The influence of EPD data on LCA results

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The influence of EPD data on LCA results

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Abstract. The built environment is responsible for reaching global climate targets such as the Paris agreement and carbon neutrality in 2050. It is a well-known fact that buildings stand for 37% of global greenhouse gas (GHG) emissions, where 10% is due to emissions from the production of building materials, while the remaining 27% comes from energy consumption [1]. The awareness of the major contribution to global GHG emissions from the built environment has enabled a great interest in developing more sustainable buildings, reducing the contribution to GHG emissions, and conducting life cycle assessments (LCA) of buildings in Denmark. In March 2021 a national strategy towards more sustainable buildings was introduced, which requires an LCA of new buildings, and compliance with the limit value of 12 kg CO_2e/m^2/year for new buildings with > 1000 m^2. The strategy underlines the urgency of educating the Danish construction sector in conducting LCAs of new buildings and gaining knowledge in environmental product declarations (EPD) available for the Danish sector to apply. Eventually, this will enable more specific and transparent LCA results of Danish buildings. We investigate the availability and applicability of EPDs from a Danish perspective in the first part of the study, and in the second part, we investigate the influence on LCA results when applying industry- or product-specific data instead of generic data (Ökobau 2020 II). Three exterior wall types A, B and C are outlined based on the same U-value, and generic data are replaced with EPD data. The results show the various combinations possible with applying the EPD data. Secondly, the LCA results are highly dependent on the chosen materials and their corresponding EPD data.

Keywords: Construction materials, Life Cycle Assessment, Global warming potential, Environmental Product Declaration (EPD), Data

1. Introduction

In March 2021 the Danish government presented a new strategy for more sustainable buildings in Denmark, which will be integrated into the building regulations from 2023. Two important aspects of the strategy shall be recognized for this study: the mandatory LCA requirement for all new buildings and compliance with a limit value of 12 $kgCO_2e/m^2$/year for all new buildings with heated floor area greater than > 1000 m^2 [2]. The benchmark value is determined based on life cycle assessments of 60 new buildings and the scope includes life cycle modules A1-3, B4, B6, and C3-4 [3].

Compliance with the limit value will be an essential aspect for building practitioners in Denmark, and many resources may be spent on it. This might lead to practitioners demanding more EPDs to achieve more precise and correct life cycle assessments for buildings and building elements.

Life cycle assessments are useful to determine environmental impacts associated with the production, construction, and demolishing of whole buildings [4]. It is however also useful in the early design stages of building design to estimate the potential environmental impacts that will occur. In the early design stages of a building, multiple design scenarios of the building elements can be considered, and decisions based on environmental assessments can be made. In this regard, generic data is evident to use to estimate the potential environmental impacts. Later in the design process, where materials of the building elements are being specified, the generic data can be replaced by industry and product-specific environmental product declarations (EPDs). This will enable a more precise life cycle assessment, more correct results, and therefore, a well-established basis for decision making. Eventually, the LCA results of buildings based on a wide variety of EPD data will enable the determination of more correct limit values.

Whether the generic data in the LCA model of the building element can be replaced by specific EPDs, depends on the availability of EPDs for buildings designers to apply in the assessments, and it is yet unclear, what influences the replacement of data has on the results of the assessments. The variations in environmental impacts across EPDs have been investigated by [5] and [6]. In the first study by Moncaster and Anderson, it was found that there is a great variation in environmental impacts from the product stage (A1-3) of several cement types. Moreover, it was found that especially white cements contribute significantly to the product stage. The second study by Rasmussen et al, which considers 81 EPDs for wood products, found that the global warming potential depends on the type of wood product. Especially, the density of the wood and the chosen end-of-life scenario were found to be crucial for the final environmental impact. This paper aims to investigate what influence the use of EPDs has on LCA results compared to results based on generic data for three exterior wall types denoted Exterior walls A, B, and C. In addition, the study aims at clarifying for the Danish construction industry how to choose products wisely when designing buildings to clarify where potential reductions in greenhouse gas emissions can be made.

2. Method

Before describing the procedure for conducting life cycle assessments of the walls, it is important to understand how to apply EPDs in the correct context. In continuation of the studies by Moncaster et al and Rasmussen et al, a preliminary investigation based on product-specific EPDs of insulation materials is conducted in this study. The results in Figure 1 show 26 EPD datasets (some EPDs declare more than a single product) for insulation materials.

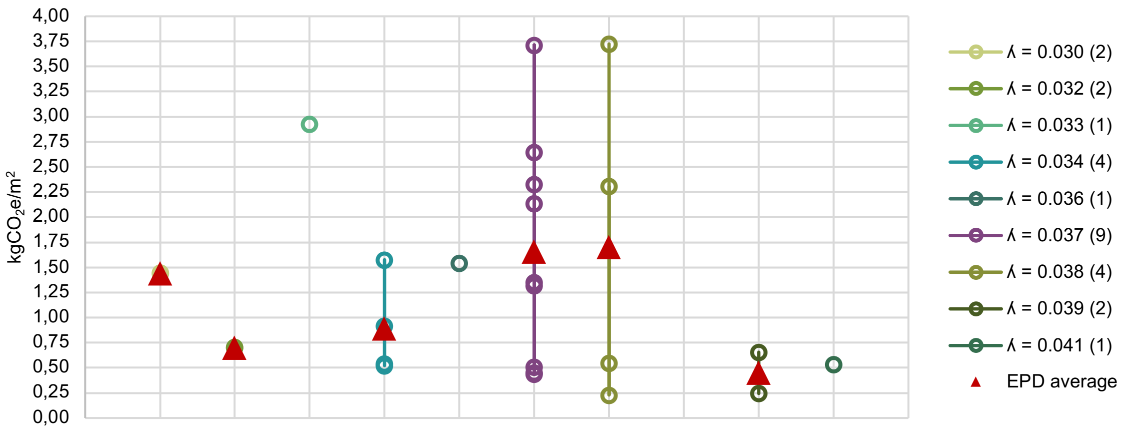


Figure 1. LCA results for insulation materials with varying thermal conductivities based on EPD datasets. The results indicate the global warming potential reported in kg CO_2e/m^2 insulation material for modules A1-3 and C3-4. B4 is not included as no replacements take place.

The insulation materials have been differentiated according to the thermal conductivity, λ, and the global warming potential is reported per square meter of insulation material. From the graph, it is seen that the

GWP results for insulation materials with λ = 0.037 W/(mK) vary from 0.44 to 3.7 kg CO_2e/m^2, which indicates that there is a great variation in the results. In addition, one cannot compare the range from λ = 0.037 W/(mK) with λ = 0.034 W/(mK) although it might look like λ = 0.034 W/(mK) might indicate lower GWP. This is because the insulation materials do not have equal thermal conductivity. Only insulation materials with equal thermal conductivity can be compared in the figure. Comparability must be ensured when life cycle assessments for building elements are conducted. The LCA practitioner must consider provided functions from the materials, especially insulation, and from this figure alone there cannot be decided on which product to implement in the building.

With the findings of the preliminary study, an indication of potential variations of results is illustrated, and that comparability must be ensured before decision making. This is considered in the following analysis of the exterior walls.

2.1. *The exterior walls and functional equivalent*

The building elements considered in the study are three types of exterior walls. They are based on the conventional walls built in Denmark and an illustration of the composition of the walls is given in Figure 2. The separation of layers of the walls is inspired by [7].

To be able to compare three wall types and different types of materials within a single wall, a functional equivalent (FU) is defined as "Calculate the LCA result for 1 m^2 exterior wall with U-value of 0.16 $W/(m^2K)$ reported in $kgCO_2e/m^2$ (GWP) with a reference study period of 50 years."

This functional equivalent is applied for all three wall types. It is important to notice that the FU only considers the service life of the materials and the U-value of the walls. Thus, properties in terms of fire and sound insulation are not considered in this study. The service life of the materials is greater than the reference study period of 50 years except for paint, which is applied every 15 years.

The U-value is calculated based on the thermal conductivity of each material in each layer. For materials providing cladding and structural functions, one value of thermal conductivity is assumed, while for insulation materials it changes depending on the specific products as shown in Figure 1.

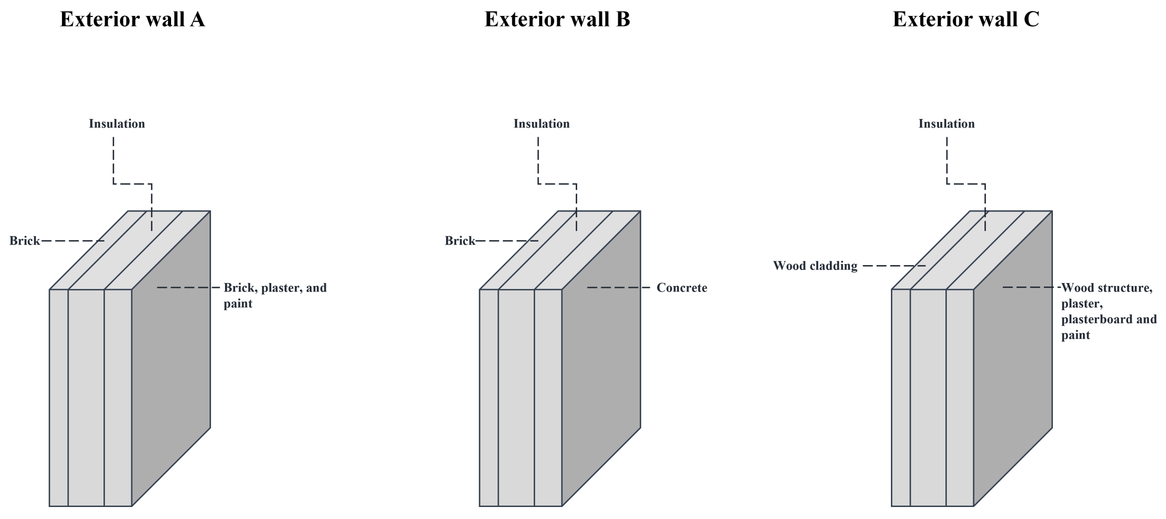


Figure 2. Illustration of the exterior walls A, B, and C considered in the study.

2.2. *Scope of the life cycle assessment*

Life cycle assessments in Denmark consider the life cycle modules A1-3, B4, B6, and C3-4. As this study only considers building elements, the global warming potential associated with module B6 is not included, thus, the results in the following sections include the global warming potential associated with modules A1-3, B4, and C3-4.

2.3. *LCA software tool*

The study is conducted with the national Danish life cycle assessment tool, LCAbyg 5.2, which is developed for users in the Danish construction industry [8] [9]. The tool contains generic environmental data from the German Ökobau.dat 2020 database. It is however possible to apply EPDs in the tool.

2.4. *Data scenarios*

To support the aim of the study, two data scenarios for the LCAs are considered. In the first scenario, the global warming potential with generic data is calculated for all three wall types only. This scenario only includes data from Ökobau.dat, therefore, it is denoted as the *Ökobau* scenario. Here only a single result for each material of the exterior wall is found as only a single dataset is considered for each type of material. Generic data is according to the definition in Ökobau modeled based on literature, expert knowledge, etc. [10].

The second scenario replaces generic data, where it is possible, with industry- and/or product-specific EPDs, which were the output of the first part of the study [11]. Here, the availability of EPDs was investigated for Danish construction. Since multiple EPDs can be applied to a material, this can result in more than one LCA result. For this second scenario, industry- and product-specific EPDs are considered.

Industry-specific EPDs are conducted by industry associations and companies based on the data on the industrial production of companies [10]. E.g., if the construction wood industry association jointly publishes an environmental product declaration of concrete or construction wood, this would be considered an industry-specific EPD. If the association is formed by national companies, the EPD will represent national conditions, and can therefore represent the environmental impacts more precisely than generic data that currently are applied in life cycle assessments of Danish buildings.

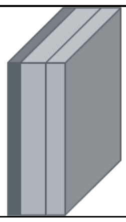
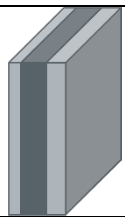
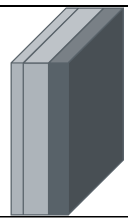
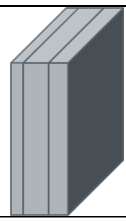
Product-specific EPDs are published by manufacturers to document environmental impacts associated with a product from one factory [10]. The product can be either a single specific product or a product offered in several sizes, weights, colors, etc.

2.5. *Material variants*

In addition to the data scenarios, several variations in materials are also outlined for each wall type for the exterior surface, the middle layer, the inner (bearing) wall, and the interior surface. This is done to achieve an indication of possible combinations in terms of materials but also EPD-datasets. The goal behind this is to show how many possible outputs an LCA can result in due to several applicable EPDs, and therefore several LCA results.

The EPD datasets applied in the study, are considered representative of the materials. It has not been possible to apply EPDs for each material where no EPD has been available, in that case, generic data has been retained. Those materials which cannot be replaced with EPDs are not shown in the results.

Table 1. Overview of the material variations in the exterior walls divided into four layers. The composition of the walls is based on conventional wall types built in Denmark [12].

Wall	Material variation	Exterior surface	Middle soft layer	Inner bearing wall	Interior surface
					
Exterior wall A	Variant 0	Brick	Stone wool	Brick	Mortar and paint
	Variant 1	-	Cellulose fiber	-	-
	Variant 2	-	Glass wool	-	-

	Variant 3	-	Wood fiber	-	-
Exterior wall B	Variant 0	Brick	Stone wool	Concrete	Mortar and paint
	Variant 1	Wood	Cellulose fiber	Aerated concrete	-
	Variant 2	Slate	Glass wool	Lightweight concrete	-
	Variant 3	Aluminum	Wood fiber	-	-
	Variant 4	Steel	-	-	-
	Variant 5	Fibre cement	-	-	-
Exterior wall C	Variant 0	Wood	Stone wool	Wood frame	Plasterboard, mortar, and paint
	Variant 1	Slate	Cellulose fiber	CLT	-
	Variant 2	Aluminum	Glass wool	-	-
	Variant 3	Steel	Wood fiber	-	-
	Variant 4	Fiber cement	-	-	-

3. Results

Figure 3 shows the global warming potential reported in kg CO_2e/m^2 for each applicable material of exterior walls A, B, and C for both the first and second scenarios. Thus, the figure does not show the total embodied carbon of the walls. It rather shows the variation in environmental impact from various materials and the possible combinations. The first scenario, Ökobau, denoted with the grey cross, results in a single value for each material. And the second scenario shows each EPD dataset applicable for each material type. Here, the average of the EPDs is also shown with the red triangle. The number of EPD datasets available and applicable for each material of exterior walls A, B, and C can be seen on the graphs, which are given in the parentheses in the legend. It is evident from the graphs that there are variations in the environmental impacts of the materials, thus, several possible LCA results for exterior walls A, B, and C. This will be further elaborated on in the following sections.

3.1. Variations due to type of material

From Figure 3 it is evident that the global warming potential of the environmental product declarations varies both across each material and within each material. This can be seen when comparing e.g., bricks and glass wool. Naturally, this leads to many potential material combinations, and therefore, several potential LCA results for exterior walls A, B, and C. For that reason, the results are highly dependent on the choices of whoever decides which materials to construct with. It should be kept in mind that for some materials, only a single EPD has been available, which limits the extent of the results for those materials.

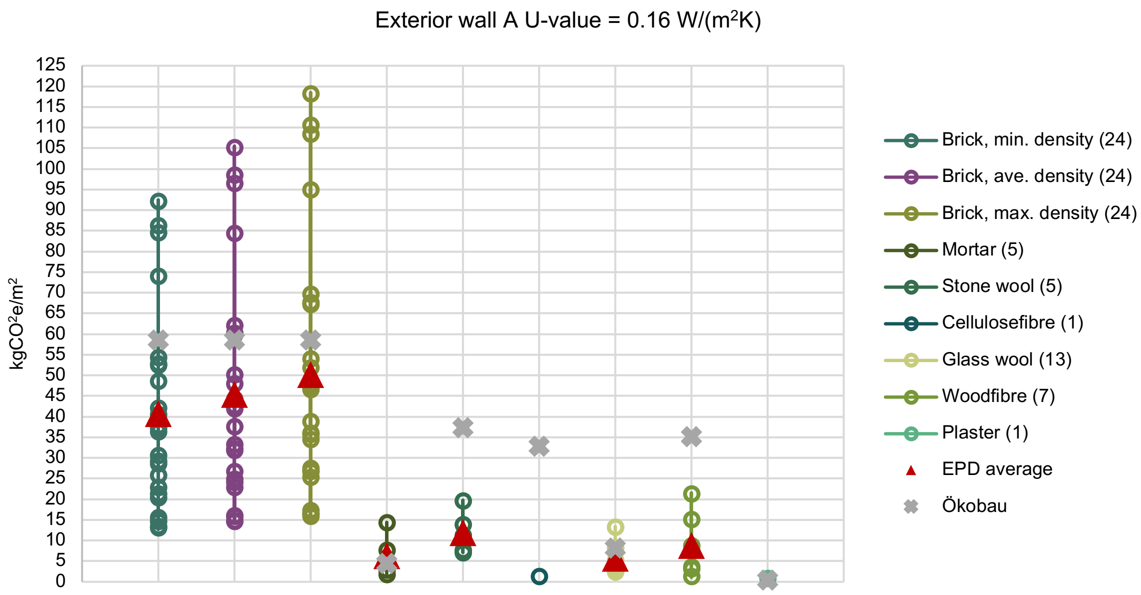
Variations in results due to changes in material properties are also indicated in the figure. For instance, the EPDs for bricks document two ranges in density, 1600-2000 kg/m^3 and 1800-2050 kg /m^3, from which the minimum, mean and maximum values are used in the study. This follows a great variation of LCA results for the bricks ranging from 13.2-118.2 kgCO_2e/m^2. Additionally, the environmental impact of the types of insulation also varies, which might indicate the differences in the thermal conductivity shown previously in Figure 1 or the material itself.

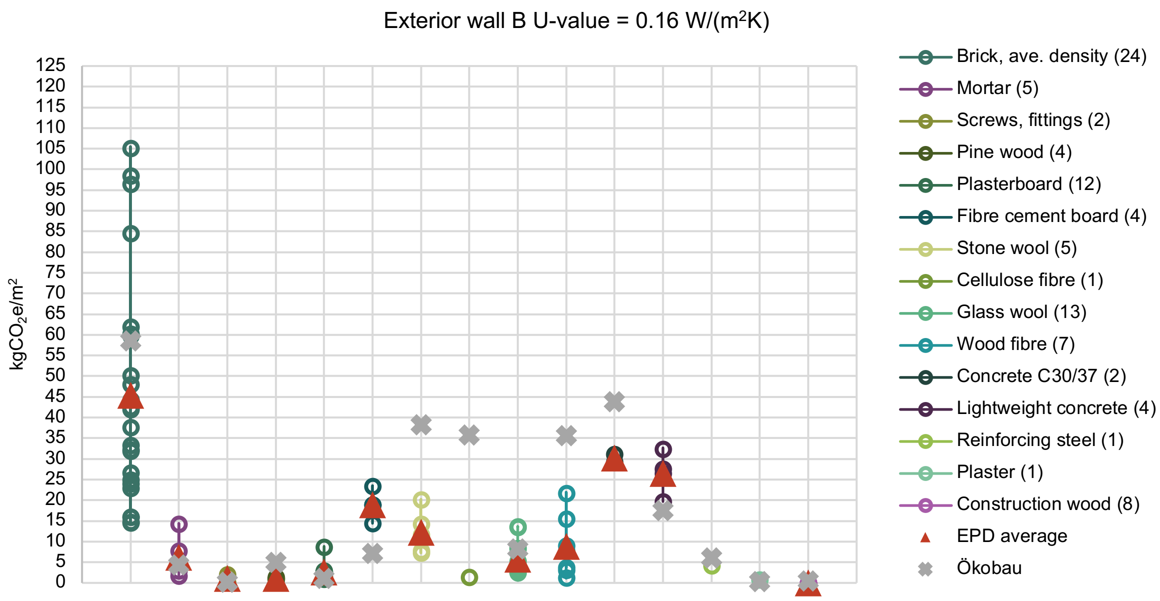
Furthermore, the processes in the production of the materials can also influence the environmental impact. For instance, the bricks included in this study are either fired with natural gas or with biogas which influences the overall environmental impact, thus, while 1 tonne of bricks fired with natural gas emits 216 kgCO_2e, 1 tonne of bricks fired with biogas emits 143 kgCO_2e in the Product stage (A1-3). This example is from an EPD that declares bricks with the same density fired with natural gas and biogas. Notice that these exact numbers of the emissions are specific for two products and must not be assumed equal to other brick production, as the emissions can be different.

Finally, the EPD ranges show that potential reductions in the global warming potential can be achieved if products with lower environmental impacts are chosen in the building design.

3.2. Variations due to the data scenario

Another important observation that appears from the figure, is that the EPD datasets do not necessarily always imply environmental benefits since the Ökobau result is either above, inside, or under the EPD ranges. For instance, the Ökobau result in exterior wall A is, in general, greater than the EPD datasets for stone wool, cellulose fiber, and wood fiber, however, for brick, mortar, and glass wool the Ökobau result is within the EPD range. In some cases, the Ökobau result approximates the EPD average, in other cases, it is far from the EPD average, and finally, in some cases it lower than the EPD average.





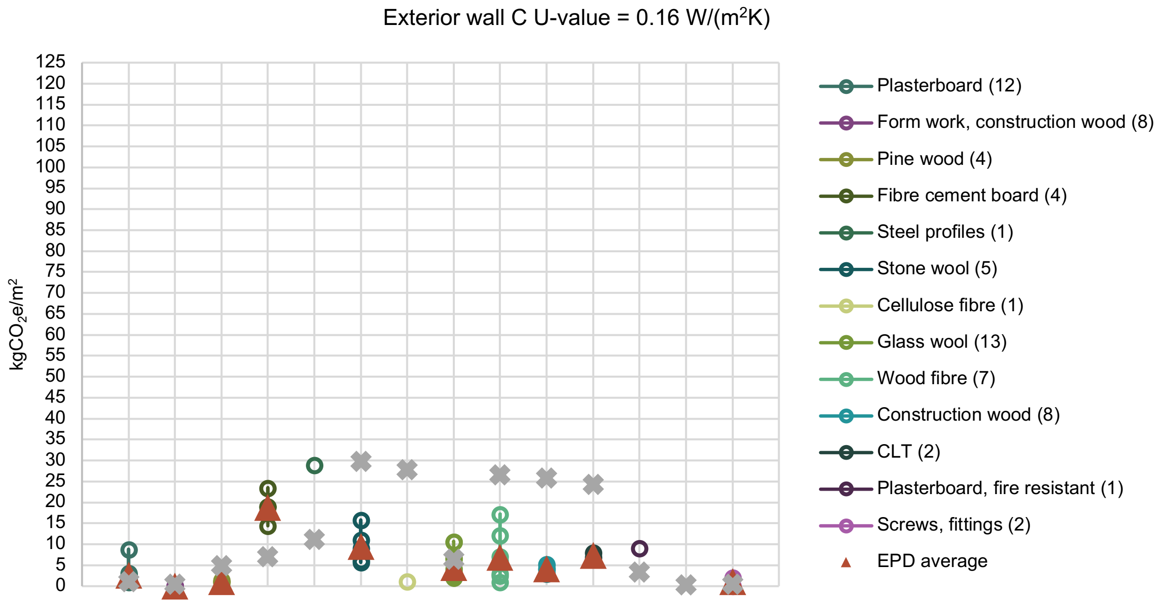


Figure 3. LCA results are based on the functional equivalent defined for exterior walls A, B, and C. The graphs show the variations in LCA results across and within each material found with EPD datasets (number of datasets given in parentheses), the Ökobau result, and the EPD average. Therefore, the graphs do not give a single LCA result for the walls, as it demonstrates the several possible combinations, and thus, several possible LCA results.

3.3. Representativeness of the EPD

It is interesting to investigate if potential differences in the GWP result occur, due to the type of EPD the product is documented with. For instance, the global warming potential of the concrete C30/37 and lightweight concrete in exterior wall B, are both documented with industry-specific EPDs. Thus, the data corresponds to the average emissions of Danish concrete (C30/37) and lightweight concrete. It is evident in the results for exterior wall B in Figure 3 that the concrete result in lower GWP compared to the Ökobau result, while lightweight concrete results in greater GWP.

The fiber cement boards, shown for both exterior walls B and C, are documented with product-specific EPDs and result in greater GWP compared to Ökobau. However, the plasterboards included for exterior wall C, which is also documented with product-specific EPDs, approximates the Ökobau result even though 12 different EPD datasets are included.

The above implies that replacing EPDs with generic data do not necessarily entail a lower environmental impact in the case of global warming potential.

4. **Discussion**

Considerations regarding the availability, applicability, and quality of EPDs will be elaborated on as well as how EPDs can influence the state-of-the-art practices of professionals in the construction industry. Moreover, the importance of publishing EPDs in the future as limit values are integrated into building regulations in several EU member states is discussed.

4.1. Scope of the assessment

It is important to note that this study is limited due to the number of EPDs available and applicable to Danish conditions. Therefore, the results could differ if additional EPDs were available to replace generic data. The data collection of this study is based on [13], where the availability of the EPDs is investigated to understand, how many and which products are represented, and which are still missing.

Furthermore, the results of the study might change if additional environmental impact categories from EN15804:2013+A1 are considered [14].

4.2. *Decision making as a building design professional*
Several parameters are relevant for an advising building design professional to consider before the owner of the building can make an informed decision on a specific combination of either exterior walls A, B, or C. The advisor must consider, the type of material, the properties of the material, and which material supplier or manufacturer to purchase from to achieve a holistic decision regarding the environmental impact. This is especially a relevant task if only product-specific EPDs are considered. The decision made will influence the overall environmental impact of the building, and potentially, the compliance with the CO_2 limit in the building regulation.

4.3. *Quality of the EPD data*
Undoubtedly, the quality of the EPD data influences the LCA results. Generic data enable estimations of environmental impacts from buildings both in the early design stages and in scenarios where no EPD data is developed. Generic data such as the Ökobau.dat offers great coverage of construction products and has in many years been applied in life cycle assessment in Denmark, however since it is a German database it is also applied in DGNB and BNB in Germany [15]. The generic data of Ökobau.dat have been crucial to estimating environmental impacts from Danish buildings, and this has supported the development of benchmarks in the Danish building regulation. Nevertheless, as more EPDs are published, generic environmental data should be replaced by them to enhance the transparency of the materials integrated into the building and the correctness of the LCA results. This can be done by replacing generic data with industry-specific EPDs, which represent the average conditions of the considered nation, and with product-specific EPDs, which represent individual products. Eventually, life cycle assessments will reflect the actual conditions and thus the environmental impact of the building.

The findings of the study regarding the replacement of Ökobau data with EPDs can be transferred to conditions in e.g., Germany. Similar results might be achieved since generic data represents data from literature or expert knowledge, and therefore, the specification of the data will deviate from it.

4.4. *Data applicability during design stages*
Preliminarily, the building design professional, who is the LCA practitioner conducting the life cycle assessment, can apply generic data in the early design stages simply to estimate the potential environmental impact. Then, design stages before and during the final design of the building, where it approximates the as-built scenario, the LCA practitioner can replace the generic data with industry and product-specific EPDs. Product-specific EPD can be preferred over industry-specific EPDs to achieve more correct and realistic results. If no EPD exists, the generic data should be retained.

Usually, developers or building design professionals already have procurement agreements with specific material manufacturers, therefore, it might be possible to identify specific EPDs, which document the products of the procurement agreements, and apply them in life cycle assessments of the early design stage.

The professionals of the construction sector must adapt to working with EPDs to firstly, clarify potential environmental benefits and secondly, to motivate material manufacturers to transition to more environmentally friendly production or more recycling. Eventually, the environmental impact will become a competitive parameter and force many manufacturers to improve their production.

4.5. *Reduction potentials*
Another important finding is underlined with the results of the graphs in Figure 3 given the variations of the EPD ranges. The EPD ranges show which products seem to contribute with the lowest impact while still fulfilling the same function. When results are considered as in Figure 3, the differences across the products become more transparent which support the LCA practitioner in advising the owner of the

building in deciding on the most environmentally friendly product. Eventually, this will lead to reductions in the embodied carbon of buildings. Thus, applying EPDs instead of generic data can enhance the transparency in a potential reduction in environmental impacts. However, the availability and applicability of EPD data will be crucial if building design professionals and their customers are going to make more environmentally friendly choices based on well-established data.

4.6. Relevance in the coming building regulations

Denmark is not the only member state in the EU planning to implement CO_2 limit values in building regulations. France, Finland, and Sweden have either integrated or planning to implement a CO_2 limit in the building regulations. In January 2022 France introduced CO_2 limit values for residential buildings, where the limit value is 640 and 740 kg CO_2e/m^2 for detached/attached and collective housing, respectively, in the embodied carbon regulation for new buildings, RE2020 [16]. The limit values are tightened gradually from 2021 to 2030. And the assessments in France will include each life cycle module [17]. Finland and Sweden are planning on limit values to be integrated in the years 2025 and 2027, respectively [18]. Potentially more member states will follow the development.

Compliance with the limit values will be crucial for the professionals of the construction industry in several states, and for that reason, EPDs that enhance the transparency, and the correctness of the results will be in high demand. An issue can arise when EPDs result in greater environmental impacts compared to generic data. A main idea of the environmental product declarations is to document environmental impacts from materials, which allows comparisons in environmental performances across materials. This will become a competitive parameter between manufacturers of the materials, which will result in encouragement to environmentally enhance building materials. Therefore, building design professionals and the owners of buildings will most likely expect EPDs to result in lower environmental impacts compared to generic data. However, the graphs in Figure 3 show the possibility of EPDs resulting in greater environmental impact compared to generic data. This can result in building design professionals applying generic data instead of EPDs, which can then influence the correctness and transparency of the life cycle assessments conducted according to the building regulations.

5. **Conclusion**

The study investigates the potential influence on LCA results when generic data from Ökobau.dat is replaced with industry- or product-specific environmental product declarations. This is done with exterior wall types A, B, and C, two data scenarios, and several variations in materials. The study clarifies that many combinations of the walls due to the several EPD datasets occur, and therefore, the LCA results depend on the context and the combination of the data. Additionally, the material properties, the type of product, and the manufacturing processes can influence the results. Thus, in a decision-making context, the LCA practitioner must consider several parameters for the owner of the building to make a holistic decision.

The study further underlines that the availability and applicability of environmental product declarations are crucial to achieving transparent and more correct and precise life cycle assessment results. Especially, as limit values are being implemented in building regulations, which building design professionals of the built environment must comply with.

Finally, the study finds that EPDs can enhance the transparency in a potential reduction in environmental impacts from building elements or buildings in general. Though, to support this more EPDs must be available and applicable to the building.

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