting out the building stages to be included in the EC account and how to perform it stage by stage. Such stage has been developed according to a reference standard, the EN 15978:2011. Particularly the EC can be associated with the following stages: Production and Construction (A), Use (B), and End-of-Life (C). As expected in the EN standard, the operational impact has not been included.
Moreover, in order to encompass the potential benefits due to mitigation strategies, also the benefits and loads stage (D) has been included. Not overlooking that the D stage needs to be investigated independently from other stages (A to C).

The third phase has identified the methodology for EC accounting in each building life cycle stage. Table 1 summarises the developed method. The first and second columns show the building's stages and sub-stages analysed. The third column defines the unit(s) – or functional unit(s) – that could be considered in the calculation. Finally, the fourth column displays the basic information necessary for EC accounting. References and standards for the calculation are also mentioned.

Tab 1. Embodied Carbon accounting

Stage	Sub-stage	Functional unit (f.u.)	Method
Production and Construction (A)	Manufacturing (A1-A3)	CO_2eq/kg CO_2eq/m^3 CO_2eq/m^2	EC associated with A1-A3 is generally available as generic data from databases or as specific data such as EPD and Carbon Footprint The EC of a material is obtained by multiplying the unit value of EC by the total quantity of material required in the design.
	Transport to the building site (A4)	CO_2eq/tkm	Distance and total amount transported in tonnes are multiplied by carbon emissions associated with transport mode (EN 16258:2013)
	Construction (A5)	CO_2eq/m^3 CO_2eq/kWh CO_2eq/MJ	The amount of diesel consumed by equipment is multiplied by its specific emission factors (e.g. SCAB, 2022) while the amount of electric energy is multiplied by other specific emission factors (e.g. ISPRA, 2021)
Use (B)	Use (B1)	/	Excluded as considered negligible
	Maintenance (B2)	/	Excluded unless specific information is given by the manufacturer
	Repair (B3)	CO_2eq/kg CO_2eq/m^3 CO_2eq/m^2	Can be assumed as 10% of the emissions from the materials used in the building throughout its life cycle
	Replacement (B4)	CO_2eq/kg CO_2eq/m^3 CO_2eq/m^2	Specific information should be provided by the manufacturer. The emissions of the replaced material are calculated by stages A1-A4
	Refurbishment (B5)	/	Excluded as out of expected life cycle
End of Life	Deconstruction (C1)	CO_2eq/kWh CO_2eq/MJ	Same method as *Construction (A5)*
	Transport to waste processing (C2)	CO_2eq/tkm	Same method as *Transport to the building site (A4)*
	Waste processing (C3)	CO_2eq/kWh CO_2eq/MJ	The energy needs by equipment, for disassembling and processing waste, is multiplied by its specific emission factor (e.g. ISPRA, 2021)
	Disposal (C4)	CO_2eq/kg	Emissions are estimated by adopting the environmental impact factor provided by US Environmental Protection Agency (e.g. EPA, 2020)

The fourth phase has focused on the normalisation process. It has summed up the single EC values accounted for each sub-stage. The functional unit (f.u.) may vary from building to building. For this reason, the working team has investigated some examples (e.g the Swiss Minergie® Certification) in

which the embodied accounting has normalised. Minergie® splits up the EC into two independent calculations. The former accounts for the total kgCO_2eq (or tons) per square meter of heated (cooled) spaces. The latter accounts for the total kgCO_2eq (or tons) per square meter of un-heated (un-cooled) spaces.
Finally, the EC has to be referred to an expected building life (year) to calculate a result estimated in kgCO_2eq*m^2*year.
The number of years - obviously - can be different, e.g., a temporary building has a short life while a permanent building has a longer lifetime (Grant, 2014; DGNB, 2020). The average value can be set at 50 years, since it is the one more frequently considered in the references.

4. Discussion and Conclusion

As described, the *Decarbonization tools* research has proposed an EC accounting method aimed at integrating the IEA report, the EN standards as well as other mentioned references.
Nevertheless, there are some specific issues that future research should cover. While the method is now developed, it will be necessary to define which data should be used for the calculation, making a distinction between data sources for designing and for building construction, materials replacement, etc. For instance, the early design stage may require generic data, while the other stages, can be analyzed through EPDs or Carbon Footprint studies.
Another important issue that should be studied is CO_2 compensation. At least two scenarios deserve to be considered: the uptake by concrete and cement products and the offsetting by trees and vegetation. Both may change - even significantly - the building's carbon balance.
Further work is also needed, such as a correlation study between operational and embodied impacts.
Finally, method validation is required. It would be useful for an investigation of several cases of studies. If the method was applied to a selection of buildings, it would be possible introducing threshold values to set out an EC rating system.

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