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*changing impacts of the environmental profile*

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# System and scenario choices in the life cycle assessment of a building – changing impacts of the environmental profile


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## Short Summary


This paper presents a life cycle assessment (LCA) case study of an office building. The case study investigates how the setting of free parameters (adopted from the CEN/TC 350 standards) influences the results of the building's LCA in the DGNB certification scheme for sustainable buildings. The parameters concern the reference study period and the energy supply scenarios. Furthermore, a set of toxicological impact categories are included in the assessment to test whether the toxicological impact potentials follow the same trends as the impact categories already included in the DGNB methodology



**Keywords:** building LCA, reference study period, energy scenarios, impact categories, DGNB


## 1. Introduction

Increased focus on sustainable production and consumption has led to numerous mappings of energy use and environmental impacts from different sectors of today's society. This mapping serves two main purposes: to quantify the potential environmental impacts of a sector and to assess where impact improvements of a sector can be made. The building and construction sector operations, associated with housing and office- and industrial services, make up as much as 40 % of society's final energy consumption [1]. Furthermore, building occupancy and structure account for up to 20-35 % of most other environmental impact categories associated with buildings such as greenhouse effect, acidification, smog formation, eutrophication, land-, resource- and water use and waste generation [2].

In a Danish context, the founding of the Green Building Council Denmark in 2010 marked the beginning of a collective effort from a range of stakeholders in the Danish building industry to develop a nationally tailored sustainability assessment framework for buildings. The German developed DGNB International certification was chosen as the role model scheme on which to base a Danish certification scheme. Since then, the parties involved have worked on the adaptation of the system to meet Danish regulations and conditions [3]. In the meantime, on a European level, the finishing of the European CEN/TC 350 standard series on Sustainability of Construction Works is approaching [4]. It is the explicit goal of the DGNB International to have the certification scheme complying with these European standards, and the Danish version of the DGNB scheme must therefore also take this framework into account in the adaptation process.

Both the CEN/TC 350 standards and the DGNB International certification scheme make use of the LCA methodology to evaluate the environmental sustainability of buildings, but whereas the CEN/TC 350 standards present a broad framework for the evaluation of sustainability, the DGNB International is a concise recipe for the evaluation process, complete with system boundary settings and benchmark values. In this sense, the DGNB International scheme serves as (one of many possible) translations of the CEN/TC 350 standards into an applicable scheme for sustainability evaluation.

Important system and scenario settings for the LCA in the DGNB International are:

1. The choice of reference study period, i.e. the period in which the environmental effects of the building's life cycle are accounted for and distributed over. For office buildings the study period is defined as 50 years
2. The choice of energy supply for the building's use stage, i.e. the data input concerning the technologies producing energy for the building's consumption of heat and electricity. For office buildings the input of electricity is specified to be the European grid mix and the reference input of district heating to be a mix of 65 % thermal energy from natural gas and 35 % thermal energy from hard coal
3. The choice of impact categories, i.e. the environmental damage categories assessed in the study. In the DGNB International scheme two resource use categories are assessed (concerning the non-renewable and the renewable primary energy use) and five environmental impact categories (global warming, eutrophication, acidification, smog-formation and ozone depletion potentials)

These system and scenario choices defined by the DGNB scheme were questioned in the Danish adaptation process of the certification scheme. This paper presents the case study that was performed to explore the environmental impacts and hence the quantitative environmental sustainability implications of the system and scenario choices.

## 2. Method and study design

The case building was assessed using the DGNB simplified LCA methodology [5], which include the life cycle stages and processes shown in table 1. The life cycle stages covered by the DGNB simplified approach is a simplified version of the life cycle stages included according to the CEN/TC 350 standards.

*Table 1: Life cycle stages and processes included in the case study*

| **Product stage** | **Use stage** | **EoL stage**<br>(End-of-life and benefits and loads for the next product system) |
|---|---|---|
| • Raw material supply<br>• Transport to manufacturer<br>• Manufacturing | • Operational energy use (heat and electricity for building operation only)<br>• Replacements of materials and components | • Waste processing<br>• Disposal<br>• Reuse, recycling, recovery potential |

The life cycle impact assessment was carried out applying the CML 2001 methodology [6]. Since one purpose of the case study was to investigate how a broadening expansion of the included impact categories could potentially change the environmental impact profile of the building, four toxicological categories (presented in *italic* in the list below) supplement the other seven categories assessed in accordance with the DGNB scheme:

- Acidification potential (AP) in [kg $SO_2$-equivalents]
- Eutrophication potential (EP) in [kg $PO_4$-equivalents]
- Global warming potential (GWP) in [kg $CO_2$-equivalents]
- Ozone depletion potential (ODP) in [kg R11-equivalents]
- Photochemical ozone creation potential (POCP) in [kg ethene-equivalents]
- Primary energy use, non-renewable (PEn.ren) in [MJ]
- Primary energy use, renewable (PEren) in [MJ]

- *Freshwater aquatic ecotoxicity potential (FAETP) in [kg DCB-equivalents]*
- *Human toxicity potential (HTP) in [kg DCB-equivalents]*
- *Marine aquatic ecotoxicity potential (MAETP) in [kg DCB-equivalents]*
- *Terrestrial ecotoxicity potential (TETP) in [kg DCB-equivalents]*

For the study we set up and analyzed different product system scenarios for the case building. Table 2 lists the free parameters and the setting of these across the four scenarios assessed. Inclusion of toxicological impact categories in the LCIA step is carried out only on the reference scenario 1.

*Table 2. Scenarios and parameters assessed in case study*

| | **Scenario 1 Reference** | **Scenario 2 Long reference study period** | **Scenario 3 Danish energy supply** | **Scenario 4 Forecast energy supply** |
|---|---|---|---|---|
| **Study period in years** | 50 | 100 | 50 | 50 |
| **Electricity supply** | EU-25 grid mix [7] | EU-25 grid mix [7] | Danish grid mix, 2010 [8][9] | Danish grid mix, average 2010-2060 [10] |
| **Heating supply** | District heating (100 % natural gas) [11] | District heating (100 % natural gas) [11] | Danish district heating mix, 2010 [10][12] | Danish district heating mix, average 2010-2060 [13] |

## 2.1 The case study

The case study office building is the headquarters of a larger Danish company. Main characteristics of the building are presented in table 3.

*Table 3. Case building main characteristics*

| | |
|---|---|
| **Building type** | Office |
| **Location** | Bagsværd, Denmark |
| **Expected use** | 45 h/week |
| **Gross floor area (GFA)** | 31,135 m2 distributed on 8 storeys (2 of these are underground, partly serving as parking space) |
| **Building structure** | Concrete, steel |
| **Building envelope** | Flat roof, ¼ of roof area made up by steel framed glass dome, façade of glass, white glazed tile, aluminium lamellas |
| **Expected energy consumption (building operation only)** | 13.8 kWh/m2/year district heating<br>12.3 kWh/m2/year electricity from grid |

### 2.1.1 Product stage.

The product stage modules accounted for cover the materials used in the following 8 building component categories: foundations/floor slabs, structural parts/columns, staircases, roofs, ceilings/floors, external walls/facade, internal walls/doors, and central heating/cooling. In accordance with the DGNB International simplified methodology the inventory does not include connecting parts (e.g. screws, bolts, concrete anchors), exterior activities (e.g. landscaping), nor user specific electronic equipment (e.g. personal computers, refrigerators, desktop lamps).

Around 50 different building materials were identified in the case building. Table 4 lists the mass of the building materials distributed on 11 main material categories.

*Table 4. Mass of building materials in main categories*

| **Building material category** | Concrete, screed and mortar | Gravel and natural stone | Steel | Gypsum based materials | Glass | Insulation materials | Tiles and ceramics | Paints and primers | Wood based materials | Plastics | Aluminium |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Total mass [1000 kg]** | 38,660 | 6,280 | 3,950 | 675 | 340 | 290 | 210 | 105 | 85 | 75 | 70 |

2.1.2 Use stage.
The use stage modules of the product system model cover the expected use of energy (i.e. heat and electricity for building operation) and the expected consumption of building materials for replacements across the entire reference study period, here set as 50 years in accordance with DGNB International.

Data on the energy demand of the case building originate from the mandatory energy simulation of new buildings in accordance with the Danish building regulations [14]. The expected energy use for building operation complies with the requirement for the Danish low energy building class 2015.

Building materials are modelled to be replaced at the end of the required service lives respectively [15].

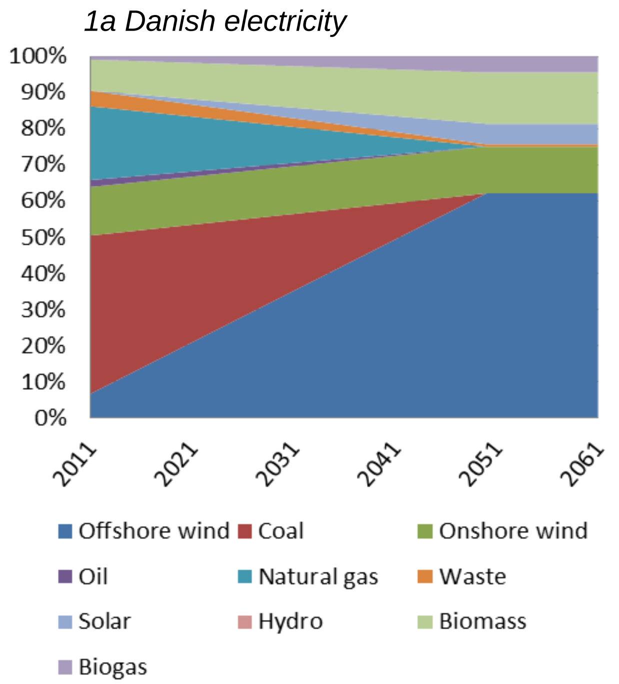
2.1.3 EoL stage and benefits and loads beyond the system boundary
Mineral waste (e.g. concrete, screed) is assumed to be recycled as road filling material, wood and plastics are assumed incinerated with energy recovery and insulation materials are assumed landfilled. Metals are assumed recycled and central heating and cooling appliances are directed according to the information given in their respective datasets.

### 2.2 Modelling of energy mixes

The case study further tested how a change from regional energy supply (EU-25) to national energy supply (Danish) influenced the results of the environmental profile. In conventional building LCAs, a status quo input of energy in the building's operation stage is used, i.e. the energy technologies used for the supply is assumed the same over the full 50 years of study period. In this study we tested the influence on results of using a projected future energy scenario with a higher share of renewable technologies in the years to come. The future energy scenarios were modelled partly as linear projections from the 2010 statistics. Endpoints in the projections are "expert projections of year 2050 scenarios" for both heat [13] and electricity [10].

The specific compositions of the energy mixes used in the modelling of scenario 3 and 4 are presented in figures 1a-b.

It was necessary to project the future energy scenarios further than the 2050 scenarios in order to reflect the full 50 years of reference study period. The period 2050-2060 is projected as a 2050 status quo. The dynamics of the energy supply composition in the full period 2010-2060 is reflected in the system modelling by applying average contribution shares from each technology within the 50-year reference study period.



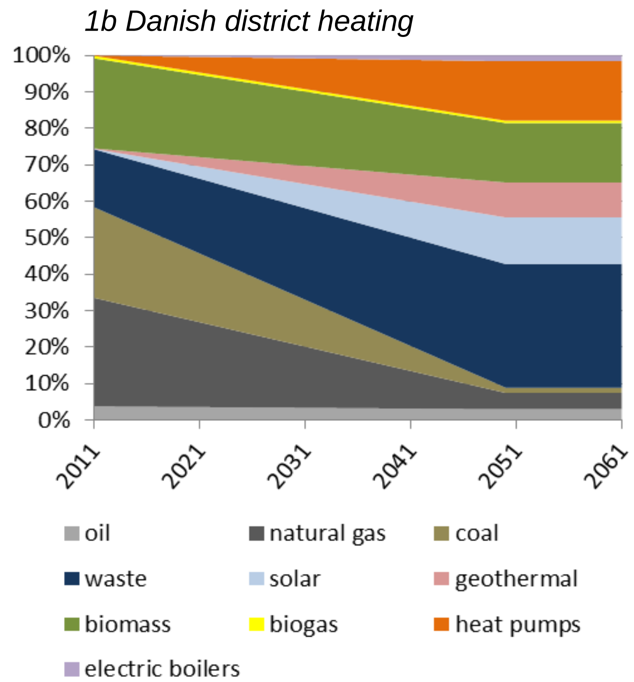




*Fig 1a. Scenario of fuel/technology shares in the Danish electricity production 2011-2061 [16]*

*Fig 1b. Scenario of fuel/technology shares in the Danish district heating production 2011-2061 [16]*

## 3. Results

Results obtained from the reference scenario 1 for the life cycle stages covered are presented in figure 2a. For all environmental impact and resource use categories, the use stage modules (heat and electricity consumption, replacements) have the largest impact contribution to the total impacts. Material-related impacts (production and replacements) are contributing with more than 50 % of the total impacts within the impact categories EP and POCP and 35-40 % of the embodied energy demand (renewable and non-renewable).

The results from scenario 2 highlight how the contributions to the total change when the reference study period is prolonged to 100 years. The total differences from the reference scenario's impact results are presented in figure 3. The 10-20 % lower impacts/m$^2$/year in the impact categories are caused by the decreased impact contributions from the building materials used in the completed building prior to the use stage. Since the impacts are given per m$^2$ per year, the impact contributions from building materials are distributed over twice the number of years (i.e. 100 years) as in the reference scenario. Thus, the contributions from building materials to the impact categories, presented in figure 2b, decrease from 20-50 % of the total impact in the reference scenario to 10-35 % of the total impact in scenario 2.

The use of the Danish electricity and district heating mixes in the modelling of the use stage yields impact results in scenario 3 that vary considerably from the reference scenario applying European energy mixes. Figure 3 reveals how the impact from the building increases with up to 5 % within the impact categories EP and GWP. For other impact categories, the total impact results are lower than the reference, up to 33 % lower within AP and 56 % lower within ODP. The impacts from PEren are app. 175 % higher in scenario 3 than in the reference scenario 1. Looking at figure 2c and the contribution from the different life cycle stages to the total results, scenario 3 also shows large changes in the share contributed from the building's energy demand (electricity and heat). In the impact categories AP, ODP, POCP and PEn.ren the contribution from the energy demand decreases by 10-20 percentage. In the EP and GWP impact categories the contribution from the energy demand increases by a few percentages from the reference scenario 1 to scenario 3. For the PEren category the contribution from the energy demand increases by 25 percentage points.

In scenario 4 the energy mixes were modelled in order to reflect a projected development of the technology composition of the energy production. Figure 3 illustrates how the impact from the case building increases considerably in the PEren category with a more than 300 % increase in scenario 4 relative to the reference scenario. In all other categories impact results are lower than the reference scenario results, ranging from 2 % lower impact in the EP category and to 53 % lower impact in the ODP category. Figure 2d illuminates how the contribution from the energy demand to the total impacts is dramatically reduced compared with the reference scenario. The contribution from the building materials (original building and replacements) is noticeable within each impact category with PEren as the only exception.

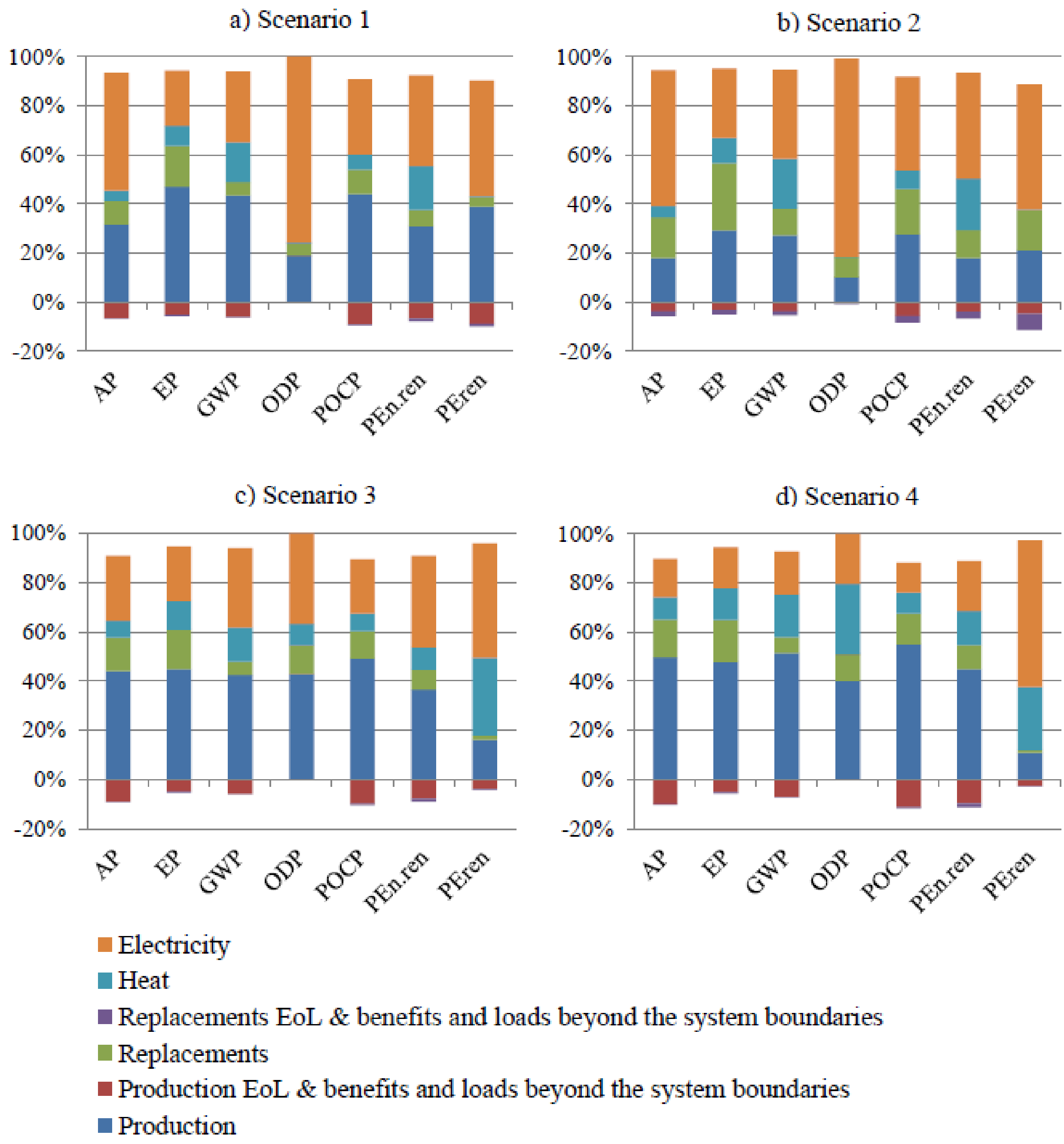



*Fig 2a-d. Environmental impact results and resource use contributions from the individual life cycle stages of the different scenarios*

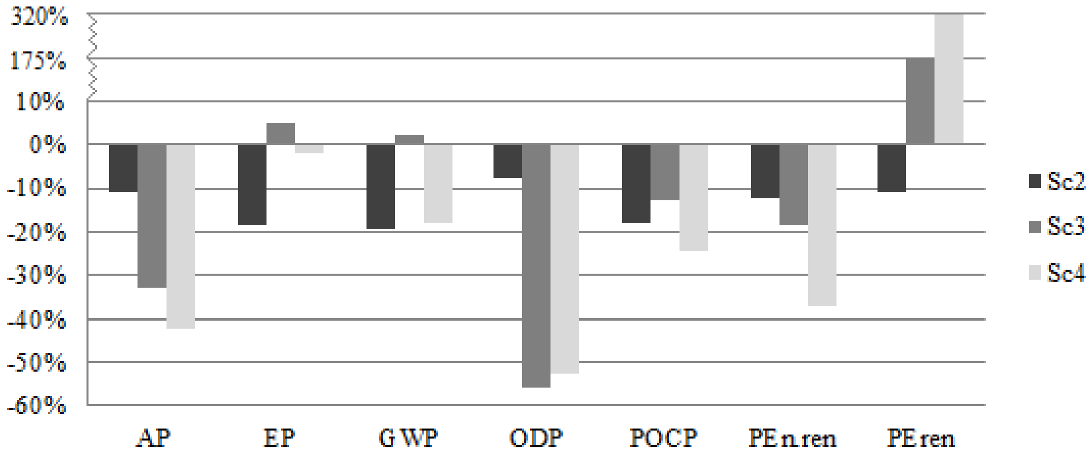



*Fig 3. Differences in impacts potentials per $m^2$/year for scenario 2, 3 and 4 relative to scenario 1*

The toxicological impact potentials from scenario 1 are given relative to the contributing life cycle stages in figure 4. Building material related impacts from the original construction and replaced materials are dominating the total impacts across all four toxicological impact categories with contributions amounting to 60-80 % of the total impact. In the FAETP category the impact from replacements is contributing with the same share of the total impact as the production of all the originally installed building materials.

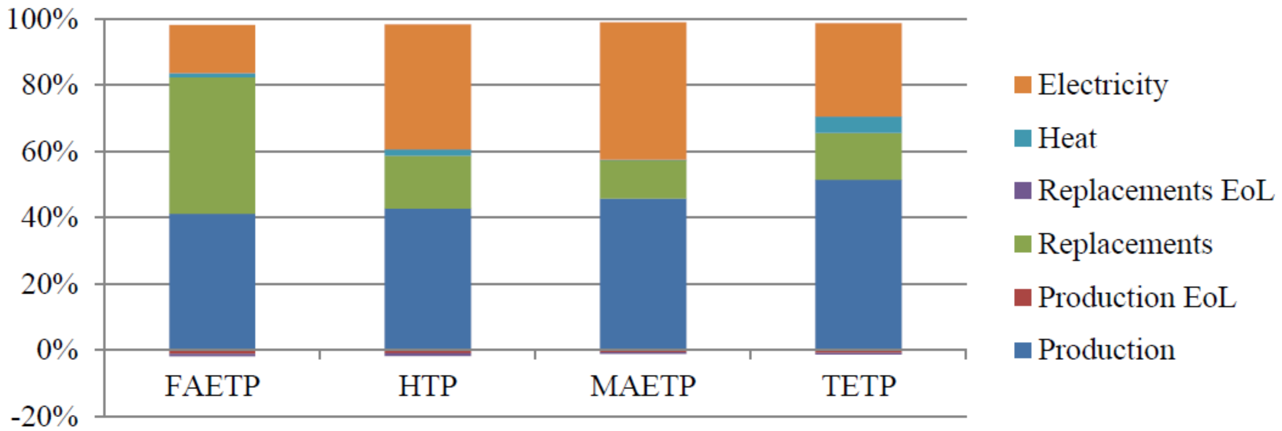



*Fig 4. Toxicological impact contributions from different life cycle stages – Scenario 1*

## 4. Discussion

As the results from this case study illustrates, the environmental burden of a building can vary as much as 20 % in some impact categories depending on whether a study period of 50 or 100 years is used (cf. figure 3). Other studies have similarly shown considerable changes in impact results for one or more impact categories [17, 18, 19, 20, 21] depending on the reference study period.

Traditional structural elements, concrete and steel, have expected service lives in the range 80-100 [15] and a required service life of a building containing these structural elements could thus easily be defined as 100 years. The use of a shorter reference study period does not justify the use of long lasting/high quality building materials. Such assumptions could possibly lead building designers to choose materials that are not necessarily environmentally beneficial. However, an expected life span and reference study period of 100 years is a long time span when scenarios are founded on current data, energy consumptions and EoL technologies. The uncertainties connected with this kind of long study periods, would hence make the results more unreliable as a whole.

Environmental impacts from energy consumption in a building's use stage have generally proven a major contributor to impact potentials of buildings [17, 22, 23, 24, 25], and the type of energy input does therefore have a potential strong effect on the environmental results. The impact results from scenario 1 to scenario 3 confirm this picture with substantial changes within some impact categories. The use of national energy mixes in the LCA modelling is hence necessary to obtain more exact results. Furthermore this way of modelling the energy supply complies with recommendations on defining energy supply system boundaries in LCA where local data should be preferred, i.e. the local district heating grid and the national electricity grid mix [26].

The focus of LCAs on energy consumption in buildings is generally on the influence of changes in the building's energy demand [27, 28, 29]. Scenario 4 explores the relevance of changes in the energy supply mix for the building. The results from scenario 4 revealed considerable changes in all impact categories, reductions in all (e.g. a 20 % reduction in the GWP and a 40 % reduction in the PEn.ren categories) but one case (PEn.ren, cf. figure 3). The energy system will in reality develop, and most likely to a composition with more input from renewable energy sources [10]. Results like those obtained from scenario 4 may hence come closer to the actual impacts of the building. However, the energy supply development could take place in a number of ways; new technologies are introduced, known technologies are improved, and a simple model of the future energy scenario will not be able to take all of these aspects into account. For the sake of comparison possibilities of building LCAs at early stages of the building's life span the status quo future scenarios (i.e. no energy supply mix dynamics) serves adequately.

The most commonly included impact categories in building LCAs are GWP, AP, EP, ODP and primary energy consumption. Toxicological impact potentials however, are rarely included in the LCA of buildings [30, 31]. Results from our study show how the toxicological impact profiles of the building do not follow the same trends as the other impact categories. Building materials, originally installed and replaced, contribute more than energy consumption to all toxicological impact categories assessed. This is opposing the general trends in the other assessed impact categories where the energy consumption, with a few exceptions, accounts for the largest impact share. The inclusion of toxicological impact categories can thus be seen as an important broadening of perspective. However, the toxicological impact categories would be difficult to include in the DGNB scheme because the background data on toxicological impacts is not included in the European standards on environmental product declarations of building materials, the EN 15804 [32].

# 5. Conclusion

This case study investigated some of the free parameters of the CEN/TC 350 standards on sustainable construction work. The free parameters investigated; the reference study period and the choice of energy data have been set in the practical application of the standards in the DGNB certification scheme for sustainable buildings. In the adaptation of the DGNB scheme to Danish conditions it has been desirable to know how the parameters affected the results of the environmental profile of the building.

The results of the case study illustrate how a 50-year study period cannot justify the use of long-lasting materials. On the other hand, a study period of 100 years increases the uncertainty of the scenarios on energy input and replacement.

National or local data on energy production should be preferred to regional data, so as to give a more correct picture of the actual environmental effects of the building. This approach is already being followed in the Danish DGNB adaptation process. The use of dynamic energy scenario modelling may prove to provide results which come closer to the actual situation of the building. However, the uncertainties connected with this kind of projections can be considerable.

The contributions from the life cycle stages to the toxicological impact categories do not follow the trends found in the other impact categories. The inclusion of toxicological impact categories thus widens the perspective of the environmental profile of the building. In practice however, it will be difficult to include the toxicological impact potentials as part of the certifications scheme, because the background data is not readily available in the standardized environmental product declarations.

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