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Measuring embodied carbon dioxide equivalent of buildings: A review and critique of current industry practice

Catherine De Wolf*, Francesco Pomponi, Alice Moncaster

University of Cambridge, Trumpington St, Cambridge CB2 1PZ, United Kingdom

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ABSTRACT

Lowering the embodied carbon dioxide equivalent (embodied CO_2e) of buildings is an essential response to national and global targets for carbon reduction. Globally, construction industry is developing tools, databases and practices for measuring embodied CO_2e in buildings and recommending routes to reduction. While the TC350 developed standardized methods for the assessment of sustainability aspects in construction works and Environmental Product Declarations, there is no consensus on how this should be carried out in practice. This paper evaluates the current construction industry practice through a review of both academic and professional literature, and through focus groups and interviews with industry experts in the field. Incentives in the available building codes, standards, and benchmarks are also analysed, as are the existing methodologies, tools and datasets. The multiple data sources are used to identify the barriers to the effective measurement and reduction of embodied CO_2e in practice. This paper recommends that Governments mandate for improved data quality and support the development of a transparent and simplified methodology.

1. Introduction and study objectives

The building sector is responsible for 40% of global energy consumption and 30% of anthropogenic greenhouse gas (GHG) emissions [1]. The life cycle energy cost and GHG impacts of individual buildings can be divided into the operational and embodied impacts. Recent innovations and regulation have helped to reduce operational impacts, but a lack of comparable methodologies, data, and regulation still hinder the reduction of the embodied impacts [2–5]. In 2011 and 2012 the European Standards Committee moved towards addressing the first of these issues in publishing the TC350 standards [5] to define the stages which should be included for the whole life cycle impact assessment of buildings. Since the publication, both industry practice and academia are moving towards more similar methodologies. Academic publications in this area have also increased rapidly over the last few years, as shown by Pomponi and Moncaster [6]. However, the authors also demonstrate that in most Life Cycle Assessments (LCA) at the building scale, still only 20–40% of the life cycle stages are included, often the production stages.

While the academic literature tends to focus on published academic case studies and approaches, the calculation of embodied carbon dioxide equivalent (embodied CO_2e) of buildings is also becoming more common within industry consultancy. However, there is very little published information on how these industry calculations are being carried out. This paper aims to address this gap, by reviewing current industry practice in embodied CO_2e calculations, and the drivers or barriers in different countries and contexts. This information is derived through qualitative methods and across a range of countries.

Section 2 explains the methodology and sources of data, which include multiple regulatory and industry documents as well as qualitative studies with industry experts. This is followed by a review of the academic literature in Section 3 and of relevant industry reports, available tools, and datasets in Section 4. An analysis of these documents and qualitative studies reveals the drivers for the calculation of embodied CO_2e in industry practice outlined in Section 5. The remaining uncertainties and barriers are discussed in Section 6. The conclusions and recommendations are given in Section 7. Embodied energy is the amount of energy consumed, while embodied CO_2e is the amount of GHG emitted, to produce a material, product or building. Note that while energy costs and GHG emissions are related they are not directly equivalent, and this paper will concentrate on the latter, using the term 'CO_2e' as short-

* Corresponding author. Present address: Massachusetts Institute of Technology, 77 Massachusetts Avenue, Cambridge, MA 02139, United States.
E-mail addresses: cdewolf@mit.edu (C. De Wolf), fp327@cantab.net (F. Pomponi), amm24@cam.ac.uk (A. Moncaster).

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hand to incorporate all GHG emissions. In practice, embodied CO_2e is also referred to as 'embodied carbon'.

2. Methodology

The methodology followed a four-stage sequential qualitative approach, combining documentary analysis, pilot study, focus groups and semi-structured interviews to develop a rich picture of current international industry practice. First a documentary analysis of the policy instruments, reports, tools and databases was used to examine the context instructing the current industry practice of measuring embodied CO_2e. These documents were identified through a web search and via the participants in the qualitative studies. They were analysed to identify commonalities and differences in industry practice in the way professionals assess embodied CO_2e in their projects, how these assessments compare with others, and what drives or enables practitioners to calculate the embodied CO_2e of buildings. An inventory of the most frequently used databases in case studies, a study of the existing regulation, and the evaluation of available benchmarks are part of this documentary analysis. The industry reports, software, datasets, and standards were evaluated to shape the context of embodied CO_2e calculation and reduction in practice.

Second, a pilot study of industry experts within the Implementing Whole Life Carbon in Buildings (IWLCiB [7]) project was used to define areas of concern and variation within practice. This was followed by six further larger scale focus groups. Table 1 illustrates the profession and company sector of the participants in the pilot study (part a) and the focus groups (part b). The participants were selected based on their expertise in embodied CO_2e of buildings. The pilot study identified variations in methods and data used and uncertainties encountered in the assessment of embodied CO_2e in industry case studies. These issues were further explored through six focus groups held as part of an Embodied Carbon and Energy Symposium at the University of Cambridge in April 2016. The focus group discussions were audio-recorded and summarized in writing. The themes of the focus groups were: embodied CO_2e calculation; what can we do in practice?; risk and uncertainty; mitigation strategies; embodied CO_2e during use phase; demolition versus refurbishment. The initial pilot study and focus groups with industry experts were used to develop a preliminary understanding of the issues and to create interview questions.

The third step in the research examined the issues which were discussed within the focus groups in greater detail, through a series of semi-structured expert interviews (Table 2), in order to develop a wider understanding of perceptions and barriers towards the implementation of measurement in industry practice. The interviews were conducted with individuals who had expertise in this area, either industry practitioners in this field, or researchers collaborating closely with industry. Participants were identified through the snowballing technique [8] using established contacts of the authors, the 2016 Embodied Carbon and Energy Symposium, and the IWLCiB project. Both a general interview guide approach and a standardised semi-structured interview were combined to ensure the same areas of information were collected, analysed and compared [9]. The 15 core questions gathered data on drivers, barriers, calculation methods, and available tools, and were supplemented with additional questions depending on the interviewee's response. The interviews lasted between 30 and 90 min. A list of the interviewees, the interviewees' roles, their company's sectors, and main countries of expertise are given in Table 2.

Fig. 1 shows the roles of the participants to the pilot study, focus groups and interviews within the construction industry. All participants were offered anonymity. The focus groups and interviews were audio-recorded and transcribed.

Table 1
Participants to pilot study (a) and to focus groups at the embodied carbon and energy symposium (b).

Profession	Company Sector
a) Pilot Study	
Head of Research	Architecture & the Environment
Senior Consultant	Carbon Consultant
b) Focus Groups	
Senior Consultant	Construction
Researcher in Engineering	Engineering
Student in Environmental Design	Environmental Building Design
Architect	Architecture
Engineer	Engineering
Student in Engineering	Engineering
Sustainable design/LCA strategist	Engineering
Structural Engineer & Senior Consultant	Structural Engineering
Researcher in Engineering	Engineering
Monitoring officer and Assessor	NGO
Director	Architecture
Energy Consultant	Energy
Partner	Construction
Sustainability Officer	Construction
Researcher in Engineering	Engineering
Sustainability Consultant	Construction
Researcher in Engineering	Engineering
Partner	Management Consulting
Sustainability Analyst	Commercial Real Estate
Professor	Engineering
Professor	Engineering
Social Entrepreneur	Architecture
Principal Sustainability Consultant	Built Environment Consulting
Senior Project Consultant	Engineering
Environmental Manager	Developer
Researcher in Engineering	Engineering
Researcher in Engineering	Engineering
Director	LCA, Carbon Footprint
Student in Engineering	Engineering
Development Manager	Insurance
Structural Engineer	Structural Engineering
Researcher in Engineering	Engineering
Chartered Structural Engineer	Construction
Engineer	Structural Engineering
Researcher in Engineering	Engineering
Senior Consultant	Carbon Consulting
Lecturer in Engineering	Engineering
Student in Structures	Engineering
Lecturer	Environmental Sciences
Researcher in Engineering	Engineering
Engineer	Engineering
Architect	Architecture
Researcher in Engineering	Engineering
Sustainability Officer	Environmental Building Design
Senior Consultant	Architecture and Engineering
Senior Consultant	Carbon Consulting
Senior Engineer	Engineering
Senior Consultant	Environmental Building Design

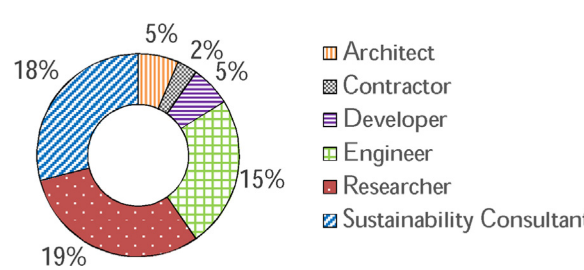

Fig. 1. The role of the participants of the pilot study, focus groups and interviews in the construction industry.