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Reference values for embodied carbon of Swedish building construction

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Important note:

A short time before this conference, we were made aware of that there could potentially be inconsistencies in the underlying Bills-of-resources handed in to us by the building case providers for 3-5 building cases in the data sample of this paper. These inconsistencies are currently being investigated and could potentially imply slightly lower embodied carbon values for a few buildings, than the ones reported in the present paper. If so, updates will be provided in an updated version of the Swedish report that this paper builds on.

Abstract

For contemporary, new buildings in contexts like Sweden, life cycle assessments clearly display that embodied carbon often represent more than half of the emissions seen over the life cycle. While policies for many years have targeted operational emissions, limited focus has been on buildings´ embodied carbon. To abate sectoral greenhouse gas emissions, policies for mandatory climate declarations or even limit values for embodied carbon are being introduced. In the Swedish case, a regulation on mandatory climate declarations is in effect from 2022, and limit values are likely to be introduced in the coming years. The need for consistent knowledge on the embodied carbon of contemporary building construction as well as the potential of various mitigation strategies, is therefore critical to step up emissions reductions in the sector. This study aimed at developing robust reference values for embodied carbon, representative for the contemporary new construction in Sweden. Based on assessments of nearly 70 new Swedish building cases, reference values were developed for central building types. The results display a high variation within each building type, thus showcasing considerable emission reduction potentials with available technologies. The study embraces many analyses, among others on the potential effects of various properties of the sampled buildings, such as noise requirements, energy standards and analyses of improvement potentials through greener product supply. The study provides a profound basis for the further development of limit values in for example procurement processes and in regulation for the Swedish context. In an academic perspective the study is unique through the representative building sample, consistent assessment methodology applied for all cases as well as displaying insights into details of the variations of embodied carbon in contemporary construction.

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1 Introduction

For contemporary, new buildings in contexts like Sweden, life cycle assessments (LCA) clearly display that embodied carbon often represent more than half of the emissions seen over the life cycle. While policies for many years have targeted operational emissions, limited focus has been on buildings´ embodied carbon. To abate sectoral greenhouse gas emissions, policies for mandatory climate declarations or even limit values for embodied carbon are increasingly being introduced. For example, Denmark introduced limit values in the regulation from 2023 (Danish Building Regulations, 2023). In Sweden a regulation on mandatory climate declarations is in effect from 2022 (Regeringskansliet, 2021) and limit values are proposed to be introduced in 2025 (Boverket, 2023c). At the European level, a climate declaration of new buildings is required in the EU taxonomy since 2023 (European Commission, 2021a) and is proposed for the revised Energy performance of buildings directive (European Commission, 2021b).

The described development has increased the industry and policy needs for consistent, robust knowledge on the whole-life and embodied carbon of contemporary building construction as well as the potential of various mitigation strategies. An important part is updated reference values valid for the assessment system boundaries of relevance for assessment approaches in individual national contexts, for example a national regulation on climate declarations for new-build. Historically, similar reference values were primarily based on assessment of individual “typical” case study buildings (e.g. Fuglseth et al., 2020; König & De Cristofaro, 2012; W/E adviseurs, 2014). However, larger compilations of case studies, generating more statistical reference values, have also been done in more recent years, such as the Annex 57 case studies (Moncaster et al., 2019; Nygaard Rasmussen et al., 2018) and for example (Röck et al., 2020; Simonen et al., 2017; Zimmermann et al., 2020). However, a majority of these compilations embrace embodied carbon assessments differing both concerning assessed system boundaries, utilized environmental background data, and ways to set up the Bill-of-Resources (BoR) of the assessed buildings. These can provide insight into variations in LCA results that are not only due to differences in design and function but also due to different method choices. However, they constitute a less good basis for the development of robust reference values or even limit values, which needs to be based on the same calculation methodology and system boundaries to really display differences due to building design.

The present paper provides a brief account of a large study aimed at developing robust reference values for embodied carbon, representative for the contemporary new construction in Sweden. A further aim was also to analyze whether certain building properties could cause difficulties to reach a potential limit value introduced in regulation. The study was commissioned by the National Board of Housing Building and Planning (Boverket) and is fully reported in Swedish in Malmqvist et al (2023). Apart from being highly disseminated for use in practice in Sweden, the study has been critical to develop limit values, proposed by (Boverket, 2023c).

2 Methods

Previous reference values have often been based on assessment of individual typical buildings that are either theoretical (shoe box models) or selected real buildings judged to be representative. In this study, reference values were instead based on "statistics" of assessments of a larger number of buildings. Thus, the real variation in building design and construction choices, could also be represented and displayed. A comprehensive call for case studies to more than 8 000 contacts was launched in 2020-2021. After numerous contacts and meetings with potential data providers, a final selection of 68 building cases was made. These were both chosen as the cases per building types studied were representative for contemporary structural solutions in the Swedish context, and BoR´s were deemed to be of enough quality after a couple of data reviewing rounds by the project team. BoR´s, primarily from quantity specifications (kg, m^2, units, etc.) of resources in production cost estimates, represent as-built data from these buildings with hand-over between 2017 and 2023. They cover several building types with gross floor areas ranging from 150 m^2 to 36 634m^2. The building types were primarily selected to represent types that together account for a large proportion of the expected construction in the coming years. Since main structural material in general plays an important role for the resulting embodied carbon of a building, the building sampling was steered towards providing a good representation for each building type under study (see Table 1), in line with current Swedish statistics for main structural materials in new-build. To our knowledge such a sampling has not been done in other similar studies, which makes this study unique.

TABLE I. Building sample sizes and their main structural solution

Building type/structure	**Number of buildings in the sample for each building type**					
	Apartment buildings	***Pre school buildings***	***Office buildings***	***School buildings***	***Single family buildings***	***Other building types***
Concrete structure	17	4	4	6	0	0
Steel structure	0	4	5	4	0	2
Timber structure	2	6	2	0	11	1

Resources in the BoR´s were mapped by the extended project team to the average data of generic components from the Boverket database (Boverket, 2023a) in priority, complemented with resources from the IVL database (IVL, 2023) and relevant environmental product declarations (EPD:s). In collaboration with the building data providers, the project team estimated the potential data gaps for each building element in each building. To compensate for the gaps, embodied carbon was counted up based on the percentage data gap for each building element. For all building cases the data gaps were estimated to be below 5%, which is to be seen as very satisfactory.

Reference values were produced covering the life cycle modules A1-A5 (European Standards, 2011) according to the requirements in the Swedish regulation (Regeringskansliet, 2021). The system boundaries for the building inventory in the current regulation covers the building envelope, load-bearing structural parts, interior walls, and any underlying garage. However, if limit values will be introduced, the scope is to represent a more complete building inventory, also covering technical installations, interior finishes and fixed furnishing (Boverket, 2020, 2023c). Reference values were produced for both these system boundaries (Malmqvist et al., 2023) but in the present paper only the latter is reported. Nevertheless, due to current assessment practice in Sweden, only a limited number of collected BoR´s contained detailed resource data on technical installations, interior finishes and fixed furnishing. Therefore, standard values per m^2 heated floor area were developed for these building elements and implemented in the assessments (Malmqvist et al., 2021, 2023).

The method used to calculate modules A1-A3 follows the EN 15978 standard according to Swedish guidelines and current regulation (Boverket, 2021, 2023b; Regeringskansliet, 2021). Following the system boundaries in the current climate declaration, biogenic carbon is not considered in the calculations. To calculate module A4, generic scenarios linked to each material resource were taken from the Boverket database (Boverket, 2023a). According to the climate declaration regulation (Boverket, 2021; Regeringskansliet, 2021) module A5 should embrace both the production emissions from modules A1 to A4 of wasted products, and emissions from on-site energy processes. The first submodule were calculated from defined waste factors from the Boverket database. For on-site energy processes, standard values based on previous studies, experience values and interviews with calculators and developers were used. All details regarding the methodologies and data used can be found in Swedish in (Malmqvist et al., 2023).

3 Results

Figure 1 displays the embodied carbon for each building in the sample for the system boundaries detailed in section 2. Median reference values for the building types in kg CO_2e/m^2 gross floor area are thus as follows: Apartment buildings – 373, Pre school buildings – 326, Office buildings – 383, School buildings – 379 and Single family buildings – 165. These reference values are rather similar for all building types apart from single family buildings due to the dominance of timber construction for this segment in Sweden. Similar to previous individual Swedish building case studies (e.g. Erlandsson et al., 2018b), modules A1-A3 dominates the embodied carbon with 84-86% of the impact depending on building type.

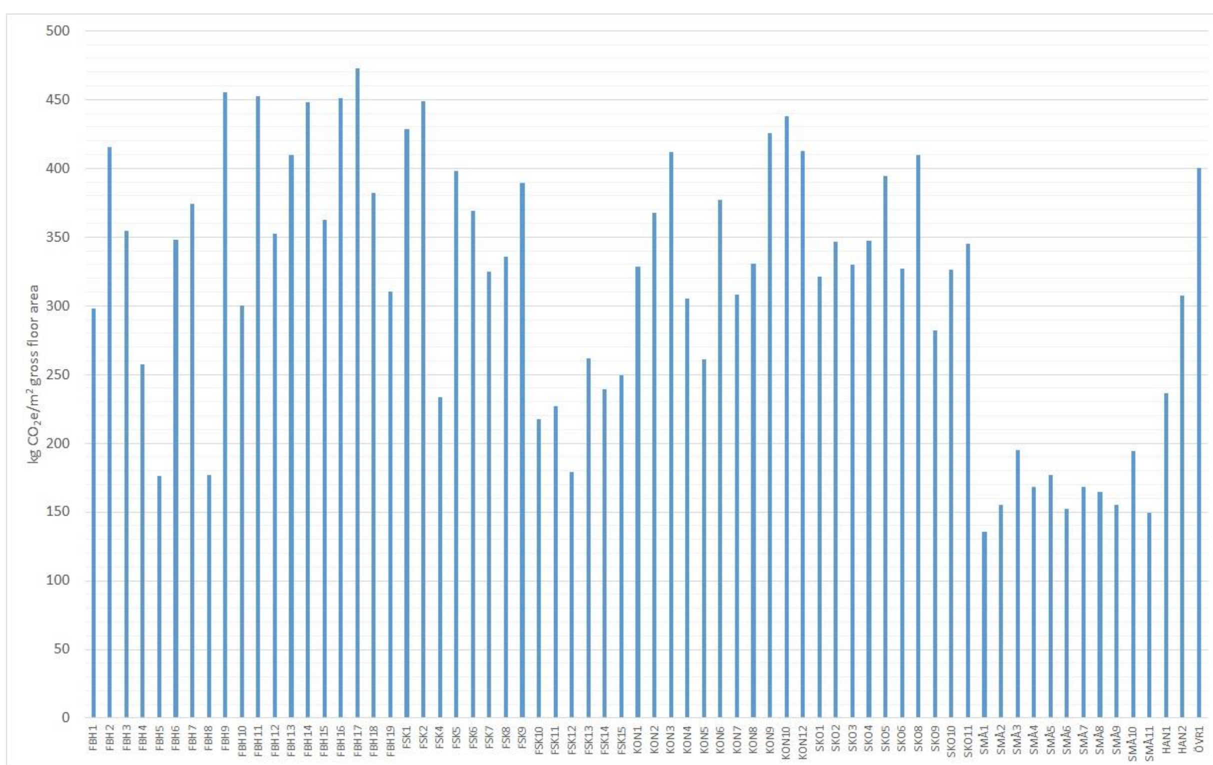

FIGURE 1: Embodied carbon (modules A1-A5) for each building in the sample. FBH=Apartment buildings, FSK=Pre school buildings, KON=Office buildings, SKO=School buildings, SMÅ=Single family buildings, HAN=Commercial buildings, ÖVR=Other.

As expected, the structural frame accounts for the largest part of the embodied carbon with around half of the impact for apartment buildings and offices, i.e. building types with numerous floors. For lower buildings, the climate shell and substructure rather dominates the embodied carbon. Looking at main contributing construction materials, concrete and metals dominate, but for the lower building types insulation materials also contribute to a substantial amount of embodied carbon.

As seen in Figure 1, the variation between individual buildings in the sample is large apart from the more functionally and structurally similar single family building type. This is somewhat surprising considering that it cannot be explained by differences in calculation methodologies and climate data. It is thus rather differences in construction techniques, design and amounts of construction products with high embodied carbon that cause this variation. The central feature is whether timber structure is used or not which is the case for FBH 5 and 8, FSK 4, 10,12-15, KON 4-5 and all single family buildings (Figure 1). However, perhaps more interesting is that buildings with concrete structure still display a high variation in assessment results. In particular, the high variation for the functionally conform apartment buildings in concrete structure is very interesting. The cause is primarily the variation in dimensioning of concrete in the structure.

A number of analyses were also performed to assess whether certain building properties could cause higher or lower total embodied carbon at building level. These include for example buildings with a higher energy performance and sound class, which could be assumed to result in higher embodied carbon values due to additional material use. For the building sample, such patterns could however not be distinguished.

4 Concluding discussion

This study provides the first systematic compilation of embodied carbon calculations for a larger number of building cases in Sweden, using the same calculation methodology, data and system boundaries. It thus provide a unique material for the further development of decarbonization strategies of the building sector in Sweden. Compared to similar, still few, studies in other countries the sampling of cases also provides a good representation of contemporary construction in the national context. In addition, much focus was put into assuring high comparability between cases as well as high quality BoR:s used for the assessments.

The study thus provides a profound basis for setting embodied carbon limit values in for example procurement processes and in regulation for the Swedish context. Limit values based on the present study were proposed by Boverket in May 2023 (Boverket, 2023c) to be introduced in the Swedish regulation in 2025. The present study clearly displays substantial reduction potentials, at least halving emissions, using existing technology. This range of potential was observed using generic climate data for the assessments. The study, however, also provides reference values using climate-improved data-sets for concrete and metals (Malmqvist et al., 2023). Developers who consciously demand climate-improved construction products could therefore reach even higher savings.

The more substantial report in Swedish (Malmqvist et al., 2023) provides useful method descriptions, data, standard values and reference values of high value for industry stakeholders for driving decarbonization practice in contemporary building design and construction. It also contains numerous additional analyses, for example regarding different building properties and their effect on the total embodied carbon for the system boundary linked to current Swedish regulation. So far, these analyses concluded that e.g variations in building form, energy performance and sound class did not affect the total embodied carbon of the buildings in the sample. However, further such studies as well as whole-life carbon assessments and more in-depth studies of improvement strategies are currently being performed in the on-going research project “Research synthesis of the climate impact of Swedish buildings” funded by the Swedish Energy Agency.

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Conflict of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Author Contributions

Conceptualization: TM, SB and ME; methodology: all; data collection and processing: SB and JB, formal analysis: SB and TM; writing: TM; project administration: TM and SB; funding acquisition: TM, SB and ME.

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