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# Application of Absolute Sustainability Assessment to New Zealand Residential Dwellings

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## Abstract

One approach to supporting the implementation of sustainable activities by industry sectors is the use of climate targets. Such climate targets have potential to be used in design and rating tools for buildings and to support government regulation for the building and construction sector. In this study, the climate targets for New Zealand residential dwellings were calculated based on assigning the global carbon budget (for limiting temperature increase to 1.5 or 2.0 °C during 2018-2050) to three building typologies: detached, medium-density housing and apartments. These budgets were assigned to the pre-existing and new-built dwellings using building stock projections for the nominated period. Separately, the climate impact of new-built dwellings in each of the three residential typologies were assessed using Life Cycle Assessment methodology. For New Zealand residential buildings, new-built dwellings exceed their 1.5 °C climate targets by a factor of 6.7, 6.8 and 10.9 for detached, medium-density housing, and apartments respectively. For the 2.0 °C climate target, these factors are 4.8, 4.8 and 7.7 for detached, medium-density housing, and apartments respectively. The results show that about two-thirds of the climate impact of residential dwellings for the period 2018-2050 is associated with pre-existing dwellings rather than new-builds. The operational energy used for space heating, water heating, lighting and plug loads makes the biggest contribution to the climate impact for all typologies of pre-built residential dwellings. For new-built residential dwellings, both the operational energy and the construction materials/products contribute most of the climate impact.

## 1. Introduction

One of the targets of the United Nations Sustainable Development Goal 12, Responsible Consumption and Production, is to “encourage companies, especially large and transnational companies, to adopt sustainable practices and to integrate sustainability information into their reporting cycle” [1]. However, there is much debate about what is meant by “sustainable practices”. One approach for supporting sustainable practices in climate change management that is rapidly gaining traction, is setting absolute targets for greenhouse gas (GHG) emissions. These targets are derived from a global carbon budget which is the maximum amount of GHG emissions (usually measured in tonnes CO<sub>2</sub>eq) that can be emitted over a defined time period whilst keeping warming of the Earth’s atmosphere below a threshold.



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The threshold is commonly defined as an observed global mean surface temperature (GMST) of 1.5 or 2.0 °C [2], or 1 Watt per square metre increase in top-of-atmosphere radiative forcing [3], relative to pre-industrial levels. The global carbon budget is divided between different countries, industry sectors, products, and/or individuals using a chosen sharing principle. Common sharing principles include “equal per capita” where the budget is divided equally between all people, and “grandfathering” where the budget is assigned to countries or industry sectors in proportion to their relative contributions to the global climate impact in a chosen reference year [4, 5].

The building sector is particularly relevant for consideration when setting climate targets. Building construction and operation account for 36% of global final energy use and 39% of energy- and process-related CO<sub>2</sub> emissions according to the *2019 Global Status Report for Buildings and Construction* [6].

Research on climate targets for residential buildings to date has focused on assessment of the climate target for a single residential building or housing for one person over one year (e.g. [7,8,9]) or commercial building for one year (e.g. [10,11]). Such targets are country-specific due to the large international variations in construction materials, climate conditions and energy mixes. Furthermore, although most of these studies account for population growth up to 2050, they do not account for the growth in the number and size (i.e. floor area) of buildings, and changes in building typology makeup. These factors are potentially significant in determining the climate target for residential buildings. For example, in New Zealand detached residential buildings are being built with larger floor areas, the number of occupants per household is declining, and more residential medium-density housing (MDH) and apartments are being constructed relative to detached houses [12].

To account for changes in the building stock up to 2050, Chandrakumar et al. [13,14] proposed integrating building stock projections into the calculation of the climate target for buildings. Essentially, for residential buildings, this involves calculating the numbers of pre-existing buildings of different building typologies (e.g. detached, MDH, apartments) and their projected service life, up to 2050. This is added to the number and size of new-built buildings of different building typologies, up to 2050. The gross floor area used over this period by different building typologies (measured in m<sup>2</sup>·yr) provides a basis for assigning the building sector’s climate budget to an individual dwelling in each building typology. It should be noted that the distinction between pre-existing and new-built buildings is important because the climate target needs to account for the construction of new buildings but this is irrelevant for pre-existing buildings as those GHG emissions occurred prior to the time period for which the carbon budget is calculated.

In this paper, the method developed by Chandrakumar et al. [13,14] is applied to the residential sector in New Zealand. It extends the previous study’s methodology on detached residential houses in New Zealand [14], applying it to the remaining two residential typologies: MDH and apartments.

## 2. Method

A set of five residential dwellings, built recently to meet the New Zealand Building Code, were chosen and modelled using LCA: three detached houses (DH), one medium-density house (MDH) and one apartment (AP). A general description of these buildings is presented in Table 1.

The method involved calculating four results for each residential typology:

- The climate impact of each new-built residential dwelling over its service life (taken as 90 years), divided into different life cycle stages (Section 2.1), and a pre-existing residential dwelling operating between 2018-2050.
- Projected total stock of pre-existing and new-built residential buildings for the period 2018-2050 (Section 2.2).
- The climate impact of the total stock of each building typology for the period 2018-2050 (Section 2.3)
- The climate impact and climate target for a new-built dwelling of each typology for the service life of the dwelling (Section 2.4).

A more comprehensive description of these calculations is available in [14].

**Table 1.** Characteristics of each building typology used in the study [15]

Building	Gross floor area (GFA in m <sup>2</sup> )		Storey(s)	Characteristics of building elements	Total stock size (no. of buildings), [total GFA in m <sup>2</sup> ]	
	Pre-existing	New-built			By 2018	2018 to 2050
<b>DH</b>	166	198	1	Timber frame; concrete slab floor; 90 mm wall & plasterboard lining; double glazed windows; concrete tile roof	1,304,126 [216,484,916]	527,609 [104,466,582]
<b>MDH</b>	115	114	2	Braced frame & shear-walled frame; reinforced concrete floor; 90 mm brick wall; double glazed windows; steel profile cladding roof	334,676 [38,487,740]	167,731 [19,118,319]
<b>AP</b>	99	94	1	Rigid frame; concrete slab floor; plaster cladding on aerated concrete blocks; double glazed windows; steel profile cladding roof	121,656 [12,043,944]	118,106 [11,127,917]

### 2.1 Climate impact of pre-existing and new-built dwellings of each typology

The method for calculating the climate impact of each **new-built dwelling** is described in [14]. The functional unit was defined as the ‘construction and occupation of a residential dwelling over its reference service life’. For this study, a service life of 90 years was considered for residential dwellings (as previously estimated in [16,17]).

Inventory data were categorised into the following life cycle stages: product (modules A1-A3), construction process (modules A4-A5), maintenance (module B2) and replacement (module B4), operational energy use (module B6), operational water use (module B7), and end-of-life (modules C1-C4). In this study, it was assumed that the buildings are properly maintained; hence, the life cycle stage repair (module B3) was not considered. And credits for recycling and biogenic carbon storage were outside the scope of this study. The GHG emissions related to the operational energy use were quantified assuming 100% grid-derived electricity as the energy source, and using an annual New Zealand grid GHG intensity calculated based on the Ministry of Business, Innovation and Employment’s (MBIE) Reference [18] for each year during the 2018-2050 period (and assuming it remained equivalent to the year 2050 after that year). Energy use for space heating and cooling was calculated to represent three different climate zones in New Zealand.

For **pre-existing dwellings**, as the climate impact data were only required in order to calculate the contribution to the total climate impact of each building typology between 2018-2050, only the life cycle stages occurring during 2018-2050 were considered. In other words, modules A1-A3 and A4-A5 were omitted, and modules C1-C4 were only included for those buildings reaching their end-of-life at some point between 2018-2050. The climate impacts of the other modules (B2, B4, B6, B7) were only considered for the projected years of operation in the period 2018-2050 for each pre-existing building. Energy use for space heating was assumed to be the same as for new-built dwellings (per square metre of gross floor area) in the absence of more detailed data. This value is similar to values at the lower end of the (limited) data sets on operational energy use for space heating in New Zealand residential buildings [19,20], recognising that existing residential dwellings are likely to become more energy-efficient over the 2018-2050 period. It should, however, be noted that existing dwellings generally have lower ambient temperatures and higher humidity than new-built dwellings.

For all the dwellings, the climate impact result for each dwelling was calculated using LCA methodology and following the EN15978:2011 standard [21]. It should be noted that data for materials represented current manufacturing processes rather than future technologies, and this represents a limitation of the study.

### *2.2 Projected total stock of building typologies 2018-2050*

A stock projection developed by the Building Research Association of New Zealand (BRANZ) was used, which was based on the long-term trend in building consents. It gives the projected numbers of pre-existing and new-built detached buildings of each building typology for each year from 2018 to 2050.

### *2.3 Climate impact of total stock of each building typology 2018-2050*

The climate impact of the total stock of each building typology for 2018-2050 was estimated based on the calculated climate impacts of the pre-existing and new-built buildings (Section 2.1), and the projected numbers of buildings for each year from 2018 to 2050 (Section 2.2).

### *2.4 Climate target for a new-built dwelling*

The procedure for calculating the climate target for a dwelling involves the following steps:

- Determine the maximum acceptable amount of GHG emissions that can be emitted globally while respecting the chosen global climate target during a specific time period (referred to as the global carbon budget). The approach proposed by [22] was used to calculate a global carbon budget of 1110 GtCO<sub>2</sub>eq for the period 2018-2050 using the 2 °C target and 786 GtCO<sub>2</sub>eq for the 1.5 °C target.
- Assign a share of the global carbon budget to New Zealand based on population projections. The sharing principle of “cumulative impacts per capita” was applied which meant that 0.06% of the global carbon budget was assigned to New Zealand for the period 2018-2050.
- Assign a share of New Zealand’s carbon budget to the residential building sector based on the relative contribution of the sector to the country’s total climate impact in 2012 (the latest year for which life cycle-based data were available, see [23]) i.e. using the grandfathering principle. This meant that 10.0% of New Zealand’s carbon budget was assigned to the residential building sector.
- Assign the residential sector carbon budget to the DH, MDH and AP building typologies on the basis of the New Zealand population in each building typology 2018-2050 (measured in cap·yr).
- Assign carbon budget shares for the embodied (A1-A5, C1-C4) and operational (B1-B7) life cycle stages of the residential sector in the same ratio as calculated for the embodied:operational impacts of the total building stock in 2018-2050 (1:4).
- Calculate the climate target (measured per square metre gross floor area) for embodied life cycle stages by dividing the sector-level carbon budget for embodied life cycle stages by the total gross floor area of the new-built residential buildings constructed in 2018-2050. Likewise, calculate the climate target for operational life cycle stages (measured per m<sup>2</sup>·yr) by dividing the sector-level carbon budget for operational life cycle stages by the total gross floor area used in 2018-2050.
- Determine the climate target for each new-built dwelling by multiplying the climate target for the embodied life cycle stage by the floor area of each single dwelling (see Table 1), and multiplying the climate target for the operational life cycle stage by the floor area and the years of operation between 2018 and 2050 (i.e. 33 years). Note that, for this calculation, it was assumed that there was zero carbon budget beyond 2050.

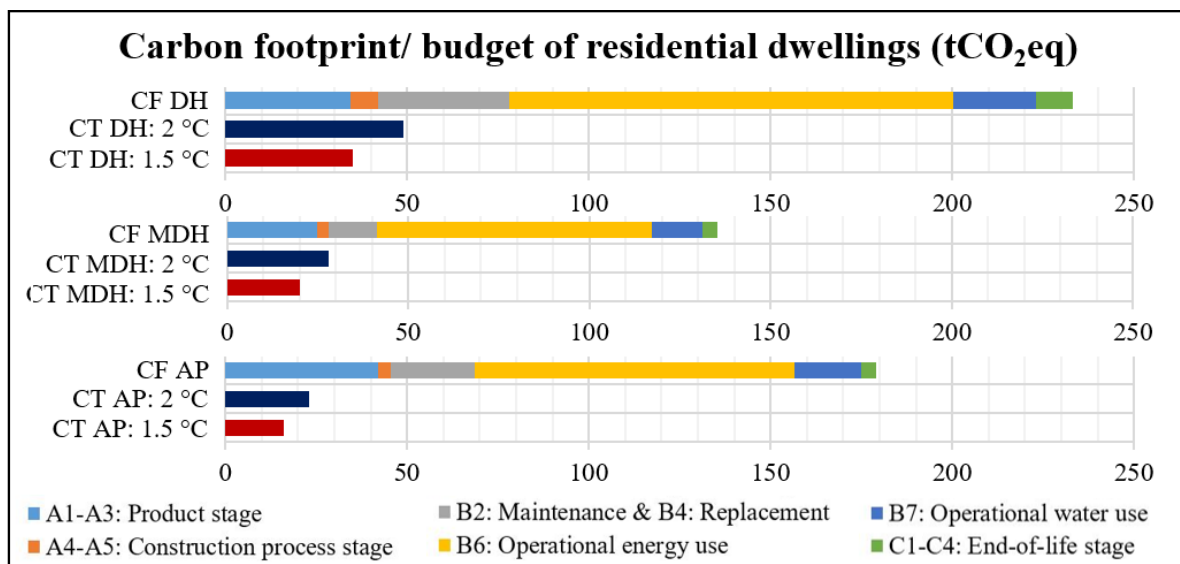
### *2.5 Climate impact and climate target for new-built dwellings in each building typology*

For the residential detached building typology, the climate impacts were calculated for each of the three dwellings separately and averaged based on their floor areas. For the MDH and AP typologies, data were available for units in just one building of each typology, so these were used for the climate impact analysis. The climate impact results were then compared with the climate targets for new-built dwellings in each typology.

### 3. Results

#### 3.1 Climate impact of New Zealand residential dwellings

As presented in Figure 1, the climate impacts of the detached house (DH), one medium density housing unit (MDH), and one apartment unit (AP) are 233, 135 and 179 tCO<sub>2</sub>eq, respectively (for a service life of 90 years) - equivalent to 13, 13, and 21 kgCO<sub>2</sub>eq·m<sup>-2</sup>·yr<sup>-1</sup>. The higher climate impact (per 1 m<sup>2</sup>·yr) for the AP dwelling is at least partly due to the floor plan (i.e. long and narrow) of the building used for the AP typology. Note that these climate impact values do not account for the biogenic carbon in the timber and engineered woods used in the buildings, and the avoided burden due to the reuse, recovery, and recycling of construction materials (module D). The majority of the carbon footprint (over the service life) is associated with the operational stages (78, 76 and 72 % for DH, MDH, and AP respectively) and is largely related to the operational energy (for space heating, hot water, lighting and plug loads). The climate impacts of the residential dwellings are comparable to the climate impacts of residential buildings in other parts of the world, although they are at the lower end of the range (10-90 kgCO<sub>2</sub>eq·m<sup>-2</sup>·yr<sup>-1</sup>) [24].



**Figure 1.** Climate impact and targets of New Zealand residential dwellings. CF= carbon footprint; CT= climate target; DH= detached house; MDH= medium density house; AP= apartment.

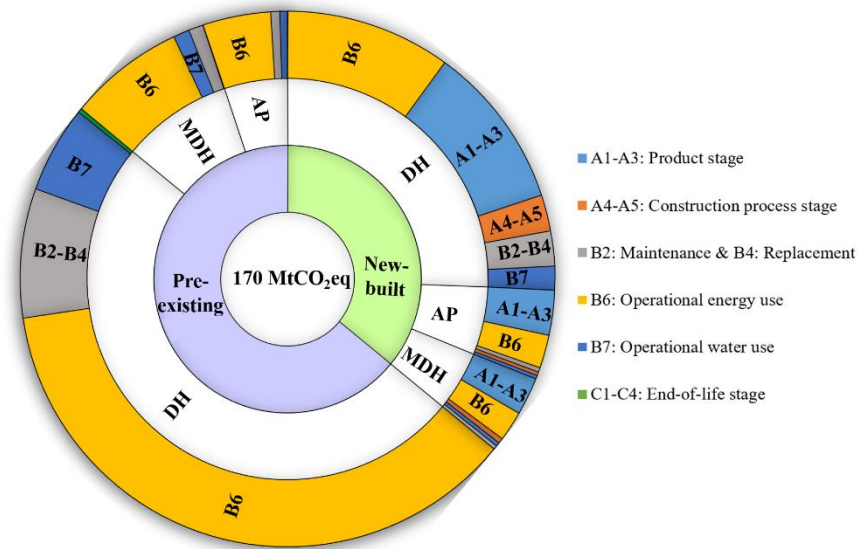
#### 3.2 Climate impact of New Zealand residential buildings up to 2050

The climate impact of New Zealand residential buildings in 2018-2050 is projected as 170 MtCO<sub>2</sub>eq, by scaling up the climate impact of both pre-existing and new-built residential dwellings using the stock projection approach (see Figure 2). According to Figure 2, the pre-existing residential buildings contribute 63% of the total climate impact, whereas the new-built buildings contribute 37% of the impact. Considering the building typologies, the largest contributor of the total climate impact is DH (77%), followed by MDH (14%), and AP (9%).

Considering the individual life cycle stages, operational energy use is the largest contributor of the total climate impact of the residential buildings (59%), followed by the product stage (16%). The third largest contributor to the climate impact of the residential buildings is maintenance and replacement stage (13%).

The large difference in the climate impact between different residential buildings is due to the relative numbers of those three typologies that are projected to exist during 2018-2050. Furthermore, the large

contribution of the operational use stage for the residential buildings can be explained by the fact that this stage contributes the highest share of the climate impact of any building over its service life.



**Figure 2.** Carbon footprint of total building stock of New Zealand residential buildings up to the year 2050.

### 3.3 Climate targets for New Zealand residential dwellings

The calculated climate targets, consistent with the 1.5 °C global climate target, for new-built DH, MDH and AP (over a 90-year lifetime) are 35, 20, and 16 tCO<sub>2</sub>eq. (for dwellings of each typology with gross floor areas shown in Table 1).

When an alternative global climate target (i.e. 2 °C) was used, the climate targets for the chosen dwellings (from Table 1) increased to 49, 28 and 23 tCO<sub>2</sub>eq respectively (a factor 1.41 increase compared with the 1.5 °C targets, see Figure 1).

## 4. Discussion and Conclusions

This study applied the absolute sustainability assessment framework developed in [13,14] to calculate climate impact and targets for a range of residential dwellings in New Zealand. The results of the analysis show that none of the New Zealand dwellings assessed in this study are aligned with either the 1.5 or 2 °C climate goals. A new-built DH exceeds its 1.5 °C-consistent climate target by a factor of 6.7, whereas new-built MDH and AP dwellings exceed their climate targets by a factor of 6.8 and 10.9, respectively. For the 2.0 °C climate target, these factors are 4.8, 4.8 and 7.7 for DH, MDH, and AP respectively. However, arguably it would be preferable to represent the targets in terms of a generic m<sup>2</sup> and/or per occupant rather than per dwelling, to represent the fact that occupants can choose to live in larger or smaller dwellings, and/or co-inhabit with others, as well as choose between dwelling typologies.

When the climate impact of the total stock of New Zealand residential buildings was compared with the assigned share of the 1.5 °C global budget for 2018-2050, the stock's climate impact (170 MtCO<sub>2</sub>eq) exceeded its climate target (47 MtCO<sub>2</sub>eq) by a factor of 3.6.

These results therefore indicate that substantial efforts (i.e. a reduction of approximately 72%) are required to enable the residential building sector in New Zealand to achieve the 1.5 °C global climate target. According to Figure 2, more than one third of the residential building stock's climate impact in 2018-2050 is associated with new-built buildings. Prioritising mitigation of these embodied emissions will contribute to avoiding or postponing the transgression of the climate target (Chandrakumar et al.,

2020), and biogenic carbon storage in construction materials is particularly relevant. At the same time, initiatives such as retrofitting and refurbishment of pre-existing buildings, and design that prioritises mitigation of the climate impact of new-built buildings, are crucial for reducing the climate impact of the residential building sector.

Further work to improve the analysis includes: modelling the climate impact of a larger set of dwellings in each building typology, accounting for the anticipated increased energy efficiency of pre-existing (through retrofitting) and new-built buildings over the next few decades, updating the electricity mix scenarios used in the analysis, and incorporating the updated electricity scenarios into calculation of the climate impact of construction materials. For the climate budget calculations, further work includes: using a more recent baseline year to assign the climate budget between sectors and building typologies, and examining the influence of different sharing principles in calculation of the targets.

However, overall, the approach described in this study has potential to be used to set climate targets that enable the building and construction sector of a country to align their operations with a global climate target, such as the 1.5 or 2 °C. As the approach accounts for the projected future growth of the building sector, it is “future proof” and as such is complementary to the commitments of a growing number of countries across the world to achieving net zero carbon status between 2030 and 2050.

### Acknowledgements

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