Greenhouse Gas Emissions in New Zealand: A Preliminary Consumption-Based Analysis

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Abstract

New Zealand's per capita greenhouse gas emissions are usually calculated by taking total emissions as reported under the Kyoto Protocol or the United Nations Framework Convention on Climate Change and simply dividing by population. However this focuses on emissions associated with production within New Zealand. From the point of view of individuals, these are not the emissions they control, and hence can mitigate. Individuals can calculate their "carbon footprint" but tools to do this typically focus on a few categories of emissions (mostly electricity, direct fuel use and waste) and emissions footprints are not available for a wide range of households so cannot be used for comparative analysis. This paper explores how the carbon emissions related to the consumption categories of households in New Zealand vary with household characteristics. We use product consumption data from the 2007 Household Economic Survey. Consumption within each category is linked to a carbon intensity multiplier (tonnes of carbon dioxide equivalent per dollar of consumption) which is derived from: the official 2007 input–output table of 106 industries produced by Statistics New Zealand; energy data on carbon dioxide per petajoule of fuel in each industry from the Energy Data File; and the Energy Greenhouse Gas Emissions Report both provided by the Ministry of Business, Innovation and Employment. Previous literature has used similar methods to calculate the incidence of a carbon tax (e.g. Creedy and Sleeman [2006]). This paper uses these methods in order to study which sectors of household expenditure offer the greatest opportunities for mitigation and how these opportunities vary with household characteristics such as income decile, region and household composition.

JEL codes

D12; D62; Q41; Q01: Q54

Keywords

Climate change, emissions, consumption, household emissions

Contents

1. Introduction

Typically when greenhouse gas (GHG) emissions are reported by industry or per capita, the statistics are presented in a production-based way which isn't necessarily meaningful to consumers in relation to their own behaviour. Also, production-related emissions are only one way to measure the benefit that a country or individual gains from greenhouse gas emissions, and only one way to track efforts to reduce greenhouse gas emissions. Reports of industry emissions tell individuals where the GHG emissions come from, and calculations of per capita emissions derived from production emissions give individuals some idea of the magnitude of their emissions, but they do not tell individuals what emissions they are personally responsible for. From the standpoint of a consumer, consumption-based emissions are the full scope of emissions they can control and take steps to mitigate. This paper uses a simple method to calculate consumption-based emissions for different types of New Zealand households. We focus on how consumption by different households in different categories affects GHG emissions rather than attempting to provide an accurate measure of total consumption emissions.

This information helps consumers understand how their current consumption profile affects their GHG emissions. This is especially important as individuals look for concrete personal steps they can take to reduce their carbon footprint.[1] This information can serve to counter the culture of paralysis surrounding the thought of GHG emissions as a societal or firm-level problem. Furthermore, the study helps us observe how consumption emissions vary over differing household characteristics. This is helpful on a higher level as it helps us see patterns across characteristics such as income deciles or differing household compositions. These descriptive statistics provide insight into emissions patterns in New Zealand and what sort of future action may be fruitful on a scale that both policy makers and the general population can better understand.

We relate production-based emissions to consumption using an approach that combines an input–output (IO) model with a household expenditure survey using carbon intensities (tonnes of carbon dioxide equivalent [CO_2-e] per dollar of output in every industry of the economy). The model is based on the input–output table, which keeps track of inter-industry transactions. The input–output model tracks both fossil-fuel and non-fossil-fuel emissions throughout the entire economy, accounting for both intermediate and final products. The input–

[1] In this paper, the popular term 'carbon footprint' typically refers to GHG emissions reported on a carbon-dioxide-equivalent basis.

output model is used to calculate the carbon intensity vector which can directly convert average household expenditure to average household emissions once industries are matched with consumption categories. The final result of our analysis is average household emissions for every household consumption category available over differing household characteristics such as income decile or region.

Some categories of consumption account for more emissions than others. The three main drivers of emissions for the average household in New Zealand are food, transport and housing utilities. We also find that that there are important drivers within those broader categories: meat/dairy, petrol and electricity generation respectively. Emissions intensity per dollar of consumption goes down as income decile and number of people in a household goes up. Moreover, we find that the composition of emissions changes as income varies and between different regions. For example, housing utilities is a larger proportion of emissions profiles for lower-income households, while transport is a larger proportion of emission profiles for higher-income households. Another example is that households in Auckland tend to create more transport emissions while households in Wellington tend to create more housing utilities emissions.

The three main household emissions categories account for a combined 89% of all emissions for the average household. This implies that we must address these areas if we want to make large emissions reductions. Furthermore, we need to look at the carbon intensities, the sources of GHGs and the mitigation options associated with these activities and determine to what extent households have control over these emissions and where a higher-level policy-based solution is necessary. Because emissions composition changes over key demographics such as household income and region, solutions will also vary across households. Some practical mitigation options on a personal level include sharing fixed emission costs of household energy by living together, using more public transport, working and consuming less and changing one's food bundle. Policy-based mitigation options include facilitating and providing incentives to reduce GHG emissions from production (and import) within each consumption class, helping low-income households improve their energy efficiency and improving public transport infrastructure to reduce private transport, at least until very low-emission vehicles are widespread.

1.1. Literature Review

The literature exploring the incidence of carbon taxes has provided a foundation for our approach. However, we differ from these carbon tax incidence papers by looking at the composition of emissions profiles across households.

Creedy and Sleeman (2006) use an input–output model based on 1996 data to derive a carbon intensity table for New Zealand industries. We update this with 2007 data. Similar calculations involving input–output models to track carbon emissions have been done for the Netherlands by Kerkhof et al. (2009), for the United Kingdom by Gough et al. (2011), and for the United States by Grainger and Kolstad (2010) and Hassett et al. (2007). Creedy and Sleeman (2006) ultimately use their input–output model to derive price changes in various industries as the results of multiple carbon tax policy options. They find that lower-income households spend more of their income on high-emissions-intensity consumption such as petrol or housing utilities. We find that the same three main drivers are responsible for most emissions but the mix of food, transport and housing utilities varies with income.

Analysis from Kerkhof et al. (2009) is very similar to ours in that they analyse the composition of household emissions over income deciles for the Netherlands. They find that housing is more important for the emissions profiles of lower-income households and that transport becomes more important as income rises. Gough et al. (2011) and Grainger and Kolstad (2010) also find that housing utilities are more important in lower-income households and transport is more important in higher-income households. This is consistent with our analysis of emissions composition over income deciles. We look further into the breakdown of these emissions within categories of consumption.

2. Methodology

2.1. Fossil Fuel Emissions Analysis

In order to relate production emissions to consumption emissions, our analysis relates an input–output (IO)-based emissions model to household expenditure as seen in Figure 1. Figure 1 splits our process into two stages and shows the components that go into each stage of analysis. The first stage transforms production emissions into a carbon intensity vector (**c**) which is measured in tonnes of CO_2/dollar[2] of gross output and covers all industries in the economy; the

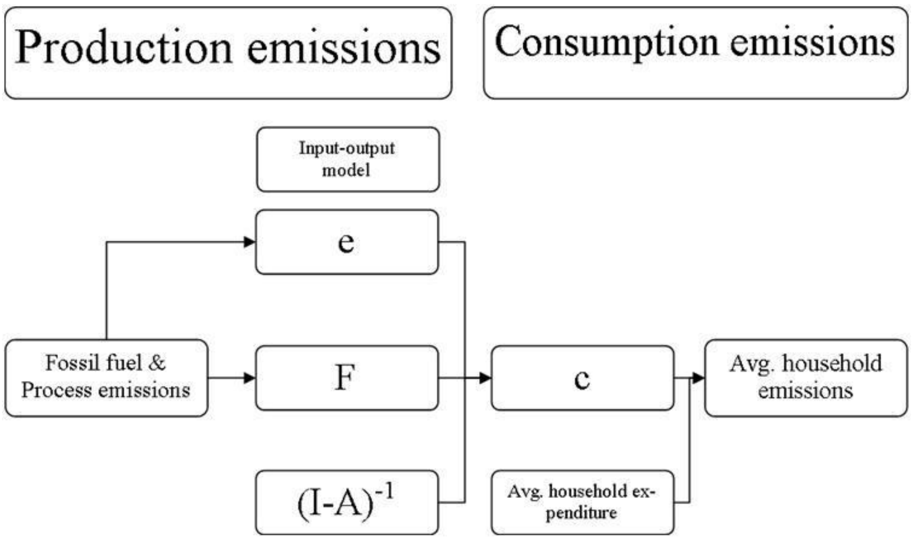
[2] In this study, emissions from fossil fuels are limited to CO_2. We do not include emissions of other GHGs produced from fossil fuel combustion (e.g. methane and nitrous oxide).

second stage uses **c** to transform household expenditure into consumption emissions. Carbon intensity is defined using emissions factors, fuel requirements and an IO model.

$$\boldsymbol{c} = \boldsymbol{eF}(\boldsymbol{I} - \boldsymbol{A})^{-1} \quad (1)$$

If there are n industries and k fuels, then **c** is a 1 x n vector of carbon intensities measured in tonnes of CO_2/dollar of output over n industries, **e** is a 1 x k vector of emission factors measured in tonnes of CO_2/petajoule (PJ) of fuel for k different fuel types and **F** is a k x n matrix of k fuel requirements measured in PJ/dollar of output for each of n industries. **A** is an n x n matrix, called the IO table, which tracks inter-industry transactions in dollars. $(\mathbf{I}\text{-}\mathbf{A})^{-1}$ is an n x n matrix comprised of coefficients which measure how many additional dollars of output each industry must outlay in order to create an additional dollar of output in the original industry. It is used to move between final demand in an industry and inter-industry transactions in the IO model. Creedy and Sleeman (2006) show how to derive it via a geometric sequence.

Figure 1: Methodology flowchart



After **c** is calculated, we relate the production-side industries to the consumption-side sectors of spending. Household expenditure is divided up into different sectors of spending (e.g. food, transport) that can be easily matched to industries in **c**. We used scalar multiplication in order to convert average household expenditure to average household emissions using the **c** vector.[3]

[3] A more detailed explanation of this overall method of relating production-based emissions to household consumption is given in Creedy and Sleeman (2006).

2.2. Process Emissions Analysis

Process emissions are non-fossil-fuel-based emissions from transforming raw materials into final products (we include only methane and nitrous oxide from agricultural production, and carbon dioxide from industrial processes such as steel and cement manufacturing[4]) and can be included through a simple extension of the baseline model. By adding total CO_2-equivalent (CO_2-e) emissions from the processes as entries in the **e** vector and placing indicator entries in **F** to allocate the emissions to the correct industry, the process emissions flow throughout the economy in the same way as the fossil-fuel-based emissions in order to form **c**. Then, **c** can be used in the same manner as in the baseline case to convert average household expenditure to average household emissions.

3. Data

We used data from as close to 2007 as possible in our analysis because it was the most recent, complete and reputable dataset that would give us all the information we needed for our analysis.[5]

3.1. Deriving the Vector of Fuel Emissions Factors (e)

Table 1: Data sources overview

	Data used in derivation (year of release)	Source
e	2007 fuel emissions factors from the Energy Greenhouse Gas Emissions web tables (2012) 2007 oil consumption data from the Energy Data File (2012) 2007 web tables from *New Zealand's Greenhouse Gas Inventory 1990–2008* provided by the Ministry for the Environment (2010)	Ministry of Business, Innovation and Employment Ministry of Business, Innovation and Employment Ministry for the Environment
F	2007 energy consumption data from the Energy Data File (2008, 2012) 2007 "Use" table and "Direct requirements" table from the National Accounts input–output tables (2012)	Ministry of Business, Innovation and Employment Statistics New Zealand
$(I-A)^{-1}$	2007 "Total requirements" table from the National Accounts input–output tables (2012)	Statistics New Zealand
Consumer expenditure	2007 Household Economic Survey web tables (2013) 2007 average table from the Household Economic Survey (2010)	Statistics New Zealand

[4] Perfluorocarbon (PFC) emissions from aluminium production are not included.
[5] All of the data referred to in this section are available in the data reference at http://www.motu.org.nz/building-capacity/dataset/consumption_based_greenhouse_gas_ emissions

Table 2: e vector values

Fuel type	Tonnes of CO_2/PJ of fuel
Coal	88200.000
Petrol	65900.668
Diesel	68694.730
Other Liquid Fuels	66118.418
Natural Gas	53214.070

Source: Data for 2007 were obtained from MBIE 2012 *New Zealand Data Tables for Energy Greenhouse Gas Emissions* http://www.med.govt.nz/sectors-industries/energy/energy-modelling/data/greenhouse-gas-emissions

In our IO model, **e** is a 1 x k vector of emission factors measured in tonnes of CO_2/petajoule (PJ) of fuel for k different fuel types. We derive **e** using the 2007 Energy Greenhouse Gas Emissions web tables from the Ministry of Business, Innovation and Employment (see Table 1 for data sources) which provides annual emissions factors in tonnes of CO_2/PJ of energy over three broad categories of energy: Coal, Liquid Fuels and Natural Gas. The data separates each broad category into several subcategories as well. We took a total of five emissions factors to put through our model by splitting Liquid Fuels into Petrol, Diesel and Other Liquid Fuels. We separated the emission factors in this way to be consistent with how the data for **F** is disaggregated from the Energy Data File.

Emissions factors were taken directly from the web tables for Diesel and Natural Gas. Emissions factors for Coal and Petrol were calculated by averaging its subcategory emissions factors because they were very similar. We broke down Other Liquid Fuels into four subcategory groups found in the oil consumption data of the 2012 Energy Data File: fuel oil, aviation fuel, other petroleum products and LPG. The emissions factor for Other Liquid Fuels was calculated by weighting each subcategory group's average emissions factor by its share of total Other Liquid Fuels consumption from the Energy Data File.

The end result provides us a 1 x 5 vector of tonnes CO_2/PJ over five fuel types (Table 2).

3.2. Deriving the Matrix of Industry Fuel Requirements (F)

In our IO model, **F** is a k x n matrix of k fuel requirements for each of n industries measured in PJ/dollar of output. We derive **F** using a combination of the Energy Data File (EDF) and the 2007 National Accounts IO table. Our method takes gross PJ usage in each EDF sector and distributes it over the 106 New Zealand Standard Industry Output Categories (NZSIOC) industries from the IO table for each fuel type. This distribution is weighted via the use table included in the IO table, which provides data on use shares for our chosen fuel types. Gross PJ usage in each NZSIOC industry is then divided by gross output in that industry in order to convert the data to PJ/dollar of output.

From the EDF we took fuel usage in PJ for broad industry sectors (e.g. agriculture, transport and commercial) for each of our five chosen fuel types. From the IO table we worked with the Use table which lists all 106 NZSIOC industries' use of commodities as measured in dollars. Each of our five fuel types is listed as a commodity (see Table 3 for classifications) in this Use table, allowing us to find the share of each fuel type that each NZSIOC industry actually uses.

Table 3: Fuel-to-commodity classifications for calculating fuel "use" shares

Fuel type	Corresponding commodity from "Use" table of input-output tables
Coal	Coal, coke and tar products
Petrol	Petrol
Diesel	Diesel
Other Liquid Fuels	Other petroleum products
Gas	Natural gas Gas

We then assigned NZSIOC industries to groups based on the broad EDF sectors. We weighted the PJ distribution between these groups of NZSIOC industries according to use shares. Weighting the PJ distribution occurred at the finest level of sector aggregation that the EDF provided for each fuel, as the information varied across fuel types. Whenever there was insufficient data on use shares for a group of NZSIOC industries from the Use table, we parcelled PJ usage out equally among the industries in that group. PJ usage data for 2007 was pulled from both the 2008 EDF and the 2012 EDF because they often differed in the level of aggregation offered. We took the breakdown that was the most specific in each case.

The result of this is a 106 x 5 matrix of gross PJ usage of five fuel types across 106 NZSIOC industries. We then divided each NZSIOC industry row of the **F** table by gross dollars of industry output from the "Transactions" IO table in each respective industry. The ensuing matrix is a 5 x 106 matrix of PJ/dollar of output in each NZSIOC industry (Appendix 8.1).

3.3. Process Emissions

Process emissions were obtained from the 2007 web tables of *New Zealand's Greenhouse Gas Inventory* (as updated in 2010), which provide total emissions for agricultural and industrial processes (Table 4). The values for total emissions were added to the beginning of the model as additional emissions factors to the e vector and the relevant 'fuel' requirements were added to the F vector. Emissions of methane and nitrous oxide were converted to CO_2-e emissions using 100-year Global Warming Potentials from the IPCC (1996). They were then assigned to an industry in the F table using an indicator ("1") in the relevant industry row. The only exceptions were enteric fermentation and agricultural soil which were split between the horticulture, sheep/beef and the dairy cattle industries (Table 5).

This method ensures that process emissions are distributed through the economy the same way that the fossil-fuel emissions are in terms of accounting for emissions from both intermediate and final products.

Table 4: Process emissions (Tonnes of CO_2-e)

Process	Emissions
Enteric fermentation	23,229,831.31
Agricultural soil	11,527,978.47
Metals (steel/aluminium)[6]	2,224,621.54
Chemicals	579,579.91
Mineral products (cement/lime)	857,289.38

Source: Data for 2007 were obtained from MFE 2010 *New Zealand's Greenhouse Gas Inventory 1990–2008*. http://www.mfe.govt.nz/publications/climate/greenhouse-gas-inventory-2010/

[6] This does not include emissions of PFCs from aluminium production.

Table 5: Allocation of process emissions across industries

Industry	Enteric Fermentation	Agricultural Soil	Metals	Chemicals	Mineral Products
Horticulture and fruit growing		40.3%			
Sheep, beef cattle and grain farming	50%	29.85%			
Dairy cattle farming	50%	29.85%			
Basic chemical and basic polymer manufacturing				100%	
Non-metallic mineral production manufacturing					100%
Primary metal and metal product manufacturing			100%		

Including process emissions meant that emissions from clothing for the average household in 2007 increased significantly. This large change can be explained by imported clothing (predominantly non-wool-based) being attributed the same emissions as locally produced clothing (predominantly wool-based). Emissions from clothing produced in New Zealand will be higher than those from imported clothing due to the agricultural emissions from producing wool. To account for this anomaly, we have transferred the output of "sheep, beef cattle and grain farming" that was used as an input into "textile and leather manufacturing", and hence the process emissions that are associated with this output, into "meat and meat product manufacturing". This is consistent with the New Zealand Emissions Trading Scheme legislation which allocates the emissions from wool production to meat production.

The emissions from the beverages category (which includes alcoholic beverages, tobacco and illicit drugs) also more than doubled when process emissions were included. This was partly due to a large amount of the output of "non-metallic mineral product manufacturing" going into the production of "beverage and tobacco product manufacturing". This output is probably glass but is being assigned the high emissions factor of concrete. To correct for this, we redistributed the output of "non-metallic mineral product manufacturing" going into "beverage and tobacco product manufacturing" across the "residential building construction", "non-residential building construction" and "heavy and civil engineering construction" industries, based on the relative size of each. The emissions from beverages still increased by a large amount when process emissions were included due to the large input into production from "horticulture and fruit growing".

3.4. Deriving the Matrix of Direct Requirement Coefficients $(\mathbf{I}-\mathbf{A})^{-1}$

$(\mathbf{I}-\mathbf{A})^{-1}$ is a n x n matrix comprised of coefficients that measure how many additional dollars of output each industry must outlay in order to create an additional dollar of output in the original industry. In our IO model, $(\mathbf{I}-\mathbf{A})^{-1}$ is a 106 x 106 matrix taken straight from the National Accounts input–output "Total requirements" table. Usually one would have to take the A matrix, (which is the "Transactions" table) and transform it manually but Statistics New Zealand provides the transformed matrix.

3.5. Calculating the Carbon Intensity Vector (c)

The vector **c** is a 1 x n vector of carbon intensities measured in tonnes of CO_2-e/dollar of output over n industries. The vector was derived using MatLab by inputting the appropriate values into the **e**, **F** and $(\mathbf{I}-\mathbf{A})^{-1}$ variables. The result is a 1 x 106 vector with tonnes of CO_2-e per dollar of output over all 106 NZSIOC industries (Appendix 8.2).

Differences across countries in fuels used in the electricity sector and both fuel usage and production composition within other key industries and changes over time make it difficult to compare **c** directly with the equivalent vector in other studies. However, after adjusting for different units of measurement, we find Common and Salma (1992), Grainger et al. (2010) and Kerkof et al. (2009) have carbon intensity vectors similar to those from our calculations. The **c** we derived is of a similar magnitude to these papers but the values differ.

3.6. Converting Production Emissions to Consumption Emissions

The last step in the process is to use the **c** vector to convert average household expenditure to average household emissions. We use the 2010 Household Economic Survey (HES), which provides average weekly household expenditure over the group (e.g. food), subgroup (e.g. fruits and vegetables), and class levels (e.g. fruits) in order of increasing specificity. Statistics New Zealand provides web tables that present data on household expenditure at the subgroup level subdivided by various household characteristics such as income deciles, household composition, region and number of people in household.

The first step was to assign NZSIOC industries to HES categories at the class level using definition tables on both sides of analysis. On the HES side, we then converted weekly household expenditures to annual household expenditure. The 2007 HES average household table from the official release provides expenditure figures at the class level. To complete our dataset, we used these figures to apply class-level weights to all of the subgroup-level figures from the web tables, by assuming that within-subgroup expenditure is consistent across household characteristics.

We then multiplied HES class-level average yearly expenditure directly by the average carbon emissions intensity of the NZSIOC industries related to it. When there were suppressions due to statistical insignificance, we either excluded the results at the HES group level (e.g. for education) or imputed results at the subgroup and class level. The result of these calculations is the tonnes of CO_2-e emissions associated with every HES class subdivided by numerous household characteristics such as income or household composition.[7]

4. Caveats – Limitations to Analysis

4.1. Imports

Our analysis assumes the carbon intensities of imports are the same as their domestic counterparts. This is a strong assumption, given that New Zealand has such a unique domestic manufacturing profile. The nature of this effect is uncertain, as it could either serve to over- or underestimate emissions depending on the industry. This is one of the key limitations of the single-region input–output model that we are using. Many studies that use similar single-region input–output models, such as Grainger and Kolstad (2010) and Creedy and Sleeman (2006), also use domestic carbon intensities for imports. An alternative approach is to use a multi-region model which is much more data intensive as it requires the input–output, trade and emissions data for New Zealand and its trading partners. Our analysis also excludes consideration of the international transport emissions associated with importing goods to New Zealand because these would be complex to calculate on the basis of household expenditure data. This could be an interesting area for further work.

4.2. Homogeneous Output Assumption

The input–output model used in our analysis assumes that output from each industry is homogeneous and hence has the same GHG content per dollar of output. This assumption can either serve to overestimate or underestimate emissions depending on the type of analysis. For example, richer people may be spending more money on a smaller quantity of eco-friendly

[7] We do not account for differences in trade margins (producer, wholesaler and retailer) across commodities.

products. This model overestimates their emissions because it assumes that they are simply buying more output from the industry. Likewise, poorer people may purchase less meat and dairy products as a share of their food, buying cheaper alternatives. Homogeneity is a standard assumption of many IO models; more discussion of this assumption is available in Gough et al. (2011).

4.3. Government-Provided or -Subsidised Consumption

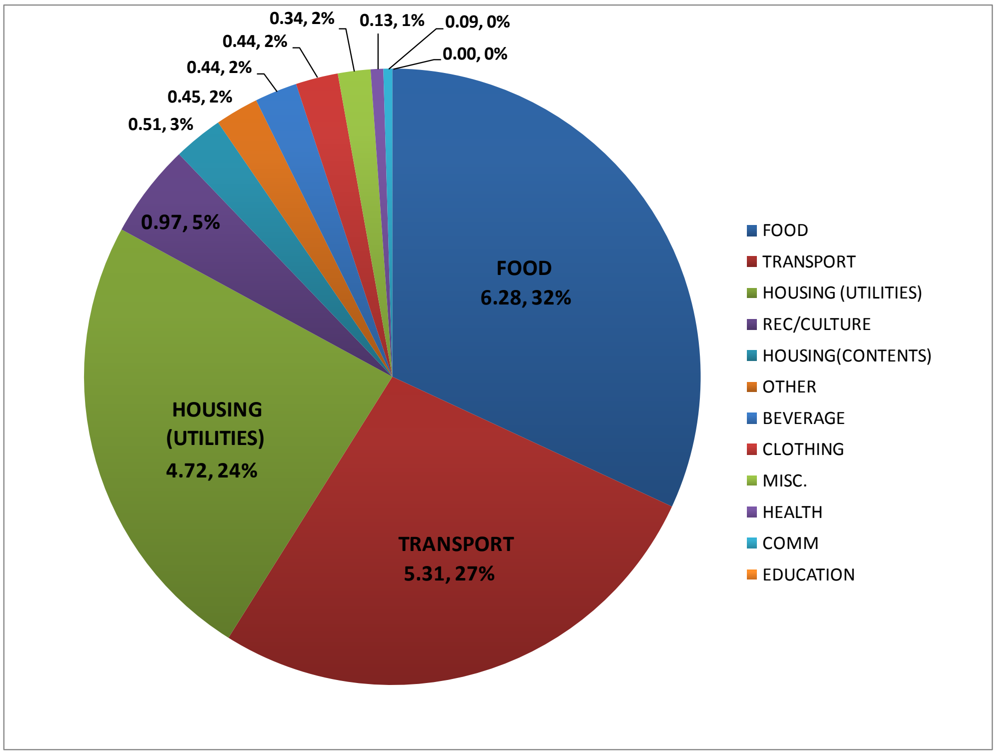
In New Zealand, the government provides or subsidises a range of goods and services that are consumed by households. Household expenditure therefore does not represent all household consumption and emissions in these areas will be understated by the model. For example, health care is heavily subsidised by the government, reducing household expenditure and resulting in our model understating the emissions associated with health care.

5. Results

The final model, including major process emissions, gives us estimates of household CO_2-e emissions on the basis of consumption at the group (e.g. food), subgroup (e.g. fruits and vegetables), and class levels (e.g. fruits) of the 2007 HES. Most of our analysis occurs at the group level, but our data at the subgroup and class levels lend insight into the underlying patterns. The raw data tables are available at http://www.motu.org.nz/building-capacity/dataset/consumption_based_greenhouse_gas_emissions.

Figure 2 shows the breakdown of household consumption emissions from private expenditure over all HES group-level categories for the average household in 2007. Total average emissions per household were 20.56 tonnes of CO_2-e. Per capita emissions for the average person was approximately 9.93 tonnes of CO_2-e based on the average number of people in each household of 2.07. It is evident from Figure 2 that not all categories of consumption are equal in their emissions intensity. The three main drivers of emissions are food, transport and housing utilities.

Figure 2: Breakdown for households' average annual CO_2-e emissions in 2007 (tonnes CO_2-e per year)



For comparison, when calculated nationally on a production basis, New Zealand's per capita emissions in 2007 were 17.61 t CO_2-e excluding the forestry sector, and 13.37 tonnes of CO_2-e including the forestry sector (WRI, CAIT 2.0 2014). As points of difference, the production-based calculations:

- include all GHGs in the national inventory calculated on a CO_2-e basis, whereas our study excludes some non-CO_2 GHGs.
- include the emissions from goods produced in New Zealand and stockpiled or exported overseas rather than consumed by New Zealand households.
- exclude all emissions associated with international aviation.
- exclude emissions associated with the production of goods imported into New Zealand.

The differences in per capita emissions calculated on a production versus consumption basis highlight the importance of considering both metrics when assessing responsibility for emissions and identifying mitigation opportunities. As discussed in section 4.3 our analysis excludes public-sector consumption and will therefore underestimate households' consumption-based emissions.

Table 6: HES subgroup level (class level in italics) breakdowns for households' average annual consumption emissions and emissions intensity in 2007

	tonnes CO_2-e	%	kg CO_2-e/$
FOOD			
Fruit and vegetables	1.2	19%	1.3
Meat, poultry, and fish	2.1	34%	1.7
Grocery food			
Milk, cheese, and eggs	1.0	17%	1.7
Other grocery food	1.3	21%	0.40
Non-alcoholic beverages	0.1	2.2%	0.31
Restaurant meals and ready-to-eat food	0.5	7.1%	0.23
Total	**6.28**	**100%**	
TRANSPORT			
Purchase of vehicles	0.36	6.8%	0.14
Private transport supplies and services			
Petrol	3.7	69%	1.8
Other private transport supplies and services	0.28	5.3%	0.17
Passenger transport services	1.0	19%	0.91
Total	**5.31**	**100%**	
HOUSING UTILITIES			
Actual rentals for housing	0.47	9.9%	0.14
Home ownership	0.64	14%	0.23
Property maintenance	0.21	4.5%	0.25
Property rates and related services	0.19	4.1%	0.15
Household energy			
Electricity	3.0	64%	1.86
Other household energy	0.15	3.2%	0.58
Other housing expenses	0.05	1.0%	0.057
Total	**4.72**	**100%**	

Table 6 shows that food contributes 32% of total consumption emissions for the average household. Within the food HES group, the main contributors to total emissions are methane from enteric fermentation and nitrous oxide from agricultural soils. Both of these sources of process emissions feed directly into food industries.

Other studies have examined the total emissions attributable to food production. For example, Vermeulen et al. (2012) estimate that globally, up to 20 percent of all GHG emissions stem from food production when associated energy, refrigerant and waste emissions across the supply chain (but not indirect emissions from land cover change) are taken into account.[8] Transport contributes 27% of total emissions for the average household. Petrol consumption is the biggest contributor of emissions in the transport HES group with 69% of total transport emissions. The emissions relating to car purchases are likely understated because New Zealand does not produce cars. Housing utilities contribute 24% of total emissions for the average household. Electricity usage is the biggest contributor of emissions in the housing utilities HES group with 64% of total housing utilities emissions. This is because the electricity generation industry requires a sizable amount of both coal and natural gas (about 48% and 69% respectively of total coals and gas usage in the economy in 2012). [9]

Table 7 shows households' average annual emissions per dollar of expenditure in 2007 in each category including and excluding process emissions. For example, if an average household increases (decreases) its consumption of food by one dollar, its emissions will, on average, increase (decrease) by 0.739 kg CO_2-e (including process emissions).

The three highest emitting categories in total also have the highest marginal emissions. Within these, the expenditure classes with the highest emissions per dollar are electricity, followed closely by petrol; meat, poultry and fish; and milk, cheese and eggs. Electricity emissions are an average over the day and across months. The actual emissions are very dependent on when electricity is used because the electricity source (hydro, wind, gas, coal or geothermal) varies. PCE (2012) explain how the source of electricity and hence the carbon emissions associated with it vary over the day (with low emissions at night and especially in the early hours of the morning) and over the year, with higher emissions in winter, especially in dry years when the hydro lakes are low. Reducing electricity use during the day in winter reduces emissions most.

[8] We do not account for non-CO_2 emissions from refrigeration.

[9] MBIE 2012 *New Zealand Data File 2012 Web Tables* http://www.med.govt.nz/sectors-industries/energy/energy-modelling/publications/energy-data-file/new-zealand-energy-data-file-2012

Table 7: Households' average annual emissions per dollar in 2007

HES Expenditure Category	Without process emissions (kg CO_2/dollar)	With process emissions (kg CO_2-e/dollar)
Food	0.176	0.739
Transport	0.700	0.726
Housing (utilities)	0.376	0.425
Clothing	0.145	0.247
Rec/culture	0.143	0.184
Housing (contents)	0.153	0.197
Beverage	0.161	0.308
Other	0.079	0.092
Misc.	0.057	0.071
Health	0.078	0.104
Communication	0.047	0.058
Education	0.000	0.000

Emissions from food are heavily derived from process emissions. Within these, methane is associated with meat and dairy products. Its impact on the climate depends on the time frame of concern because it is a relatively short-lived gas. Process emissions also increase housing utilities' emissions because of the industrial process emissions involved in, for example, steel and cement production.

5.1. Income

Figure 3: Annual tonnes of CO_2-e emissions over average total expenditure by income deciles in 2007

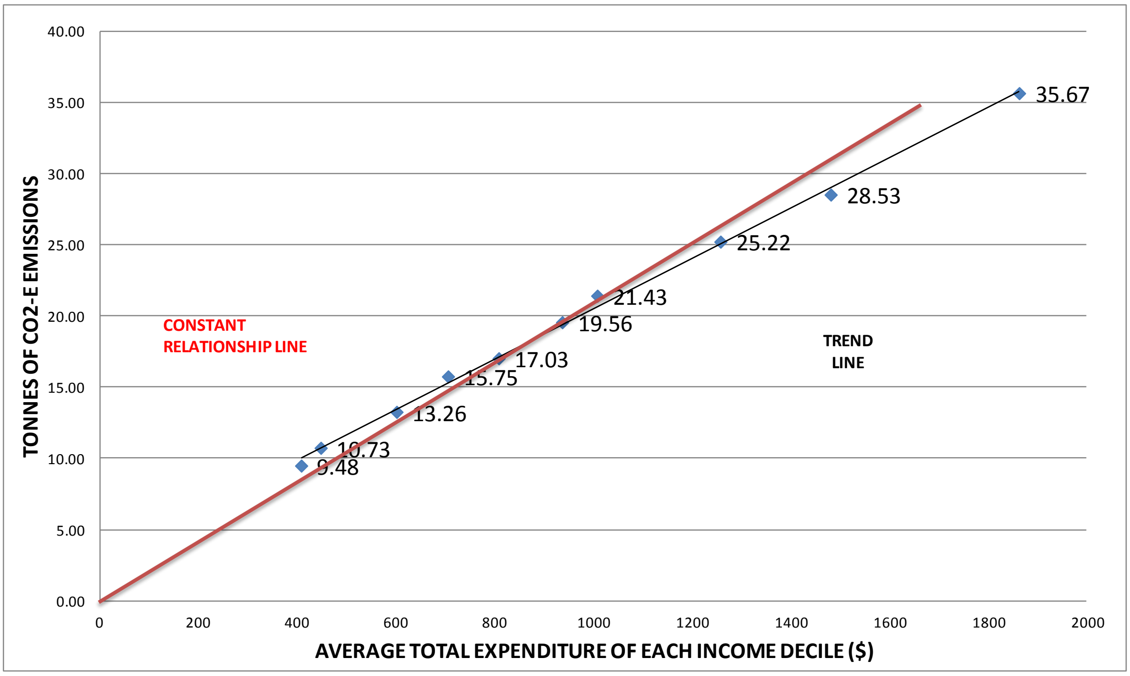
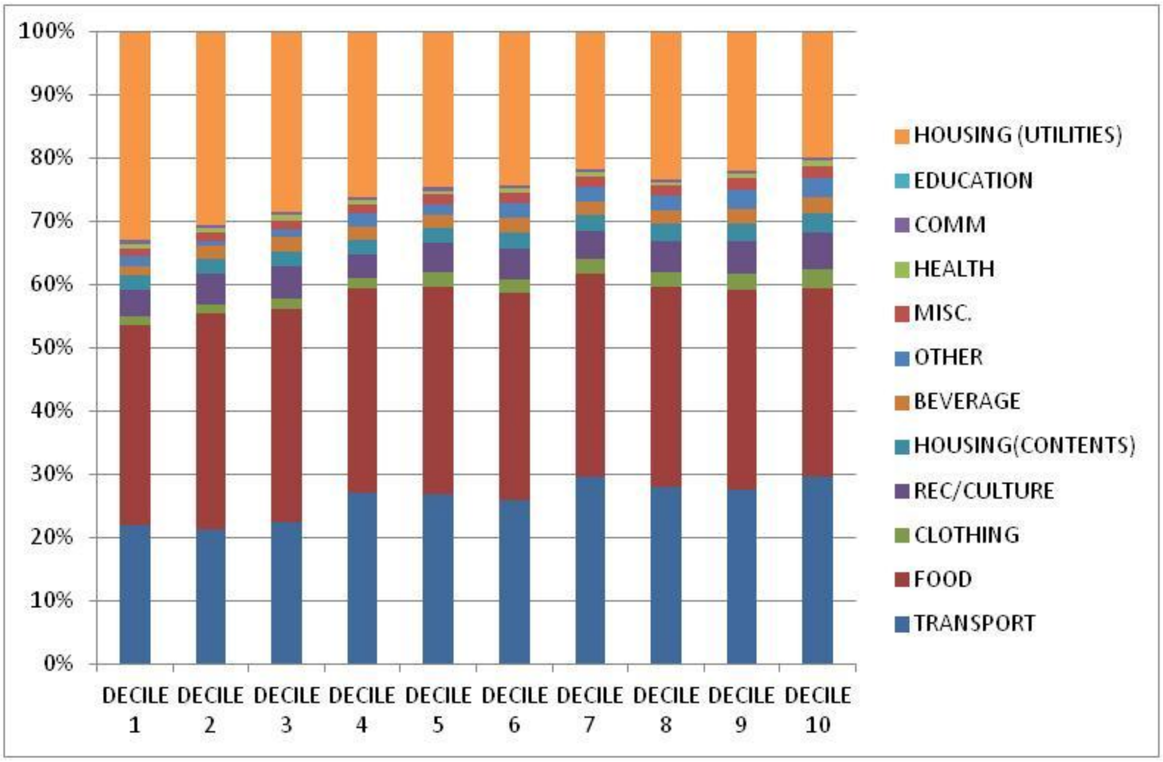


Figure 3 shows tonnes of CO_2-e emissions against average total expenditure by income deciles as defined by Statistics New Zealand. It is evident that there is a positive relationship between income and total emissions. At the same time, one can see that the emissions intensity of consumption falls as consumption rises. Gough et al. (2011), Creedy and Sleeman (2006) and Grainger and Kolstad (2010) all find results consistent with carbon intensities decreasing as income increases. However, not only does the emissions intensity of expenditure fall, its composition also changes.

Figure 4 shows the composition of the CO_2-e emissions from each HES category over income deciles. It shows the differences in the composition of emissions at different income levels. Emissions attributable to food stay at about a third of total emissions over income deciles in our model. As income rises, the data shows that families are more likely to partake in restaurant or takeaway meals. It is possible that the emissions intensity per dollar spent may fall as a result. We cannot observe this. Most of the variation comes in housing utilities and transport. For poorer households, housing utilities are a bigger percentage of emissions than transport. For richer people, transport becomes a bigger percentage of emissions than housing utilities. As income rises, the data also shows that emissions from passenger transport services increase as a percentage of transport emissions (mostly air and road transport).

Figure 4: Composition of annual CO_2-e emissions by income decile in 2007



5.2. Region

Figure 5 shows that the carbon intensity of expenditure differs across regions. More urbanised regions emit less per dollar of expenditure. Auckland and Wellington emit less per dollar then the rest of the North Island. A similar but weaker pattern can be seen with Canterbury in relation to the rest of the South Island. These findings are consistent with Herendeen and Tanaka (1976) and Kerr (2001), who find that urban areas are less energy intensive than rural areas.

Figure 6 shows the composition of CO_2-e emissions in the regions of Auckland and Wellington. Despite the similar average total CO_2-e emissions per household from Auckland and Wellington at about 22.16 and 22.08 tonnes respectively, and similar emissions intensity of consumption, there are interesting differences in the composition of their emissions. Households in Auckland tend to emit more in transportation (specifically, petrol) and households in Wellington tend to emit more in housing utilities (specifically, household energy).

Figure 5 – Annual kg of CO_2-e emissions per dollar of expenditure by region in 2007

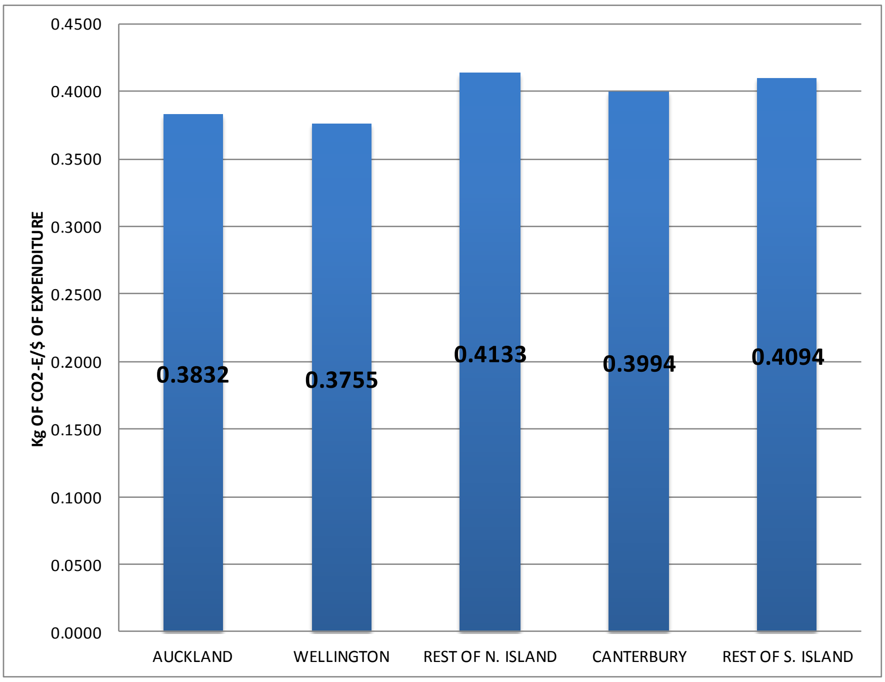
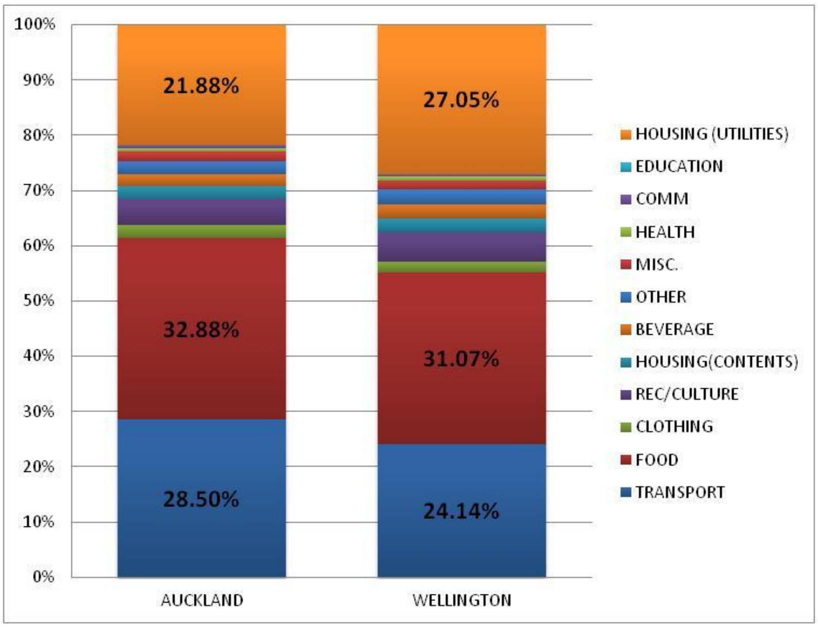


Figure 6 – Composition of annual CO_2-e emissions in Auckland and Wellington in 2007



5.3. Household Composition

Figure 7 – CO_2-e emissions per dollar of expenditure by household compositions in 2007

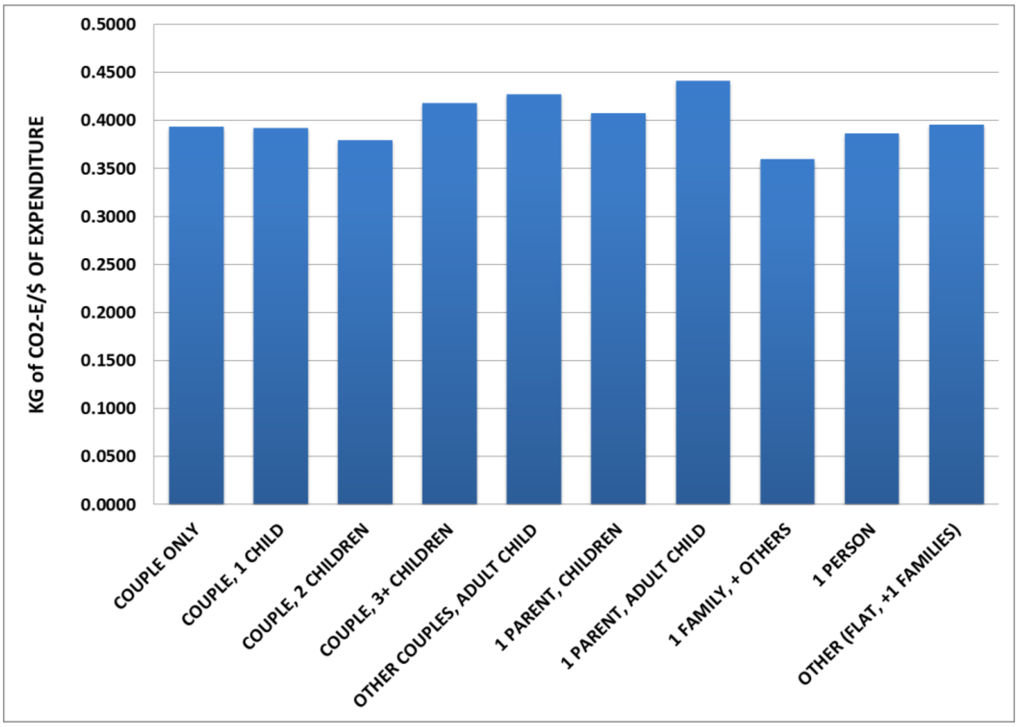
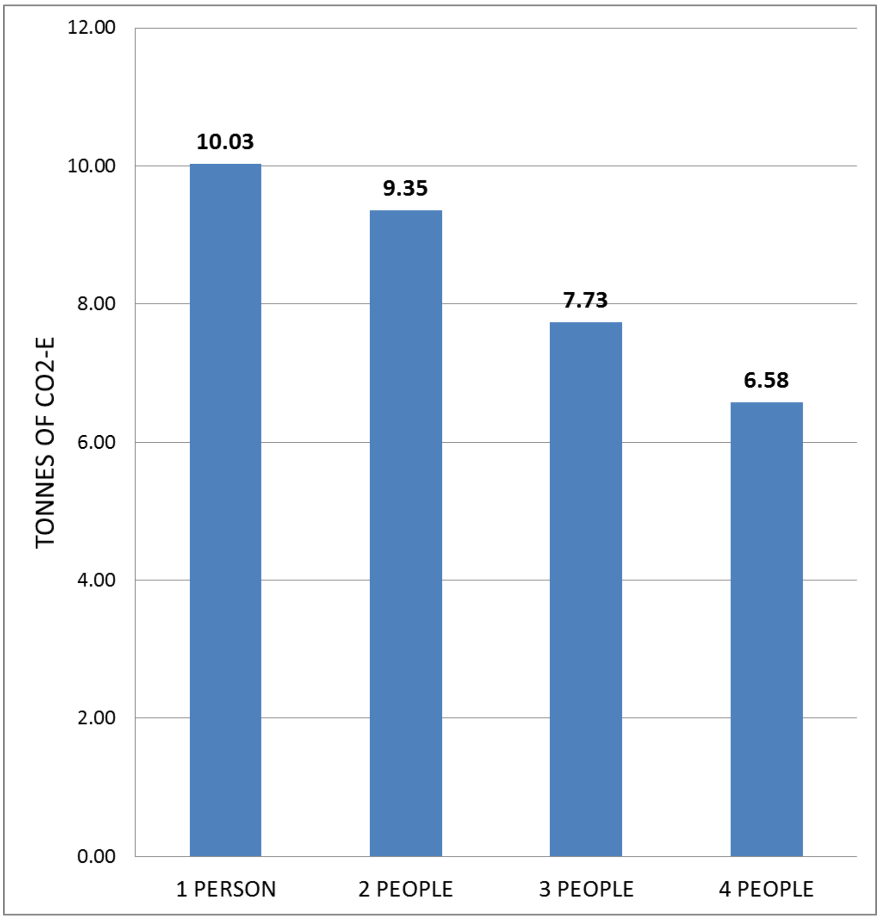


Figure 7 shows that households with different compositions have different carbon intensities per dollar of expenditure. Having another child in the household tends to decrease carbon intensity per dollar of expenditure until the household has more than three children. Moreover, having more adults in the household tends to increase the carbon intensity per dollar of expenditure as seen in some of the highest categories, such as Other Couples, Adult Child; 1 Parent, Adult Child and Other (Flat, +1 Families). These effects could, however, be driven primarily by differences in household income.

5.4. Number of People in Household

Figure 8 shows the tonnes of CO_2-e emissions per capita by number of people in the household. Per capita emissions decrease as the number of people in each household increases, despite total emissions increasing as the number of people in each household increases.

Figure 8 – Annual per capita CO_2-e emissions by number of people in household in 2007



6. Conclusions

6.1. Observations

To summarise, our model uses a carbon intensity vector to transform household expenditure into household GHG emissions from direct private consumption and compares households over characteristics such as income, region and the number of people in a household.

We find that household consumption-related emissions are concentrated in a few key categories and that some consumption items are associated with higher emissions than others. Understanding the sources of emissions allows households to focus on making the biggest and most efficient reductions through targeted and purposeful behaviour. This also helps public officials and policy makers to focus their emissions reductions strategies.

The main drivers of household consumption-related GHG emissions in New Zealand are food, transport and housing utilities (accounting for 89% of emissions). If we want to make large reductions in household emissions, we must address these areas. The fact that transport and housing utilities are very emissions intensive is intuitive, but a more surprising result is that food emissions comprise a third of CO_2-e consumption-related emissions. This highlights the importance of options for mitigating emissions of nitrous oxide that is associated with all food production and the relatively short-lived methane from ruminant animals as we aim for more stringent emission reduction targets and as climate change becomes less of a future possibility and more of a current reality.

Within the key categories (food, housing and transport) some specific categories of spending emit the most both in terms of intensity and in total: meat and dairy within the food category; petrol consumption within the transport category; and average electricity use within the housing utilities category.

In terms of food bundles, meat and dairy consumption are responsible for about half of food emissions and have the highest carbon intensities per dollar of expenditure. There is a relatively high marginal effect of reducing consumption of meat (especially from ruminants) and dairy; the extent to which households can change their food bundle will vary with current diet. The nature of transport and housing utilities makes them more conducive to reductions by sharing. If more people benefit from the same fixed emissions, overall emissions can be reduced. By electing to live with more people under one roof or by carpooling in order to share transport, emissions can be reduced by a large amount.

Those who spend less tend to emit less. This effect is not proportionate as income decile rises because carbon intensity decreases per dollar of expenditure as income rises. Consumption by low-income households is more emissions intensive per dollar of expenditure than by high-income households. However, lower-income households may have fewer options to change their emissions profiles as they may be constrained by credit availability (e.g. for insulation) and their already low total emissions.

We must take care not to prescribe the same solutions to all households across income deciles. It is clear that the composition of emissions changes as income increases. For poorer households, the fixed emissions cost of housing utilities is a bigger part of their emissions than transport. A significant fall in the emissions of poorer people might require policies that establish higher energy efficiency codes in low-income housing. Richer people can reduce household energy use and could also take fewer, longer international trips rather than short, frequent ones and invest in video conferencing technology to reduce the amount of highly emissions-intensive travel they may be doing. They may also have a higher capacity to change their lifestyle without compromising their basic needs, possibly by substituting leisure for consumption.

Households in urban areas emit less per dollar of expenditure than rural areas. This makes sense because people living in urban areas live in denser conditions, with shorter commutes and more opportunities for sharing fixed emissions costs such as housing utilities. Households in different regions have different emissions patterns. A real impact could be made if the local governments in these cities make a commitment to improving conditions in problem sectors. In Wellington a key issue is improving the energy efficiency of homes; in Auckland, reduced commuting, more efficient cars and greater use of public transportation are key.

The effect of household composition on emissions is difficult to interpret because many confounding factors, including income, affect the statistics. It would be better to use an econometric approach to explore this effect. The emissions added by an adult seem to be higher than those of a child. This makes sense because having more adults in a household increases the need for private transport and consumption that cannot be shared. At the same time, having more people in a household appears to be good for emissions efficiency per dollar of consumption. Emissions per capita are reduced as the number of people in a household increases. This result reinforces the idea that fixed emissions costs can be shared among individuals.

6.2. Moving Forward

Accessing unit record data from the Household Economic Survey from Statistics New Zealand would allow us to analyse household emissions in greater depth, controlling for many factors with an econometric approach. This would allow us to make our calculations more personal and find more meaningful patterns to interpret. A time series approach could also be used. This would allow us to see how New Zealand households' consumption emissions and their composition are changing over time.

Ideally, a multi-region input–output table would be used in further work. No such model has been created for New Zealand and it would allow us to get more accurate estimates of consumption-based emissions, especially in import-heavy spending categories. This step could inform discussion within New Zealand on how to choose import partners in a way that is the most conducive to emissions reductions.

The intention of this paper is to help individuals and the policy makers who can facilitate their actions to focus their climate change mitigation in areas where marginal reductions will be large for small changes in consumption, and where ultimately large reductions can be achieved. It is important that emissions reductions become less of a national story and more of a local and personal story if we are to make effective reductions in our emissions and avoid dangerous impacts on the climate system.

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8. Appendix

8.1. F Table (Energy Emissions Only)

F TABLE	FUEL REQS IN PJ				
2007 I/O TABLES NZSIOC	**COAL**	**PETROL**	**DIESEL**	**OTHER OILS**	**GAS**
Horticulture and fruit growing	0.209	0.249	1.704	0.346	0.000
Sheep, beef cattle and grain farming	0.209	0.332	3.633	0.404	0.000
Dairy cattle farming	0.209	0.366	2.287	0.634	0.000
Poultry, deer and other livestock farming	0.209	0.283	1.525	0.480	0.000
Forestry and logging	0.209	0.166	1.166	0.077	0.000
Fishing and aquaculture	0.209	0.632	2.467	0.231	1.808
Agriculture, forestry and fishing support services	0.209	0.199	4.620	0.115	0.000
Coal mining	0.000	0.002	0.683	0.010	0.000
Oil and gas extraction	0.000	0.006	0.140	0.131	0.560
Metal ore and non-metallic mineral mining and quarrying	0.000	0.001	1.437	0.000	0.000
Exploration and other mining support services	0.000	0.009	0.245	0.050	0.020
Meat and meat product manufacturing	1.920	0.004	0.035	0.030	0.620
Seafood processing	0.000	0.001	0.035	0.010	0.775
Dairy product manufacturing	3.626	0.019	0.508	0.141	5.425
Fruit, oil, cereal and other food product manufacturing	0.000	0.004	0.105	0.040	2.480
Beverage and tobacco product manufacturing	0.213	0.003	0.088	0.030	0.775
Textile and leather manufacturing	0.213	0.005	0.123	0.030	0.020
Clothing, knitted products and footwear manufacturing	0.000	0.002	0.053	0.010	0.007
Wood product manufacturing	0.213	0.008	0.245	0.090	1.364
Pulp, paper and converted paper product manufacturing	0.213	0.007	0.193	0.070	3.788
Printing	0.427	0.023	0.613	0.141	0.152
Petroleum and coal product manufacturing	0.000	0.064	1.753	0.472	0.521
Basic chemical and basic polymer manufacturing	0.000	0.003	0.088	0.020	6.948
Fertiliser and pesticide manufacturing	0.000	0.000	0.000	0.000	3.474
Pharmaceutical, cleaning and other chemical manufacturing	0.000	0.001	0.035	0.010	0.116
Polymer product and rubber product manufacturing	0.000	0.003	0.070	0.020	0.027
Non-metallic mineral product manufacturing	6.186	0.015	0.403	0.181	0.081
Primary metal and metal product manufacturing	19.198	0.004	0.105	0.593	2.564
Fabricated metal product manufacturing	0.000	0.004	0.088	0.050	0.440
Transport equipment manufacturing	0.000	0.007	0.175	0.040	0.007
Electronic and electrical equipment manufacturing	0.000	0.002	0.053	0.030	0.007
Machinery manufacturing	0.000	0.003	0.070	0.010	0.007
Furniture manufacturing	0.000	0.001	0.035	0.010	0.000
Other manufacturing	0.000	0.007	0.175	0.040	0.007
Electricity generation and on-selling	34.226	0.015	0.333	0.070	104.086
Electricity transmission and distribution	1.067	0.001	0.035	0.010	0.000

F TABLE	FUEL REQS IN PJ				
2007 I/O TABLES NZSIOC	**COAL**	**PETROL**	**DIESEL**	**OTHER OILS**	**GAS**
Gas supply	0.000	0.007	0.193	0.040	3.198
Water supply	0.000	0.000	0.000	0.000	0.000
Sewerage and drainage services	0.000	0.000	0.000	0.000	0.007
Waste collection, treatment and disposal services	0.000	0.012	0.333	0.070	0.000
Residential building construction	0.000	0.024	0.666	0.141	0.000
Non-residential building construction	0.000	0.058	1.945	0.673	0.000
Heavy and civil engineering construction	0.000	0.071	1.910	0.864	0.000
Construction services	0.000	0.056	2.909	0.472	0.000
Basic material wholesaling	0.000	0.012	0.104	0.073	1.829
Machinery and equipment wholesaling	0.000	0.023	0.201	0.146	0.000
Motor vehicle and motor vehicle parts wholesaling	0.000	0.004	0.030	0.024	0.000
Grocery, liquor and tobacco product wholesaling	0.000	0.010	0.089	0.073	0.000
Other goods and commission based wholesaling	0.000	0.022	0.194	0.134	0.000
Motor vehicle and parts retailing	0.000	0.011	0.089	0.061	0.000
Fuel retailing	0.000	0.007	0.067	0.036	0.000
Supermarket and grocery stores	0.000	0.001	0.007	0.012	0.000
Specialised food retailing	0.000	0.000	0.000	0.000	0.000
Furniture, electrical and hardware retailing	0.000	0.016	0.000	0.012	0.000
Recreational, clothing, footwear and personal accessory retailing	0.000	0.005	0.045	0.036	0.000
Department stores	0.000	0.000	0.000	0.012	0.000
Other store based retailing; non-store and commission-based retailing	0.000	0.005	0.037	0.036	0.000
Accommodation	0.000	0.004	0.030	0.036	0.000
Food and beverage services	0.000	0.004	0.037	0.049	0.021
Road transport	0.000	78.443	50.596	2.242	0.004
Rail transport	0.000	6.472	4.274	0.190	0.004
Other transport	0.080	1.553	3.234	0.190	0.004
Air and space transport	0.000	20.193	13.400	16.757	0.004
Postal and courier pick up and delivery services	0.000	0.000	0.000	0.000	0.004
Transport support services	0.000	4.142	2.195	0.109	0.004
Warehousing and storage services	0.000	0.005	0.045	0.049	0.000
Publishing (except internet and music publishing)	0.256	0.040	0.351	0.231	0.470
Motion picture and sound recording activities	0.000	0.002	0.022	0.012	0.000
Broadcasting and internet publishing	0.000	0.002	0.015	0.012	0.000
Telecommunications services including internet service providers	0.000	0.002	0.022	0.012	0.000
Library and other information services	0.000	0.000	0.000	0.000	0.000
Banking and financing; financial asset investing	0.000	0.001	0.007	0.012	0.000
Life insurance	0.000	0.000	0.000	0.000	0.000
Health and general insurance	0.000	0.000	0.000	0.000	0.000
Superannuation funds	0.000	0.000	0.000	0.000	0.000
Auxiliary finance and insurance services	0.000	0.001	0.015	0.000	0.000
Rental and hiring services (except real estate); non-financial asset leasing	0.000	0.007	0.067	0.036	0.000
Residential property operation	0.275	0.000	0.000	0.000	2.827
Non-residential property operation	0.000	0.001	0.007	0.000	0.000
Real estate services	0.000	0.010	0.089	0.049	0.000
Owner-occupied property operation	0.275	0.002	0.638	3.850	2.827
Scientific, architectural and engineering services	0.085	0.012	0.112	0.061	1.929
Legal and accounting services	0.000	0.000	0.007	0.000	0.000
Advertising, market research and management services	0.000	0.004	0.030	0.012	0.000
Veterinary and other professional services	0.000	0.000	0.000	0.000	0.000
Computer system design and related services	0.000	0.007	0.067	0.036	0.000
Travel agency and tour arrangement services	0.000	0.002	0.007	0.049	0.000
Employment and other administrative services	0.000	0.001	0.007	0.000	0.000
Building cleaning, pest control and other support services	0.000	0.017	0.157	0.085	0.000
Local government administration	0.000	0.000	0.000	0.000	0.000

F TABLE	FUEL REQS IN PJ				
2007 I/O TABLES NZSIOC	**COAL**	**PETROL**	**DIESEL**	**OTHER OILS**	**GAS**
Central government administration and justice	0.000	0.008	0.075	0.036	0.000
Defence	0.000	0.015	0.134	0.073	0.450
Public order, safety and regulatory services	0.000	0.012	0.104	0.061	0.000
Preschool education	0.000	0.000	0.007	0.000	0.000
School education	0.341	0.006	0.052	0.024	0.148
Tertiary education	0.341	0.004	0.037	0.024	0.000
Adult, community and other education	0.000	0.004	0.037	0.024	0.000
Hospitals	1.109	0.006	0.052	0.085	1.032
Medical and other health care services	0.000	0.012	0.112	0.134	0.000
Residential care services and social assistance	0.000	0.011	0.097	0.121	0.688
Heritage and artistic activities	0.000	0.000	0.000	0.000	0.000
Sport and recreation activities	0.000	0.030	0.268	0.182	0.000
Gambling activities	0.000	0.000	0.000	0.000	0.000
Repair and maintenance	0.000	0.024	0.216	0.146	0.000
Personal services; domestic household staff	0.000	0.005	0.045	0.024	0.000
Religious services; civil, professional and other interest groups	0.000	0.001	0.015	0.012	0.000
TOTAL	**71.728**	**113.858**	**110.832**	**32.570**	**151.529**

8.2. c Vector (Including Process Emissions)

C TABLE	
2007 I/O TABLES NZSIOC	PROCESS EMISSIONS CARBON INTENSITIES (TONNES OF CO_2-E/DOLLAR OUTPUT)
Horticulture and fruit growing	0.00210
Sheep, beef cattle and grain farming	0.00349
Dairy cattle farming	0.00298
Poultry, deer and other livestock farming	0.00043
Forestry and logging	0.00032
Fishing and aquaculture	0.00061
Agriculture, forestry and fishing support services	0.00035
Coal mining	0.00028
Oil and gas extraction	0.00016
Metal ore and non-metallic mineral mining and quarrying	0.00030
Exploration and other mining support services	0.00021
Meat and meat product manufacturing	0.00250
Seafood processing	0.00037
Dairy product manufacturing	0.00178
Fruit, oil, cereal and other food product manufacturing	0.00040
Beverage and tobacco product manufacturing	0.00031
Textile and leather manufacturing	0.00026
Clothing, knitted products and footwear manufacturing	0.00024
Wood product manufacturing	0.00029
Pulp, paper and converted paper product manufacturing	0.00042
Printing	0.00024
Petroleum and coal product manufacturing	0.00022
Basic chemical and basic polymer manufacturing	0.00131
Fertiliser and pesticide manufacturing	0.00045
Pharmaceutical, cleaning and other chemical manufacturing	0.00018
Polymer product and rubber product manufacturing	0.00020
Non-metallic mineral product manufacturing	0.00088
Primary metal and metal product manufacturing	0.00149
Fabricated metal product manufacturing	0.00030
Transport equipment manufacturing	0.00014
Electronic and electrical equipment manufacturing	0.00019
Machinery manufacturing	0.00018
Furniture manufacturing	0.00022

C TABLE	
2007 I/O TABLES NZSIOC	PROCESS EMISSIONS CARBON INTENSITIES (TONNES OF CO_2-E/DOLLAR OUTPUT)
Other manufacturing	0.00018
Electricity generation and on-selling	0.00186
Electricity transmission and distribution	0.00047
Gas supply	0.00071
Water supply	0.00013
Sewerage and drainage services	0.00010
Waste collection, treatment and disposal services	0.00018
Residential building construction	0.00019
Non-residential building construction	0.00025
Heavy and civil engineering construction	0.00023
Construction services	0.00016
Basic material wholesaling	0.00027
Machinery and equipment wholesaling	0.00012
Motor vehicle and motor vehicle parts wholesaling	0.00013
Grocery, liquor and tobacco product wholesaling	0.00031
Other goods and commission based wholesaling	0.00016
Motor vehicle and parts retailing	0.00008
Fuel retailing	0.00012
Supermarket and grocery stores	0.00023
Specialised food retailing	0.00019
Furniture, electrical and hardware retailing	0.00012
Recreational, clothing, footwear and personal accessory retailing	0.00013
Department stores	0.00011
Other store based retailing; non-store and commission-based retailing	0.00015
Accommodation	0.00020
Food and beverage services	0.00022
Road transport	0.00183
Rail transport	0.00167
Other transport	0.00054
Air and space transport	0.00083
Postal and courier pick up and delivery services	0.00023
Transport support services	0.00023
Warehousing and storage services	0.00018
Publishing (except internet and music publishing)	0.00023
Motion picture and sound recording activities	0.00009
Broadcasting and internet publishing	0.00007
Telecommunications services including internet service providers	0.00004
Library and other information services	0.00005
Banking and financing; financial asset investing	0.00004
Life insurance	0.00004
Health and general insurance	0.00004
Superannuation funds	0.00010
Auxiliary finance and insurance services	0.00005
Rental and hiring services (except real estate); non-financial asset leasing	0.00008
Residential property operation	0.00008
Non-residential property operation	0.00014
Real estate services	0.00012
Owner-occupied property operation	0.00006
Scientific, architectural and engineering services	0.00010
Legal and accounting services	0.00004
Advertising, market research and management services	0.00009
Veterinary and other professional services	0.00008
Computer system design and related services	0.00006
Travel agency and tour arrangement services	0.00011
Employment and other administrative services	0.00007
Building cleaning, pest control and other support services	0.00011

C TABLE	
2007 I/O TABLES NZSIOC	PROCESS EMISSIONS CARBON INTENSITIES (TONNES OF CO_2-E/DOLLAR OUTPUT)
Local government administration	0.00015
Central government administration and justice	0.00008
Defence	0.00012
Public order, safety and regulatory services	0.00006
Preschool education	0.00005
School education	0.00007
Tertiary education	0.00011
Adult, community and other education	0.00010
Hospitals	0.00009
Medical and other health care services	0.00005
Residential care services and social assistance	0.00008
Heritage and artistic activities	0.00008
Sport and recreation activities	0.00015
Gambling activities	0.00005
Repair and maintenance	0.00011
Personal services; domestic household staff	0.00006
Religious services; civil, professional and other interest groups	0.00010

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