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A top-down approach for setting climate targets for buildings: the case of a New Zealand detached house

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Abstract. Climate change mitigation requires the construction of low/zero-carbon buildings, and this is a challenge for designers. The use of Life Cycle Assessment (LCA) provides useful information to support eco-efficiency improvements and therefore, to reduce the climate impacts of building designs. However, it does not provide information about whether a proposed design aligns with achieving the global climate target of limiting global warming to below 1.5°C or 2°C. This study, therefore, introduces an LCA-based top-down approach for setting climate targets for the whole life cycle of buildings in terms of greenhouse gas emissions. It involves assigning a share of the 2°C global carbon budget for 2018-2050 to a country, to the construction sector of the country, and finally to a building. The approach includes a stock model that accounts for the projected growth in the number of buildings and associated climate impacts in a country up to 2050. The proposed approach was applied to a detached house in New Zealand, the most common residential building type in the country; it was found that the climate target of a New Zealand detached house over a 90-year lifetime is 71 tCO_2eq. This modelling approach has potential to guide designers and other interested stakeholders in development of building designs enabling the building sector to operate within a selected global climate target (such as the 1.5°C or 2°C target).

1. Introduction

The construction sector fulfils several human needs (e.g. provision of housing, hospitals, schools and transport infrastructure), but mostly at the cost of a range of environmental impacts including climate change [1, 2]. For example, the sector uses 40% of global energy and therefore contributes around 30% of global greenhouse gas (GHG) emissions annually [1]. At the same time, due to the growing population and economic activities, the demand for construction is rapidly increasing globally and this will lead to more climate impacts in the future. Thus, it is timely to consider the issue of climate change mitigation for the construction sector.

Efforts to mitigate climate impacts from this sector in the past have tended to focus on the use phase of buildings. However, as energy use in the operation of buildings becomes more efficient and there is greater uptake of renewable energies, researchers are becoming more interested in opportunities to reduce the so-called "embodied GHG emissions" associated with the manufacturing of construction materials and to the construction, maintenance and end-of-life of buildings [3]. This requires analysis of the climate impacts associated with buildings (including materials and elements) throughout the complete life cycle [4, 5]. Life Cycle Assessment (LCA) accounts for all inputs, outputs and flows within the complete life cycle of a building and can be used for this type of analysis [6, 7]. Evaluating the climate impacts of a building using LCA is, however, not sufficient to mitigate climate change globally [3, 8], as LCA only provides information about the climate impacts of a building relative to another building and does not provide information about the building's performance in terms of any global climate target (or threshold) [9-13]. For example, building X may be considered better than building Y if it emits less GHG emissions over its lifetime; however, it may be that neither of them can be considered sustainable if their GHG emissions are more than their assigned shares of the global carbon budget. This insight has led researchers to focus on the development of benchmarks using a top-down approach [3-5, 14, 15]. A top-down benchmark, in general, aims to cascade global climate targets down to sub-global levels [5].

Some researchers have already calculated top-down benchmarks for buildings. For example, Zimmermann et al. [4] suggested that the climate impacts of a global citizen should be limited to 1 tonne carbon dioxide equivalent per capita per annum [$tCO_2eq/(c.a)$] by 2050 to stay within the 2 degree Celsius (°C) climate target, according to the *2000 Watt society vision* [16]. They subsequently set a climate target for a Swiss single-family house based on the relative share of household expenditure for residential buildings in Switzerland, following the sharing principle of *final consumption expenditure* [17]. Following this method, the climate target of a Swiss single-family house was 370 kilogram $CO_2eq/(c\cdot a)$ [$kgCO_2eq/(c\cdot a)$]. Another similar top-down approach, also based on the 2000 Watt society vision [16], was recently developed for Switzerland [3]. However, when assigning a share of the carbon budget (of 1 $tCO_2eq/(c.a)$ in 2050) to a residential building, Hollberg et al. [3] rather used the *grandfathering* sharing principle [13, 17], which assigned a share of the carbon budget to the residential sector based on its relative contribution to the national GHG emissions. According to this approach, the climate target of a Swiss single-family house was 360 $kgCO_2eq/(c\cdot a)$.

In another study, Brejnrod et al. [8] defined climate targets for a single-family house in Denmark (for the year 2010). They calculated the carbon budget available for a global citizen in 2010 (985 $kgCO_2eq/(c\cdot a)$ for 2°C and 522 $kgCO_2eq/(c\cdot a)$ for 1 Watts per square meter [Wm^{-2}] targets), and assigned a share of it to a Danish single-family house using the sharing principle of final consumption expenditure (i.e. the relative share of household expenditure for housing), as was previously done in [4]. Following this method, the climate targets of a Danish single-family house were 110 $kgCO_2eq/(c\cdot a)$ and 58 $kgCO_2eq/(c\cdot a)$ for 2°C and $1Wm^{-2}$ respectively. Given the aim of the study was only to calculate GHG emissions reduction targets for existing buildings (in the year 2010), no climate targets for future buildings were recommended. Similar efforts to propose climate targets for commercial buildings exist [e.g. 5, 14]. For example, Russell-Smith et al. [14] estimated a target of 2.29 tCO_2eq/m^2 for the whole life cycle of a commercial building in the USA, considering a 50-year lifetime. The target was based on the GHG emissions projections in the IPCC Fourth Assessment Report [18], which recommended a 70-80% GHG emissions reduction below 1990 levels by 2050 in order for buildings to operate within the 2°C climate target. Likewise, using a similar approach of Zimmermann et al. [4], Hoxha et al. [5] proposed climate targets for a set of commercial buildings in 2050, including offices (14 $kgCO_2eq$ per square metre floor area per annum [$kgCO_2eq/(m^2\cdot a)$]), restaurants (20.3 $kgCO_2eq/(m^2\cdot a)$), food stores (19.8 $kgCO_2eq/(m^2\cdot a)$) and hotels (11.7 $kgCO_2eq/(m^2\cdot a)$).

Overall, although studies defining climate targets using a top-down approach for both residential and commercial buildings in different countries exist [e.g. 3, 4, 8, 15], no similar study is available for New Zealand. The climate targets proposed in other studies are not generalizable given the large variations in the construction materials, climate conditions and energy mix in different parts of the world. Moreover, the existing studies are limited in several aspects. In particular, while all the existing studies have considered population growth when setting climate targets for buildings in 2050, none of them has modelled the growth in the number and size (i.e. floor area) of buildings nationally and/or globally (through to 2050). However, temporal aspects such as the growth in the number and size of buildings are critical in determining the available share of the global carbon budget of a building, and should be addressed when setting climate targets for future buildings. Also, many of the studies have proposed a single climate target value for the whole life cycle of a building, and it would be challenging for building designers to use the proposed target as a guide in the design process given the lack of transparency regarding environmental hotspots. This study, therefore, developed an LCA-based top-down approach to propose a climate target for the whole life cycle of a building in any country that also accounts for future construction of buildings up to 2050, and provides a breakdown of this target into individual life cycle stages. The proposed approach was subsequently applied to a detached house in New Zealand, which is the most common type of residential building in the country, representing almost 80% of residential buildings [19].

2. Methods

2.1. Overview of the top-down approach

The procedure for calculating the climate target for a building was:

- Determine the maximum acceptable amount of GHG emissions that can be emitted while respecting the chosen global climate target during a chosen time period (referred to as the global carbon budget).
- Assign a share of the global carbon budget to a country based on population projections.
- Assign a share of the country's carbon budget to the country's construction sector based on the relative contribution of the sector to the country's total climate impacts in a reference year (or period).
- Calculate the climate target for different building categories by assigning the construction sector carbon budget to the different building types based on the LCA climate impact of each type of building and the projected number of those buildings, both pre-existing and built in the chosen time period. Note that this means that, for example, buildings constructed in 2030 will only include 20 years of utilisation if the chosen time period extends to 2050.

The following sub-sections describe the proposed top-down approach in detail, illustrated for a case study of the New Zealand detached house (see Figure 1). In this study, the term 'detached house building sector' refers to the total number of detached houses in New Zealand.

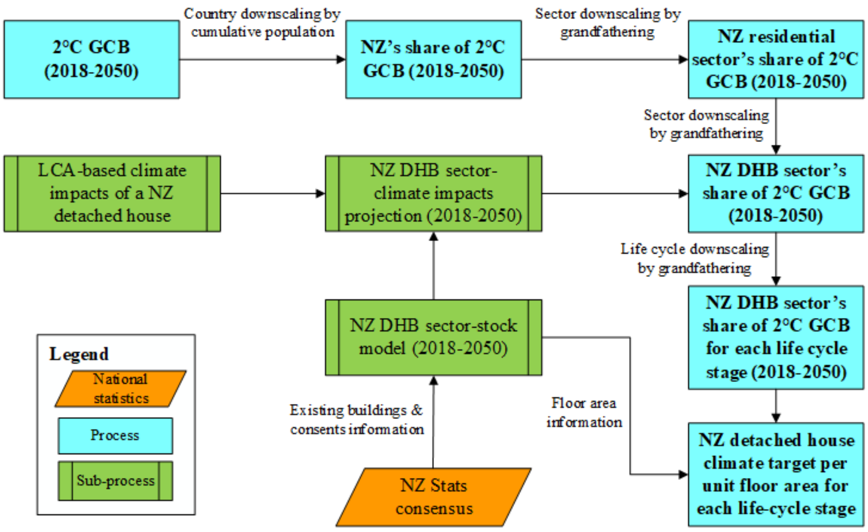

Figure 1. Proposed top-down approach to set a GHG emissions target for New Zealand (NZ) detached house. GCB= global carbon budget; and DHB= detached house building.

2.2. Global climate target and carbon budget

In this study, 2°C was chosen as the global climate target i.e. the maximum amount of GHG emissions that can be emitted and still limit average global warming to below 2°C above pre-industrial levels. The

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chosen global climate target was subsequently translated into a global carbon budget of 1110 $GtCO_2eq$ for the period of 2018-2050 ($CB_{Glo,2018\text{-}2050}$), using the approach proposed by Rogelj et al. [20]. The year 2018 was chosen as the starting point due to the accessibility of good quality data developed as part of BRANZ's New Zealand whole-building whole-of-life framework research [21]; data were modelled up to 2050, the year chosen for the target year of many on-going climate change negotiations, including the New Zealand Zero Carbon Act [22].

2.3. Carbon budget of New Zealand

To assign a share of the 2°C global carbon budget to New Zealand, the so-called sharing principle of *cumulative impacts per capita* was applied. The principle focuses on achieving equality in terms of the cumulative climate impacts of different populations [23]. This means that, if the people of New Zealand emit more GHG emissions today than the global average per capita, future people of New Zealand should be restricted to emit a smaller proportion of GHG emissions in future based on the global carbon budget. And people in less-developed regions who may emit less GHG emissions today than the global average per capita, will be entitled to emit a higher proportion of GHG emissions in future based on the global carbon budget. The cumulative carbon budget available for New Zealand for 2018-2050 was calculated as follows:

$$CB_{NZ,2018\text{-}2050} = \frac{POP_{NZ,2018\text{-}2050}}{POP_{Glo,2018\text{-}2050}} \times CB_{Glo,2018\text{-}2050} \quad (1)$$

where:

$CB_{NZ,2018\text{-}2050}$ - the share of the global carbon budget available for New Zealand for 2018-2050
$POP_{NZ,2018\text{-}2050}$ - the cumulative population of New Zealand for 2018-2050
$POP_{Glo,2018\text{-}2050}$ - the cumulative population of the world for 2018-2050
$CB_{Glo,2018\text{-}2050}$ - the global carbon budget for 2018-2050.

2.4. Carbon budget of New Zealand detached house building sector

The *grandfathering* sharing principle was used to assign a share of New Zealand's carbon budget to the New Zealand detached house building sector (as previously applied in [3, 8]). The grandfathering principle assigns a carbon budget share to the chosen sector based on its relative contribution to New Zealand's climate impacts in a reference year (or period), as represented in Equation 2. Ideally, this year should have been 2017, which is the year prior to the period under analysis. However, due to data limitations, the year 2012 was selected and it was assumed that the relative contribution of the detached house building sector to New Zealand's consumption-based climate impacts remained unchanged during the period 2012-2050.

$$CB_{NZ,DHB,2018\text{-}2050} = \frac{GHG_{NZ,DHB,2012}}{GHG_{NZ,2012}} \times CB_{NZ,2018\text{-}2050} \quad (2)$$

where:

$CB_{NZ,DHB,2018\text{-}2050}$ - the share of the global carbon budget available for the New Zealand detached house building sector for 2018-2050
$GHG_{NZ,DHB,2012}$ - the GHG emissions of the New Zealand detached house building sector in 2012
$GHG_{NZ,2012}$ - the consumption-based GHG emissions of New Zealand in 2012
$CB_{NZ,2018\text{-}2050}$ - the share of the global carbon budget available for New Zealand for 2018-2050.

2.5. Stock model of New Zealand detached house building sector

In order to estimate the climate impacts of the New Zealand detached house building sector, a stock model developed by BRANZ was used, which was based on several assumptions including socio-economic growth in different regions of New Zealand, net floor area of a (future) detached house and demolition rate [R Jaques, personal communication, Dec 21, 2018].The model consisted of two components: one projected the growth in the number and net floor area of detached houses up to 2050 and the other estimated the associated climate impacts. Firstly, the total number and the net floor area of detached houses that existed at the end of 2017 were modelled. Next, the number and net floor area of detached houses for 2018-2050 were projected based on the long-term trend in building consents, considering the anticipated changes in building regulations [R Jaques, personal communication, Dec 21, 2018]. Finally, using the climate impacts of a typical New Zealand detached house [D Dowdell, personal communication, Jan 11, 2019], the LCA climate impacts of the complete detached house building sector (both existing and future detached houses) for 2018-2050 were estimated.

2.6. Climate target of New Zealand detached house

The carbon budget share of the detached house building sector for 2018-2050 ($CB_{NZ,DHB,2018\text{-}2050}$) was shared between the existing and future stock using the grandfathering principle (see Section 2.4). Similarly, using the same principle, $CB_{NZ,DHB,2018\text{-}2050}$ was shared between different life cycle stages. Then, for each life cycle stage, the associated total floor area of the detached house building sector was calculated. By dividing the available carbon budget for each life cycle stage by the associated total floor area of the sector, climate targets per unit floor area for individual life cycle stages were determined. Finally, to determine the climate target for the whole detached house: (i) the climate targets per unit floor area for product life cycle stages, construction process life cycle stages and end-of-life stages were multiplied by the projected floor area of a detached house; (ii) the climate targets per unit floor area per annum for maintenance and replacement, total operational energy use, and operational water use stages were multiplied by the floor area and the time period of utilisation; (iii) and then, the two values were summed.

3. Results and Discussion

3.1. Climate target of New Zealand detached house

Using the proposed top-down approach, the climate target for the whole life cycle of the New Zealand detached house over a 90-year lifetime was calculated as 71 tCO_2eq. This was equivalent to a climate target of 292 $kgCO_2eq/(c.a)$ when normalized, given the average household size in New Zealand is 2.7 [24]. A breakdown of the climate target in terms of individual life cycle stages is presented in Table 1. The largest share of the climate target was assigned to total operational energy use (42%) followed by operational water use (22%), product life cycle stages (15%), maintenance and replacement (13%), end-of-life stages (7%) and construction process life cycle stages (2%). These results, which have a relatively higher proportion of the carbon target assigned to the use phase compared with a conventional LCA study of a building, can be explained by the sharing principle (i.e. grandfathering) applied to assign a share of the New Zealand detached house building sector's carbon budget to individual life cycle stages. This principle assigned a carbon budget share based on the GHG emissions contribution of each life cycle stage to the GHG emissions of the New Zealand detached house building sector during 2018-2050. Thus, the percent-wise GHG emissions contributions of different life cycle stages to the New Zealand detached house building sector were comparable to the percent-wise shares of the climate target of the detached house, as represented in Table 1.

3.2. Comparison with other studies

Direct comparisons between the climate targets of this study and previous work [3, 4, 8] were not possible due to the significant differences in the top-down approaches and underlying assumptions. To understand the uncertainties associated with the choice of top-down approach for setting climate targets, both with and without consideration of future building projections, the approaches available in the literature were applied in the context of a New Zealand detached house without accounting for the growth in the detached house building sector (see Section 1 for the details of the approaches). As observed from Figure 2, when the approach of Zimmermann et al. [4] (i.e. based on the final consumption expenditure principle) was applied to New Zealand detached house, the climate target of the detached house reduced to 260 $kgCO_2eq/(c\cdot a)$. This was due to the low household expenditure share of New Zealand (26%, [25]) compared with the household expenditure share of Switzerland for housing (37%, [4]). Similarly, when the approach of Hollberg et al. [3] was applied (i.e. based on the

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grandfathering principle), the climate target of the New Zealand detached house was further reduced to 57 $kgCO_2eq/(c·a)$. This significant reduction was due to the low contribution of the New Zealand detached house building sector to the national GHG emissions (approximately 6%, according to this study) compared with the Swiss residential sector (36%, [3]). Furthermore, according to the top-down approach developed by Brejnrod et al. [8] (i.e. based on the final consumption expenditure principle), the climate target of New Zealand detached house was 256 $kgCO_2eq/(c·a)$. This was because the share of household expenditure of New Zealand (26%, [25]) was more than twice the share of household expenditure of Denmark for housing (11%, [8]).

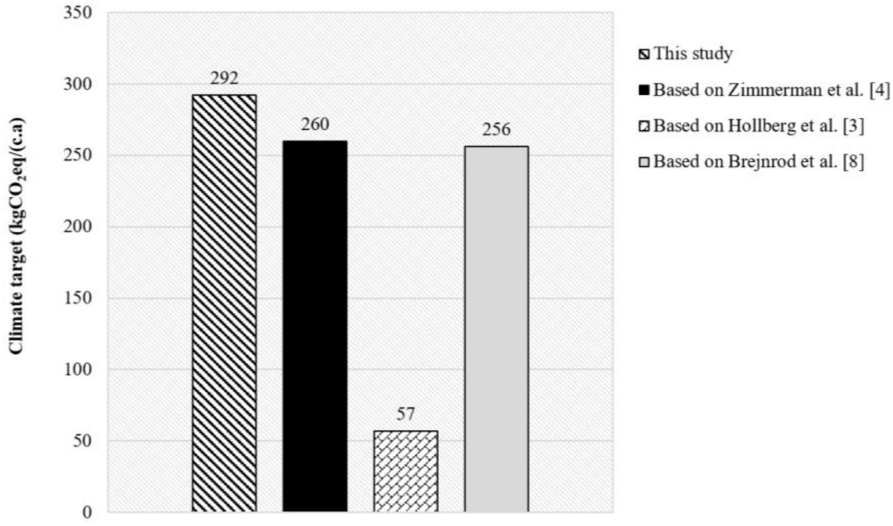

Figure 2. Comparison of climate targets of the New Zealand detached house calculated using the top-down approaches available in the literature.

4. Conclusion

This study introduces a new top-down approach for setting a climate target for the whole life cycle of a building and a breakdown in terms of individual life cycle stages. This approach, for the first time, includes a stock model that accounts for the projected growth in the number (and size) of buildings and associated climate impacts in a country up to 2050. The proposed approach was applied to a detached house in New Zealand to define a climate target. The study has highlighted the importance of accounting for the temporal aspect when setting climate targets for future buildings, which includes the selection of time period and the projected number of future buildings. On the other hand, it should also be noted that the approach and climate targets are associated with a large amount of uncertainty. For example, when assigning a share of the New Zealand carbon budget to the detached house building sector, the grandfathering principle was applied but other sharing principles could be used instead (such as the final consumption expenditure principle). Likewise, to estimate the climate impacts of the New Zealand detached house building sector, the stock model developed by BRANZ was used [R Jaques, personal communication, Dec 21, 2018] which was based on several assumptions including socio-economic growth in different regions of New Zealand, building regulations, net floor area of a (future) detached house and demolition rate. These assumptions, of course, are also associated with a significant amount of uncertainty. Further research is, therefore, necessary to quantify the uncertainty associated with these aspects. However, overall, the proposed approach and climate target provide an approach that can potentially support designers and other interested stakeholders (including architects, civil engineers, scientists and investors) in aligning their building designs with global climate targets such as the 2°C climate target.

Table 1. Results of the application of the top-down approach to New Zealand detached house.

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Life cycle stage [a]	LCA impacts- detached house over a 90-year lifetime [b] ($ktCO_2eq$)	LCA impacts- detached house building sector (2018-2050) ($MtCO_2eq$)			Carbon budget - detached house building sector (2018-2050) ($MtCO_2eq$)	Net floor area- detached house building sector (2018-2050) ($10^6\times m^2$)	Climate target per unit floor area ($kgCO_2eq/m^2$)	Climate target- detached house over a 90-year lifetime [e] (tCO_2eq)
		Existing	Future	Total				
Product life cycle stages	33	-	18	18 (18%)	5	109	50	10 (15%)
Construction process life cycle stages	5	-	3	3 (3%)	0.9	109	8	2 (2%)
Maintenance & replacement	29	10	3	13 (13%)	4	8,272 [c]	0.5 [d]	9 (13%)
Total operational energy use	71	35	8	42 (43%)	13	8,272 [c]	1.6 [d]	30 (42%)
Operational water use	38	18	4	22 (22%)	7	8,272 [c]	0.8 [d]	15 (22%)
End-of-life stages	15	-	0.6	0.6 (1%)	0.2	8	23	5 (7%)
Whole life cycle	**191** [f]	**-**	**-**	**98** [f]	**31** [f]	**-**	**-**	**71** [f]

[a] The LCA was conducted following the EN 15978:2011 standard [26].
[b] The LCA climate impacts were from [D Dowdell, personal communication, Jan 11, 2019].
[c] Since the net floor area of this life cycle stage is a function of area and time the unit is square meter annum ($m^2\cdot a$).
[d] The unit is $kgCO_2eq/(m^2\cdot a)$.
[e] The projected average floor area of a (future) detached house is 207 m^2.
[f] Column totals may not add up due to rounding.

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