

Identification and life cycle based allocation of building emissions based on a systematic literature review

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Abstract. Even though it is scientifically well known that there are various building emissions with harmful impacts on human health and the environment, existing evaluating approaches only refer to selected emissions and life cycle phases. Especially in today's building sector harmful emissions are mainly evaluated in the use stage and the target is to minimize rather than avoid them. However, in order to avoid subsequent negative impacts, implementation strategies have to be developed and applied during early planning phases. This research presents an overview of relevant building emissions as well as a life cycle based approach to allocate these emissions and to show possibilities of influence towards zero emission buildings.

1. Introduction

To face global challenges such as global warming, pollution, environmental degradation, waste and social conflicts, a fundamental change in our economy and society is needed. According to the Sustainable Development Goals of the UN [1] as well as the European Green Deal [2] this should be a transformation towards a climate neutral and circular economy, wherein future generations have at least the same chances of life quality and prosperity as today's society. The building sector counts among one of the biggest resource consumers, causing 28 % of the total global energy-related CO₂-emissions and 38 % with the inclusion of CO₂-emissions from the building construction industry [3]. Therefore, it is essential to avoid, reduce and compensate emissions in this area. Although CO₂ is the most important gas in terms of greenhouse gas (GHG) emissions and climate change [4], there are significantly more emissions with negative environmental impacts. For example, air pollution is the most important driver of the environmental burden of disease in Europe followed by noise [5]. Since humans spend up to 90 % of their time inside of buildings, further emissions regarding indoor air quality and associated risks to both physical and mental health and well-being (e.g. acoustic emissions and pollutants, particular matter, volatile organic compounds (VOCs)) should be taken into account [6, 7]. Although selected emissions, such as CO₂, VOCs or noise (acoustic emissions) are already considered in the planning phase of a building, e.g. in green building certification systems such as DGNB [7] and ZEB [8], a more holistic and life cycle based assessment of building emissions is missing. Hence, this research provides an approach to identify and allocate building emissions during its life cycle to achieve a zero emission building sector.



2. Methodology

The study is divided into two parts, (a) a literature review and (b) the allocation of building emissions. Based on existing literature, the definition of the terms “emissions” and “zero emissions” are analyzed. Further, the different emission types and their relevance for the building sector are identified.

The identified emissions are categorized: firstly, regarding their impact level and secondly, due to their occurrence in the life cycle stages according to DIN EN 15978 (“Sustainability of construction works – Assessment of environmental performance of buildings – Calculation method”) [9]. The structured emissions are then evaluated, whether they are regulated legally, voluntarily by certification systems or guidelines, or not (yet) considered at all.

3. Definition of emissions and zero emissions

According to the German Environment Agency (Umweltbundesamt – UBA) “emission refers to the emission of greenhouse gases and air pollutants into the atmosphere” [10]. The Federal Immission Control Act – BImSchG [11] defines emissions as air pollution, noise, vibrations, light, heat, radiation and similar phenomena emanating from an installation. Furthermore, emissions can also be described as “the concomitants of human activity [...] An emission-free activity of humans is a utopia after all past experience. However, it can serve as an ambitious goal, which we are approaching in small steps” [translated according to 12]. Looking at “zero emission” buildings it becomes apparent that the definition of this term is also complex and depends on the level of consideration. On the one hand, “zero emissions” can mean that there are no emissions of one single parameter related to one life cycle stage, e.g. CO₂-emissions due to operational energy use [8, 13]. On the other hand, it can be expanded meaning that the released emissions of a building do not exceed the absorption capacity of the local, regional, and global environment [14].

Due to the holistic approach of this research, all reviewed definitions are combined [7, 10–15]: Emissions include environmental impacts such as GHG, phosphate and sulfate emissions, pollutants, sound, light and radiation which are emanating from a building during its entire life cycle (product, construction process, use and end of life stage). A zero-emission building or building sector respects the limits of the ecological carrying capacity of ecosystems and has no harmful influences on the environment and health.

4. Emissions in the building sector

In order to reach global and national climate goals (climate neutrality by 2050 or earlier [16, 17]), especially the CO₂-emissions have to be reduced dramatically within the next few decades. As shown in [4, 13, 16–19], the building sector plays a large role when speaking of GHG emissions and the necessary reduction of emissions. But not only GHG gases (carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), and fluorinated greenhouse gases (F-gases) [4]), have to be taken into account when speaking of a zero emission building as shown in Section 3.

To gain a well-arranged overview of the emissions with concern to the building sector, spatial criteria are developed. The different emissions are allocated to three different areas regarding their direct impact level: global emissions, emissions by the building on the onsite environment (local) and emissions inside the building. The allocation regarding the life cycle stages according to DIN EN 15978 [9] and the evaluation is shown in Table 1.

4.1. Global emissions

Global emissions can be estimated with the life cycle assessment (LCA) method. With this, environmental indicators such as the global warming potential (GWP) can be assigned to a building. Other relevant indicators are the ozone depletion potential (ODP), photochemical ozone creation potential (POCP), acidification potential (AP) and eutrophication potential (EP). [7, 9] These indicators might not be related directly to global warming or climate change, but describe a building’s wider impact on the environment.

4.2. Local emissions

Local emissions describe substances emitted directly by the building. By leaching, pollutants such as heavy metals, salts and organic substances can enter waters and groundwater. For buildings, sources can be copper and zinc roofs, corresponding roof and facade elements, coatings and building materials for facades, foundations, roofing membranes, hydraulic blocks and aggregates for substrates. [20]

Biocides can get into the environment through their use for protection against algae, fungi or animal pests, especially for paints, varnishes, adhesives, sealants, plasters, wood, roofing tiles, paving slabs and other building products for outdoor use. [20]

Burning fossil fuels or wood causes CO₂-emissions and other pollutants with risk to human health [13, 21, 22].

During the construction stage various other emissions can occur. These include dust, chemical effects on ground and water due to usual construction site conditions as well as noise of construction machineries and work processes. [7]

4.3. Emissions inside the building

As the European Environment Agency (EEA) Report No 21/2019 shows, the principal environmental factor driving disease with around 400,000 premature deaths annually in the EU is air pollution [5]. Especially urban air quality will be an important health issue in the future due to increasing industry, burning fossil fuels and traffic [23–25]. As this paper focuses on emissions which are directly linked to the building sector, emissions due to transport in the product, construction process and end of life stage are considered.

Indoor air quality depends not only on the outside air quality and ventilation, but also on a number of other factors. Onsite air pollution and radon exposure as well as emissions from burning solid fuels, cleaning and consumer products and smoking in interplay with building products and materials influence indoor air quality. [5, 24, 26] Moreover, building products and materials can contain a considerable amount of pollutants and substances of very high concern such as biocides, VOCs, flame retardants and heavy metals [6, 7, 20, 24, 26–28].

For instance, a structured overview for German-speaking areas is given by “WECOBIS“, a web portal with building materials information for healthy and environmentally compatible construction [29], and the German Sustainable Building Council certification system (“DGNB System”) [7], where an English version is available (“DGNB System Version 2020 International”).

According to [5], noise is the second most significant environmental risk. Therefore, indoor noise reduction for good acoustic conditions, meaning good speech intelligibility and low noise pressure level, are also relevant to promote health and well-being.

4.4. Allocation of emissions to life cycle stages

In the following, an approach to allocate the identified emissions to a building’s life cycle stages is proposed. In Table 1, the different types of emissions (see Section 3) are allocated to the life cycle stages according to DIN EN 15978 [9]. The emissions are further classified in five categories: emissions which occur outside the system boundary (“o”), emissions that occur within the system boundary but are not yet considered by law or guidelines etc. (“--”), emissions that are partly considered (“-”), emissions that are voluntarily considered (certification, guidelines, etc.) (“+”), and emissions that are mandatorily considered (legal) (“++”). Since it is possible that emissions within one category can be considered differently (e.g. acoustic emissions between residential units are considered by law “++”, but within one unit they are only voluntarily considered “+”), multiple assessments within one LCA stage may occur.

As shown in Table 1, almost half of the identified emissions during a building’s life cycle are not legally regulated in Germany even though they do occur (47 times “--” out of 102 total allocated emissions). For instance, calculating an LCA is standardized in EN ISO 14040 (“Environmental management – Life cycle assessment – Principles and framework”), EN ISO 14044 (“Environmental management – Life cycle assessment – Requirements and guidelines”) and DIN EN 15978, but it is not mandatory when constructing a building.

Table 1. Life cycle stages according to DIN EN 15978:2012-10 [9] and allocation of emissions.

Building Assessment Information	Product			Construction Process		Use							End of Life				Recycling
	A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D
GHG-emissions	+	+	+	--	--	--	--	--	+	--	+/++	--	--	--	+	+	+
Further environmental impacts	+	+	+	--	--	--	--	--	+	--	+	--	--	--	+	+	+
Pollutants	--	--	-/+ / ++	--	+	+	--	--	+	--	--	--	--	--	-/+	--	--
Acoustic emissions	--	--	--	--	+	+/++	--	--	--	--	--	o	--	--	o	o	o
Light emissions	o	o	o	o	--	+	o	o	o	o	o	o	--	o	o	o	o
Radiation	--	o	--	o	--	+	o	o	o	o	-/- / ++	o	--	o	o	o	o

o emissions outside system boundary; -- emissions occur, but are not considered; - emissions are partly considered;
+ emissions are voluntarily considered; ++ emissions are mandatory considered

Around 25 % of the identified and allocated emissions are already voluntarily considered by certifications, guidelines etc. (24 times “+”).

Regarding acoustic emissions only the stages A5 and B1 are considered. Requirements and recommendations for good acoustic conditions in interiors are given by DIN 18041 (“Acoustic quality in rooms”) and VDI 2569 (“Sound protection and acoustical design in offices”). Although these are not introduced by law, they are known as generally accepted technical rules and at least considered in the use stage.

Looking at light and radiation emissions it is evident that these are barely considered during a building’s life cycle and that they are not regulated by law, although there is a guidance on the measurement, assessment and mitigation of light emissions, which shows that light emissions can count as harmful environmental effects [30].

5. Discussion

Based on the results it is evident that emissions occur during each life cycle stage. However, just a limited number of emissions is legally regulated. For instance, building law requirements only take the use stage into account (e.g. energy demand [31, 32], noise and air pollution of technical building equipment and plants [33–35]). In addition, the CO₂-emissions for the whole building sector regulated by the German law for climate protection is also limited to the use stage [36]. Regulations about other emissions such as embodied carbon (CO₂-emissions), impact on acidification or eutrophication, light emissions or VOCs in indoor air are not yet mandatory and only considered voluntarily, e.g. in building certification systems.

With regard to global and national climate targets it is necessary to reduce the overall CO₂-emissions during a building’s life cycle. Furthermore, when looking at the effect a building has on human health and well-being, i.e. the indoor air quality, further emissions such as noise or light and pollutants have to be taken into account. Since these do not only affect humans, but also the environment, e.g. biodiversity and vital ecosystem services, emissions also have to be considered on a local and global scale.

The challenge is not only to identify the occurring and relevant emissions. Moreover, further research regarding the determination of the system boundary for the allocation of emissions and their impact needs to be done.

6. Conclusion

This research has identified a large number of emissions that are relevant for the building sector based on a literature review and categorised them with a view to their integration in LCA tools. In order to realize zero emission buildings (buildings with no harmful influences on the environment and health), emissions have to be considered during the whole life cycle. It is important to not only look at the use stage and minimize negative impacts but moreover, consider and avoid them already in early planning phases.

To deal with climate change and environmental protection the general procedure of efficiency and reducing emissions is insufficient. A paradigm shift from a less-bad to a zero emission and positive building sector must be achieved. This is only possible by regulating and taking into account all the relevant emissions and their effects. In addition, awareness of society towards harmful impacts on human health and the environment due to building emissions has to be created.

An expansion of LCA to include the emissions identified and categorised in this study will therefore be essential.

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