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A comparative assessment of the development of GHG emission criteria and benchmark values for buildings in Norway

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Abstract. GHG emission criteria and benchmark values for buildings are being developed internationally to meet climate goals in the Paris agreement. However, there is a distinct lack of harmonisation in approaches making it difficult to compare construction projects or implement and apply benchmarking at a national or international level. Norway is no exception. In recent years, multiple GHG emission criteria and benchmark values have been developed and tested to measure and evaluate the environmental sustainability of Norwegian buildings during their life cycle. These include proposals from Ydalir Masterplan, the research centre for zero emission buildings in smart cities, FutureBuilt ZERO and BREEAM-NOR v6.0. This paper presents and reviews these approaches in relation to recent Norwegian building code requirements for the reporting of GHG emissions. The paper compares the approaches in terms of methodologies, typologies, reference study period, life cycle modules, building parts, limitations and advantages. The results show that there are large differences in approaches which leads to a disparity in benchmarking levels. Further work is required to harmonise and create an accepted branch standard for benchmarking GHG emissions from buildings for the construction industry in Norway. In addition, it would be of benefit to establish a national database for GHG emission accounting so that better benchmark values can be established.

1. Introduction

The construction industry is responsible for about 23% of global carbon emissions [1]. Norway is committed to reducing national greenhouse (GHG) emissions by 50-55% by 2030 and by 90-95% by 2050 [2]. To meet national and international climate goals, various GHG emission criteria and benchmark values for buildings are being developed [3]. However, there is a distinct lack of harmonisation in methods and approaches making it difficult to compare construction projects or implement and apply benchmarking at a national or international level [4,5]. Norway is no exception. In recent years, multiple GHG emission criteria and benchmark values have been developed and tested to measure and evaluate the environmental sustainability of Norwegian buildings during their life cycle. These include proposals from Ydalir Masterplan [6–9], the research centre for zero emission buildings in smart cities (FME ZEN) [10,11], FutureBuilt ZERO [12], and BREEAM-NOR v6.0 [13]. Having different benchmark values with varying methodologies and system boundaries makes it difficult for project owners to select the appropriate benchmark level for their construction project. This paper presents and reviews these approaches in relation to recent Norwegian building code requirements for the reporting and benchmarking of GHG emissions in buildings [14].

2. Background

Previous studies have compared environmental sustainability assessment schemes for buildings, whereby GHG emissions is often identified as an important criteria [15–21]. More recently, the IEA EBC Annex 72 has investigated net zero emission buildings and the next generation of benchmark and calculation rules and found that there are large differences in GHG emission targets for buildings [4]. Another study has investigated indicative baseline and decarbonisation pathways for embodied life cycle GHG emissions of buildings across Europe and found that whole life cycle (WLC) embodied carbon emissions range from 400 - 800 $kgCO_2e/m^2$ (6.6 - 13.3 $kgCO_2e/m^2/yr$), averaging at 550 $kgCO_2e/m^2$ (9.2 $kgCO_2e/m^2/yr$) for residential buildings [5]. According to the EU taxonomy, new buildings over 5000 m^2 shall (amongst other criteria) calculate WLC GHG emissions to be considered sustainable [22]. Here the European framework for sustainable buildings - Level(s) calculation and assessment tool can be used with *EN 15978-1: 2021 Sustainability of construction works - Methodology for the assessment of performance of buildings - Part 1: Environmental Performance* to assess life cycle global warming potential of buildings [23,24]. In 2018, Standard Norge launched a Norwegian method for calculating GHG emissions in buildings (NS 3720) [25]. Some main differences in NS 3720 include:

- Thematic grouping of life cycle modules e.g., materials (A1-B5, C1-C4), construction (A4-A5), energy (B6), and introduction of life cycle module B8 for operational transport.
- A basic level (building envelope, materials, construction, and energy) and advanced level (whole building and WLC) for reporting GHG emissions.
- Two scenarios for electricity emission factors in B6 (Scenario 1: Norwegian consumption mix ca. 30 gCO_2e/kWh, Scenario 2: European consumption mix ca. 136 gCO_2e/kWh).
- *NS 3451: 2022 Table of building elements* for structuring inventories and calculations [26].

Since, multiple actors in Norway have developed GHG emission benchmark values for buildings [27]. In 2021, the Norwegian Directorate for Building Quality proposed GHG emission requirements for material use (life cycle modules A1-A3 and B4-B5) for apartment buildings (6 $kgCO_2e/m^2/yr$) and commercial buildings (4.5 $kgCO_2e/m^2/yr$). This was replaced in 2022 by a requirement in the Norwegian building code (TEK) for GHG emission accounting of apartments and commercial buildings [14,28].

Many Norwegian actors use OneClickLCA's carbon designer modelling programme to generate a project-specific reference building based on conventional Norwegian construction and set GHG emission target values based on a percentage reduction compared to the reference building [29]. One such example is demonstrated in Ydalir's Masterplan, whereby a consultant was engaged by Elverum municipality to generate benchmark values for residential property developers [6–9]. Ydalir's reference building has total GHG emissions of 888 $kgCO_2e/m^2$ or 14.8 $kgCO_2e/m^2/yr$ and material GHG emissions of 336 $kgCO_2e/m^2$ or 5.6 $kgCO_2e/m^2/yr$. According to Ydalir's Masterplan, property developers must document at least a 50% reduction in life cycle GHG emissions (444 $kgCO_2e/m^2$ or 7.4 $kgCO_2e/m^2/yr$), and at least a 20% reduction from materials (A1-A3, B4), 270 $kgCO_2e/m^2$ or 4.5 $kgCO_2e/m^2/yr$.

FME ZEN builds upon work from the previous research centre on zero emission buildings (FME ZEB) which provided a definition of a zero emission building [30–32] by developing a range of ambition levels ranging from the lowest ambition level of ZEB-O whereby GHG emissions from operational energy use (O) are compensated for with renewable energy generation (corresponds to the energy performance of buildings directive's (EPBD's) definition of zero emission building [33]), to the highest ambition level of ZEB-COMPLETE whereby all GHG emissions from the WLC of the building from the construction phase (C), operational energy use (O), material production and replacement (M), use, repair and maintenance (PLE), operational transport use (T) and the end of life phase (E) are compensated for with renewable energy generation. In 2020, FME ZEN carried out a meta-analysis of over 130 Norwegian building life cycle assessments (LCAs) to analyse GHG emission results and suggest benchmark values [10,11]. The results show residential buildings emit between 192 – 1278 $kgCO_2e/m^2$ or 3.2 – 21.3 $kgCO_2e/m^2/yr$ and have an average of 432 $kgCO_2e/m^2$ or 7.2 $kgCO_2e/m^2/yr$ from life cycle modules A1-A3 and B4. For the purposes of this study the average results from the meta-analysis are used. This meta-analysis has been used as a basis for developing GHG emission benchmark values for FutureBuilt Zero [12], Powerhouse Paris Proof and BREEAM-NOR v6.0, and will also be used to develop official GHG emission benchmark values in the ongoing work on the ZEN definition, assessment criteria and key performance indicators [34,35].

FutureBuilt is an organisation for improving environmental qualities in buildings in Norway, owned by multiple municipalities in the Oslo region. FutureBuilt has developed its own methodology (FutureBuilt Zero) for GHG emission accounting in buildings and gives diminishing GHG emission target values for every year towards 2050 [12]. FutureBuilt Zero differs from the other methodologies since it includes time- and technology-weighting. It is also ambitious since the goal is to always be 50% better than current practice. In 2022, WLC GHG emission target values in FutureBuilt projects correspond to 401 $kgCO_2e/m^2$ or 6.7 $kgCO_2e/m^2/yr$, with maximum 256 $kgCO_2e/m^2$ or 4.3 $kgCO_2e/m^2/yr$ for materials and 185 $kgCO_2e/m^2$ or 3.1 $kgCO_2e/m^2/yr$ for energy.

It should be noted that a different environmental sustainability programme in Norway, Powerhouse Paris Proof [36], which aims to reduce WLC GHG emissions from buildings in line with the Paris Agreement has a similar GHG emission reduction curve. However, at the time of writing further details on the methodology and benchmark values were not available and the programme has thus been excluded from this comparative assessment.

BREEAM-NOR is an environmental sustainability programme led by the Norwegian Green Building Council (NGBC) and adopts BREEAM to a Norwegian context [13]. BREEAM-NOR has goals on cutting GHG emissions from the Norwegian construction industry by 55% in 2030 and 95% in 2050. A report on climate friendly building materials [37] has been used to develop BREEAM-NOR v6.0's MAT01 sustainable material choice criteria and GHG emission calculator [13] as well as the directorate for administration and financial management (DFØ)s GHG emission calculator for buildings [38]. The scope is limited to life cycle modules A1-A4 and B4 and provides benchmark values for a range of building types, the benchmark value for residential buildings is 480 $kgCO_2e/m^2$ or 8 $kgCO_2e/m^2/yr$.

3. Method

This paper compares approaches to developing GHG emission benchmark values for Norwegian buildings in terms of system boundaries and methodological aspects. The scope of system boundaries includes building typologies, life cycle modules and building parts. Methodological aspects include reference study period, biogenic carbon, carbonation, time-weighting, and technology-weighting. Information is gathered through collecting official documentation and guidelines on the various approaches, and reporting results in a tabular format. The results from the comparative assessment are then discussed. In addition, the various benchmark values are tested against a residential development in Ydalir, Hedmark, Norway. Ydalir is one of nine FME ZEN pilot areas. The residential development consists of 13 timber-framed terraced housing units, ranging from 54 to 126 m^2 in heated floor area (1510 m^2 in total). Previously, a holistic sustainability assessment of the development was carried out, more details can be found in [39,40]. The results from this previous study show total GHG emissions of 7.0 – 7.7 $kgCO_2e/m^2/yr$ (depending on whether the building is built to passive house standard or TEK (following Norwegian regulations as per 2017, respectively), with material emissions between 1.7 – 2.3 $kgCO_2e/m^2/yr$ (TEK and passive house standard, respectively).

4. Results

Despite all the approaches following NS 3720 and NS 3451, the results show large differences in system boundaries and methodologies which leads to a disparity in benchmarking values, see Table 1. Figure 1 presents the GHG emission benchmark values for different Norwegian building typologies. Commonality between the approaches includes a minimum of residential buildings, life cycle modules A1-A3 and B4, and building parts 21 – 26, 28 and 47. All approaches have a reference study period of 60 years and consider biogenic carbon and carbonation (except TEK). For that reason, these parameters have been used for the comparison of benchmark values against Ydalir in Figure 2.

Figure 1 shows that the various approaches have all established GHG emission benchmark values for materials (A1-A3, B4-B5) for residential buildings, ranging from 156 – 480 $kgCO_2e/m^2/yr$ or 2.6 – 8 $kgCO_2e/m^2/yr$. The FutureBuilt Zero GHG emission benchmark values do not distinguish between building typologies, and therefore have the same value across all building typologies (256 $kgCO_2e/m^2$ or 4.3 $kgCO_2e/m^2/yr$ in 2022). FutureBuilt Zero has the most ambitious GHG emission benchmark value for residential buildings since it is based on a 50% reduction compared to current practice. BREEAM-NOR v6.0 has the most comprehensive set of GHG emission benchmark values for different Norwegian building typologies and includes an option for buildings with/without heated basements. FME ZEN is the only approach to consider a GHG emission benchmark value for rehabilitation projects.

Table 1. Comparative assessment of system boundaries and methodology for TEK and various approaches to GHG emission benchmarking values in Norwegian buildings.

	Norwegian building code (TEK)	Ydalir Masterplan	FutureBuilt	BREEAM-NOR	FME ZEN
Method	NS 3720	NS 3720	NS 3720	NS 3720	NS 3720
Building typologies					
- Residential	*Apartments only*	*Yes*	*Yes*	*Yes*	*Yes*
- Commercial	*Yes*	*No*	*Yes*	*Yes*	*No*
- Office	*No*	*No*	*Yes*	*Yes*	*Yes*
- School	*No*	*Yes*	*Yes*	*Yes*	*Yes*
- Nursery	*No*	*Yes*	*Yes*	*No*	*Yes*
- Nursing home	*No*	*No*	*Yes*	*Yes*	*No*
- Heated basement	*No*	*No*	*Yes*	*Yes*	*No*
- Unheated basement	*No*	*No*	*Yes*	*Yes*	*No*
- Rehabilitation	*No*	*No*	*Yes*	*No*	*Yes*
Life cycle modules					
A1-A3	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
A4	*Yes*	*Optional*	*Yes*	*Yes*	*No*
A5	*Waste only*	*No*	*Yes*	*No*	*No*
B1	*No*	*No*	*Yes*	*No*	*No*
B2	*No*	*No*	*Yes*	*No*	*No*
B3	*No*	*No*	*Yes*	*No*	*No*
B4	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
B5	*Yes*	*No*	*Yes*	*Yes*	*No*
B6	*No*	*Yes*	*Yes*	*No*	*No*
B8	*No*	*No*	*No*	*No*	*No*
C1-C4	*No*	*Optional*	*Yes*	*No*	*No*
D	*No*	*Yes*	*Yes*	*No*	*No*
Building parts (NS 3451)					
- 21 Groundworks and foundations	*Pile and direct foundations only*	*Yes*	*Yes*	*Yes*	*Yes*
- 22 Load-bearing system	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
- 23 Outer walls	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
- 24 Inner walls	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
- 25 Slabs	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
- 26 Roof	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
- 28 Balconies and stairs	*No*	*Yes*	*Yes*	*Yes*	*Yes*
- 47 Photovoltaics	*No*	*Yes*	*Yes*	*Yes*	*Yes*
Reference study period	50	60	60	60	60
Biogenic carbon	No	Yes	Yes	Yes	Yes
Carbonation	No	Yes	Yes	Yes	Yes
Time-weighting	No	No	Yes	No	No
Technology-weighting	No	No	Yes	No	No

Figure 2 compares the GHG emission results from material use (A1-A3, B4-B5) in Ydalir for two scenarios: TEK and passive house, compared to the GHG emission benchmark values for materials (A1-A3, B4-B5) for residential buildings across the various approaches. It should be noted that Ydalir TEK and passive house scenarios are highly optimised to reduce WLC GHG emissions. The reason why Ydalir TEK has lower GHG emissions from material use compared to Ydalir passive house is because these results only consider material GHG emissions from life cycle modules A1-A3, B4-B5 and less insulation material and thinner walls are used in the TEK scenario. More information on Ydalir TEK and Ydalir passive house can be found in [39,40]. The results show that Ydalir TEK and Ydalir passive house have lower GHG emissions than the benchmark values presented in all approaches.

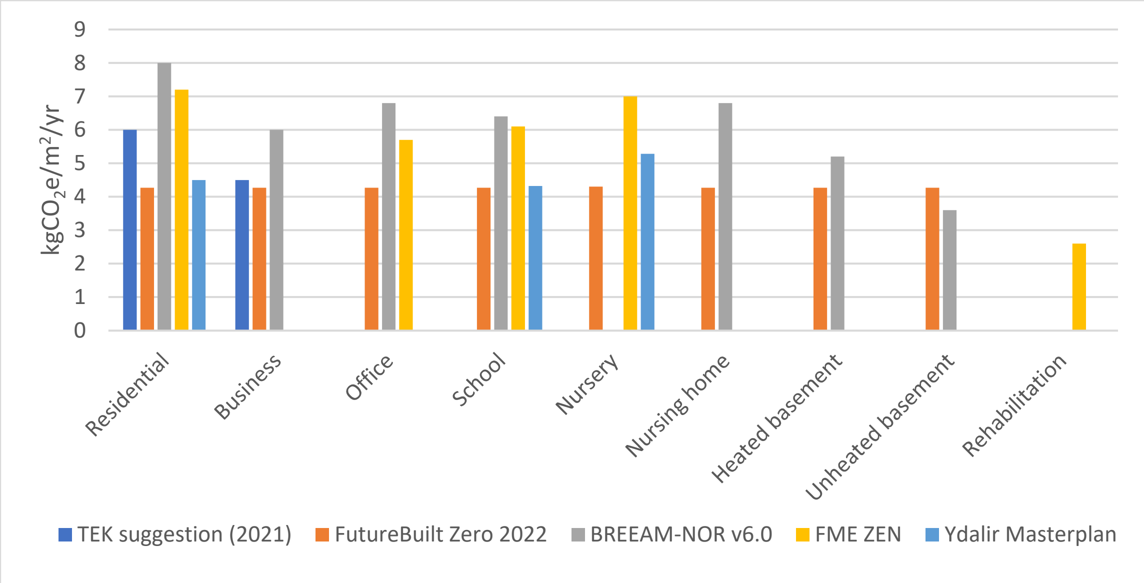

Figure 1. Comparison of GHG emission benchmark values for materials (A1-A3, B4-B5) across different Norwegian building typologies.

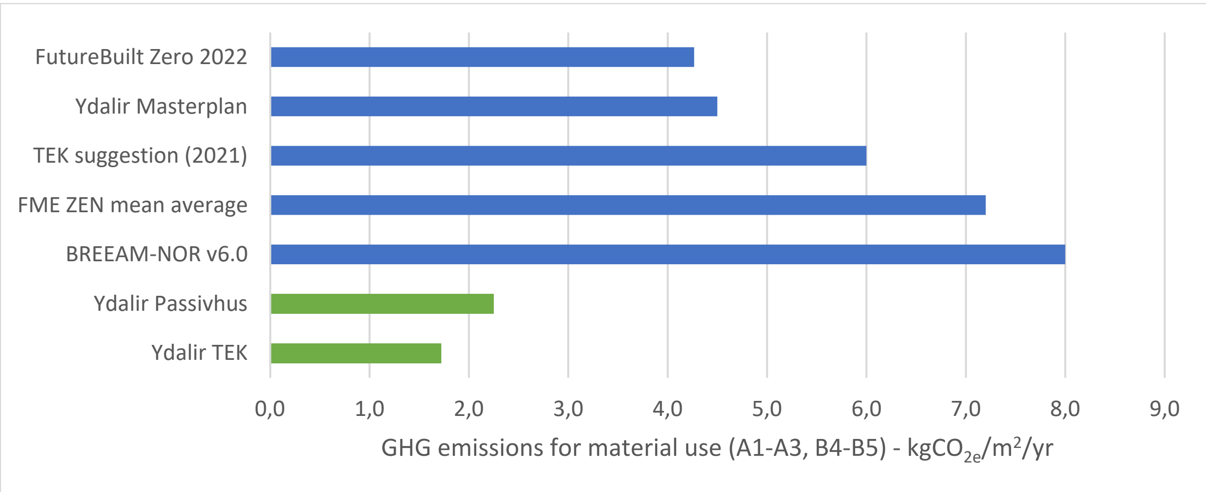

Figure 2. Comparison of GHG emission benchmark values for materials (A1-A3, B4-B5) and material GHG emission results for Ydalir.

5. Discussion

This comparative assessment demonstrates that all the approaches follow NS 3720 and NS 3451, and that there is a degree of overlap, which makes it easier to interpret and compare results. However, the thematic approach used in NS 3720 and ZEB-OM ambition level (covering operational energy use and materials) has led to LCA practitioners reporting embodied GHG emissions from materials as an aggregated result, which in turn has led to an aggregated benchmark value for materials (A1-A3, B4-B5) instead of per life cycle module, which makes it challenging to establish separate benchmark values for production (A1-A3) and replacement (B4). In addition, the basic level in NS 3720 has led to a minimum reporting of just the building envelope and does not encourage practitioners to include technical systems or infrastructure in GHG emission calculations. Such observations indicate that it may be time to revise NS 3720, despite being a relatively new standard, and increase the basic level of reporting to facilitate for the development of benchmark levels for all life cycle modules and building parts. The results show that there are large differences in system boundaries and methodologies, which leads to higher levels of uncertainty. Some of the methodological differences include biogenic carbon in biomaterials, carbonation of cement-based products, time- and technology-weighting. Other methodological choices that fall outside the scope of this study include land use and land use change, energy production emission factors, allocation of district heating, export of own production and mobility. These methodological choices become relevant when the system boundary for GHG emission benchmark values is expanded to the WLC, and highlights scope for further work.

A disadvantage of the approach used in Ydalir Masterplan, is that it requires project-specific benchmark values to be developed for each building typology in the development. This is a laborious process, which is difficult to implement on a larger scale and difficult to quality assure and compare. Establishing national benchmark values will eliminate these issues.

The comparison of benchmark values to Ydalir TEK and passive house may be biased towards the Ydalir Masterplan and FME ZEN since the residential development is a ZEN pilot area and was designed according to the requirements outlined in the Ydalir Masterplan. It should also be noted that the Ydalir Masterplan will be revised according to methodological changes and latest developments in the ZEN definition, assessment criteria and key performance indicators [34]. One weakness in directly comparing benchmark values against Ydalir TEK and passive house is that the GHG emission results from Ydalir have not been adapted to the different methodologies presented in Table 1, as illustrated by the differences in time- and technology-weighting in the FutureBuilt Zero approach, or the shorter reference study period in TEK since this will require considerably more work for the property developer. It is expected that time- and technology-weighting will have little effect on the results from Ydalir TEK and passive house since this would only apply to GHG emissions from replacement or refurbishment in life cycle modules B4 and B5, which corresponds to around 1% of WLC GHG emissions.

An observation from the comparative assessment has highlighted differences between the various approaches and requirements in TEK. It is suspected that this disparity in methodological choices can be explained by DIBKs efforts to harmonise national GHG emission calculations for buildings with Nordic and European systems, which differ from the methodological development and development of benchmark values in Norway. Examples of this are highlighted in DIBKs GHG emission calculation guidelines [28], whereby the system boundary is limited to direct and pile foundations instead of including all groundworks and foundations, and changing the reference study period to 50 years when 60 years is common practice in the Norwegian construction industry. FME ZEN has given feedback to DIBK regarding these methodological choices since it will have far reaching consequences for, for example, Norwegian environmental product declarations (EPDs) which is the main input for building LCA calculations in Norway, since Norwegian EPDs typically develop LCA scenarios based on a 60 year references study period for buildings [41].

All the approaches assessed in this study are part of a larger system for environmental sustainability assessment of Norwegian buildings and/or neighbourhoods. The results from this comparative assessment highlight the need for a consistent approach to developing GHG emission benchmarks and the need for the development of benchmark values for the WLC. This comparative assessment is not exhaustive but covers the main approaches used in Norway for establishing GHG emission benchmarking levels in buildings. This study provides useful information for project owners to help navigate the different benchmarking approaches available. Further work is required to harmonise these approaches and create an accepted branch standard for the benchmarking of GHG emissions from buildings for the construction industry in Norway. Such parameters that can be harmonised include building typology, system boundary, life cycle modules, building lifetime, building parts, biogenic carbon, carbonation, time-weighting, and technology-weighting. A harmonised approach will simplify the calculation workload for practitioners. The Ydalir Masterplan benchmark values are not suited for wide-spread implementation since they are project-specific. An ideal solution would be for TEK to set national benchmark values for all building typologies, for all building parts across the whole life cycle of a building using the NS 3720 method. However, NS 3720 was originally published in 2018, and there has since been methodological developments in fundamental international standards such as EN 15804:2012+A2:2019/AC:2021 for EPDs and EN 15978-1: 2021. It will be of benefit to revise NS 3720 to align with recent Nordic and EU methodological and benchmark value development. In addition, it would be of benefit to establish a national database for GHG emission accounting so that better benchmark values can be established in the future.

6. Conclusion

This assessment compares leading approaches to GHG emission benchmarking of buildings in Norway and provides a guide for practitioners to understand what is included in the various approaches. It also gives recommendations for the future harmonisation of methodologies and the development of a national GHG emission database for buildings to further develop future WLC benchmark values for buildings.

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