Readjusting the climate change hyperfocus: how expanding the scope of impact categories will affect the evaluation of wood buildings

Hansen, Rasmus Nøddegaard; Hoxha, Endrit; Andersen, Camilla Marlene Ernst; Rasmussen, Freja Nygaard ; Ryberg, Morten; Birgisdottir, Harpa

Published in:
Journal of Physics: Conference Series

DOI (link to publication from Publisher):
10.1088/1742-6596/2600/15/152023

Publication date:
2023

Document Version
Publisher's PDF, also known as Version of record

Journal of Physics: Conference Series

PAPER • OPEN ACCESS

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To cite this article: R N Hansen *et al* 2023 *J. Phys.: Conf. Ser.* **2600** 152023

Readjusting the climate change hyperfocus: how expanding the scope of impact categories will affect the evaluation of wood buildings

R N Hansen[1*], E Hoxha[1], C E Andersen[1], F N Rasmussen[2], M W Ryberg[3], H Birgisdottir[1]

[1] Dept. of the Built Environment, Aalborg University (AAU), Copenhagen, Denmark
[2] Dept. of Civil and Environmental Engineering, Norwegian University of Science and Technology (NTNU), Trondheim, Norway
[3] Sustainability, Building Division, Sweco A/S, Copenhagen, Denmark

* Corresponding author: rnh@build.aau.dk

Abstract. The sole focus on reducing the climate impact of dwellings by using wood is neglecting other impacts on nature. Therefore, this study clarifies the potential burden shift by considering ten more impact categories than greenhouse gas emissions. It assesses four wood buildings and one reference concrete building by using the method of life cycle assessment. What stands out is that wood dwellings perform better than the concrete building in most impact categories except for abiotic depletion potential and ozone layer depletion potential (ODP). The latter also experiences an impact increase when wood is used to decrease climate impact as global warming potential (GWP). The wood dwellings have a general inverse correlation between GWP ranking and ODP and some resource use indicators where plastics and cement-based materials influence the latter. Bio-based materials' contribution to acidification and eutrophication is more considerable than to GWP. Upon the findings, increased inclusion of impact categories among researchers and practitioners must follow to expand the knowledge base. A foundation for future conscious decisions of using wood in dwellings and the challenging debate of reaching consent of which other impact categories should attain focus for being improved.

Keywords: Impact assessment, Burden shift, LCA, Dwellings, Midpoint, Wood, Case study.

1. Introduction

Climate change is in focus because emissions have global effects, meaning everyone can principally be affected by impacts everywhere, independent of the geographical location of emission. Evidence shows that buildings have a large impact on the climate from their material consumption and operational energy use [1]. Wood has emerged as a low-carbon material that can reduce the embodied climate impact of buildings [2], [3]. Despite recognising climate change as central to mitigating adverse societal effects, this climate hyperfocus results in neglecting other impacts on nature.

The life cycle assessment (LCA) methodology is central to assessing the climate impacts of buildings. However, LCA can also identify the impact on other impact categories than climate. Recently, studies analysed other impacts than climate change of concrete buildings [4] by endpoint categories in Canada [5], though based on consequential LCA, and in the US for wood buildings [6]. Another study suggests looking beyond energy consumption and climate change because other environmental impacts lack sufficient examination [7]. A recent study covered several impact categories for four buildings in Greenland, though mainly covering renovation [8].

Most studies in the field of building LCA have primarily focused on climate impact and energy depletion [9]..In contrast, a broader scope of impact categories is yet to gain ground. Therefore, it can be problematic to recommend wood [3] only based on climate assessment when knowledge and conscious consideration of potential burden shift is not well-known. Therefore, this case study seeks to examine which environmental impact categories are prone to burden shifting when comparing residential wood buildings to a conventional concrete building. Second, the study highlights the component types and material categories contributing to the burden shift and how to act upon it.

2. Methodology

This study uses five real dwellings as case studies to investigate an expanded scope of impact categories. The case studies, the LCA, and included impact categories are clarified in the following sections.

2.1. Case buildings

The case buildings comprise four wood dwellings and one business-as-usual (BAU) concrete dwelling as the reference building, all constructed between 2010 and 2021. The buildings come from collaborating with architecture companies and follow a level of development (LOD) similar to LOD 300-350 [10]. The case buildings represent a broader scope of wood dwellings to denote different features in terms of structure, dimensions, and size, as presented in Table 1. Further, all the buildings represent more than one building block. The building data collection combines bill of quantities, drawings, project plans, and building information models.

Table 1. Description of the five building case studies, incl. building typology, structural typology, cladding type(s), total area, and foundation type.

Case	Building Typology	Structural typology	Cladding	Area [m2]	Foundation
BAU	2-storey terraced house	Concrete	Fibre cement + alu-sheet + wood	3,767	Concrete raft
M01	3-4 storey apartment building	Wood frame (prefab)	Wood + slate	17,530	Concrete raft
R01	1-2 storey terraced house	Cross-laminated timber	Fibre cement	3,720	Concrete raft
R02	1-2 storey terraced house	Wood frame (prefab)	Wood	4,196	Concrete footing
R03	2-storey terraced house	Wood frame (prefab)	Steel sheets + wood	13,010	Concrete raft

2.2. Life cycle assessment

The evaluation utilises a life cycle approach by conducting an LCA according to the EN 15978 standard [11]. The functional unit (FU) is 1 m^2 of gross floor area of two to four storeys for a 50-year reference period. The system boundary of the study includes the life cycle stages A1-A5, B4, and C3-C4, omitting operational energy because of the focus on the potential burden shift related to embodied impacts. The study manages biogenic carbon according to the -1/+1 methodological concept recommended in the EN 15804:2019 standard [12].

LCAbyg was applied to conduct the LCA, a tool developed for the Danish building industry that uses the Ökobaudat database [13]. The expected service lives of the building materials were estimated according to Haugbølle et al. [14]. A holistic application of impact categories followed the EN 15978 standard as if integrated into the LCAbyg tool, see Table 2.

Table 2. The covered impact categories with name, abbreviation, and unit in a separate column for each indicator type. For further explanation, see EN 15978. ren=renewable, sec=secondary.

Environmental impact indicators		Resource use indicators	
Global warming potential, GWP	Kg CO_2 -eq	Use of non-ren. primary energy total, PENRT	MJ
Ozone layer depletion potential, ODP	Kg CFC 11-eq	Use of ren. primary energy total, PERT	MJ
Tropospheric ozone photochemical oxidants, POCP	Kg ethene-eq	Use of non-ren. sec. fuels, NRSF	MJ
Acidification potential – land and water, AP	Kg SO_2-eq	Use of ren. sec. fuels, RSF	MJ
Eutrophication potential, EP	Kg $(PO_4)^{3-}$-eq		
Abiotic resource depletion for elements, ADPe	Kg Sb-eq		
Abiotic resource depletion for fossil fuels, ADPf	MJ		

3. Results

This section first presents the impacts set relative between the four wood buildings and the BAU. Then follows an assessment of the ranking of the wood buildings among the eleven impact categories and a breakdown of contribution to the impact categories on component types and material categories.

3.1. Relative environmental impacts between buildings and a ranking analysis

All four wood buildings have a lower GWP score relative to the BAU building by constituting 50-80% of the impact of the BAU. The BAU building has the greatest impact on all impact categories except for ODP, ADPe, and PERT. The reduction in GWP of using wood in buildings leads to an increase in ODP for all wood dwellings compared to the BAU and an increase in ADPe and PERT for cases R03 and R01, respectively (see Figure 1). Particularly the ODP impact increases considerably where the BAU building only constitutes 5% of the impact of the most impacting wood building. The BAU building reveals a factor 4-20 lower ODP impact than the wood cases, where the wood buildings among themselves have a difference of factor five.

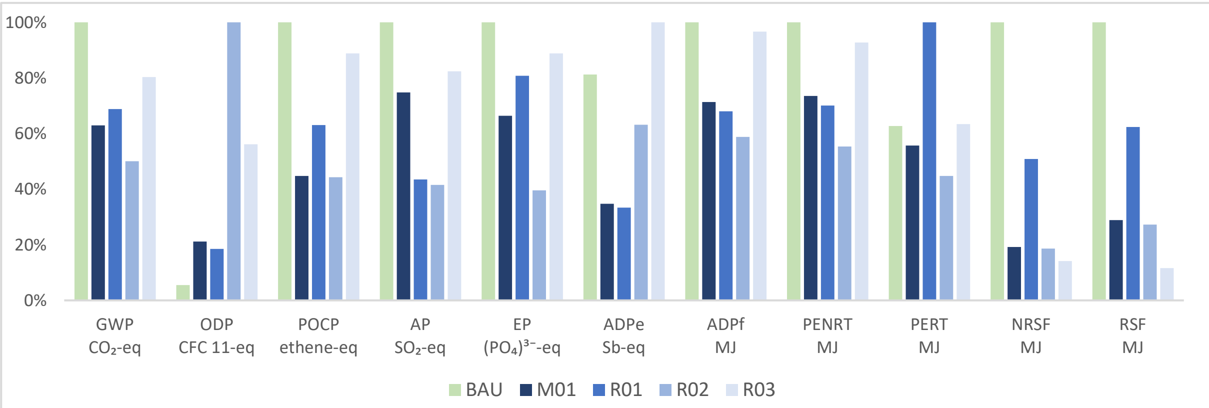

Figure 1. Impact scores (%) set relative between the BAU and the four wood buildings. The building with the greatest impact in each impact category is 100%, and the others are set relative to that building. The impact scores are based on impact per m^2 per year.

As displayed in Table 3, it is apparent that the case building with the least GWP score (R02) instead increases the impact on ODP immensely. Meanwhile, this case building, R02, generally performs well in the other impact categories aside from the depletion potential of minerals and metals (ADPe) and non-renewable secondary fuel (NRSF). The acidification and eutrophication potential correlate with the four buildings' GWP ranking. The ranking of POCP, ADPf, and PENRT is overall similar to the ranking of GWP. The building with the most significant GHG emissions demonstrates the highest impact for six other indicators and the second highest for two other indicators. Contrarily, it is the best performing regarding resource use of the two secondary fuels impact categories (NRSF and RSF).

Table 3. The rank of the cases for the eleven impact categories per m^2 per year, including the BAU case as a reference. The lightest colour represents the lowest impact, and the darkest is the most considerable impact.

	GWP kg CO_2-eq	ODP kg CFC 11-eq	POCP kg ethene-eq	AP kg SO_2-eq	EP kg $(PO_4)^{3-}$-eq	ADPe Sb-eq	ADPf MJ	PENRT MJ	PERT MJ	NRSF MJ	RSF MJ
R02	4.1	3.1×10^{-7}	0.0024	0.010	0.0026	1.4×10^{-4}	57	61	38	0.26	0.17
M01	4.2	6.7×10^{-8}	0.0015	0.013	0.0031	8.0×10^{-5}	66	70	47	0.23	0.19
R01	4.4	5.8×10^{-7}	0.0026	0.014	0.0043	7.6×10^{-5}	58	62	152	0.68	0.40
R03	6.3	1.8×10^{-7}	0.0047	0.019	0.0058	2.3×10^{-4}	92	100	79	0.17	0.07
BAU	7.4	1.7×10^{-7}	0.0049	0.021	0.0058	1.9×10^{-4}	95	99	36	1.37	0.65

3.2. Contribution to impacts from component types

The three most contributing component types to GWP are exterior walls, foundations, and floors. The foundations exhibit a significantly higher share of impacts of POCP, NRSF, RSF, and partly ODP than their share of GWP impact (see Figure 2). Overall, the floors illustrate a slightly higher impact on ODP, AP, EP, and PERT than their GWP impact. The exterior walls impact a significant share of AP, EP, ADPf, PENRT, PERT, and partly in ODP and ADPe. But the share is generally similar to the share of GWP. The roofs shift the GWP impact to ADPe in two cases, while it shifts the burden to ADPf and PENRT for the roofs in all four buildings. The inconsistent impact of some components on some impact categories requires a deeper look into the material categories used in the four cases.

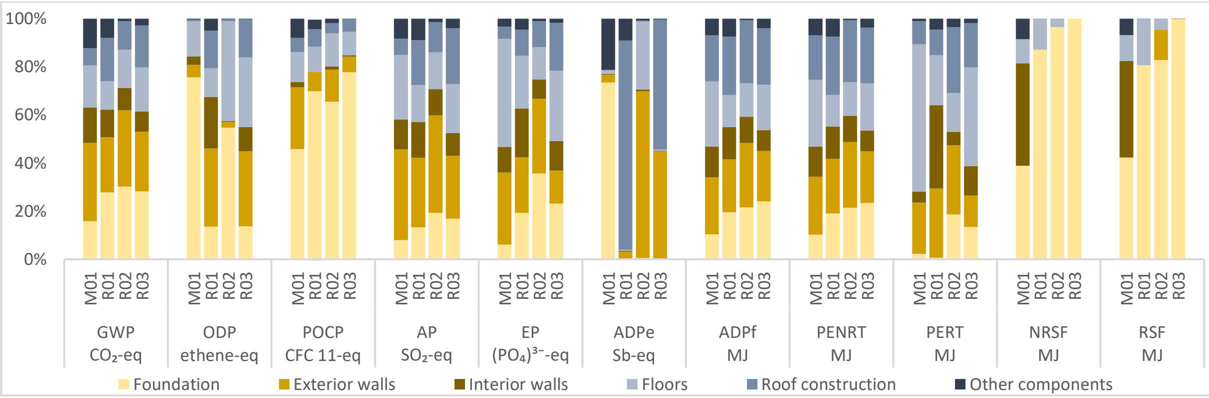

Figure 2. Distribution of the 11 impact categories normalised per m^2 per year.

3.3. Contribution to impacts from material categories

What stands out in Figure 3 is the pattern of the GWP impact share of bio-based materials, where most of the other impact categories follow that pattern except for EP, PERT, and ODP in two cases where the impact increase. Cement-based materials shift the share of impacts to NRSF and RASF, while insulation has a remarkable share of POCP compared to its GWP impact. Plastics primarily cause ADPe impact.

Another interesting observation is that the trend of the GWP impact of the bio-based materials is almost mirrored in the trend of impact on ODP. It is primarily the bio-based materials and insulations that contribute to the impact on ODP, where the impact of insulation in cases M01 and R02 stems largely from polyurethane foamboard and partly expanded polystyrene (EPS).

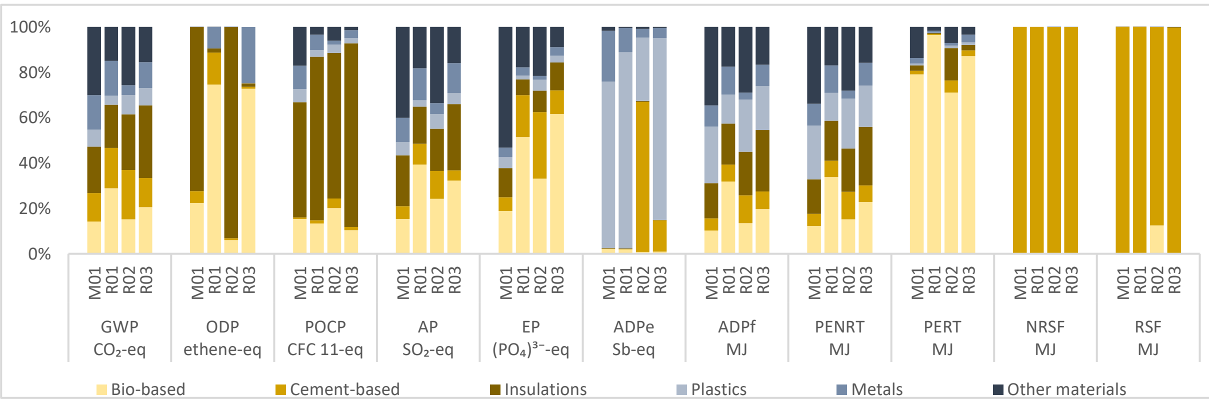

Figure 3. Distribution of the 11 impact categories normalised per m2 per year.

4. Discussion

The results confirm the GHG mitigation potential of transitioning from concrete to wood-based residential building practices. However, introducing more wood buildings probably result in a significant manifold burden shift to ODP instead, where this study reveals a correlation between the

GWP impact of bio-based materials and the impact on ODP. In the same way, the use of polyurethane foam board for insulation also plays a role in ODP impact, an aspect to which building designers and LCA practitioners must pay attention. Foundations or exterior walls cause a major impact on ODP; hence these components can be the focus of mitigating the burden shift in building with wood.

The observations of the lowest climate-impacting buildings show that bio-based materials are not the root causes of the burden shift to ADPe, NRSF, and RSF. It is a side effect of plastics for ADPe and cement-based materials for the two other impact categories. Hence, reducing the burden shifts to these impact categories requires cutting down the use of plastics and cement-based materials in designing and building with wood. For the ADPe, further analysis is needed to understand which components require improvements because the most impactful component differs greatly among this study's buildings.

This study's research outcome demonstrates the need for efficient and effective use of wood in buildings because the bio-based materials significantly influence the PERT impact category. The PERT category may play a vital role in the land use associated with wood buildings, an impact category not considered in this study due to limitations of the applied LCA tool. A review of wood buildings also suggests that increased use of wood leads to increased land use impact, particularly indirect land use change [15], thus calling for further future investigation.

It is also essential to ask how important these affected impact categories are compared to the climate impact. In contrast to ODP being subject to the most considerable burden shift when transitioning from the BAU building to wood buildings, the results demonstrate that the impact is significantly lower when compared to the impact of an average world citizen. A note of caution is due here since the normalisation only relates the magnitude of the impact to the magnitude of the emission of an average world citizen. It implies that already high impacts of a citizen in a particular impact category will make the results seems less severe and vice versa. Measuring the results against planetary boundaries [16] is needed, where possible, to examine the severity of the burden shifts in the respective impact categories.

A limitation of this study is the small sample size; caution must be applied, as the findings might only partially represent wood buildings nationally and regionally. Further, the study only analyses one BAU building, which will also have variations. Therefore, there is a need to compound more case buildings of wood and BAU cases to conclude something significant. However, the present study raises a hypothesis of how the burden shift might look, and it is significantly present for the ODP.

5. Conclusion

The present research aimed to investigate the effect of building with wood on other impact categories than climate change and analysed the components and materials causing it. Thus, it evaluated potential burden shifting by comparing four wood dwellings to a reference conventional concrete dwelling.

The wood dwellings emerged as the best performing cases compared to the concrete building in most impact categories except for partly the ADPe and the ODP, where the latter experience a significant burden shift of factor 3-21 when building with wood. These two impact categories and NRSF generally also emerge with an inverse correlation compared to the climate impact of the wood buildings. The bio-based materials and insulations cause the ODP impact, essentially the polyurethane foam board and EPS. The bio-based materials, cement-based materials, and insulations exhibit an overall pattern as the most significant contributors to most impact categories. The burden shift to some of the resource use indicators is not directly related to the use of wood but rather plastics and cement-based materials.

This research raised essential questions about overlooking potential and significant burden shifting if climate change is the only lens that reflects environmental sustainability. The practical implication is now for researchers and industry LCA practitioners to implement a broader scope of impact categories to improve empirical knowledge to increase awareness and conscious decisions on building with wood. Moreover, a natural progression would be to consensually prioritise impact categories regarding their essentiality to society, mainly focusing on ODP and the resource (depletion) categories. Relating the impacts to planetary boundaries could be one approach to inform that debate.

Acknowledgement of funding
The authors would like to acknowledge and thank the financial support from VILLUM Fonden, grant no. 00029297 and 37169, and Real Dania for financing the case study collection, grant no. PRJ-2020-00273. The funding sources had no role in conducting the research in this article.

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