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Australasia

The carbon footprint of New Zealand's built environment

Hotspot or not?

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Title:	**The carbon footprint of New Zealand’s built environment: hotspot or not?**
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Summary

Energy use in buildings contributed 19% of society's global carbon footprint in 2010, according to the Intergovernmental Panel on Climate Change. The value quoted for New Zealand is typically around 5% (Figure 1a) and sometimes as low as 2% (considering only direct combustion of fuels). These values derive from *New Zealand's Greenhouse Gas Inventory* and have been popularised in recent years by the Productivity Commission and the Royal Society, among other organisations.

Taken in isolation, 2-5% seems small enough to conclude that the built environment is relatively unimportant and that other sectors are higher priorities for emissions reduction at a national level. However, there are two issues when using these figures: (1) they consider only the energy used in buildings, but not the construction of these buildings or their eventual demolition, and (2) they present the carbon footprint of everything produced in New Zealand, rather than what is actually consumed.

If we consider the full life cycle (construction, use and end-of-life), the contribution of the built environment (i.e. buildings and infrastructure) increases to approximately 13% of New Zealand's gross carbon footprint (Figure 1b). If we then adjust for the carbon footprint embodied in our exports (dairy, meat, etc.) and our imports (cars, trucks, clothes, etc.), this share climbs to 20% (Figure 1c) – a value that highlights the built environment as a key hotspot in our national carbon footprint.

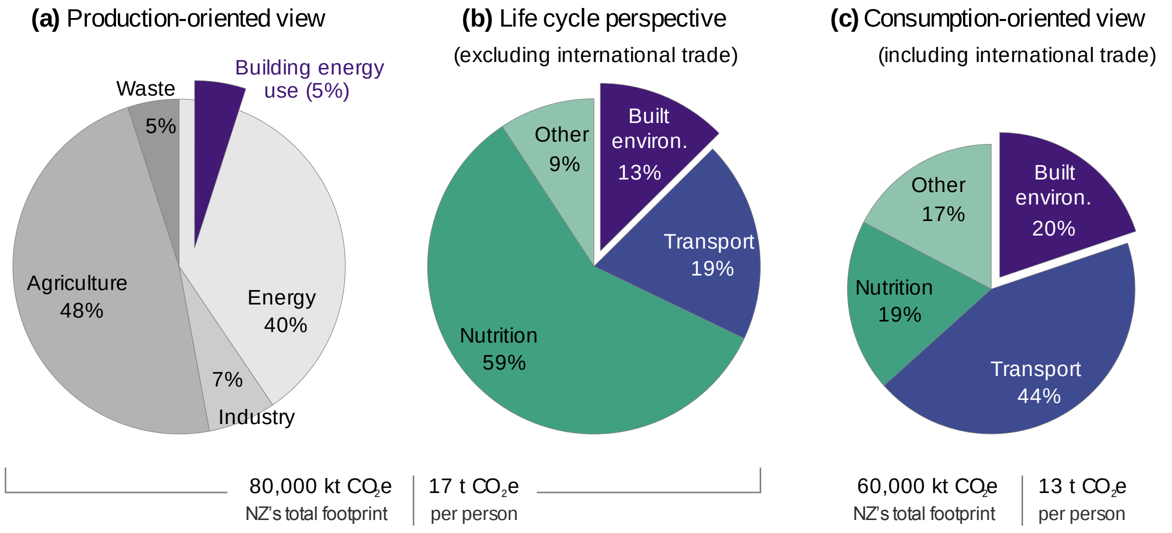

Figure 1: A breakdown of New Zealand's carbon footprint in 2015 from (a) a production perspective, (b) a life cycle perspective, and (c) a life cycle consumption perspective

There are two main reasons why the New Zealand figure for the carbon footprint for energy use in buildings appears to be four times smaller than the global average of 19%: (1) we use low-carbon electricity and wood for most of our building heating, and (2) the percentages are distorted by New Zealand's large share of direct agricultural emissions, which account for roughly half of our total gross carbon footprint (Figure 1a).

The consumption-oriented view presented in this report highlights the areas in which New Zealand organisations and households can have the greatest influence on climate change through their purchasing decisions. It does not replace the production-oriented view, which is mandatory for reporting at an international level. However, if the production-oriented view is used alone, it allows nations to shift production offshore to meet their national targets. Shifting the burden will not help us to tackle climate change; instead, we need to action on the emissions we are responsible for.

Given that climate change is a shared problem, it seems logical that both producers and consumers need to be part of the solution.

1. Introduction

1.1. Background

In 2010, buildings contributed 19% of global society's total gross carbon footprint, or 25% if agriculture and forestry were excluded (Lucon, et al., 2014). Other sources estimate that buildings account for up to one-third of human society's carbon footprint (UNEP, 2013). Yet, in New Zealand, the value that is quoted is typically in the order of 2-5% (Productivity Commission, 2018, pp. 388-9).

The starting point for this report was a simple question: *Can the carbon footprint of New Zealand's built environment really be so different to the rest of the world?*

The answer is both **no** and **yes**.

No: The built environment is a larger part of New Zealand's carbon footprint than it appears:

1. The percentage contribution from the built environment (and all non-agricultural sectors) is diluted by direct greenhouse gas (GHG) emissions from agriculture. These emissions make up roughly half of New Zealand's total carbon footprint – a share that is far larger than any other country in the OECD (Figure 2). While New Zealand must address agricultural emissions to meet our national GHG reduction commitments, these emissions are largely 'embodied' in products exported from New Zealand for foreign consumption.

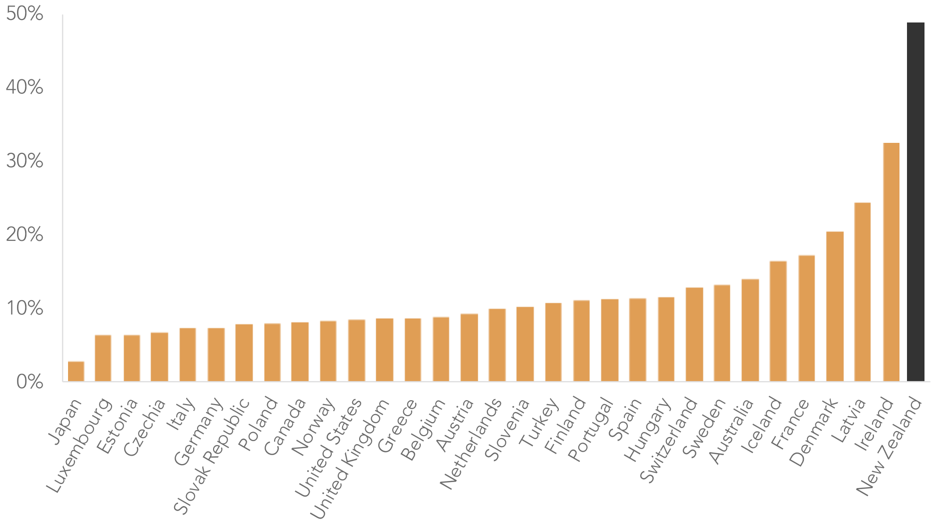

Figure 2: Agricultural emissions as a percentage of gross emissions across OECD countries in 2014. Reproduced with permission from (Productivity Commission, 2018, p. 29).

2. The 2% and 5% values lack a life cycle perspective, focusing on direct energy consumption only. 2% is direct thermal energy consumption in buildings, while 5% also includes electricity consumption in buildings (excluding fugitive emissions from electricity generation) (Productivity Commission, 2018, pp. 388-9). But what about production of building materials and treatment of building waste? And why are fugitive emissions from electricity generation not typically reported when they are a necessary part of producing the electricity that we use? Within *New Zealand's Greenhouse Gas Inventory*, these values are bundled up inside the 'industry' 'waste' and 'energy' categories and not split out.

Yes: New Zealand's built environment might reasonably be expected to have a lower carbon footprint than other developed countries because:

1. Much of our building heating is electric or wood (versus natural gas in many other developed countries).
2. Our electricity grid mix is roughly 85% renewable (MBIE, 2017).
3. We don't heat or cool our buildings nearly as much as many other developed countries, particularly in the residential sector. This is partly due to our climate and partly due to our building stock historically having relatively poor levels of insulation and draught-proofing.

1.2. Purpose

The purpose of this report is to present an alternative way of looking at New Zealand's carbon footprint by applying life cycle thinking and considering emissions from a consumption perspective rather than a production perspective. This report is intended as a conversation starter, rather than as a presentation of the 'right' answer. Our aim is to give an approximate view of how New Zealand's carbon footprint looks through this alternative lens.

1.3. What is a carbon footprint?

When applied to a product, a carbon footprint is the "sum of greenhouse gas emissions and removals in a product system, expressed as CO_2 equivalents and based on a life cycle assessment using the single impact category of climate change" (ISO, 2013, section 3.1.1.1).

A carbon footprint of a nation state is the same except the 'product system' becomes a national boundary. In this report, we focus on 'gross' greenhouse gas emissions, i.e. we exclude removals of carbon dioxide from the atmosphere, primarily due to growth of trees. This is done simply because we are interested in sources of greenhouse gas emissions, not sinks for them. When carbon dioxide stored in forests is included, this is referred to as 'net' GHG emissions or a 'net' carbon footprint.

1.4. Structure

The remainder of this report is broken into the following sections:

- Chapter 2: Our approach: viewing GHG consumption through a life cycle lens.
- Chapter 3: Our method to regroup *New Zealand's Greenhouse Gas Inventory* using life cycle thinking and adjusting for imports and exports.
- Chapter 4: How valid are our key assumptions?
- Chapter 5: Results and conclusions from applying a life cycle approach.

2. Approach

2.1. A consumption-oriented approach

Production is the lens through which New Zealand's carbon footprint is most commonly analysed, e.g. (RSNZ, 2016), (Vivid Economics, 2017) and (Productivity Commission, 2018). Based upon *New Zealand's GHG Inventory*, prepared as part of the United Nations Framework Convention on Climate Change (UNFCCC), the economy is split into five overall sectors: 'energy', 'industry', 'agriculture', 'land use, land-use change and forestry' and 'waste'. 'Energy' is often further divided into 'transport', 'electricity' and 'heat'. Emissions are allocated in the sectors where they occur, e.g. methane from cows falls under 'agriculture' and combustion of fossil fuels falls under 'energy'.

This production-oriented view is entirely appropriate in the context of reducing our national carbon footprint, given that we are responsible for everything that happens within our own geographic boundary at the international level. However, a production-oriented view does not help us to understand the demand that ultimately drives production. Furthermore, as a national inventory, anything that happens offshore is automatically out of scope – something that is potentially problematic in New Zealand's open economy.

In carbon footprint terms, *New Zealand's GHG Inventory* covers Scope 1 and Scope 2. Three 'scopes' are used when calculating the carbon footprint of an organisation (GHG Protocol, 2015):

- Scope 1 is direct emissions, e.g. combustion of fossil fuels on-site.
- Scope 2 is indirect emissions, notably consumption of electricity.
- Scope 3 is upstream and downstream emissions, e.g. production of raw materials.

Given that it is relatively uncommon to use fossil fuels for space heating in New Zealand, it is unsurprising that the Scope 1 emissions of the built environment equate to only 2% of New Zealand's total carbon footprint. It is similarly unsurprising that Scope 2 emissions are also small given that New Zealand's electricity is approximately 85% renewable (MBIE, 2017). However, what about Scope 3 emissions? While these are out of scope of our international obligations, using life cycle thinking to account for Scope 3 emissions is vital to prevent burden-shifting.

To understand why burden-shifting is important, consider this example:

> How do we meet our national target of reducing New Zealand's carb footprint by 30% from 2005 levels by 2030?
>
> One simple though controversial answer would be to wind down our domestic dairy and meat industries, import dairy and meat products instead, and substitute lost export earnings with tourism. This 'solution' works because enteric fermentation from livestock is the single biggest GHG hotspot in our national inventory, contributing 35% of total gross carbon footprint in 2015, while there are no emissions from international travel because they occur over international waters (emissions are calculated, but they are reported as standalone values) (MfE, 2017).
>
> While this might meet our international climate obligations, this approach would likely lead to an increase in carbon footprint at a global level unless all New Zealanders became vegetarians overnight. This is because long-haul flights (to support our tourism industry) would increase, global demand for meat and dairy would remain the same, additional

production capacity for meat and dairy would emerge somewhere else (with potentially higher GHG emissions per unit production), and these products would now need to be shipped to New Zealand rather than produced domestically.

Climate change is a global problem. GHG emissions released in New Zealand have essentially the same impact as those produced anywhere else in the world. We therefore need to find solutions that reduce our domestic carbon footprint while also reducing global emissions. Put another way, we need to understand both the production-oriented and consumption-oriented views. This report includes Scope 1, Scope 2 and Scope 3 emissions and uses a consumption-oriented approach.

2.2. Analysing an intermediate level of the economy

While less common that the production-oriented view, there are existing analyses of New Zealand's carbon footprint from a consumption viewpoint, notably Romanos and colleagues (Romanos, et al., 2014). The main difference between this report and past work is the unit of analysis. Romanos and colleagues use a technique called economic input-output life cycle assessment (EIO-LCA) to relate carbon footprint to categories of household expenditure. Using this approach, it is only possible to split out impacts of the residential built environment, as the impacts of the commercial built environment, infrastructure and industry are divided up into the various categories of household expenditure. For example, the carbon footprint of getting your hair cut includes the emissions from heating your hair dresser's building, their electricity consumption, disposal of their waste, and all other components of their carbon footprint. This splitting across multiple categories also occurs in the production-oriented view where production of building materials falls under 'industry', building operation falls under 'energy' and treatment of demolition waste falls under 'waste'.

The purpose of this report is to present the built environment in its entirety, not split across multiple categories. As such, rather than focus on consumption by households (final consumers), we focus on consumption at an intermediate level of the economy. Alongside the 'built environment', we split out 'nutrition', 'transport' and 'other'. ('Other' includes sanitation, clothing and other emissions not easily included elsewhere, as described in Table 5.) While nutrition and transport are not the focus of this report, these three categories (nutrition, transport and the built environment) are the main hotspots from the perspective of final consumption in both New Zealand (Romanos, et al., 2014) and the European Union (Tukker, et al., 2006).

2.3. A life cycle perspective

The aim of this report is to look at the built environment in its entirety, not just its energy use during operation. By applying life cycle thinking to the built environment, we must consider production of building products, construction of buildings and infrastructure, operational energy and water use, disposal of construction and demolition waste, and the transport throughout these stages.

'Life cycle thinking' is used here as a general term to describe the various life cycle approaches standardised at an international level: ISO 14040 and ISO 14044 for life cycle assessment (LCA) of products and services (ISO, 2006), ISO/TS 14072 for LCA of organisations (ISO, 2014) and related standards such as ISO/TS 14067 on the carbon footprint of products (ISO, 2013).

The core of life cycling thinking is its holistic approach – an approach designed to help prevent burden-shifting when making comparisons. This burden-shifting can occur in many ways: from one region to another, from one time to another, from one media to another (e.g. exchanging soil emissions for water emissions), from one environment impact to another (e.g. exchanging carbon emissions for acidifying emissions), etc. Unlike a full LCA, a carbon footprint only considers one environmental indicator (climate change); however, the approach is otherwise the same.

This report considers the full life cycle of each category (built environment, nutrition and transport) from ‘cradle to grave’ to the extent possible with the national data available. Given that transport is its own category, transport of building products and food (and their associated waste products) are included in ‘transport’ rather than ‘built environment’ or ‘nutrition’. Similarly, farm buildings are considered as part of ‘built environment’ rather than ‘nutrition’. Our goal has been to include those things that either make up or are required to deliver the final product/service. This approach broadly follows the Greenhouse Gas Protocol’s distinction between ‘attributable’ and ‘non-attributable’ processes, where material and energy flows that do not become part of the final product can be considered ‘non-attributable’ and are optional within the carbon footprint (GHG Protocol, 2013, pp. 35-36). A description of what is included within each category is provided in Table 1.

Table 1: Categories included within this report

Category	Includes	Excludes
Built Environment	• Construction and maintenance of residential buildings, commercial buildings and infrastructure (roads, railways, bridges, wastewater treatment networks, etc.). • Operation of buildings. • Disposal of building waste and garden waste.	• Transport of building materials to site (included under Transport). • Operation of transport networks (included under Transport). • Production of building products for export.
Nutrition	• Production of food and beverages for domestic consumption, including on-site emissions and food manufacturing. • Treatment of food waste in landfill and in residential wastewater.	• Transport of food and beverages (included under Transport). • Residential cooking (included under Built Environment). • Production of food for export.
Transport	• Manufacture of vehicles (cars, trucks, etc.) • Use of vehicles.	• Disposal of vehicles (as hard to separate and low emissions).

3. Method

Starting from *New Zealand's Greenhouse Gas Inventory 2017*, which reports data for the 2015 calendar year, we:

1. Regrouped New Zealand's emissions into three key categories by demand/consumption: 'built environment', 'transport' and 'nutrition'. Everything else was grouped as 'other'.
2. Adjusted for imports and exports.

Each step is described in further detail below.

3.1. Regroup New Zealand's GHG Inventory

We broke New Zealand's emissions into three key categories by final demand/consumption: 'built environment', 'transport' and 'nutrition'. Everything else was grouped as 'other'. Within our results, the regrouped results are referred to as 'unadjusted' as no adjustments for imports and exports have been made (described in the next step). Our key assumptions are described below, with additional detail on the (sub-)groups and data sources used described in Table 5 on page 24..

Key assumptions for the **built environment**:

- **Building products:** We assumed that all metals and minerals were used within the built environment and all built environment materials were produced in New Zealand. (The plausibility of this assumption is examined in section 4.1.)
- **Use phase:** We included 56% of all public electricity production (MBIE, 2017) and all fuel combusted for direct use in heating residential and commercial buildings. Fugitive emissions produced during electricity generation were included, as these are part of the energy generation process.
- **End-of-life phase:** We included only the emissions associated with garden waste and wood in landfills, as almost all other construction and demolition waste in landfill is inert. (While there are some emissions from decomposition of wood, paper on plasterboard, etc., these emissions are relatively low in the context of the life cycle of a whole building.) We included managed landfills only, as were unable to separate unmanaged landfills and farm fills. Building waste disposed in unmanaged landfills is likely to be inert 'clean fill'; therefore, these landfill types have been included under 'other'. Emissions from decomposition of food waste in landfill and domestic wastewater treatment are counted as 'nutrition'.

Key assumptions for **nutrition** include:

- **On-farm emissions:** We have included emissions occurring during the production of unprocessed agricultural food products. These emissions are mostly due to emissions produced through the enteric fermentation process within the digestive system of farmed animals, accounting for 35% of New Zealand's gross carbon footprint in 2015 (MfE, 2017). Other emission sources include materials used for farming such as the production of fertilisers, farm equipment and electricity, including fugitive emissions, and the production and combustion of fossil fuels used for agricultural purposes.

- **Food processing:** The production of food products includes the combustion and production of fuels used within the food industry, along with the production of electricity used within this sector, including fugitive emissions.
- **Disposal:** Waste deposited in managed landfills was divided into separate waste streams (MfE, 2017). Emissions produced from the decomposition of waste in landfill has been included within this category, along with emissions occurring from the treatment of domestic waste water, which is closely linked to food consumption.

Key assumptions for **transport** include:

- **Vehicle manufacturing:** As almost all vehicles used in New Zealand are manufactured in other countries, no manufacturing emissions are accounted for within the unadjusted results. Section 3.2 shows the adjustment made for imports and exports, including vehicle manufacture.
- **Direct combustion emissions:** Emissions from the production of fuels (including fugitive emissions) and their combustion in vehicles.
- **End-of-life phase:** Emissions from the disposal of vehicles could not be separated due to the lack data covering this level of detail. However, the emissions associated with the disposal of vehicles is seen to be minor in relation to New Zealand's emissions. Any other disposal emissions within New Zealand are accounted for under the 'other' grouping.

3.2. Adjust for imports and exports

Adjustments for imports and exports of goods and services would be best calculated using a multi-regional input-output life cycle assessment – a form of environmental assessment that accounts for GHG emissions embodied in products and services imported from our foreign trading partners alongside domestic emissions for domestic consumption. However, this level of data is not yet available for New Zealand (Romanos, et al., 2014; Ghose, 2018). As such, we have applied the following approach:

- **Removed GHG emissions associated with exported agricultural products:** As New Zealand is a net exporter of agricultural products, the emissions related to domestic consumption have been calculated by scaling down New Zealand's total agricultural emissions. Consumption has been calculated based on national economic input-output tables with the latest data available (2012/13 financial year) (Stats NZ, 2016a). Our definition of agricultural products includes primary products (e.g. 'cattle', 'sheep' and 'vegetables'), processed products (e.g. 'meat and offal', 'prepared vegetables' and 'beer, soft drinks and fruit juices') and the material inputs into the agricultural sector (e.g. 'fertilisers and pesticides'). While not all agricultural products are used as food, non-food products (e.g. wool at $620M) are small compared to the overall total (approximately $45B) and, as such, have been left within the 'nutrition' category for simplicity (Stats NZ, 2016a). Forestry and wood products are excluded, as they are captured separately within *New Zealand's GHG Inventory*.

  To determine a ratio between domestic consumption and export, 'total final consumption expenditure' from (Stats NZ, 2016a) was divided by the sum of itself plus exports (which collectively represent total domestic production). When considering all agricultural products, New Zealand was found to consume 37% ($16.6B) of our total production ($44.9B) domestically, with the remaining 63% ($28.2B) exported. As such, all emissions associated with agriculture and food production have been scaled down to 37% of their original values. This includes all inputs such as energy use and chemical use as well as direct emissions from farms. The only exception made was for enteric fermentation in ruminant animals (cattle, sheep, etc.), which contributed 35% of New Zealand's total gross carbon footprint in 2015. This value was scaled by the subset of agricultural products that originate from animals, given that we consume only 9% ($4.1B) of these products directly, with 91% ($19.6B) of total production ($23.7B) exported (Stats NZ, 2016a). Emissions associated with the disposal of food products in landfill and wastewater treatment have not been scaled as these emissions are a direct result of consumption within New Zealand.

- **Included imports and exports of durable goods and services traded internationally (e.g. cars):** International trade has been calculated based on carbon intensity per New Zealand Dollar (NZD). This adjustment accounts for the top 30 imported and top 30 exported goods and services categories of 2015 (Stats NZ, 2016b), excluding construction products and food products which are considered separately (see Table 6 on page 27). The adjustment was made by calculating the net imports (or exports) of each category by dollar value and matching it to an emissions profile from the US EIO-LCA model (CMU, 2008). The US EIO-LCA model calculates the entire direct and upstream carbon footprint across all industries that supply a product or service per US Dollar (USD). Adjustments were made to convert the emissions (measured in 2002 USD) to 2015 NZD by adjusting for inflation (BLS, 2018) and exchange rate (IRD, 2016). Imported and exported emissions were assigned to a single category wherever possible, e.g. vehicle manufacture was assigned to 'transport'. Where the emissions were for an activity that underlies the whole economy, e.g. insurance or telecommunications, they were split proportionately across all categories. As can be seen from Table 6, the top imports are those things for which New Zealand's domestic industry is small, e.g. vehicle manufacture, mechanical machinery manufacture, textiles and clothing, and crude oil extraction.
- **International transport:** Fuels used for international transport (international aviation and sea freight) were calculated as part of *New Zealand's GHG Inventory* but reported separately to the main inventory. These emissions are calculated from the total fuel used during refuelling in New Zealand for planes and ships travelling international routes. An adjustment has been made to reflect direct consumption of air travel by New Zealanders and the freight impacts needed to import goods into New Zealand for domestic consumption. For air travel, New Zealanders accounted for 43% of all international trips in 2015 (Stats NZ, 2015a). We assumed that all travel would be return trips and have therefore scaled air transport emissions to 86% of the reported value. The carbon footprint associated with the running of the air travel industry (e.g. in operating airports and travel agencies) have been subtracted from the domestic inventory to account for the fact that New Zealand is a net exporter of air travel services (Stats NZ, 2016b). This adjustment uses the US EIO-LCA model, which calculates indirect emissions to be approximately 29% of direct emissions (CMU, 2008). For sea travel, which primarily transports goods rather than people, emissions associated with exports (63% of the total tonnes of cargo) have been removed from the domestic inventory (Stats NZ, 2015b). In line with air transport, an adjustment has also been made to remove indirect GHG emissions from sea freight based on the US EIO-LCA model, which were calculated as 16% of direct emissions.

4. Validity of key assumptions

4.1. New Zealand manufactures building products locally

Despite the large-scale shift to offshore manufacturing over the past 30 years, New Zealand has retained a significant share of our building products industry. We produce virtually all of our own sand and gravel, we make most of our own steel (mining our own iron sand to do so), we make much of our own cement (in Portland, near Whangarei, and – in 2015 – also at Westport (now closed)), we grow our own trees and produce most of our own wood products (for timber framing, wood panels for joinery, etc.). While we do import buildings products (e.g. flat glass), we export some too, including large amounts of wood and aluminium (relative to the size of our economy).

We have assumed that demand for building products is met by local production and that imports and exports largely cancel each other out. This assumption results in 6.3% of New Zealand's gross carbon footprint coming from the production/construction phase of the built environment: 2.6% from steel, 1.6% from aluminium, 1.9% from cement and other non-metallic minerals (e.g. aggregates), and 0.1% from other sources (note: these numbers add to 6.2% due to rounding) (MfE, 2017). Wood products are excluded as (a) their emissions cannot be easily separated from pulp and paper, and (b) their maximum contribution is relatively small at 0.5% of the New Zealand total.

To assess whether this assumption is reasonable, consider imports and exports of metals and non-metallic minerals separately:

Metals: In 2015, 45% of domestically-produced steel (BlueScope Steel, 2016, p. 10) and 90% of domestically-produced aluminium was exported (NZAS, 2018). If there were no imports, this would reduce the production phase of the built environment from approximately 6.3% of the New Zealand total to 3.6%. However, these exports are largely matched by imports. $1.7B of basic metals were exported in 2015 while $1.35B were imported, resulting in a net outflow of only 20% (Stats NZ, 2016b). Additionally, New Zealand is a net importer of structural steel and fabricated products, further reducing any net exports (Stats NZ, 2016a). Since 2016, the balance has shifted even further towards using local production to meet local consumption as Pacific Steel's electric arc furnace in Otahuhu was decommissioned and its rolling mills acquired by New Zealand Steel. This means that both structural and reinforcing steel are now produced from primary steel manufactured at New Zealand Steel's Glenbrook plant – New Zealand's only remaining steel mill. This shift towards lower exports can already be seen in New Zealand Steel's Annual Reports, with exports of steel falling from 39% to 25% from FY2016 to FY2017 (Bluescope Steel, 2017, p. 10).

Cement and non-metallic minerals: In 2015, imports ($21M) and exports ($31M) of cement were negligible compared to a domestic industry of approximately $550M (Stats NZ, 2016a). International trade in non-metallic minerals for use in the building and construction industry is very small (except for high value items such as slate) given that these minerals (e.g. construction aggregates) are typically both bulky and heavy, making long-distance freight very expensive. Non-metallic minerals do not register in New Zealand's top 30 imports or top 30 exports (Stats NZ, 2016b).

4.2. 91% of domestically-produced animal products are exported

This study calculates that only 9% of domestically-produced animal products are for domestic consumption, with the remaining 91% exported. This value seems plausible when compared to the share of domestic consumption calculated for major animal products categories shown in Table 2. Only products derived from cattle and sheep are shown, as these are the largest contributors to domestic emissions within *New Zealand's GHG Inventory*.

Table 2: Production and consumption of selected cattle and sheep products within New Zealand in 2014-16 (OECD/FAO, 2017), (USDA, 2017).

Product	Production (kt)	Imports (kt)	Consumption (kt)	Exports (kt)	Consumed in New Zealand
Beef and veal	670	13	85	598	12%
Mutton and lamb	485	5	16	480	3%
Butter	572	2	125	493	22%
Cheese	321	10	39	292	12%
Fresh milk	21,224	2	497	242	2%
Whole milk powder	1,352	3	17	1,338	1%
Skim milk powder	503	4	81	425	16%

Furthermore, direct agricultural emissions contributing 14% of New Zealand's total gross emissions (see Table 4 on page 20) is plausible compared to a global average of 12% (FAO, 2018). New Zealand's higher-than-average meat and dairy consumption and relatively low carbon electricity grid supports agricultural emissions representing a higher proportion than the world average.

4.3. US production is representative of imported goods and services

As mentioned in section 3.2, an adjustment for imported goods and services would be best calculated using a multi-regional input-output life cycle assessment that accounts for trade with New Zealand's specific trading partners. However, this level of data is not yet available for New Zealand (Romanos, et al., 2014; Ghose, 2018). Instead, adjustments for imports and exports are based on the US EIO-LCA model (CMU, 2008). This should provide a reasonable approximation of international production as the US has one of the most complete economies in the world, with most industries represented within the US alone, even without imports from other countries. The US EIO-LCA model has been cross-checked against a Chinese EIO-LCA model for the first two industry tiers (Liang, et al., 2016) and was found to be in the same order of magnitude for all import/export sectors included in this report, indicating that the results generated from the US EIO-LCA model are plausible. The Chinese model was not used directly as further extension of the calculations would be needed to derive results with the same level of precision as the US model.

4.4. Construction products account for nearly half of the built environment's impacts

A key finding from this report – discussed in chapter 5 – is that the carbon footprint from the production stage of the built environment (5,021 kt CO_2e at the national level, unadjusted for international trade) is similar to the carbon footprint from the operational stage (4,814 kt CO_2e). This finding is surprising given that building-level carbon footprints typically find the operational stage to be the single largest hotspot, even when factoring in New Zealand's low-carbon electricity grid (Berg, et al., 2016; Drysdale & Nebel, 2009).

There are at least three reasons why this might be the case:

1. The 'built environment' category within this report includes the production of infrastructure (roads, bridges, railways, etc.) and the production of buildings; however, we only account for the operational phase of buildings in 'built environment', with operation of infrastructure largely captured under the 'transport' category.
2. Our analysis considers a one-year snapshot of New Zealand's total built environment, not the life cycle of a given building. As such, there are a range of events that can influence the ratio between emissions from building products and emissions from operational energy: an increase in the rate of new-builds or renovations, a particularly warm winter (leading to lower building heating loads), a particularly cool summer (leading to lower cooling loads), a good year for hydropower (leading to lower carbon footprint per kWh of electricity), etc.
3. Bottom-up carbon footprints are typically based on (a) embodied carbon data from other countries, as there have been few datasets for New Zealand until recently, and (b) operational energy and GHG data from the year in which the study is commissioned, projecting this across the life of the building. As a result, (a) embodied GHG emissions may not reflect New Zealand conditions, and (b) operational GHG emissions are highly sensitive to assumptions made regarding the building's service life (50 years, 80 years, etc.), energy use profile and the carbon intensity of the electricity grid (which may decrease over time to meet our commitments under the Paris Agreement). These factors contribute uncertainty to the bottom-up results when applied at the national level.

Given the potential importance of this finding, we conducted a plausibility check on the national figures by scaling bottom-up building carbon footprint data to the national level in 2015. This was done by calculating the carbon footprint per square metre of a reference residential building and a reference commercial building using data from building life cycle assessment (Table 7 on page 28) and multiplying by the total residential and commercial floorspace added in New Zealand for 2015. Renovation activities were converted to equivalent new-build area by dollars spent.

The calculated value from *New Zealand's GHG Inventory* of 5,021 kt CO_2e is plausible given that it is within the range of 900 kt CO_2e to 5,800 kt CO_2e shown in Table 3. While it is at the upper end of this range, it is important to remember that these top-down calculations include production of infrastructure while the bottom-up calculations do not.

Table 3: Carbon footprint of building products in New Zealand's built environment in 2015

Item	Value	Unit	Source
Building activity in 2015: new-build			
Residential $ spent	8,796,498,776	NZD	(Stats NZ, 2018)
Non-residential $ spent	4,404,116,772	NZD	(Stats NZ, 2018)
Residential floor area	4,855,202	m^2	(Stats NZ, 2018)
Non-residential floor area	3,354,092	m^2	(Stats NZ, 2018)
Building activity in 2015: renovation			
Residential $ spent	1,726,647,280	NZD	(Stats NZ, 2018)
Non-residential $ spent	1,514,879,942	NZD	(Stats NZ, 2018)
Residential floor area (if it were new-build)	953,018	m^2	(Stats NZ, 2018)
Non-residential floor area (if it were new-build)	1,153,704	m^2	(Stats NZ, 2018)
Building activity in 2015: total			
Residential floor area (if it were new-build)	5,808,220	m^2	Calculated
Non-residential floor area (if it were new-build)	4,507,796	m^2	Calculated
Carbon footprint per m^2			
Residential: low estimate	75	kg CO_2e/m^2	(Drysdale & Nebel, 2009)
Residential: most likely	145	kg CO_2e/m^2	(Carre, 2011)
Residential: high estimate	535	kg CO_2e/m^2	(Monahan & Powell, 2011)
Non-residential: low estimate	112	kg CO_2e/m^2	(Berg, et al., 2016)
Non-residential: most likely	352	kg CO_2e/m^2	(Berg, et al., 2016)
Non-residential: high estimate	600	kg CO_2e/m^2	Upper limit for Australian high-rises from confidential studies reviewed by thinkstep
Carbon footprint at the NZ scale in 2015			
Residential: low estimate	437	kt CO_2e	Calculated
Residential: most likely	841	kt CO_2e	Calculated
Residential: high estimate	3,107	kt CO_2e	Calculated
Non-residential: low estimate	504	kt CO_2e	Calculated
Non-residential: most likely	1,589	kt CO_2e	Calculated
Non-residential: high estimate	2,705	kt CO_2e	Calculated
Total: low estimate	***941***	***kt CO_2e***	***Calculated***
Total: most likely	***2,429***	***kt CO_2e***	***Calculated***
Total: high estimate	***5,812***	***kt CO_2e***	***Calculated***
vs. emissions from NZ's GHG Inventory	***5,021***	***kt CO_2e***	***Calculated***

5. Results, conclusions and outlook

The built environment is often quoted as being responsible for 2-5% of New Zealand's carbon footprint (Productivity Commission, 2018, pp. 388-9). However, if we go beyond operational energy and consider the full building life cycle, from raw materials through operation to eventual demolition, the significance of the built environment climbs to 13% of domestic emissions (Figure 3b). If we also adjust for international trade, this share climbs higher to 20%, or one-fifth of New Zealand's total gross carbon footprint (Figure 3c). These figures suggest that the built environment offers greater opportunities to reduce New Zealand's carbon footprint than is typically assumed.

It is important to note that the pie charts in Figure 3 represent different total carbon footprints. When excluding international trade (i.e. focusing on domestic production), New Zealand produced 80,155 kt CO_2e in 2015, or approximately 17 t CO_2e per capita (Figure 3a and Figure 3b). When trade is considered (i.e. focusing on domestic consumption), the New Zealand total falls to approximately 60,000 kt CO_2e, or 13 t CO_2e per capita (Figure 3c). New Zealand is therefore a net exporter of approximately 25% of our total gross GHG emissions. These emissions are embodied in products – primarily agricultural products – destined for consumption in other countries.

The contrast between the two approaches (production-oriented and consumption-oriented) highlights the importance of viewing New Zealand's emissions from both perspectives. Considering emissions from a production-oriented view highlights the sectors of the economy (such as energy and agriculture) where we have the greatest opportunities to reduce emissions at a global scale (Figure 3a). The consumption-oriented view considers the demand-side within New Zealand, i.e. carbon footprint due to the products and services consumed by New Zealand organisations and households. It indicates the areas that New Zealand consumers can have the greatest influence on, be they households, businesses, government or NGOs.

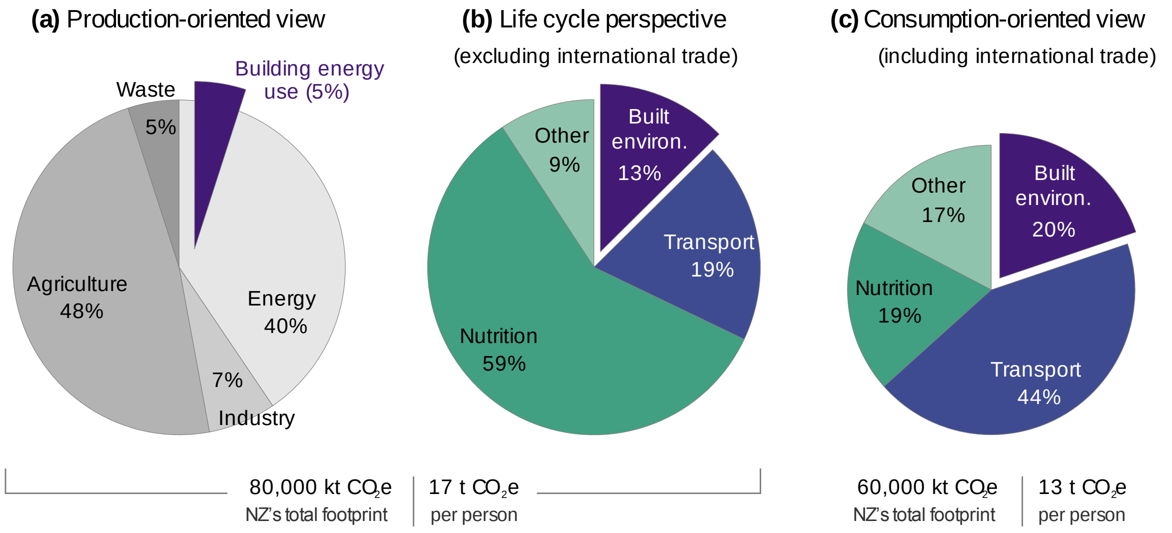

Figure 3: A breakdown of New Zealand's carbon footprint in 2015 from (a) a production perspective, (b) a life cycle perspective, and (c) a life cycle consumption perspective

The 20% contribution from the built environment to New Zealand's total gross carbon footprint from a consumption perspective (after adjusting for international trade) is made up of 8.6% from energy, 8.7% from building products, 2.1% from imported emissions (primarily services such as insurance) and 0.5% from building and garden waste (Figure 4).

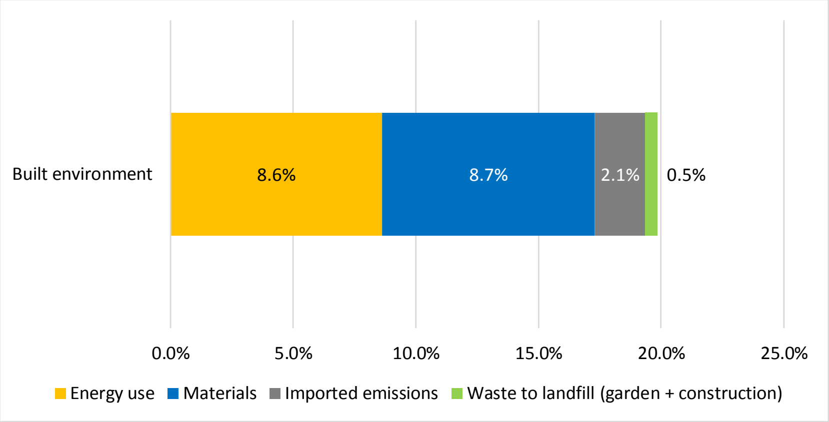

Figure 4: Contribution of the built environment to New Zealand's total gross carbon footprint in 2015, after adjusting for international trade

Perhaps the most significant finding from this report for the built environment is the importance of building products to the carbon footprint over the full life cycle in the New Zealand context. While building products are widely recognised to be environmentally relevant, they are often considered of secondary importance compared to the energy used during building occupation. However, this analysis shows that material efficiency is equally important as energy efficiency in the New Zealand context (noting the caveats in section 4.4). The key reason for this is likely to be New Zealand's reliance on low-carbon electricity and wood for space heating, rather than on GHG-intensive fossil fuels (as is common practice in many other countries, including those of the OECD).

What is required now is action to reduce the carbon intensity of the built environment – both operational carbon and embodied carbon. This action needs to occur from both the production side and the consumption side. The consumption-oriented approach presented in this report is intended to highlight what matters most (i.e. GHG hotspots) so that consumers can understand the levers available to drive decarbonisation through their purchasing decisions.

Table 4: Breakdown of New Zealand's total gross carbon footprint in 2015, both before and after adjusting for imports and exports

	Unadjusted		Adjusted	
	Emissions (kt CO_2 eq.)	**% of gross emissions**	**Emissions (kt CO_2 eq.)**	**% of gross emissions**
Built environment (Total)	**10,127**	**13%**	**11,882**	**20%**
Energy use	**4,814**	**6%**	**5,172**	**9%**
Electricity production & fugitive emissions	3,014	4%	3,014	5%
Fossil fuel production, combustion & fugitive emissions	1,800	2%	2,158	4%
Materials	**5,021**	**6%**	**5,185**	**9%**
Electricity production & fugitive emissions	949	1%	949	2%
Fossil fuel production, combustion & fugitive emissions	829	1%	994	2%
Direct emissions	3,243	4%	3,243	5%
Garden & construction waste landfill emissions	**292**	**0.4%**	**292**	**0.5%**
Imported emissions	**-**	**0%**	**1,233**	**2%**
Transport (Total)	**15,591**	**19%**	**26,090**	**44%**
Domestic road transport	**14,028**	**18%**	**16,814**	**28%**
Domestic road combustion emissions	13,282	17%	13,282	22%
Domestic road fuel production emissions	746	1%	3,531	6%
Other domestic transport	**1,563**	**2%**	**1,873**	**3%**
Other domestic combustion emissions	1,480	2%	1,480	2%
Other domestic fuel production emissions	83	0.1%	393	1%
Imported vehicles, parts & other	**-**	**0%**	**4,572**	**8%**
International transport	**-**	**0%**	**2,831**	**5%**
Nutrition (Total)	**46,986**	**59%**	**11,528**	**19%**
Agriculture	**43,005**	**54%**	**8,366**	**14%**
Direct emissions	38,809	48%	6,539	11%
Electricity production & fugitive emissions	492	1%	182	0.3%
Fossil fuel production, combustion & fugitive emissions	3,704	5%	1,645	3%
Processing & disposal	**3,981**	**5%**	**1,995**	**3%**
Electricity production & fugitive emissions	326	0.4%	121	0.2%
Fossil fuel production, combustion & fugitive emissions	3,203	4%	1,422	2%
Emissions from landfill of food waste & domestic waste water	452	1%	452	1%
Imported emissions	**-**	**0%**	**1,168**	**2%**
Other (Total)	**7,452**	**9%**	**10,394**	**17%**
Industry direct emissions	1,648	2%	1,648	3%
Electricity production & fugitive emissions	622	1%	622	1%
Fossil fuel production, combustion & fugitive emissions	1,925	2%	2,198	4%
Emissions from landfill of industry waste & industrial waste water	3,257	4%	3,257	5%
Imported emissions	-	0%	2,670	4%
Total	**80,155**	**100%**	**59,894**	**100%**

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Annex A: Supporting data

Table 5: Groupings and data sources

Category	Sub-categories	Components	Sources
Built environment	Energy use	Electricity production	(MBIE) (GHG inventory) % of total electricity consumption calculated for: • Mining • Basic metals % applied to total electricity generation emissions + fugitive emissions from electricity production
		Fuel production & combustion	(GHG inventory) (import/export stats) (US I/O tool) Total fuel production & combustion emissions for: • Metal industry • Mineral industry (MBIE) % of fuel use applied to fugitive emissions from used fuel sources
	Materials	Electricity production	(MBIE) (GHG inventory) % of total electricity consumption calculated for: • Residential • Commercial % applied to total electricity generation emissions + fugitive emissions from electricity production
		Fuel combustion	(GHG inventory) (import/export stats) (US I/O tool) Total fuel production & combustion emissions for: • Residential • Commercial (MBIE) % of fuel use applied to fugitive emissions from used fuel sources
		Direct emissions	(GHG inventory) direct emissions from the metal and mineral industries
	Garden & Construction waste landfill emissions	Garden & Construction waste landfill emissions	(GHG inventory) Waste streams back calculated from background report. This category includes emissions from the following waste streams: • Garden/green waste • Wood

Category	Sub-categories	Components	Sources
	Imported emissions	Imported emissions	(import/export stats) (US I/O tool) Embodied emissions in products/services imported and used for built environment operation. E.g. construction machinery, etc.
Transport	Road domestic transport	Combustion emissions	(GHG inventory) Emissions from Road transport (cars, trucks etc.)
		Fuel production emissions	(GHG inventory) Percentage of petroleum refining emissions split by same proportion of combustion emissions
	Other domestic transport	Combustion emissions	(GHG inventory) Emissions from other domestic transport (domestic air travel, rail, sea etc.)
		Fuel production emissions	(GHG inventory) Percentage of petroleum refining emissions split by same proportion of combustion emissions
	Imported vehicles, parts & other	Imported vehicles, parts & other	(import/export stats) (US I/O tool) Embodied emissions in imported vehicles, parts, tires and services.
	International transport	Direct emissions + embodied emissions in materials and services	(GHG inventory) (US I/O tool) Direct combustion emissions & embodied emissions in vehicle production, fuel use, services etc. for international transport of NZ citizens and goods for consumption in NZ
Nutrition	Agriculture	Direct emissions	(GHG inventory) Direct emissions from agriculture (e.g. enteric fermentation) and fertiliser production.
		Electricity production	(MBIE) (GHG inventory) % of total electricity consumption calculated for: • Agriculture • Chemical production (primarily fertilisers) % applied to total electricity generation emissions + fugitive emissions from electricity production
		Fuel production & combustion	(GHG inventory) (import/export stats) (US I/O tool) Total fuel production & combustion emissions for: • Agriculture • Chemical production (primarily fertilisers) (MBIE) % of fuel use applied to fugitive emissions from used fuel sources
	Food processing and disposal	Electricity production	(MBIE) (GHG inventory) % of total electricity consumption calculated for: • Food production industry % applied to total electricity generation emissions + fugitive emissions from electricity production

Category	Sub-categories	Components	Sources
		Fuel production & combustion	(GHG inventory) (import/export stats) (US I/O tool) Total fuel production & combustion emissions for: • Food production industry (MBIE) % of fuel use applied to fugitive emissions from used fuel sources
		Emissions from landfill of food waste and domestic waste water	(GHG inventory) Waste streams back calculated from background report. This category includes emissions from the following waste streams: • Food All emissions generated due to domestic waste water have been included in this category
	Imported emissions	Imported emissions	(import/export stats) (US I/O tool) Embodied emissions in products/services imported and used for agriculture or food production. E.g. agricultural and factory equipment etc.
Other	Industry direct emissions	Industry direct emissions	(GHG inventory) Direct emissions from industries not included elsewhere
	Electricity production & fugitive emissions	Electricity production & fugitive emissions	(MBIE) (GHG inventory) % of total electricity consumption calculated for: • Wood, pulp, paper & printing • Other minor sectors % applied to total electricity generation emissions + fugitive emissions from electricity production
	Fossil fuel production, combustion & fugitive emissions	Fossil fuel production, combustion & fugitive emissions	(GHG inventory) (import/export stats) (US I/O tool) Total fuel production & combustion emissions for: • Wood, pulp, paper & printing • Other minor sectors • Any remaining fuel emissions not accounted for elsewhere (MBIE) % of fuel use applied to fugitive emissions from used fuel sources

Category	Sub-categories	Components	Sources
	Emissions from landfill of industry waste & industrial waste water	Emissions from landfill of industry waste & industrial waste water	(GHG inventory) Waste streams back calculated from background report. This category includes emissions from waste streams not included elsewhere, such as: • Paper • Textiles • Nappies Emissions from unmanaged waste and other unaccounted waste have been included here. All emissions generated due to industrial waste water have been included in this category
	Imported emissions	Imported emissions	(import/export stats) (US I/O tool) Embodied emissions in products/services imported and not included elsewhere. E.g. imported durable goods, textiles etc. exports of durable goods are also considered here

Table 6: Net imports of other international goods and services

Import/export category	Net imports ($M NZD)	Emission intensity CO_2e / $M (NZD)	Net imported emission (kt CO2e)	Assigned group	Reported as
Vehicles, parts, and accessories	6,571	300	**1,970**	Transport	Reported as "Imported vehicles, parts & other"
Aircraft and parts	1,936	197	**381**	Transport	
Rubber and rubber articles	589	548	**323**	Transport	
Mechanical machinery and equipment	5,009	347	**1,736**	All groups	The total is split into all groups, weighted by proportion of total emissions from each group. Reported as "Other" for each group
Electrical machinery and equipment	3,180	202	**643**	All groups	
Plastic and plastic articles	1,465	1,336	**1,958**	All groups	
Charges for the use of intellectual property	1,184	99	**117**	All groups	
Insurance and pension services	1,003	62	**62**	All groups	
Optical, medical, and measuring equipment	727	190	**138**	All groups	
Inorganic chemicals	461	1,161	**536**	All groups	
Management fees	461	99	**46**	All groups	
Telecommunications, computer, and information services	81	113	**9**	All groups	

Import/export category	Net imports ($M NZD)	Emission intensity CO_2e / $M (NZD)	Net imported emission (kt CO2e)	Assigned group	Reported as
Financial services	-182	39	**-7**	All groups	
Petroleum and products	4,151	1,060	**4,398**	All groups	Split into all groups, weighted by proportion of total fuel emissions from each group. Reported as "Fossil fuel production, combustion & fugitive emissions" for each group
Textiles and textile articles	1,800	602	**1,083**	Other	Reported under the "Other" group as "Imported emissions"
Pharmaceutical products	1,213	179	**217**	Other	
Other chemical products	532	1,448	**770**	Other	
Toys, games, and sports requisites	531	326	**173**	Other	
Essential oils, perfumes, and toiletries	482	315	**152**	Other	
Precious metals, jewellery, and coins	-779	397	**-310**	Other	
Confidential items	-1,082	329	**-355**	Other	

Table 7: Carbon footprint of building products used in residential and commercial buildings

Building type	kg CO_2e / building	Gross floor area (m^2)	kg CO_2e / m^2	Country code	Source
Commercial office S3a	415,550	2,021	206	NZ	(Berg, et al., 2016)
Commercial mixed S3	313,281	1,933	162	NZ	(Berg, et al., 2016)
Commercial office S3b	387,772	1,814	214	NZ	(Berg, et al., 2016)
Commercial office S4a	2,613,688	7,789	336	NZ	(Berg, et al., 2016)
Commercial office S4b	2,175,925	5,911	368	NZ	(Berg, et al., 2016)
Commercial mixed S4a	712,433	6,373	112	NZ	(Berg, et al., 2016)
Commercial mixed S4b	1,457,551	6,625	220	NZ	(Berg, et al., 2016)
Commercial mixed S5	5,187,639	22,912	226	NZ	(Berg, et al., 2016)
Commercial office S5a	3,020,299	10,864	278	NZ	(Berg, et al., 2016)
Commercial office S5b	4,668,708	13,247	352	NZ	(Berg, et al., 2016)
Residential timber-framed eco-house	10,980	146	75	NZ	(Drysdale & Nebel, 2009)
Residential timber-framed brick-clad house (elevated)	26,085	202	129	AU	(Carre, 2011)
Residential timber-framed brick-clad house on concrete slab	29,183	202	145	AU	(Carre, 2011)

Building type	kg CO_2e / building	Gross floor area (m^2)	kg CO_2e / m^2	Country code	Source
Residential steel-framed brick-clad house (elevated)	34,232	202	170	AU	(Carre, 2011)
Residential steel-framed brick-clad house on concrete slab	33,593	202	167	AU	(Carre, 2011)
Residential timber-framed weatherboard house (elevated)	18,867	202	94	AU	(Carre, 2011)
Residential timber-framed house	55,512	223	249	CA	(CWC, 2004)
Residential timber-framed timber-clad house	~33,615	83	405	UK	(Monahan & Powell, 2011)
Residential timber-framed brick-clad house	~44,405	83	535	UK	(Monahan & Powell, 2011)
Residential block internal wall and brick-clad house	~50,796	83	612	UK	(Monahan & Powell, 2011)

About thinkstep Australasia

thinkstep's mission is to enable organisations worldwide to succeed sustainably, by developing strategies, delivering roadmaps and projects, and implementing leading software solutions. We help large organisations such as Fletcher Building, Downer, New Zealand Steel and Lendlease to embed life cycle thinking into the design of building products, buildings and infrastructure. thinkstep Australasia is is locally owned and part of the global thinkstep group, with 300 sustainability experts worldwide. www.thinkstep.com

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