IOP Conference Series: Earth and Environmental Science

GHG emission requirements and benchmark values for Norwegian buildings

To cite this article: MK Wiik *et al* 2020 *IOP Conf. Ser.: Earth Environ. Sci.* **588** 022005

BEYOND 2020 – World Sustainable Built Environment conference IOP Publishing
IOP Conf. Series: Earth and Environmental Science **588** (2020) 022005 doi:10.1088/1755-1315/588/2/022005

GHG emission requirements and benchmark values for Norwegian buildings

MK Wiik[a], E Selvig[b], M Fuglseth[c], C Lausselet[d], E Resch[d], I Andresen[d], H Brattebø[d], U Hahn[e]

[a]SINTEF Community, Børrestuveien 3, 0373 Oslo, [b]Civitas, [c]Asplan Viak, [d]NTNU Department of Energy and Process Engineering, Trondheim, [e]Futurebuilt.
marianne.wiik@sintef.no

Abstract. As a response to the Paris agreement, Norway is committed to reducing greenhouse gas (GHG) emissions by 50 percent by 2030. Highly energy-efficient buildings have a greater proportion of embodied GHG emissions from material use (55-87%) compared to operational emissions. A new national standard, NS3720:2018 a methodology for greenhouse gas emission calculations for buildings, has harmonised the life cycle assessment (LCA) calculation of environmental impacts arising from Norwegian buildings and has led to an increase in LCAs. This paper aims to collect life cycle GHG emission data on Norwegian building case studies to help form recommendations for national GHG emission requirements and benchmark values that can be used by the Research centre for zero emission neighbourhoods in smart cities (FME ZEN), Futurebuilt and in Norwegian building codes (TEK). To do this, a statistical analysis of a reference sample is carried out to provide bottom-up derived reference values. Empirical life cycle GHG emission data results are collected from Norwegian building case studies in the reference, design and as-built project phases, sampled from Norwegian programmes and research centres such as Futurebuilt, Framtidens Byer, ZEB and ZEN. Altogether 133 Norwegian building cases have been gathered from 2009-2020, covering 1,023,738m^2 of heated floor area for 49,360 building users. A functional unit of '1m^2 of heated floor area over a building lifetime of 60 years is used. The results show an interquartile range of 240-492 kgCO$_{2eq}$/m^2 or 4-8.2 kgCO$_{2eq}$/m^2/yr, a median of 396 kgCO$_{2eq}$/m^2 or 6.6 kgCO$_{2eq}$/m^2/yr and a mean of 324 kgCO$_{2eq}$/m^2 or 5,4 kgCO$_{2eq}$/m^2/yr for all building typologies in the as-built phase. These results can be used to form initial indications for GHG emission requirements and benchmark values in Norway.

1. Introduction

The United Nation's sustainable development goals (UN SDG) focus on a range of issues to be addressed by society [1]; including sustainable cities and communities (SDG 11), responsible consumption (SDG 12) and climate action (SDG 13), which are also some of the issues addressed in this paper. As a response to the Paris agreement in 2015 [2], Norway is committed to reduce greenhouse gas (GHG) emissions by 50 percent by 2030 compared to 1990 levels. At the European level, the revised directive on Energy Performance of Buildings (EPBD) requires that all new buildings should be nearly zero energy by 2020 [3, 4]. For most passive houses, GHG emissions from the production of building materials are equal to the emissions from operation throughout the building lifetime [5]. However, research shows that highly energy-efficient buildings have a greater proportion of embodied GHG emissions from material use (55-87% of embodied GHG emissions) where the building envelope makes up ca. 65%, and that construction phase emissions can equal operational energy use emissions [6-8]. NS3720:2018, a methodology for GHG emission calculations for buildings, has harmonised the life cycle assessment (LCA) calculation of environmental impacts arising from buildings in Norway [9], and has led to an increase in life cycle GHG emission assessments of Norwegian buildings. Creating national benchmarking and target values for buildings from this data will be a valuable resource for the decision-making process in improving the environmental performance of buildings [10].

The aim of this paper is to collect life cycle GHG emission data on Norwegian building case studies to help form recommendations for national GHG emission requirements and benchmark values for different Norwegian building typologies that can be used by the Research Centre on zero emission neighbourhoods in smart cities (ZEN Research Centre), Futurebuilt and in Norwegian building codes (TEK) [11, 12]. The paper starts by outlining the background and methodology for data collection and developing national greenhouse gas emission requirements and benchmark values, it then presents the results. A discussion on data collection and the development of GHG emission requirements and benchmark values takes place before concluding remarks are given.

2. Background

The world green building council (WGBC) urges governments to commit to occupying only certified net-zero carbon buildings before 2030 and encourages NGOs to develop certification programmes for net-zero carbon buildings as well as create roadmaps, incentives and tracking systems for the rapid development of net-zero carbon buildings [13]. They envision all new buildings, infrastructure and renovations to have 40% less embodied carbon and be zero operational carbon by 2030, and that all new buildings, infrastructure and renovations will have net-zero embodied and operational carbon by 2050 [14]. The WGBC define a net-zero embodied carbon building as highly resource-efficient with upfront carbon minimised to the greatest extent possible and all remaining embodied carbon reduced or, as a last resort, offset to achieve net-zero across the life cycle [14]. Building life cycle assessments (LCA) have commonly been used in building certification programmes such as LEED (US) [15], DGNB (Germany) [16], BREEAM (UK) [17] and Level(s) (EU) [18]. The International Energy Agency (IEA) Energy in Building and Communities (EBC) Annex 57 has analysed over 80 building case studies and found that the product stage (A1-A3) dominates total embodied emissions at 64%, followed by replacements (B4) at 22% and waste treatment and disposal (C3-C4) at 14% [19]. They also found that embodied GHG emissions for the product stage are around 2.1 $kgCO_{2eq}/m^2/yr$ for refurbished buildings (3.8 when including replacements), 3.5-6.6 $kgCO_{2eq}/m^2/yr$ for office buildings, 3-5.3 $kgCO_{2eq}/m^2/yr$ for residential buildings and 2.5-10 $kgCO_{2eq}/m^2/yr$ for school buildings [19]. To follow, IEA EBC Annex 72 will assess life cycle related environmental impacts caused by buildings from 2016 - 2021 [20, 21]. In addition, the forthcoming ISO 21678 offers a method for the development of benchmarks for sustainable buildings [22].

In 2013, the Netherlands became the first European country to introduce legislative requirements to report embodied material impacts from buildings [23]. Hollberg et al. discuss how environmental benchmarks can support the design process and present a method for combining a top-down and bottoms-up approach to encourage design guidance at the material or element level [24]. In Switzerland, the Swiss energy efficiency path provides target values for operational, mobility and embodied impacts based on a top-down approach [25]. Another study ascertained reference values from 24 statistically-based dwelling archetypes, representative of the EU housing stock, and found that dwellings typically contribute 6.36 tCO_{2eq}/yr (covering modules A1-A5, B4, B6, C1-C4) when considering a 100-year building lifetime [26]. In 2016, in France, an LCA-based labelling scheme 'energie positive and réduction carbone (E+C-)' was established and later guidance values were identified from 40 low-energy houses at 8.4 $kgCO_{2eq}/m^2/yr$ given a 50-year building lifetime [27]. Similarly, the Swedish Green Building Council is developing a benchmarking tool for residential buildings. Early indications already show a benchmark level between 220-262 $kgCO_{2eq}/m^2$ which equates to 3.6-4.4 $kgCO_{2eq}/m^2/yr$ when considering a 60-year building lifetime. From 2022, Sweden will require the use of environmental product declarations (EPD) for all new buildings, excluding single-family homes [28]. Denmark has developed benchmark GHG emission values based on 7 residential buildings (A1-A3, B4, B6, C3-C4) of which 6 $kgCO_{2eq}/m^2/yr$ are embodied emissions and 2.17 $kgCO_{2eq}/m^2/yr$ are operational emissions, based on a

120-year building lifetime [10]. Italy has also developed benchmark GHG emission values based on 28 residential buildings (A1-A5, B4, B6, B7, C2-C4) of which 3.8 $kgCO_{2eq}/m^2/yr$ are embodied emissions and 10.4 $kgCO_{2eq}/m^2/yr$ are operational emissions, based on a 100-year building lifetime, and using natural gas for heating [10]. GHG emissions from New Zealand residential and office buildings need to be reduced by at least 67% to operate within their shares of the global carbon budget, whereby New Zealand detached residential buildings have a climate target of 71 tCO_{2eq} over a 90-year lifetime [29]. One previous study reviewed LCA results of 95 residential buildings and found total embodied emissions for buildings ranged between 3.0 – 17.5 $kgCO_{2eq}/m^2/yr$ (adjusted for a 60-year building lifetime) [30]. Another study reviewed 200 buildings and found total embodied emissions ranged between 4.2 - 11.7 $kgCO_{2eq}/m^2/yr$ [31]. The study also found that healthcare buildings have typically higher embodied emissions and that hotels have similar embodied emissions to residential buildings [31]. Another study systematically reviews 650 LCA studies and finds embodied emissions are escalating as buildings become more energy efficient [32]. The Czech Republic combine a top-down and bottom-up approach to obtain climate goals in accordance with the Paris Agreement, and found that the bottom-up analysis exceeds the top-down goal by a factor of 2.5 [33]. The Norwegian Green Building Council is also working towards 'Paris proof buildings' in BREEAM-NOR, and defines it as a building that uses materials with low CO_2 emissions from production and transport, low operational energy use, uses renewable energy sources, has a fossil or rather emission-free construction site and facilitates for public and fossil or rather emission-free transport [34].

3. Method

LCA is an established methodology for assessing the environmental performance of buildings [9, 35-37]. The methodology used in this paper, involves collecting empirical life cycle GHG emission results from Norwegian building case studies sampled from Futurebuilt [5, 38], Framtidens Byer and Framtidens Bygg [39], the zero emission building (ZEB) research centre [40] and the ZEN Research Centre's industry partners [11]. A meta-analysis has been carried out for a total of 133 Norwegian building cases, which have been collected from 2009-2020, covering in total 1,023,738m^2 of heated floor area for 49,360 building users. Some of the cases are variations of the same building, however, using different sets of data. Each case study has calculated embodied GHG emission results in either Simapro [41], klimagassregnskap.no (KGR, a precursor to OneClick LCA) [42], OneClick LCA [43] or the MS Excel-based ZEB tool for GHG emission calculations developed by the ZEB Research Centre [44], all of which follow to some degree the LCA methodology outlined in [9, 36, 37]. All studies have the same functional unit, but the gathered data has not been further harmonised, which may lead to a variation in results due to varying practices and tools used. The data has then been used to perform a statistical analysis to provide bottom-up derived reference values, with minimum values, maximum values, 5th, 25th, 75th and 95th percentiles, as well as mean and median values. In the forthcoming ISO 21678, a limit value is defined as the lowest value of acceptable performance, and in this study that is the 75th percentile; the reference value is defined as state-of-the-art or business as usual, in this study this is the median value; whilst the target value represents the upper limit of the scale of what is theoretically possible, in this case the 5th percentile. Building typologies include 1 library, 4 museums, 15 nurseries (kindergartens), 6 nursing homes, 25 offices, 37 residential buildings, 39 schools, 2 swimming pools, 3 sports halls, 1 hotel and 1 neighbourhood, of which 14 cases are refurbishment projects. GHG emission results are reported, where available, in terms of project phases (i.e. reference, design and as-built), per life cycle module and per building part according to NS 3720 and NS 3451 [9, 45]. Tests were performed to determine if the difference between the means of the project phases, as well as between building typologies, were statistically significant. Other important data, available to various degrees for each case, includes location, year, GHG emission calculation tool used, building typology (according to [46]), number of users, number of floors, and floor areas: gross floor area, built-up area, heated floor area and net floor area according to NS 3940. Embodied GHG emissions are reported in terms of global warming potential (GWP) impacts with a functional unit of '1m^2 of heated floor area over a building lifetime of

60 years' (kgCO_{2eq}/m^2/yr). A preliminary screening of the LCA results has allowed the authors to narrow the scope of this research to life cycle modules A1-A3 and B4.

4. Results

Figure 1 shows the embodied material emissions (A1-A3, B4) for 59 case studies that reported data for the as-built phase. The figure also illustrates which calculation tools have been used over time, according to methodological development, and the temporal introduction of new standards and calculation tools. and the development of calculation tools. The results show a decrease in emissions from 2012/13 at the time in which EN15804 and EN15978 are introduced, as well as klimagassregnskap.no v.4 with an improved emission factor database and the introduction of the ZEB tool. This result is likely a result of the introduction of more standardised data sources from for example environmental product declarations (EPDs) and the Ecoinvent database. It will be interesting to see what influence the introduction of NS3720 and the current wide-spread use of OneClick LCA since 2018 will have on future life cycle GHG emission calculations and results in Norway. The German EPD foundation, IBU, has also observed that selecting products with EPDs have a positive impact on the ecological footprint of a building [47]. Figure 1 presents two anomalies of high embodied emissions compared to the other case studies. The first case did not optimise material emissions during the design process and incorporated large amounts of exposed concrete to utilise its thermal mass properties. The other case included a detailed material inventory of all technical equipment, thus leading to higher embodied emissions from technical equipment. Renovation projects (pink) have significantly lower emissions compared to new buildings.

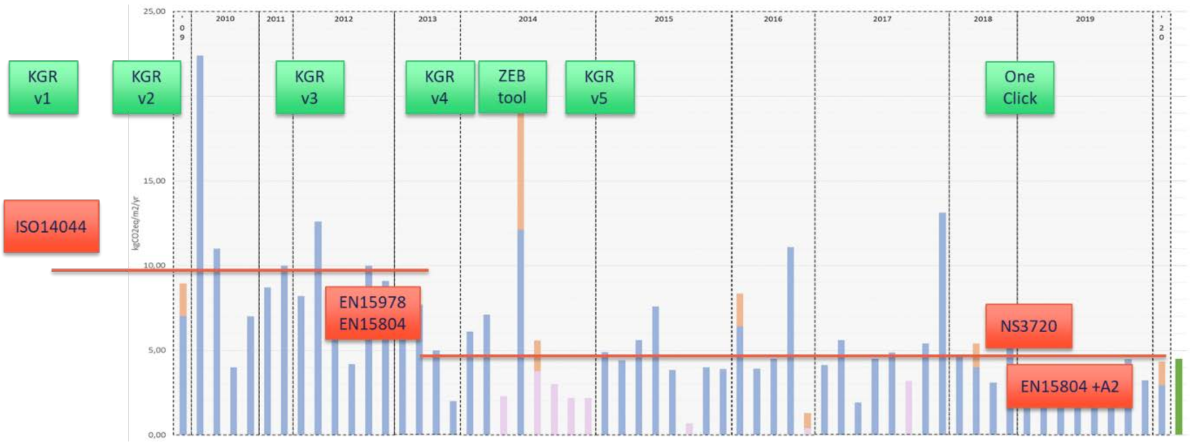

Figure 1: Embodied GHG emissions for life cycle modules A1-A3 (blue) and B4 (orange) in the as built phase in chronological order. All case studies from Futurebuilt have aggregated embodied material emissions into one score (blue). Renovation projects are shown in pink. The average for all cases is shown in green.

Figure 2 presents the statistical results from the building case studies grouped by project phases (reference, design and as-built) for all buildings and by building typologies that had more than ten cases, in addition to refurbishments. When excluding refurbishments, the reduction between the reference, design and as built phases are all statistically significant ($p \leq 0.005$, paired t-tests), while the difference between the means of building types is not significant ($p \geq 0.47$, t-tests, and $p=0.89$, ANOVA). These results indicate that benchmark values should be harvested from statistical results for design or as-built project phases, and with all buildings as empirical basis. Later, when a larger population of cases are available, one could use benchmark values for different building typologies, if the data value differences are statistically significant. The results show an interquartile range of 240-492 kgCO_{2eq}/m^2 or 4-8.2 kgCO_{2eq}/m^2/yr, a median of 396 kgCO_{2eq}/m^2 or 6.6 kgCO_{2eq}/m^2/yr and a mean of 324 kgCO_{2eq}/m^2 or 6 kgCO_{2eq}/m^2/yr for all building typologies in the as built phase. There are major outliers in the higher end of the distribution, since the median is lower than the mean. This points to using the median instead of the mean as a reference value. The results show significantly lower embodied emissions from refurbishment projects ($p<0.007$, t-tests) since load-bearing materials are not replaced. It was observed that all nursery cases are of a similar size, with timber construction, and built to passive house standards. Thus, there is less variation in the statistical analysis of nursery buildings.

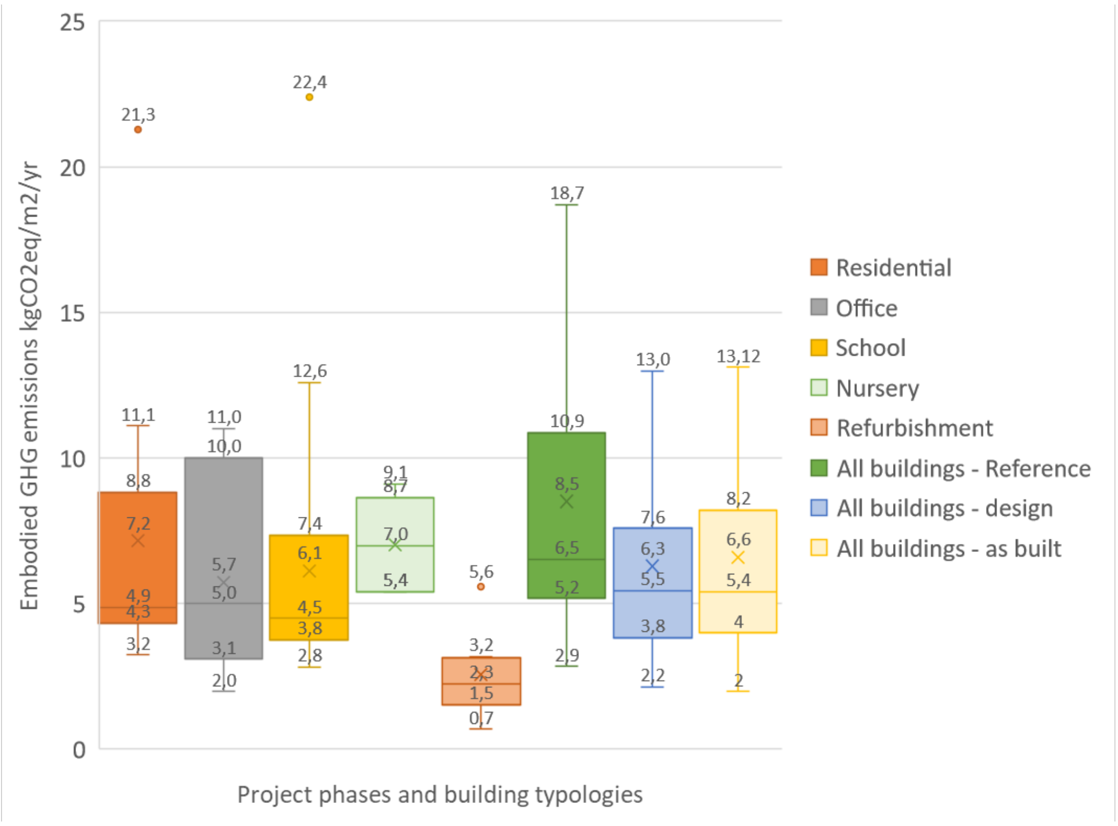

Figure 2: Boxplot of embodied GHG emissions across different project phases and building typologies (A1-A3, B4).

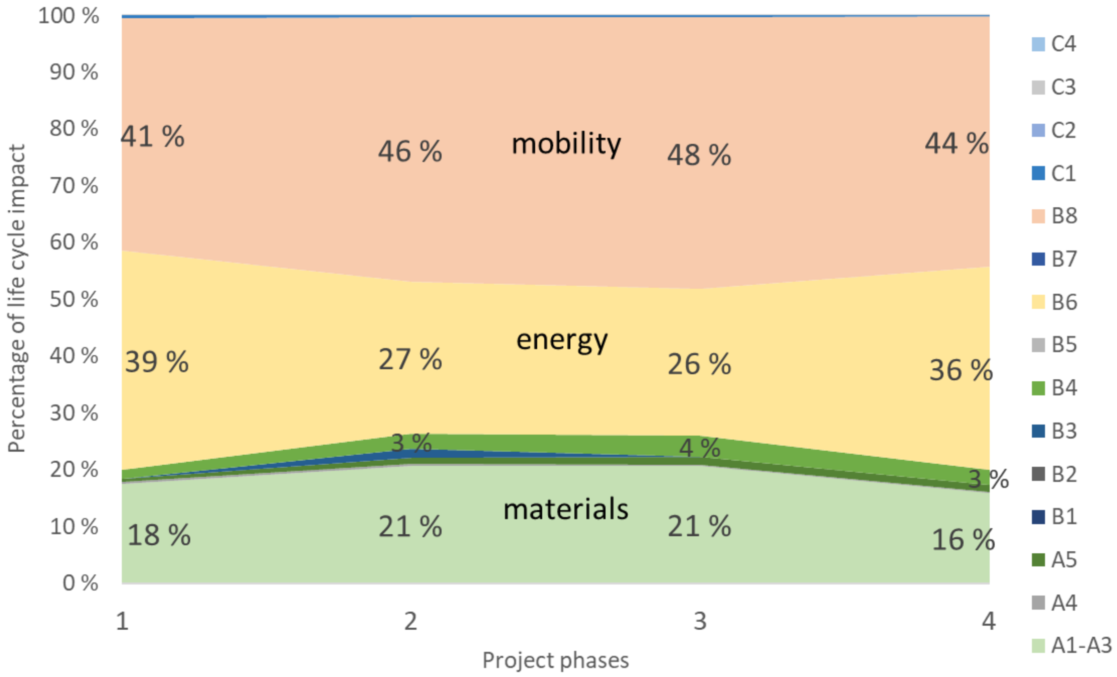

Figure 3: Life cycle total impact (A1-C4) across project phases, whereby 1) reference, 2) design 3) as-built and 4) in-use phase.

Figure 3 shows the life cycle impacts from A1-C4 across project phases and confirms there is a lower share of impacts from life cycle modules B1-B4 and C. However, these modules are typically underreported in Norwegian building LCAs. A4-A5 emissions are only now beginning to be documented in the design and as-built phases. Arguably, production phase emissions occur today and are more important for emission reduction targets. The proportion of embodied material emissions (A1-A3, B4) is fairly constant across project phases (ca. 25%), whilst the proportion of operational energy emissions (B6) are estimated high in the reference phase (39%), predicted at a reduced proportion in the design and as-built phases (ca. 26%), and rise slightly when measured in the operational phase (36%). The proportion of operational transport emissions i.e. transport activity of building users over its lifetime (B8), increases across the project phases (from 41-48%).

5. Discussion

Buildings are by nature complex products for LCA involving often thousands of processes. This is challenging as many variables need to be harmonised to establish benchmarks; for example building design parameters such as typology, context, location, climate, function, design, technology, materials and stakeholders, as well as methodological considerations such as system boundaries, scenarios, background data, inventory completeness, functional unit, reference study period, reference service lifetimes, electricity mix, definition of area, data quality, and LCI databases. However, in reality, building designs will vary and LCAs will be carried out by different stakeholders, so any proposed benchmarks should consider this to be robust. It is preferable to set benchmarks at the whole building level since CO_{2eq} emission requirements set at the material production level only do not account for consumed material quantities or the function of materials in terms of the building context. One suggestion involves using the results of this study to form environmental performance classes e.g. A, B, C, D, E whereby E corresponds to the limit value (75th percentile), C to the reference value (median) and A to the target value (5th percentile). Benchmark values may allow professionals to compare and optimise their projects relative to current common practice and encourages no single solution for optimised environmental performance. The results are in line with the benchmark values observed in IEA EBC Annex 57, ranging from 4-8.2 $kgCO_{2eq}/m^2/yr$ in the as built phase. For refurbishment projects our (Norwegian) results are slightly lower (2.3 $kgCO_{2eq}/m^2/yr$), for office buildings our range is slightly wider (3.1-10 $kgCO_{2eq}/m^2/yr$), for residential buildings our results are slightly higher (4.3-8.8 $kgCO_{2eq}/m^2/yr$) whilst for school buildings our results have a slightly narrower range (3.8-7.4 $kgCO_{2eq}/m^2/yr$). The reasons for these differences are unclear and require further study. There is also a need for validating, and harmonising details in the approaches and methodologies across the 133 Norwegian cases.

This study presents the largest known survey to date of embodied GHG emissions from Norwegian buildings. In Norway, there are 4.2M buildings (covering 5490 km^2 of developed land (this study covers 0.02%)), of which 1.5M are residential, 39,000 office and 48,000 school buildings. Norway has a population of 5.3 million (this study covers 0.9%). The gathered LCA studies are detailed, and contain data collected by third parties that was available at the time of the study. The database may be too small a sample to draw robust conclusions on a national level. The study is also subject to convenience and may represent extreme sampling, since the cases are the ones we happened to gain access to, and they are exemplary buildings from programmes such as Futurebuilt and the ZEB Research Centre that strive for reduced energy and low material and transport emissions, and they document this through LCAs, which is not yet common practice in Norway. However, we assume that results for the reference project phase are more representative of business as usual, whilst the design and as-built phases show the potential of what is possible to achieve today. However, the various project phases are subject to data quality and availability (e.g. material quantities) at the time calculations were carried out.

The results from such a bottom-up approach are subject to variability due to technological differences across cases, also over time. Resch et al. introduce the concept of technological improvement factors for future emission reductions in material production and transport [48]. Technological improvements can arise from material, production and transport technology, recycling rate, prefabrication, automation, the electrification of processes and the decarbonisation of the electricity grid. Here, technological vectors are modelled as linear decreases, 50% lower for production and 90% lower from transport in 60 years [49]. These factors may be applied to future development of CO_2 emission requirements and benchmark values instead of or as well as relying on a large sample of case studies. Scope for further work may also include recalculating benchmark values when a larger body of LCAs are available so that benchmarks can be developed for different building typologies, expanding the study to more life cycle modules so that benchmarks can be developed for the whole life cycle, and combining the results from this study with a top-down approach to develop performance targets in accordance with the Paris Agreement.

6. Conclusion

The results of this research are useful to help form initial indications for GHG emission requirements and benchmark values in Norway and may be used in either future Norwegian building codes (e.g. TEK20), by Futurebuilt and as benchmark values applicable in the ZEN Research Centre. Statistical significance test results indicate no statistical difference between building typologies, on the basis of a population of 133 cases, and that one should use emission data from the design or as-built project phases of buildings.

References

[1] United Nations General Assembly. Transforming our world: the 2030 agenda for sustainable development online: United Nations; 2015

[2] United Nations General Assembly. United Nations Climate Change Conference Paris2015.

[3] Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings, (2010).

[4] IPCC 2013. The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. 2013.

[5] Futurebuilt. Futurebuilt 10 years. Futurebuilt annual report 2019. Oslo: 07 Media; 2019.

[6] Selvig E., Wiik M. K., Sørensen Å. L. Campus Evenstad - Jakten på nullutslippsbygget ZEB-COM. 2017.

[7] Wiik MK, Fufa SM, Kristjansdottir T, Andresen I. Lessons learnt from embodied GHG emission calculations in zero emission buildings (ZEBs) from the Norwegian ZEB research centre. Energy and Buildings. 2018;165:25-34.

[8] Wiik MK, Sørensen ÅL, Selvig E, Cervenka Z, Fufa SM, Andresen I. ZEB Pilot Campus Evenstad. Administration and educational building. As-built report. The Research Centre on Zero Emission Buildings. ZEB Project report no 36.; 2017

[9] NS 3720. Method for greenhouse gas calculations for buildings. Standard Norge; 2018.

[10] Rasmussen FN, Ganassali S, Zimmermann RK, Lavagna M, CAmpioli A, Birgisdottir H. LCA benchmarks for residential buildings in Northern Italy and Denmark - learnings from comparing two different contexts. Building Research and Information. 2019.

[11] ZEN FME ZEN - The research centre on zero emission neighbourhoods in smart cities 2016 [Available from: https://www.ntnu.no/zen and http://fmezen.com/.

[12] TEK 17. The Norwegian building regulations (Byggteknisk forskrift, TEK 17). 2017.

[13] Laski J, Burrows V. From Thousands to Billions. Coordinated action towards 100% net zero carbon buildings by 2050. online: WGBC; 2017.

[14] Adams M, Burrows V. Bringing embodied carbon upfront. Coordinated action for the building and construction sector to tackle embodied carbon. online: WGBC; 2019.

[15] USGBC. LEED v4.1 online: USGBC; 2019 [Available from: https://build.usgbc.org/leed-v41.

[16] Konig H, Cristofaro LD. Benchmarks for life cycle costs and life cycle assessment of residential buildings. Building Research & Information. 2012;40:558-80.

[17] BREEAM-NOR. BREEAM-NOR New Construction 2016. Technical Manual SD5075NOR, Norwegian Green Building Council. 2016.

[18] Dodd N, Cordella M, Traverso M, Donatello S. Level(s) - A common EU framework of core sustainability indicators for office and residential buildings. online: JRC; 2017.

[19] Moncaster AM, Rasmussen FN, Malmqvist T, Wiberg AH, Birgisdottir H. Widening understanding of low embodied impact buildings: Results and recommendations from 80 multi-national quantitative and qualitative case studies. Journal of Cleaner Production. 2019;235:378-93.

[20] Birgisdottir H, Moncaster A, Wiberg AH, Chae C, Yokoyama K, Balouktsi M, et al. IEA EBC Annex 57 'Evaluation of Embodied Energy and CO2eq for Building Construction'. Energy and Buildings. 2017;154.

[21] IEA EBC. IEA EBC Annex 72 - Assessing Life Cycle Related Environmental Impacts Caused by Buildings online2016 [Available from: http://annex72.iea-ebc.org/

[22] ISO/DIS 21678. Sustainability in building and civil engineering works - Indicators and benchmarks - Principles for the development and use of benchmarks. Switzerland: ISO 2019.
[23] Scholten N, van Ewik H, editors. Environmental performance regulations in the Netherlands. 4th International Conference Civil Engineering`13 Proceedings; 2013 Jelgava: Latvia University of Agriculture Faculty of Rural Engineering.
[24] Hollberg A, Lutzkendorf T, Habert G. Top-down or bottom-up? - How environmental benchmarks can support the design process. Building and Environment. 2019;153:148-57.
[25] SIA. SIA-Effizienzpfad Energie (SIA 2040). 2017.
[26] Lavagna M, Baldassarri C, Campioli A, Giorgi S, Valle AD, Castellani V, et al. Benchmarks for environmental impact of housing in Europe: Definition of archetypes and LCA of the residential building stock. Building and Environment. 2018;145:260-75.
[27] Lasvaux S, Lebert A, Achim F, Grannec F, Hoxha E, Nibel S, et al. Towards guidance values for the environmental perforamance of buildings: application to the statistical analysis of 40 low-energy single family houses' LCA in France. International Journal of Life Ccle Assessment. 2017;22(5):657-74.
[28] Boverket. Klimatdeklaration vid uppförande av byggnad online: Boverket; 2019
[29] Chandrakumar C, McLaren SJ, Dowdell D, Jaques R. A top-down approach for setting climate targets for buildings: the case of a New Zealand detached house. IOP ConfSeries: Earth and Environmental Science. 2019;323.
[30] Chastas P, Theodosiou T, Kontoleon KJ, Bikas D. Normalising and assessing carbon emissions in the building sector. A review on the embodied CO2 emissions of residential buildings. Building and Environment. 2018;130:212-26.
[31] DeWolf C. Material Quantities in building structures and their environmental impact. Massachusetts: Massachusetts Institute of Technology; 2014.
[32] Rock M, Saade MRM, Balouktsi M, Rasmussen FN, Birgisdottir H, Frischknecht R, Habert G, Lutzkendorf T, Passer A. Embodied GHG emissions of buildings – The hidden challenge for effective climate change mitigation. Applied Energy. 2020; 258
[33] Palensky D, Lupisek A. Carbon benchmark for Czech residential buildings based on climate goals set by the paris agreement for 2030. Sustainability. 2019;11.
[34] Grønn byggallianse. Paris proof bygg og paris proof BREEAM. Hvordan bygge og drifte bygg så det monner i forhold til PArisavtalen. Oslo: GBA; 2018.
[35] ISO 14040. Environmental management - Life Cycle Assessment - Principles and framework. Geneva, Switzerland: International Organization for Standardization; 2006.
[36] ISO 14044. Environmental Management - Life Cycle Assessment - Requirements and Guidelines. Geneva, Switzerland: International Organization for Standardization; 2006.
[37] EN 15978. Sustainability of construction works - assessment of environmental performance of buildings - calculation method European Committee for Standardization, Belgium; 2011.
[38] Futurebuilt. Forbildeprosjekter online: Futurebuilt; 2016 [Available from: https://www.futurebuilt.no/Forbildeprosjekter
[39] Framtidens Byer. Prosjekter online: Norske Arkitekters Landsforbund; 2014 [Available from: https://www.arkitektur.no/framtidens-byer1
[40] ZEB. 2019 [Available from: http://www.zeb.no/.
[41] PRE Consultants. Simapro. LCA software for fact-based sustainability: Simapro; 2019
[42] Statsbygg. Klimagassregnskap.no er under avvikling: Statsbygg; 2019
[43] Bionova. OneClick LCA: Bionova; 2018
[44] Wiik MK, Schlanbusch RD, Wiberg AH, Kristjansdottir T. ZEB tool - technical guide. Version 1. A tool for life cycle GHG emission calculations of buildings. 2017.
[45] NS 3451. Table of building elements. Oslo, Norway: Standard Norge; 2009.
[46] NS 3457-3. Klassifikasjon av byggverk. Del 3 bygningstyper. Oslo: Standard Norge; 2013
[47] Gantner J. IBU study shows that the use of products with an EPD has a positive impact on the ecological footprint of a building and its DGNB rating online: Fraunhofer Institute for Building Physics 2019.
[48] Resch E, Lausselet C, Brattebø H, Andresen I. An analytical method for evaluating and visualizing embodied carbon emission in buildings. Building and Environment. 2019.
[49] Resch E. Embodied emission profiles of building types: guidance for emission reduction in the early phases of construction projects. 2019.