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New Zealand's Food Waste: Estimating the Tonnes, Value, Calories and Resources Wasted

Christian John Reynolds [1,*], Miranda Mirosa [2] and Brent Clothier [3]

1. The Barbara Hardy Institute, University of South Australia, Mawson Lakes Boulevard, Mawson Lakes, SA 5095, Australia
2. Consumer Food Science, Department of Food Science, University of Otago, Dunedin 9054, New Zealand; miranda.mirosa@otago.ac.nz
3. Plant & Food Research, Food Industry Science Centre, Palmerston North 4442, New Zealand; Brent.Clothier@plantandfood.co.nz

* Correspondence: christian.reynolds@unisa.edu.au; Tel.: +61-400-94-2636

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Abstract: We used macro-economic data and aggregated waste data to estimate that, in 2011, New Zealand households generated over 224,000 tonnes of food waste, and New Zealand industry generated over 103,000 tonnes of food waste. We split New Zealand's food waste into 14 food-waste categories and found that 7% is related to "fresh" produce, and 93% "processed" food waste. The value of New Zealand's food waste in 2011 is estimated to be NZ $568 million, or $131 per person. Furthermore, New Zealand's food waste represents 163 × 10^9 calories in total, and avoidable food waste would be able to feed between 50,000 and 80,000 people a year. New Zealand food waste embodies 4.2 × 10^6 tonnes of CO_2-e, 4.7 × 10^9 m^3 of water, and 29 × 10^3 TJ of energy. Nonetheless, we find that, compared to other nations, New Zealanders waste less food per capita by weight, value and calorie.

Keywords: food waste; input-output; life cycle analysis; food security; New Zealand; food losses; wastage; footprint; SEEA; LCA; Life Cycle Analysis

1. Introduction

It is estimated that 30%–50% of all food produced never reaches a human stomach [1,2], and up to 60% of the food tossed into landfills is still edible fresh food [3–6]. With consideration of finite land and water resources, climate change and the environmental impacts of food production and consumption [7–9], it is easy to understand how food waste has emerged as a global public health and environmental issue that can simultaneously be combatted by both governments, industry and the individuals [10,11]. The quantification of food waste allows (1) identification of wasted foods and proposing behaviors that require intervention; (2) the costs (and potential savings) of food waste to be comprehended; and (3) the clear communication of the scale of food waste to the community to enable actions.

Attempts to quantify food waste at a country level have been successful in the United States (60 million tonnes of total food waste [12–14]), the UK (8.3 million tonnes of municipal food waste [3–5,15–17]), and Australia (with 4 million tonnes of municipal food waste [18,19] and 7.3 million tonnes of total food waste [20]). Other countries are just beginning to measure the scale of food wastage [21–28].

Until 2014, New Zealand had little quantitative or even qualitative metrics of food waste behaviors, tonnages, and impacts. There were government reports that discussed food waste as part of the organic waste stream [29–31], media reports that valued New Zealand household food waste at $750 million dollars a year [32,33], an audit of hospital food waste [34], a master's thesis that investigated household food waste with an intervention case study [35], a literature review by the Waiheke Resources Trust [36], and a consulting report for WasteMINZ , the largest representative body of the waste and resource recovery sector in New Zealand [37]. These final three documents provide a solid review of pre-2014 New Zealand food waste knowledge and opportunities. However, there are large data gaps.

In 2013, WasteMINZ launched the National Food Waste Prevention Project. The first part of the project was to calculate estimates of nationwide household food waste. The main research methods used to collect this data were bin audits (audits of 1402 household bins were conducted across 12 different councils; food waste was separated and weighed [38]) and a nationally representative online survey of attitudes and behaviors that led to food waste (with 1365 households [39]). The audit of the formal municipal solid waste (MSW) stream found that 122,547 tonnes of food waste, or the equivalent to $872 million worth of edible food, is thrown away every year. This information is now being disseminated via infographics [40,41] and council websites [42] as part of a nationwide Love Food Hate Waste campaign (https://www.facebook.com/lovefoodhatewastenz). This is an application of the highly successful Love Food Hate Waste campaign that has been running in the United Kingdom (UK) for the last 20 years [43]. In 2015, WasteMINZ published *New Zealand Food Waste Audits,* in which bin audits of 1402 households across 12 different councils were conducted in New Zealand. The contents of the bins were separated and weighed [38].

The waste-estimation method used in the *New Zealand Food Waste Audits* report is a "bottom up" survey method, where data from a representative sample is expanded up to the whole. More information on survey and audit methods can be found in the Food Loss and Waste Protocol Accounting and Reporting Standard [44]. The *New Zealand Food Waste Audits* report considers only MSW, and they do not quantify commercial and industrial food waste, or food waste disposed of via "non-formal" disposal routes. These "informal" avenues are described by Reynolds *et al.* [45] as backyard composting, feeding to animals, food rescue or sewer disposal. This leaves New Zealand with an important data gap in terms of quantification of food waste.

In order to estimate municipal solid-waste and commercial and industrial food-waste, a "top-down" direct-inputs waste-estimation methodology was proposed by Reynolds *et al.* [20]. In this waste-estimation method, waste generation is assumed to be proportional to production and the consumption in each sector, and is analyzed as part of the material flows of the economy. This methodology has previously been used to quantify waste flows in Australia [20].

In this paper, we use the top-down direct-inputs waste-estimation methodology [20] to quantify the New Zealand food-waste tonnages for the 2011 time period. We then use Waste Input-Output Life Cycle Analysis (WIO-LCA) methodology [46] to quantify the cost, greenhouse gas equivalents, water and energy emissions embodied in New Zealand food waste in 2011.

2. Data Sources and Methods

2.1. Waste Tonnage Estimation

The estimation of waste tonnage per category of waste was performed as per Reynolds *et al.* [20]. A 2011 New Zealand input-output supply-use table was sourced from the Eora database (versions 199.82) [47,48]. This table had 209 commodities and 126 industry sectors. The input-output supply-use table is reported in US dollars. The 2011 time period was selected, as this was the latest time period that had full waste tonnages and Input-Output tables accessible.

The aggregated New Zealand waste data for the 2011 time period was sourced from the Ministry for the Environment's monthly landfill disposal waste-levy data [49]. It was assumed that New Zealand MSW and industrial solid waste disposal spilt of total waste generation followed the trend of other developed countries, such as Australia and the United Kingdom [50,51]. Therefore, 50% of total waste generation was allocated to MSW, and 50% to industrial solid waste. Furthermore, the industrial solid waste tonnage were split again 50:50 to construction and demolition, and commercial and industrial waste streams. This resulted in 2,512,298 tonnes of total waste, of which 1,256,149 tonnes were MSW, while 628,074.5 tonnes were allocated to both commercial and industrial and construction and demolition waste streams.

Modifying Reynolds *et al.* [20], the commercial and industrial tonnages were allocated to specific sectors using an averaged proportion vector $\mathbf{p}_{\mathrm{C\&I}}$ (see Equations (1) to (3)), this used input from economic data from the Eora database: $\mathbf{x}_j$, total sectoral gross output per sector j, and $\sum_i T_{\mathrm{ij}}$, the sum of inputs of production per intermediate sector j. This disaggregation links economic activity to total sectoral waste generation.

$$\mathbf{p}_{\mathrm{X}} = \frac{1}{[\sum_i \hat{\mathbf{c}}\mathbf{x}_i]}\hat{\mathbf{c}}\mathbf{x} \tag{1}$$

$$\mathbf{p}_{\mathrm{T}} = \frac{1}{\left[\sum_j \hat{c}_j \sum_i T_{ij}\right]}\hat{\mathbf{c}}{\mathbf{T}_{\mathrm{ij}}}^{\mathbf{T}_{\mathrm{ij}} 1_{\mathrm{ij}}} \tag{2}$$

$$\mathbf{p}_{\mathrm{C\&I}} = a_{\mathrm{T}}\mathbf{p}_{\mathrm{T\,C\&I}} + a_{\mathrm{X}}\mathbf{p}_{\mathrm{X\,C\&I}} \tag{3}$$

where $\mathbf{c}$ is an $n \times 1$ dimension binary concordance matrix, with rows that sum to one and the n of $\mathbf{c}$, the same as the n of the proportion vector, and $a_{\mathrm{T}} + a_{\mathrm{X}} = 1$, which in this case of equal weighting means $a_{\mathrm{T}} = a_{\mathrm{X}} = \frac{1}{2}$.

The proportion vector, $\mathbf{p}_{\mathrm{C\&I}}$, is multiplied by the total waste produced by the commercial and industrial waste stream, $\sum_{\mathrm{i}} \mathrm{w}_{\mathrm{C\&I\,ij}}$, to give $\widetilde{\mathbf{w}}_{\mathrm{C\&I}}$, a vector of total waste produced by each sector as shown in Equation (4). Note that the inclusion of the symbol ~ above $\mathbf{w}$ denotes that this is no longer a single value (the total amount of waste generated of that waste type); rather, the single value is disaggregated to all the active sectors (i) of $\mathbf{p}$.

$$\widetilde{\mathbf{w}}_{\mathrm{C\&I}} = \mathbf{p}_{\mathrm{C\&I}} \sum_{\mathrm{i}} \mathrm{w}_{\mathrm{C\&I\,ij}} \tag{4}$$

MSW was disaggregated as per Reynolds *et al.* [20], and the total volume of waste generated for the MSW stream, $\sum_{\mathrm{i}} \mathrm{w}_{\mathrm{MSW\,ij}}$, was assigned to a single aggregated $\mathbf{F}$ (final household consumption sector), renaming it $\widetilde{\mathbf{w}}_{\mathrm{MSW}}$ (Equation (5)).

$$\widetilde{\mathbf{w}}_{\mathrm{MSW}} = \sum_{\mathrm{i}} \mathrm{w}_{\mathrm{MSW\,ij}} \tag{5}$$

Total sectoral waste from industry $\widetilde{\mathbf{w}}_{\mathrm{C\&I}}$, and municipal waste $\widetilde{\mathbf{w}}_{\mathrm{MSW}}$, was then disaggregated to 22 waste categories (22 Waste types: 14 Food waste categories: Apple and pear growing waste, Kiwifruit growing waste, Other fruit growing waste, Sheep and beef cattle farming waste, Dairy cattle farming waste, Fishing waste, Meat processing waste, Poultry processing waste, Bacon, ham and small good manufacturing waste, Dairy product manufacturing waste, Fruit and vegetable, oil and fat, cereal manufacturing waste, Bakery, sugar and confectionery manufacturing waste, Seafood processing waste, Other food manufacturing waste; 8 other waste categories: Other Organic waste, Paper waste, Plastic waste, Metal waste, Glass waste, Construction and Demolition waste, Other waste, Potentially hazardous waste).

This disaggregation was achieved by multiplying the total waste vector ($\widetilde{\mathbf{w}}_{\mathrm{C\&I}}$ or $\widetilde{\mathbf{w}}_{\mathrm{MSW}}$) by $\mathbf{C}_{\mathrm{StoW}}$, a sector to waste type concordance matrix, and $\mathbf{A}$, the direct requirements matrix of the Input-Output table. As shown in Equations (6)–(8), $\mathbf{C}_{\mathrm{StoW}}$ is transposed and multiplied on the right by the direct requirements matrix $\mathbf{A}$ to give the estimated waste production of each sector $\mathbf{M}_{\mathrm{C\&I}}$.

We normalize the matrix $\mathbf{M}_{\mathrm{C\&I}}$ by dividing each cell by its column sum $M_{\mathrm{C\&I}_{ij}} \left(\widehat{1^{\mathrm{T}\prime}\mathbf{M}_{\mathrm{C\&I}}}\right)^{-1}$. For a vector $\mathbf{v}$, $\widehat{(\mathrm{v})}$ denotes a diagonal matrix. This gives the relative waste produced per industry for C&I waste, $\overline{\mathbf{M}}_{\mathrm{C\&I}}$. These operations are shown in Equations (6)–(8).

$$\mathbf{C}_{\mathrm{StoW}} = \mathbf{C}_{\mathrm{StoP}}\mathbf{C}_{\mathrm{PtoW}} \tag{6}$$

$$\mathbf{M}_{\mathrm{C\&I}} = \mathbf{C}_{\mathrm{StoW}}{}^{\mathrm{T}}\mathbf{A} \quad (7)$$

$$\overline{\mathbf{M}}_{\mathrm{C\&I}} = \mathbf{M}_{\mathrm{C\&I}}\left(\widehat{1^{\mathrm{T}\prime}\mathbf{M}_{\mathrm{C\&I}}}\right). \quad (8)$$

Multiplying $\overline{\mathbf{M}}_{\mathrm{C\&I}}$ by $\widehat{\widetilde{\mathbf{w}}_{\mathrm{C\&I}}}$, the waste stream produced by each sector gives an expanded listing (in tonnes) of waste generation of each sector (i) sorted by waste type (j), $\mathbf{W}_{\mathrm{C\&I}}$, as shown in Equation (9):

$$\mathbf{W}_{\mathrm{C\&I}} = \overline{\mathbf{M}}_{\mathrm{C\&I}}\widehat{\widetilde{\mathbf{w}}_{\mathrm{C\&I}}}. \quad (9)$$

This direct input estimation method implicitly assumes that the intensity with which a product is used in the production or consumption process is the only determinate in how much the sector wastes of that product/waste type. There is no assumption that some products are more wasteful, or that technology allows for less wasteful production in certain industries.

Furthermore, this disaggregation method is based on the assumption of an *industry to product to waste* relationship. Here, each industry supplies a primary product, and that product has a chief type of waste associated with its production. Thus, when a sector consumes other goods in the manufacture of products, this disaggregation will assume that waste is produced that is associated with that input sector.

An exception to this is in the service sectors, which were assumed not to have one primary waste type. Instead, they were allocated a percentage of waste to all 8 waste categories. This was based on the waste composition proportions for the national indicator sites from 2007 to 2008 [31]. In addition, the total organics waste generated by the sectors of wholesale trade, retail trade, accommodation, bars, clubs, cafes and restaurants was evenly divided into all food waste and organics categories.

The 22 waste categories were based upon 8 waste categories from the Ministry for the Environment's 2009 Environmental Report Card [31]. The organics category was expanded to 14 food waste categories as well as 1 "other organics" category. This category could include waste types such as garden waste, timber waste, and not directly identifiable food waste. The 14 food waste categories were selected due to specific food industry size to allow for quantification of food waste at different stages of the supply chain by separating "fresh" from "processed" food waste, and to account for differing environmental impacts of processed products *versus* fresh products.

2.2. Accounting for Monetary Value, Calories and Environmental Impacts

To determine the monetary value, food security (calorific) benefit, and environmental impacts, we followed the quantification methodology introduced by Reutter *et al.* [52] and Reynolds *et al.* [53,54].

2.3. Value

To calculate the basic value per tonne value of the associated food products Fi, we sourced Gross Production Values in US dollars at a constant price 2004–2006. The production quantities and values were taken from the FAOSTAT database [55] (Table 1). Additional data on seafood, manufactured and baked goods, fruits, and vegetables were taken from New Zealand government and industry reports. These were converted to US dollars using the 2011 average NZ-US exchange rate of 0.7911 [56–58]. To ensure reproducibility, the values per tonne used are provided in the online accompanying data. Similar to Reutter *et al.* and Reynolds *et al.*, we assumed that waste was still priced at market value, and has the same amount of "use value" (durability) that it had when first bought [59,60].

To estimate the US dollar value of food waste by category i (K_i), the tonnages of food waste categories (W_i) were multiplied by the price per tonne of the associated food category (F_i).

$$K_i = W_i \times F_i \quad (10)$$

$$(US\$) = (Tonnages) \times (US\$ \ \ Per \ \ Tonne)$$

Table 1. Tonnages of waste generation in New Zealand in 2011.

	Municipal Solid Waste	**Commercial and Industrial**	**Total**
Apple and pear food waste	311	3179	3490
Kiwifruit food waste	16	2920	2936
Other fruit food waste	573	3929	4502
Sheep and beef cattle farming food waste	0	4946	4947
Dairy industry food waste	0	3258	3258
Fishing waste	0	4545	4545
Meat processing waste	16,532	17,182	33,715
Poultry processing waste	19,676	5210	24,886
Bacon, ham and small good waste	41,078	7462	48,540
Dairy product waste	33,938	23,231	57,169
Fruit and vegetable, oil and fat, cereal waste	34,077	7160	41,237
Bakery, sugar and confectionery waste	39,889	6305	46,194
Seafood processing waste	15,964	7981	23,945
Other food waste (processed foods)	22,112	6075	28,187
Other Organic waste	100,461	51,917	152,378
Paper waste	375,206	121,392	496,598
Plastic waste	278,971	88,570	367,541
Metal waste	107,615	52,243	159,857
Glass waste	75,454	20,844	96,298
Construction and Demolition (related waste)	32,008	146,454	178,463
Other waste	52,031	29,708	81,740
Potentially hazardous waste	10,235	13,563	23,798
	Total Municipal solid waste food waste generation	Total commercial and industrial food waste generation	Total food waste generation
	224,167	103,384	327,551
Per capita (tonnes)	0.05	0.02	0.07

2.4. Calories

We sourced the calorific values of associated food product per tonne from the Wolfram Alpha database [61]. The calorific values were based on globally averaged nutrient values for generic food products such as lamb, beef, and flour. Vegetables, fruits, and processed goods were provided as an average calorific value per tonne from a basket of associated products selected by Wolfram Alpha. To ensure reproducibility the calories per tonne used are provided in the online accompanying data.

To estimate the calories embodied in food waste by category i (J_i), the tonnages of food waste categories (W_i) were multiplied by the calorific values of each food category per tonne (C_i).

$$J_i = W_i \times C_i \tag{11}$$

$$(Calories) = (Tonnages) \times (Calories \quad per \quad Tonne)$$

2.5. Environmental Impacts

To calculate the water, energy, and greenhouse gas metrics CO_2 equivalents (GHG-CO_2e) embodied in New Zealand food waste, we performed an environmentally extended Input-Output Analysis. This is explained in detail in the Appendix of Reynolds [62].

The environmental impacts data were sourced from the Eora database (versions 600.61 and 199.82) in US dollars [47,63,64] and featured GHG CO_2e, energy (TJ), and water (m^3) [65]. The greenhouse gas equivalents and energy account were from the year 2011, with the water account from the year 2000. This difference in base years is due to data availability. To ensure reproducibility, the total environmental impact multipliers per tonne used are provided in the online accompanying data.

The resources embodied in food waste by category i ($P_{water\ i}$, $P_{GHG\ i}$, $P_{energy\ i}$) were calculated by multiplying the value of food waste (K_i) by the total environmental impacts of production per dollar spent in sector s ($E_{water\ s}$, $E_{GHG\ s}$, $P_{energy\ s}$) to find P_i, the total environmental impacts of food waste.

$$P_{water\ i} = K_i \times E_{water\ i}. \qquad (12)$$

$$(m^3 \ \ of \ \ Water) = (US\$) \times (M^3 \ \ of \ \ Water \ \ Per \ \ US\$)$$

3. Results and Discussion

3.1. Waste Tonnages

New Zealand households generated over 224,000 tonnes of food waste in 2011, with industry generating over 103,000 tonnes of food waste. Food waste is 17% of the total New Zealand waste stream. Furthermore, if accompanied by "other" organic waste (8% of total waste stream), this 25% "total" organics is comparable to the 28% organic waste found via the Environmental Report Card [31]. The 122,547 tonnes of MSW food waste, estimated by the National Food Waste Prevention Project [38,40], is also in a similar order of magnitude. However, since they are estimates for different years, they are not directly comparable. Like the National Food Waste Prevention Project, our estimate is for waste disposed via "formal" disposal methods, and does not include food waste disposed of via backyard composting, feeding to animals, food rescue or sewer disposal. Table 1 lists the disaggregated waste for commercial and industrial and MSW streams. A full sectoral detail is provided in the online accompanying data.

We estimate that the largest component of the MSW food waste stream was the bacon, ham and small-goods waste (41,078 tonnes), followed by bakery, sugar and confectionery waste (39,889 tonnes), and then fruit and vegetable, oil and fat, cereal waste (34,077 tonnes). The largest waste categories in the commercial and industrial food waste stream were estimated to be dairy-product waste (23,231 tonnes), meat processing waste (17,182 tonnes) and seafood processing waste (7981 tonnes).

Our model estimates that households generate 901 tonnes (0.4%) of the food waste that can be directly linked to "fresh" products or those bought directly from the agricultural sector. The remaining 223,266 tonnes is either "processed" or has been purchased through a supermarket, restaurant, or other intermediary processor. Industry generates 22,778 tonnes (22%) of food waste that can be directly linked to "fresh" products, with 80,606 tonnes linked to pre-household processing waste. In total, approximately 23,678 tonnes (7%) of New Zealand's food waste is related to "fresh" produce, and 303,873 tonnes (97%) to "processed" produce.

Our model estimates that only 50 kg (municipal) or 70 kg (total) of food waste is generated per person per year [66]. The National Food Waste Prevention Project's municipal audit estimated a similar 79 kg per person per year [38,40,41]. Both New Zealand estimates are comparable to the 70 kg per person per year municipal food waste generation in the UK [67], and the FAO's North America and Oceania estimate of 110 kg per capita per year.

3.2. The Value of Food Waste

We estimate that New Zealand wasted US $450 million of food waste in 2011. Of this, households wasted US $292 million worth of food, and industry wasted nearly US $158 million. When converted back into New Zealand currency at 2011 exchange rates, New Zealand total food waste is estimated to be NZ $568 million, with commercial and industrial and MSW food waste respectively valued at NZ $199 million and NZ $369 million. Based on the 2011 population of New Zealand [66], this equates to NZ $131 per person per year (Table 2).

Our household figure is only 42% of the National Food Waste Prevention Project's audit estimation for MSW ($872 million) [38,40,41]. The National Food Waste Prevention Project has also estimated by survey that New Zealand households waste food to the value of $144 per capita per year, or $600 million of food in total (municipal) [39]. Our household estimate is 62% of this figure. This difference could be explained by the National Food Waste Prevention Project's audit and survey estimates being provided in consumer purchase price. While our estimate is provided in basic purchase price—before taxes and other costs such as transport are added.

In addition, both our estimate and the estimate from the National Food Waste Prevention Project are much smaller than other global estimates. Comparable yearly food waste value estimates are £420 (NZ $1,023) per household in the United Kingdom [67], £430 (NZ $1,047) per household in Scotland [68], AU $239 (NZ $ 268) per capita in Australia [69]. This implies that New Zealand wastes less valued food per capita than other comparable countries.

3.3. Embodied Calories

We estimate that New Zealand food waste embodied 163×10^9 calories in total, with 121×10^9 coming from MSW, and 51×10^9 from commercial and industrial waste. A person is understood to be "food secure" when they have access to an average of 3000 calories a day [70]. The average New Zealand male consumed 2480 calories daily in 2008–2009. If total calorific food waste is apportioned per person [66], every month each person in New Zealand generates 3100 calories of food waste.

It should be noted that not all food waste is edible; WRAP reported that 1/3 of the total UK food waste was not-avoidable, while one third was possibly-avoidable and one third was avoidable [22]. The National Food Waste Prevention Project found that 54% of household waste was avoidable [38].

If we assume that one third of total New Zealand food waste is "avoidable" as per the WRAP metric [5], this would mean that 49,000 people a year could be fed on the calories of the avoidable food wasted. If we used the National Food Waste Prevention Project estimate of 54%, this would mean that 50,000 people a year could be fed on the calories of the avoidable household food waste, and 80,000 people a year could be fed on the calories of the total avoidable food wasted. However, this is an over simplification, as food waste is not all generated at these consistent ratios. Therefore, these numbers are at best only a broad approximation.

The National Food Waste Prevention Project has estimated that New Zealand's food waste could feed 262,917 people a year. Our calorific result is only 19% (WRAP estimate) or 21% (New Zealand household estimate) of this figure. However, the National Food Waste Prevention Project's figure is based on a days' worth of food being 1.277 kg, rather than a calorific measure [38,40,41,71]. If we use this weight measure, our estimate for 1/3 avoidable total food waste is 234,247 people per year, 89% of the National Food Waste Prevention Project's infographic. Our estimate of 54% avoidable household food waste indicated that 259,706 people per year could be fed on our MSW estimate, which is 99% of the National Food Waste Prevention Project's infographic.

The calorific estimates in this paper are significantly lower than previous estimates by the United States Department of Agriculture. They estimated that the US generates 1249 calories per capita per day of food waste [12]. In addition, the estimates in the National Food Waste Prevention Project would also not allow a level of caloric wastage that would match United States estimates. From this, we can conclude that New Zealand is more efficient in terms of waste generation per calorie per capita than the United States.

3.4. Embodied CO_2e Emissions

We estimate that New Zealand food waste embodied 4.2 × 10^6 tonnes of CO_2-e, with 2.3 × 10^6 tonnes of CO_2-e from household food waste, and 1.9 × 10^6 tonnes of CO_2-e from industry. At a per capita level, we estimate that New Zealand generates food waste that embodies 963 kg of CO_2-e per individual [66]. This is close to the FAO's estimate of 900 kg of per capita embodied greenhouse gases in the North America and Oceania region [72]. However, there are large variances in food waste GHG impacts. Studies in the United Kingdom [15] and United States [73] have estimated impacts at around 300 kg CO_2-e per capita (Table 3).

The National Food Waste Prevention Project's audit figure estimated that New Zealand household municipal solid-food waste generates 325,975 tonnes of CO_2e emissions (325 Gg of $C0_2e$). This is a rather different mass from our calculation, as it describes the CO_2e generation potential of food waste rather than the embodied CO_2e emissions in creating the food that is wasted, and in addition to a "conservative" adjustment of WRAP LCA data [15,38,40,41]. If we used the National Food Waste Prevention Project's audit CO_2e generation potential of 2.66 tonnes of CO_2-e for every tonne of food wasted, our comparable figure would be 871,285 tonnes of CO_2e emissions (871 Gg of CO_2-e). This is 2.67 times the mass calculated in National Food Waste Prevention Project's audit estimate. Per capita, this would equate to 197 tonnes of CO_2e emissions per capita per year—a mass similar in magnitude to the per capita CO_2e emissions in previous global studies [15,73].

3.5. Embodied Water

We estimate that New Zealand food waste embodied 4.7 × 10^9 m^3 of water. This is 1087 m^3 of water per capita per year. Approximately 3.1 × 10^9 m^3 of water are embodied in food waste generated by households, and 1.6 × 10^9 m^3 of water are embodied in food waste generated by industry (Table 4).

There are no other estimates of the water embodied in New Zealand's food waste. Water embodied in food waste for North America and Oceania has been estimated at 42 m^3 of water per capita per year [74] and 44 m^3 of water per capita per year [72]. In the United Kingdom, it has been estimated at 106 m^3 of water per capita per year [15]. However, our estimated water footprint is not directly comparable to other footprints, as the water dataset from which we derived our results uses crop water use to define water use by agriculture. This is not the method that is used by other prior publications; thus, we cannot compare our result with other publications.

3.6. Embodied Energy

We estimate that New Zealand food waste embodied 29 × 10^3 TJ of energy. This is 6.6 GJ of energy per capita per year. Approximately 19 × 10^3 TJ of energy are from household food waste, and 9.8 × 10^3 TJ of energy are from industrial food waste. There are no other estimates of the energy embodied in New Zealand's food waste. However, Cuellar *et al.* [7] estimated that domestically consumed food waste in the US embodied approximately 2.1 × 10^6 TJ per year or 7.6 GJ per capita per year. This is in the same order of magnitude as our estimate (Table 5).

Table 2. Value (US Dollars) of food waste generated in New Zealand in 2011.

	Value of Food Waste	MSW	C & I	Total
Fresh and Agricultural Related Food Waste	Apple and pear growing waste	USD 247,161	USD 2,523,406	USD 2,770,567
	Kiwifruit growing waste	USD 24,181	USD 4,286,081	USD 4,310,261
	Other fruit growing waste	USD 1,337,646	USD 9,179,828	USD 10,517,474
Processed and Consumption Related Food Waste	Sheep and beef cattle farming waste	USD 55	USD 10,904,630	USD 10,904,685
	Dairy cattle farming waste	USD 2	USD 733,146	USD 733,148
	Fishing waste	USD 172	USD 18,375,288	USD 18,375,460
	Meat processing waste	USD 35,547,477	USD 36,945,186	USD 72,492,663
	Poultry processing waste	USD 21,890,311	USD 5,795,893	USD 27,686,204
	Bacon, ham and smallgood manufacturing waste	USD 69,776,246	USD 12,674,763	USD 82,451,009
	Dairy product manufacturing waste	USD 7,638,059	USD 5,228,301	USD 12,866,360
	Fruit and vegetable, oil and fat, cereal manufacturing waste	USD 47,412,462	USD 9,961,597	USD 57,374,059
	Bakery, sugar and confectionery manufacturing waste	USD 27,231,015	USD 4,304,564	USD 31,535,579
	Seafood processing waste	USD 65,886,176	USD 32,941,548	USD 98,827,724
	Other food manufacturing waste	USD 15,133,481	USD 4,157,685	USD 19,291,166
	Total	USD 292,124,443	USD 158,011,917	USD 450,136,360
	Per capita	USD 66.35	USD 35.89	USD 102.23

Table 3. Total GHG-CO_2e (tonnes) embodied in food waste generated in New Zealand in 2011.

	GHG-CO_2e (Tonnes)	MSW	C & I	Total
Fresh and Agricultural Related Food Waste	Apple and pear growing waste	2393	24,431	26,824
	Kiwifruit growing waste	147	26,073	26,220
	Other fruit growing waste	15,531	106,583	122,114
Processed and Consumption Related Food Waste	Sheep and beef cattle farming waste	2	437,839	437,841
	Dairy cattle farming waste	0	20,262	20,262
	Fishing waste	1	66,215	66,216
	Meat processing waste	722,147	750,542	1,472,689
	Poultry processing waste	145,905	38,631	184,536
	Bacon, ham and smallgood manufacturing waste	509,337	92,520	601,857
	Dairy product manufacturing waste	114,751	78,548	193,299
	Fruit and vegetable, oil and fat, cereal manufacturing waste	304,643	64,007	368,650
	Bakery, sugar and confectionery manufacturing waste	146,665	23,184	169,849
	Seafood processing waste	277,023	138,505	415,529
	Other food manufacturing waste	108,645	29,849	138,494
	Total	2,347,190	1,897,188	4,244,379
	Per capita	0.5	0.4	1

Table 4. Total water embodied (M3) in food waste generated in New Zealand in 2011.

	Water Total Impact	**MSW**	**C & I**	**Total**
Fresh and Agricultural Related Food Waste	Apple and pear growing waste	1,169,250	11,937,520	13,106,770
	Kiwifruit growing waste	118,288	20,966,836	21,085,124
	Other fruit growing waste	4,618,460	31,694,975	36,313,435
Processed and Consumption Related Food Waste	Sheep and beef cattle farming waste	512	102,301,459	102,301,971
	Dairy cattle farming waste	14	4,643,725	4,643,740
	Fishing waste	1458	155,887,506	155,888,965
	Meat processing waste	444,351,362	461,823,029	906,174,392
	Poultry processing waste	201,939,372	53,467,448	255,406,820
	Bacon, ham and smallgood manufacturing waste	717,051,095	130,251,385	847,302,480
	Dairy product manufacturing waste	109,203,668	74,750,620	183,954,288
	Fruit and vegetable, oil and fat, cereal manufacturing waste	647,128,946	135,965,051	783,093,997
	Bakery, sugar and confectionery manufacturing waste	98,812,225	15,619,821	114,432,047
	Seafood processing waste	741,758,661	370,861,998	1,112,620,659
	Other food manufacturing waste	196,888,193	54,091,926	250,980,119
	Total	31,63,041,506	1,624,263,301	4,787,304,808
	Per capita	718	369	1087

Table 5. Total Energy (TJ) embodied in food waste generated in New Zealand in 2011.

	Energy (TJ)	**MSW**	**C & I**	**Total**
Fresh and Agricultural Related Food Waste	Apple and pear growing waste	13	131	144
	Kiwifruit growing waste	1	228	230
	Other fruit growing waste	82	560	642
Processed and Consumption Related Food Waste	Sheep and beef cattle farming waste	0	490	490
	Dairy cattle farming waste	0	29	29
	Fishing waste	0	1159	1159
	Meat processing waste	2373	2466	4838
	Poultry processing waste	1236	327	1563
	Bacon, ham and smallgood manufacturing waste	3892	707	4599
	Dairy product manufacturing waste	456	312	768
	Fruit and vegetable, oil and fat, cereal manufacturing waste	3016	634	3650
	Bakery, sugar and confectionery manufacturing waste	3366	532	3898
	Seafood processing waste	3974	1987	5961
	Other food manufacturing waste	1082	297	1379
	Total	19,490	9859	29,349
	Per capita	0	0	0.01

4. Conclusions

We have estimated total, household, and commercial food waste tonnages for New Zealand in 2011 from macro-economic data and aggregated waste data. We have split New Zealand food waste into 14 food waste categories to separate "fresh" from "processed" food waste. In addition we have estimated the value and calorific value of the food wasted, and have performed Waste Input-Output Life Cycle Analysis to quantify the greenhouse gas equivalents, water and energy emissions embodied within New Zealand food waste. Our estimate of New Zealand's food waste indicates New Zealand is wasting less per capita per year in terms of calories, value or weight than other comparable developed countries such as Australia, the United States and the United Kingdom. This is a positive finding. However, we consider that this number can be reduced further, as New Zealand households generated over 121,000 tonnes of avoidable food waste in 2011.

The use of the top-down direct-inputs waste estimation methodology has produced results that are comparable with other estimation methods, both in New Zealand and internationally. However, caution should be taken when using this data set, as the top-down direct-inputs method is simply a disaggregation of macro-economic data and waste data. The numbers provided are at best a broad estimate. Their similarity to previous studies provides assurance of the reliability of these studies and other waste estimation methodologies. Potential future research might aim to constrain and enhance our top-down estimate with additional data from external bottom-up sources to produce a more realistic model. This would be similar to what occurs within the Industrial Ecological Virtual Laboratory in Australia [75]. In addition, our estimate is only for waste that has been "formally" disposed of, and does not account for pre-harvest, on-farm, or informal food disposal. Estimating these additional food waste volumes needs to be carried out in order to understand better the full scale and impacts of New Zealand food waste.

Furthermore, the differences in our estimation of environmental impacts could be due to the Eora database having slightly higher impacts than other environmental databases due to differences in its Leontief inverse, emissions' data and final-demand estimation [76–78]. Further modeling with other life cycle analysis databases is required to produce a more accurate picture of the environmental impacts of food waste in New Zealand.

The household and commercial waste data present here opens many avenues of investigation. A similar data set of Australian food waste was estimated for the 2008 time period [20]. This has now been used to perform economic and environmental analysis of waste flows in Australia, with specific focus on the economic and environmental food waste interventions, including the introductions of curbside food waste recycling, and statewide food rescue operations [54]. Similar analysis could be performed upon these New Zealand data.

The waste data produced by our estimation are also harmonized with the Eora New Zealand Input-Output tables. These data could be easily transformed into the Australian and New Zealand Standard Industrial Classification. These could then be used in New Zealand's System of Environmental-Economic Accounting framework [79–81].

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