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A Rapid Review of the Environmental Impacts Associated with Food Consumption in Australia and New Zealand

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Abstract

Purpose of Review The 2013 Australian Dietary Guidelines (ADG) have been criticised for making only brief reference to sustainability considerations. With the ADG currently under review, the purpose of this rapid review was to determine the environmental impacts associated with food consumption in Australia and New Zealand.

Recent Findings Of the 20 articles included, greenhouse gas emissions (GHGe) were the most common environmental indicator ($n=12$), followed by water use and water footprint ($n=7$), and carbon footprint ($n=3$). Whilst there are commonalities between different environmental indicators such as the large impact of discretionary food consumption on GHGe, cropland scarcity footprint, and water scarcity footprint, there is wide variation in these indicators for other food groups. Furthermore, modelling of current food consumption data to the recommended diet does not necessarily result in improvement of all indicators.

Summary The next iteration of the ADG should promote consumption of foods and dietary patterns that are associated with positive health and environmental outcomes.

Keywords Food consumption · Dietary patterns · Environmental impacts · Sustainability · Australia · New Zealand

Introduction

"*The pressures we exert on the planet have become so great that scientists are considering whether the Earth has entered an entirely new geological epoch: the Anthropocene, or the age of humans. It means that we are the first people to live in an age defined by human choice, in which the dominant risk to our survival is ourselves.*" Achim Steiner, UNDP Administrator (pg. 7) [1].

Current food production methods and consumption patterns are unsustainable in supporting human and planetary health [2••,3•,4]. It is estimated that 21–37% of the total net greenhouse gas emissions (GHGe) [3•, 5••] are a result of the inputs and actions required to sustain the current global food system. The 2019 Intergovernmental Panel on Climate Change (IPCC) [5••] quantified that, on average, 16–27% of global anthropogenic emissions were a result of actions and inputs from the food system up to the farm gate (i.e. food production), while the remaining 5–10% were post-farm gate (i.e. food processing, consumption, and waste). Therefore, factors across the whole food chain are important to consider. Fifty percent of the world's habitable land is used for agriculture [6], and 60% of terrestrial biodiversity loss is related to food systems [7]. Furthermore, an estimated two-thirds of freshwater withdrawals are for irrigation [8]. Changes to the food system provide critical opportunities for solutions to help mitigate climate change, as recognised by global bodies [2••, 9]. International goals that aim to achieve such solutions include the United Nations' Sustainable Development Goal number 12 (Ensure sustainable

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production and consumption) [3•, 4] and the 2016 Paris Agreement on Climate Change emission targets [10], to which Australia and New Zealand (NZ) are signatories. The most recent 2021 IPCC report signifies a code red warning that immediate change is required to mitigate climate warming that is likely to reach 1.5 °C above pre-industrial levels between 2030 and 2052 if it continues to increase at the current rate [11••].

Undoubtedly, both food production and consumption practices need to shift to feed the predicted nearly 10 billion people by 2050, to achieve human health within finite planetary boundaries [2••]. The EAT Lancet report published in 2019 has drawn attention to more sustainable dietary practices required to meet this challenge and coined the term "The Great Food Transformation" [2••]. Within countries, recommendations about the food and dietary patterns associated with health are provided by evidence-based dietary guidelines, with pictorial food guides often used to translate dietary guideline statements into practical advice for consumers [12]. Despite attempts to incorporate environmental sustainability, the 2013 Australian Dietary Guidelines (ADG) have been criticised for making only brief reference to sustainability considerations in an appendix [13]. In comparison, the recently updated NZ Eating and Activity Guidelines for NZ adults have considered environmental sustainability [14]. With the ADG currently under review, it is timely to consider the environmental impacts associated with food consumption in Australia.

One approach to contribute to meaningful debate on practical and holistic policy changes, including the development of dietary guidelines, is to consider both the health and environmental impacts associated with consumption of foods and dietary patterns [15, 16•]. The aim of this rapid review was to assess the environmental impacts associated with food consumption (both actual and apparent) in Australia and NZ. Due to the shared food standards between Australia and NZ (Food Standards Australia and New Zealand), and the close geographical proximity of the two countries that facilitates food trade, the environmental impacts of food consumption in both countries were assessed.

Methods

The rapid review protocol was registered with PROSPERO (CRD42020221623). Exposures of interest were actual and apparent consumption of individual foods, food groups, or dietary patterns in Australia and NZ. Outcomes of interest included but were not limited to, land use, water use, biodiversity loss, and GHGe (Appendix 1). Search terms were developed to reflect the Populations, Exposures, and Outcomes of interest. Keyword searches were executed across four databases (Environmental Science Index, Web of Science, Scopus, and Medline). A grey literature search using Google with country filters was also conducted using a reduced number of keywords.

Database searches were limited to the English language and primary studies, reviews, and reports that presented data from Australia and/or NZ were eligible for inclusion. Publications that included data from other countries were eligible for inclusion only if it was possible to extract relevant data specific to Australia and/or NZ. A publication limit was set to the last 10 years (01/01/10 to 02/12/20) to include publications since the evidence review [17] that informed the 2013 ADG. The reference lists of included studies and reports were also used to identify relevant literature.

Results of the database searches were uploaded to Covidence and duplicates removed. Two authors (SF, LG) independently screened titles and abstracts of identified articles, while the full text of those deemed relevant was screened by SF and EB, and discrepancies were resolved by a fourth reviewer (KC). Data from the included articles was extracted by two reviewers (SF and EB) using a standardised proforma with discrepancies being resolved in conjunction with a fourth reviewer (KC).

Findings

A total of 21,428 unique articles were identified through database searches (Fig. 1) resulting in 308 full-text articles being assessed for eligibility, of which 283 were excluded, leaving 25 articles for final inclusion. An additional two reports identified from the grey literature search were included. Due to the heterogeneity of the data extracted only the following environmental indicators are reported: GHGe, land use, ecological footprint, cropland footprint, and water use/footprint/scarcity which meant that seven studies that did not report these outcomes were excluded. Environmental indicators not included were phosphorus footprint, nitrogen footprint, river environments, and energy use. For a glossary of terminology, refer to Appendix 2.

Table 1 provides a summary of the 20 included articles. Most articles provided Australian data ($n=18$) while two provided NZ data. Over half of the articles examined individual foods or food groups ($n=15$). Of the articles that examined dietary patterns ($n=13$), over half also provided data on the foods or food groups that were included within those dietary patterns ($n=8$). There was a high degree of heterogeneity in the environmental indicators that were used within the cited studies with GHGe being most commonly reported ($n=12$), followed by water use ($n=4$), water footprint ($n=3$), carbon footprint ($n=3$), land use ($n=2$), and, lastly, ecological footprint ($n=2$). The following indicators were additionally included in some of the articles: non-CO_2

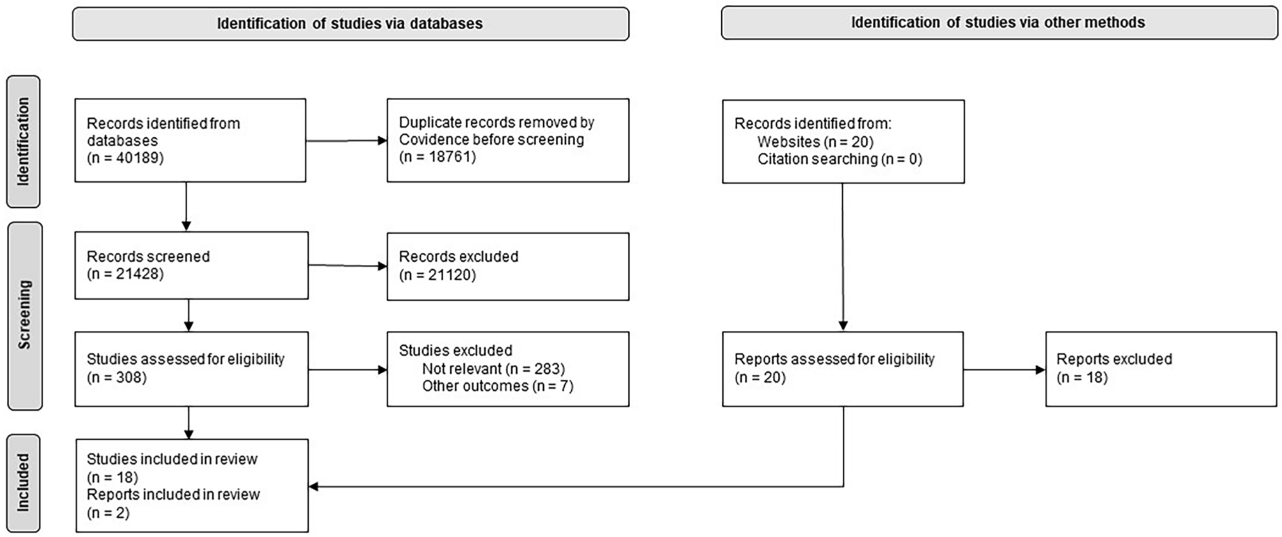

Fig. 1 PRISMA flow diagram of studies and reports included in the rapid review

GHGe ($n=1$), water scarcity footprint ($n=1$), and cropland footprint ($n=1$).

The findings for the following environmental indicators are described below: GHGe; water use/footprints, and water scarcity footprints; and land use, ecological footprints, and cropland footprints.

GHGe

The industrialisation of farming and food production systems and rising volumes of food waste in landfill has led to the food system becoming one of the leading greenhouse gas-emitting industries responsible for one-quarter of total global emissions [3•, 8]. To measure and compare the quantity of total emissions from the food industry, many researchers utilise kilograms of carbon dioxide equivalents (kg CO_2e), a metric that accounts for all greenhouse gases and their relative potential for warming the earth's surface over the next hundred years [3•].

Australia's total GHGe for 2020 was an estimated 510.1 Mt CO_2e [38], and food system-related GHGe currently represent 14.2% of the country's total annual emissions [30]. Weekly food consumption based on household expenditure is estimated to be responsible for an average of 80 kg CO_2 week^{-1} household^{-1} [31]. This estimate excludes other greenhouse gases and additionally does not consider the emissions related to the act of food preparation in the home or food wasted. Food waste is estimated to contribute 6% of Australia's total food-related GHGe [30].

Using estimates from recent national data on Australia's food consumption patterns, the average Australian's diet is responsible for a total of 19.7 kg CO_2e person^{-1} day^{-1}; however, the standard deviation varies considerably due to the highly varied dietary intakes of Australians [28]. The average estimated GHGe increased by 5.2 kg CO_2e person^{-1} day^{-1} between 1995 and 2011 [27]. These differences over time can be explained by (1) an increase in average energy intake per person between dietary surveys (9400 kJ vs 10,224 kJ per day) as total energy intake has been found to be positively correlated with total dietary GHGe ($r=0.54$ ($p<0.001$)) [28] and (2) the use of an updated environmentally extended input–output (EEIO) model in the later study. Despite similar average energy intakes to Australians, the average NZ diet (mean 9103 kJ) has lower emissions, with a typical diet consumed by an adult male estimated to emit 10.1 kg CO_2eq person^{-1} day^{-1} [36] and an average adult diet emitting 6.6 kg CO_2eq person^{-1} day^{-1} [22•].

When the average Australian diet was compared to the ADG-recommended diet in two studies [18, 20••], the diets had similar GHGe (Table 1). Conversely, when Hendrie et al. [28] compared the GHGe of two other current dietary patterns to the recommended eating pattern for adults aged 19–50 years, the GHGe was approximately 5 kg CO_2e day^{-1} higher for those adults who consumed a lower quality, higher GHGe diet (LQHE diet), compared to the recommended diet. In contrast, those adults who consumed a higher quality, lower GHGe (HQLE) diet had emissions 6.5 kg CO_2e day^{-1} lower than the ADG-recommended diet. The HQLE diet comprised less than half the number of serves of discretionary foods compared to an average Australian diet and included an average of 0.2 serves less of milk and dairy foods.

The quantity of GHGe produced by a country is influenced by the composition of the population's diet. In the ADG, foods are categorised as core foods (e.g. fruit, vegetables, cereals, lean meat, eggs, poultry, dairy) or non-core "discretionary" foods (e.g. sugar-sweetened beverages, alcohol, confectionary, processed meats). Table 2 provides an overview of the GHGe associated with consumption of core food groups and discretionary foods. Four studies provided

Table 1 Summary of included articles ($n=20$)

Author (year)	Objective/Purpose	Country	Exposures (consumption of foods, food groups, and/or dietary patterns)	Outcomes (environmental indicators)	Results†	
					Dietary patterns	Foods and/or food groups
Candy et al. (2018) [18]	To develop and test a methodology to quantify Melbourne's "foodprint" i.e. how much land and water it takes to produce the food to feed Melbourne, and the food waste and GHGe that are generated	Australia	Average Australian diet profile by Turner et al. [19•] which was derived using data from the Australian Health Survey's National Nutrition and Physical Activity Survey (NNPAS) 2011–2012 to provide the daily food eaten per capita for the Australian Stocks and Flows Framework food types	GHGe Water use Land use	Food consumption accounts for over 0.9 t of GHGe per capita per year or 4.1 million tonnes total for Melbourne 758 gigalitres total water used in Melbourne related to food consumption 16.3 million hectares per year of land used to feed Melbourne	Approximately 58% of food-related GHGe are due to red meat production (beef and lamb) and 21% are associated with dairy production Beef and lamb are responsible for 26.3% of water use. Dairy has a higher water use of 53.1% compared to beef and lamb Beef and lamb consumption is responsible for 90% of land use. Dairy (2.6%) and pig and chicken meat (2.2%) were the next two highest contributors
Candy et al. (2019) [20••]	To investigate the direct food availability and environmental implications of implementing strategies that shift Australia's current dietary pattern to one or other of two healthier dietary patterns, a healthy mixed diet consisting of a mixture of animal and plant foods, and healthy plant-based diet containing only plant foods	Australia	Current dietary pattern -The Path We're On diet (TPWO): initial consumption quantities were determined using data from NNPAS 2011–2012 Two modelled dietary patterns based on recommendations of the Australian Dietary Guidelines (ADG) -Healthy mixed (HM) (includes meat, eggs, and dairy) -Healthy plant-based (HPB) diet (excludes eggs, meat, and dairy. Dairy substitutes assumed to be legume-based)	GHGe Water use Land use	TPWO diet had a lower GHGe than a HM diet and higher GHGe than a HPB diet. GHGe from agricultural production for the different diet scenario was higher for TPWO compared to HM and HPB. Food waste was not taken into account Water use for domestic consumption of the TWPO scenario is the lowest of the three diet scenarios and highest for the HM diet HPB diet had the lowest land use and the HM diet the highest land use. This was mainly related to beef and dairy consumption. TPWO had a 25% lower land use than the HM diet	

Table 1 (continued)

Author (year)	Objective/Purpose	Country	Exposures (consumption of foods, food groups, and/or dietary patterns)	Outcomes (environmental indicators)	Results†	
					Dietary patterns	Foods and/or food groups
Commissioner for Sustainability and the Environment (2019) [21]	To respond to the statutory requirement to provide the ACT community and Government with commentary and analysis about the environment in the territory	Australia	ACT household consumption based on expenditure in 2017–2018	Ecological footprint Carbon footprint	Impacts from food expenditure accounted for 50% of the ACTs total ecological footprint in 2017–2018. The total Ecological Footprint was 2.12 million hectares in 2017–2018 which is over nine times the size of the ACT The carbon footprint related to food expenditure was just under 1.2 million tonnes CO_2e	
Drew et al. (2020) [22•]	To build a more nuanced picture of climate-friendly diets by examining the degree to which contextual differences may cause a deviation from international trends, using New Zealand as a case study	New Zealand (NZ)	Current dietary pattern -Average NZ diet based on data from the NZ Adult Nutrition Survey (NZANS), 2008–2009 One modelled dietary pattern -Shifted current consumption to meet the minimum necessary changes to meet the NZ Ministry of Health's (NZMOH) Eating and Activity Guidelines for NZ Adults (NZDGs)	GHGe	Annual emissions associated with the NZ diet equate to 9.2 $MtCPO_2s$/y. After removal of GHGe embodied within foods produced overseas, diet-related emissions in NZ were found to be ~ equivalent to 9.4% of the country's total annual emissions. A typical NZ adult's diet equated to 6.6 kg CO_2e day^{-1} with avoidable food waste contributing 12% (0.8 kg CO_2e day^{-1}). A 4% reduction was observed in GHGe when the eating pattern was shifted to meet the minimum recommendations of the NZDGs. In other dietary scenarios which went above and beyond the minimum recommendations in the NZDG, there were further reductions	The highest contributions were from meat, seafood, and egg consumption (35%) and highly processed foods (24%). For highly processed foods i.e. cookies, cakes, ice cream and foods high in added sugar the range in GHGe was 2–4 kg CO_2e kg^{-1}

Table 1 (continued)

Author (year)	Objective/Purpose	Country	Exposures (consumption of foods, food groups, and/or dietary patterns)	Outcomes (environmental indicators)	Results†	
					Dietary patterns	Foods and/or food groups
Farmery et al. (2015) [23]	To quantify the carbon footprint of seafood products available in Australia	Australia	The five most consumed seafood groups (prawns, fish consumed crumbed/battered, Atlantic salmon, luxury seafood, several less popular fish species in Australia were chosen from six peer-reviewed LCAs, one conference paper and two PhD theses (supplementary data)	Carbon footprint		Seafood imported into Australia does not necessarily have a higher carbon footprint than domestically produced seafood, despite the increased distance between production and consumption. Wild capture in Australia can, in some cases, be higher in carbon footprint than imported seafood
Froemelt et al. (2020) [24]	To investigate consumption patterns in Sydney and Melbourne and understand their impact on emissions	Australia	Overall consumption of food based on Household Expenditure Survey (HES) data from 2015 to 2016	Total carbon footprint	Overall food consumption contributed to 25% of the total carbon footprint for Sydney and Melbourne	The most significant food subcategories were expenditures in restaurants, for fast food and for dairy products
Hadjikakou et al. (2017) [25]	To quantify the share of food-related environmental impacts associated with discretionary foods across several key environmental indicators	Australia	Data from NNPAS 2011–2012 and the Australian HES from 2009 to 2010 to identify the nature of discretionary food consumption in Australia and food product categories	GHGe Ecological footprint Water use		High discretionary food consumption (35.4% of total energy) contributes 33% to total food-related CO_2e (141 kg CO_2e). The main contributors are processed meats (16.2%), alcohol (4.8%) and condiments and confectionary (4.6%) Contribution of discretionary foods to the Ecological Footprint estimated at 35% (total food-related impact 0.031 gHa). Processed meats had the highest contribution (17%) followed by alcohol (7%) The average total water use was 41,798 L, of which discretionary foods contributed 35.3%. The major food category contributors were processed meats (9.2%), alcohol, and condiments and confectionary (7.3%) each

Table 1 (continued)

Author (year)	Objective/Purpose	Country	Exposures (consumption of foods, food groups, and/or dietary patterns)	Outcomes (environmental indicators)	Results†	
					Dietary patterns	Foods and/or food groups
Han et al. (2019) [26]	To explore the agricultural CH_4 and N_2O emission characteristics of 42 major economies and to evaluate how the international trade in the era of economic globalisation has influenced the Agricultural non-CO_2 greenhouse gas emissions (ANGHG)	Australia	Overall household consumption using data from the World Bank	Non-CO_2 greenhouse gas emissions: CH_4 and N_2O		Australia has larger production-based agricultural non-CO_2 GHG (ANGHG) emissions than consumption-based emissions. Consumption-based emissions for agricultural products in Australia were 108.1 Mt CO_2e (per capita 4.6). Embodied CH_4 and N_2O emissions, respectively, are final demand 56.2 Mt CO_2e and 51.8 Mt CO_2e; household consumption 40.5 Mt CO_2e and 37.2 Mt CO_2e. The main emission sources driven by household consumption were livestock-related CH_4 emissions (41.9 Mt CO_2e) and N_2O (23.7 Mt CO_2e). Cropland N_2O contributed 12.4 Mt CO_2e and rice CH_4 2.4 Mt CO_2e Household consumption had the highest embodied ANGHG emissions in final demand 77.7 Mt CO_2e
Hendrie et al. (2014) [27]	To conduct an assessment of the GHGe from the average Australian diet as of 1995 and compare these data with a diet that fits the AGHE	Australia	Current dietary pattern -Average diet based on Australian National Nutrition Survey 1995 Three modelled dietary patterns based on the ADG -Minimal non-core foods diet: adjusted average diet to exclude processed meat, snack foods, confectionery, soft drinks, saturated fats and oils, and alcohol -Foundation diet: dietary pattern based on the ADG food groups which provides the nutrient needs, however, does not meet the energy requirements for all people -Total diet: dietary pattern based on the ADG food groups which provides the nutrient needs and meets the energy requirements for all individuals	GHGe	The average Australian diet had GHGe of 14.5 kg CO_2e person^{-1} day^{-1}. GHGe for two dietary patterns, the average Australian diet with minimal core foods consumed and the total diet GHGe, were similar (11.0 vs 11.1 kg CO_2e person^{-1} day^{-1}, respectively). The 1995 average Australian diet has about 25% higher GHGe than the GHGe of a diet following the Foundation diet due to the lower intake of fruit, vegetables, legumes, and dairy and higher intake of non-core foods (saturated fat, added sugar, salt, and alcohol)	Non-core foods accounted for 27% of the emissions from the average Australian diet in 1995 and had the highest GHGe contribution out of the food groups assessed at 3.9 kg CO_2e person^{-1} day^{-1}

Table 1 (continued)

Author (year)	Objective/Purpose	Country	Exposures (consumption of foods, food groups, and/or dietary patterns)	Outcomes (environmental indicators)	Results†	
					Dietary patterns	Foods and/or food groups
Hendrie et al. (2016) [28]	To quantify the greenhouse gas emissions of the current Australian daily diet and compare current patterns of eating, which vary in the diet quality and greenhouse gas emissions, to the diet recommended in the population dietary guidelines	Australia	Three current dietary patterns using data from NNPAS 2011–2012: -average Australian diet (average daily diet quality score of 43/100, and average GHGe of 15.3 kg CO2e/day) -a higher quality, lower GHGe (HQLE) diet which was determined using the best of existing Australian adults' intake (average daily diet quality score of 59/ 100 and average GHGe of 8.5 kg CO2e/day) -a lower quality, higher GHGe (LQHE) diet determined using the worst of existing Australian adults' intake (average daily diet quality score of 27/100, and average GHGe of 26.3 kg CO2e/day) One modelled dietary pattern -Diet based on recommended dietary intake pattern of the ADG	GHGe	GHGe for the average Australian diet was 19.7 kg CO_2e day^{-1}. The GHGe for the different dietary patterns were: 25.2 kg CO_2e day^{-1} for a lower quality, higher GHGe diet, 20.4 kg CO_2e day^{-1} for the recommended diet for adults aged 19- 50 years old, and 13.9 kg CO_2e day^{-1} for a higher quality, lower GHGe diet	Core foods contributed 68.4% to the total GHGe with the fruit (3.5%) and vegetables (6.5%) food groups being the two smallest contributors to total dietary GHGe, and fresh meat and alternatives (33.9%) the highest contributor. Red meat and non-core foods contribute the highest amount to GHGe
Mekonnen et al. (2010) [29]	To determine the water footprint of wheat consumption for the major wheat-consuming countries	Australian data within global study	Wheat consumption per capita	Water footprint		Australia has a relatively high water footprint (total: 2085 Mm^3 $year^{-1}$; per capita: 1082 m^3 $year^{-1}$) related to wheat consumption compared to other major wheat-consuming countries. This can mostly be explained by the high wheat consumption per capita alone (fraction of world average: 5.4%7). The fraction of the world average for the water footprint per capita is 6.11%
Reutter et al. (2017) [30]	To critique the environmentally extended input–output (EEIO) methodology for analysing environmental and socio-economic impacts of food systems in order to address food waste problems	Australia	Purchases that lead to non-economic activities such as household consumption of food eaten and food wasted	GHGe Water use	The food eaten and the food wasted by consumers represented 14.2% and 6%, respectively, of the total GHGe (979,582 Cg) The food system contribution to the total of 98.939 GL was 13% for food eaten and 4.8% food waste by consumers	

Table 1 (continued)

Author (year)	Objective/Purpose	Country	Exposures (consumption of foods, food groups, and/or dietary patterns)	Outcomes (environmental indicators)	Results†	
					Dietary patterns	Foods and/or food groups
Reynolds et al. (2015) [31]	To model the environmental impacts of the weekly food consumption of Australia's households sorted by income quintile in 2003	Australia	Household food consumption data from the 2003–2004 HES	GHGe Water footprint	Embodied in the weekly food consumed at the household level is on average 80 kg of CO_2 Households on average used 35 m^3 of water	The highest contributors to the average total CO_2 were meals out and fast foods (20%) and meat (16%). Bakery products, flour and cereals, and meat combined contributed 29% to CO_2 The highest contributors to the water footprint were bakery products, flour and cereals (39%), and meat (19%)
Ridoutt et al. (2010) [32]	The mapping of food waste through the distribution and consumption stages of the product life cycle and the use of water foot printing to assess the impact on water resources	Australia	Household consumption determined from retail sales of fresh mango from Horticulture Australia Limited	Water footprint		The water footprint of fresh mango was estimated at 87 L kg^{-1} with 53% of the footprint associated with distribution and consumption waste. Consumption of 1 kg of fresh mango by an Australian household had the same potential to contribute to water scarcity as the direct consumption of 217 L of water in Australia
Ridoutt et al. (2019) [33•]	To quantify the water-scarcity footprint and diet quality score of a large (> 9000) population of self-selected adult daily diets	Australia	Three current dietary patterns based on NNPAS 2011–2012 -mean Australian diet -a higher quality, lower in water-scarcity footprint diet (best of existing Australian adults' intake) -a lower quality, higher in water-scarcity footprint diet (worst of existing Australian adults' intake One modelled dietary pattern -the recommended dietary intake pattern which complied with the ADG	Water scarcity footprint	Water scarcity footprint for the Australian adult daily diets averaged 362 L-eq $person^{-1}$ day^{-1} +/− 218 L-eq $person^{-1}$ day^{-1}	Discretionary foods contributed 24.6% to water-scarcity footprint, fruits 18.9%, dairy and alternatives 16.1%, breads and cereals 12.6%, fresh meat and alternatives 11.6%, beverages 7%, vegetables 7%, and healthy fats and oils and miscellaneous foods 0.9% each

Table 1 (continued)

Author (year)	Objective/Purpose	Country	Exposures (consumption of foods, food groups, and/or dietary patterns)	Outcomes (environmental indicators)	Results†	
					Dietary patterns	Foods and/or food groups
Ridoutt et al. (2020) [34•]	To assess the prevalence of dairy food intake among higher diet quality and lower GHG emission diets in Australia and within these diets assess the association between level of dairy food intake and adequate intake of a broad range of nutrients	Australia	Two current dietary patterns based on NNPAS 2011–2012 -average daily diet -a higher diet quality, lower GHG emission (HQLE) subgroup (37% higher diet quality score and a 43% lower GHGe compared to the average diet)	GHGe		The major factor that differentiated the two diets was the intake of discretionary foods. The HQLE group consumed less than half the number of serves compared to the average Australian adult. HQLE had on average 1.6 serves from the milk, yoghurt, cheese, and their alternatives group which was 0.2 serves lower than the average Australian diet. Core dairy foods (milk, cheese, yoghurt) were consumed in 90% of HQLE daily diets. The results demonstrate "that in the Australian dietary context, the current recommended intake of dairy foods is compatible with a dietary pattern that has substantially lower GHG emissions" (p283)
Ridoutt et al. (2020) [35]	To identify dietary patterns existing within the Australian community that are characterised by higher diet quality and lower environmental impacts related to cropland use	Australia	Three current dietary patterns based on NNPAS dietary intake data 2011–2012 for adults aged 19–50 years -mean Australian diet -a higher diet quality, lower cropland footprint (HDQ-LCF) diet (better diets of existing Australian adults' intake) -a lower diet quality, higher cropland footprint (LDQ-HCF) diet (poorer diets of existing Australian adults' intake) One modelled dietary pattern -the recommended dietary intake pattern which complied with the ADG	Cropland footprint	Cropland scarcity footprints (CSF) of adult daily diets averaged 7.09 m^2 year-e $person^{-1}$ and the cropland biodiversity footprint 1.19×10^{-12} PDF $person^{-1}$. If an adult (19–50) years were to consume the recommended diet which had an average CSF intensity, the CSF increases from 7.41 to 7.71 m^2 year-e $person^{-1}$. The average Australian adult diet has a CSF that is too large for the proposed global cropland planetary boundary	Discretionary foods contributed the highest share to total cropland footprints (36%), followed by meat and alternatives group (23.9–27.4%): bread and cereals (~ 12%); poultry (9.5–11.7%); beef and lamb (7.3–8.8%); vegetarian alternatives (3.4–3.9%); pork (2.5–2.9%); and seafood (0.7%)
Turner et al. (2018) [19•]	To explore near-term environmental and economic ramifications of the "The Path We're On"	Australia	The Path We're On diet (TPWO): initial consumption quantities were determined using data from the NNPAS 2011–2012. In this diet, the typical Australian adult consumes 35% of energy from discretionary foods	GHGe	If Australians continue consuming TPWO diet, agriculture will continue to contribute substantially to GHGe	

Table 1 (continued)

Author (year)	Objective/Purpose	Country	Exposures (consumption of foods, food groups, and/or dietary patterns)	Outcomes (environmental indicators)	Results†	
					Dietary patterns	Foods and/or food groups
Wilson et al. (2013) [36]	To perform optimization analyses around foods and dietary patterns to help inform food policies available to central governments concerned with preventing non-communicable diseases, reducing food insecurity, and increasing the sustainability of food production	New Zealand	One current dietary pattern based on data from the NZ Adult Nutrition Survey (NZANS) 2008–2009 -Typical diet for a NZ man (10,380 kJ) Optimised dietary scenarios that minimised GHGs whilst meeting the requirements in the NZDGs -four dietary scenarios containing more familiar meals based on NZ dietary habits -a vegan dietary pattern -a dietary pattern which minimised GHGe while achieving nutrient levels and a cost of < NZD$9/day	GHGe	Estimated GHGe for a male-typical NZ diet of 10.1 kg CO_2e person^{-1} day^{-1}. The four dietary scenarios which included more familiar foods had CO_2e person^{-1} day^{-1} ranging from 4.24 to 5.98. The dietary pattern with the lowest impact on GHGe (1.31 CO_2e person^{-1} day^{-1}) was one which minimised GHGe while achieving nutrient levels and had a cost < NZD$9/day. When this scenario was modelled with a vegan diet, the GHGe was higher at 1.9 CO_2e person^{-1} day^{-1}	
Weidemann et al. (2013) [37]	To quantify the environmental impacts of two Queensland beef supply chains for domestic and premium export beef and to produce credible data on climate change impacts and water use in these supply chains (to the general public)	Australia	Beef purchased in Australia and consumed in the home	GHGe		GHGe were 30.8 kg CO_2e kg^{-1} beef consumed in the home in Australia for the SW QLD supply chain. Impacts from shipping, supermarket, home (4.2%), and wastage contributed 21% to the total GHG emissions

†Percentages represent the contribution of the particular food/food group to the environmental indicator measured

Table 2 Average GHGe from consumption of core food groups and discretionary foods in Australia and New Zealand

	Average % contribution to total food-related GHGe				Average GHGe (kg CO_2e kg^{-1})			Average GHGe (kg CO_2e day^{-1})	
Author (year)	Candy et al. (2018) [18]	Hendrie et al. (2014) [27]	Hendrie et al. (2016) [28]	Hadjikakou et al. (2017) [25]	Drew et al. (2020) [22•]	Farmery et al. (2015) [23]	Weidmann et al. (2014) [37]	Hendrie et al.(2016) [28]	Hendrie et al. (2014) [27]
Core foods		72.9	68.4	66.9				15	10.6
Meat and alternatives		27.1	33.9	26				9.5	
Red meat (lamb, beef, pork)	57.8 Beef and lamb		17.6		Beef 21 Lamb 17 Pork 11		Beef 30.8	Beef 4.86	8.0
Poultry	4 (incl. pork)		11		3.9			2.24	0.24
Seafood	Fish 1.0		Fish 3.3	Fish 1	Fish 5.9 Shellfish 11–43	0.9–20			Fish 0.12
Legumes	0.7				1.5				
Nuts	0.4								
Nuts, seeds, and dried fruit					3.6				
Eggs	0.5				4.9				
Dairy	20.9		10.5	5	Butter 11 Cheese 10 Yoghurt 3.3			1.7	0.72
Fruit	5.2		3.5	11	1.2			0.7	0.28
Vegetables	3.5		6.5		1.8			1.1	0.46
Bread and cereal grains	2.8			4	Cereals 1.8 Grains 1.4			2.0	0.63
Rice	1.2				4.1				
Unsaturated fats and oils	2.3		1.8						0.05
Discretionary (total)		27	29.4	33.1				4.7	3.9
Alcohol			5.7	4.8					0.44
Beverages			3.1	1.4					
Baked products				3.5					
Coffee, sugar, tea	Sugar 0.7								0.58
Condiments and confectionary				4.6					
Dairy			2.1	0.4					
Processed meat			11.3	15.4	12				1.76
Snack foods									1.12

data on the percent contribution to total food-related GHGe, three on GHGe per kg of food consumed (kg CO_2e kg^{-1}), and two on GHGe per day (kg CO_2e day^{-1}). There were some differences in categorisation of foods which makes comparisons challenging.

Core foods are estimated to contribute 67–73% to total food-related GHGe in Australia [25, 27, 28], whereas discretionary foods are estimated to contribute between 27 and 33% of the total food-related GHGe in Australia and NZ [22•, 25, 27, 28]. Processed meats were the highest contributors (11–15%) [25, 28]. The high contribution from discretionary foods highlights not only the impact of the production of these foods on the environment but also the higher than recommended consumption of these low nutritional quality foods in Australia and NZ.

Of the core foods, 26–34% of contributions come from the meat and alternatives group in Australia. Fruit (3.5%) and vegetables (6.5%) were the two lowest contributors, but intake of fruit and vegetables currently falls far below recommended intakes nationally [28]. In contrast, in NZ, the highest contributions to food-related GHGe were from meat, seafood, and egg consumption (35%) followed by highly processed foods such as bakery items and ice cream (24%) [22•]. A similar pattern is observed for GHGe per kg of food consumed and GHGe per day with red meat, in particular beef being the main contributor to the GHGe of core foods. There is a difference in emissions for beef between Australia and NZ (NZ 21 kg CO_2e kg^{-1} and Queensland beef 30.8 kg CO_2e kg^{-1}) [22•, 37]. The seafood group had the largest range in average GHGe per kg. Comparing emissions per kg of food may not be a particularly useful metric as overall contribution from that food will depend on the quantity consumed per serve, as well as the frequency of consumption. For example, discretionary foods may have a lower CO_2e kg^{-1} value than red meat but may be consumed multiple times a day by some consumers.

Water Use/Footprints and Water Scarcity Footprints

In Australia, the amount of water required for food production is high, with 60% of the water available for human use being used for irrigated agriculture [39]. Of the eight million megalitres (ML) of water used for Australia's agricultural production in 2018–2019, 1 million of this was used for fruit and nut crops, 882,000 ML for sugar cane, 388, 933 ML for vegetable crops for human consumption, and 75,600 ML for rice [40]. With most of Australia's agricultural production exported (71%), total water used does not accurately reflect that used for food consumed in Australia [41].

Seven studies in Australia have looked at the impact of total dietary intake and/or food products on environmental indicators related to water, but differences in measures between studies make comparisons difficult. One approach is to measure total use, as reported above and the other similar measure is the water footprint (m^3). There is a large variation in these measures across different food products. Reutter et al. [30] analysed the food system contribution to total water use in Australia using data from 2000. Approximately 60% of water used was for food production, with 13% embodied in the food as consumed, on average, by the Australian consumer [30]. Almost 5% is embodied in the food that is wasted by the consumer. In another study, researchers used national intake data to determine the contribution of consumption to water footprint. The average weekly water footprint of Australian households related to their food consumption was estimated at 35 m^3 [31]. The three highest contributors to this water footprint, based on household expenditure data, were bakery products, flour and cereals (39%), meat (20%), and meals outside the home and fast food (16%) [31]. This is likely an underestimate of the water footprint for household food consumption as the researchers did not account for water used when households prepared or consumed the food at home.

In comparison, Candy et al. [18] found that the highest contributors to the overall 758 GL of water per year used in Greater Melbourne for food production were dairy (53.1%), beef and lamb (26.3%), followed by vegetables (8.2%), nuts (7.7%), and sugar (3.6%). All other food product groups contributed less than 2% each. Hadjikakou et al. [25] estimated the percent contribution to total blue water (i.e. irrigation) of different types of discretionary foods that were purchased by households per week. The three highest contributors were processed meat products (9.2%), alcohol (7.3%) and condiments, confectionary, food additives, and pre-prepared meals (7.3%). Researchers in two other studies used food expenditure or purchasing data. The relatively high water footprint in Australia (total: 2085 Mm^3 $year^{-1}$; per capita: 1082 m^3 $year^{-1}$) related to wheat consumption can help explain why the bakery products, flour, and cereals of food group category are the highest contributor [29]. Another example cited in our review is the water footprint of fresh mango, that has been estimated as 87 L kg^{-1} with 53% of the footprint associated with distribution and consumption waste [32].

Currently, Ridoutt et al. [33•] are the only researchers to determine the water scarcity footprint (WSF) of Australian adult dietary patterns. Ridoutt and colleagues [33•] addressed specific environmental concerns related to water use by estimating the associated WSF. The WSF for Australian adult daily diets averaged 362 L-eq $person^{-1}$ day^{-1}; however, this estimate is highly variable (SD = 218 L-eq $person^{-1}$ day^{-1}) due to wide differences in dietary patterns [33•]. Discretionary foods contributed 24.6% to the overall WSF of Australian adult diets, followed by fruits (18.9%), dairy and dairy alternatives (16.1%), bread and cereals (12.6%), and fresh meat and alternatives (11.6%) [33•]. When these findings are compared to those of Reynolds et al. [31], there are some differences in contribution between foods, such as fruit and nuts only contributing 2% to the total water footprint, but contributing 18.9% to the WSF.

Land Use, Ecological Footprints, and Cropland Footprints

The percent of land used for agriculture globally is 77% for livestock, meat, and dairy and 23% for crops (excluding feed) [6]. In Melbourne, land use related to agriculture was higher than the global average with beef and lamb consumption being responsible for 90% of land use [18]. The next two highest contributors were dairy (2.6%) and pig and chicken meat (2.2%) [18]. Consequently, when dietary patterns exclude these agricultural products, land use is lower. Candy et al. [20••] modelled two dietary patterns, a healthy mixed (HM) diet and a healthy plant-based (HPB) diet, compared to the current diet (TPWO). The HPB diet had the lowest land use, while the HM diet required 25% more land use than the current diet.

In terms of overall food consumption, research from the Australian Capital Territory (ACT) found that the impacts from apparent food consumption, estimated from food expenditure data, accounted for 50% of the territory's total Ecological Footprint (2.12 million hectares) in 2017–2018, which is over nine times the size of the ACT [21]. One demand component of the Ecological Footprint is the cropland footprint. Ridoutt et al. [35], in accordance with best practice to address specific environmental concerns related to cropland use, estimated three types of cropland footprints: cropland scarcity footprint (CSF), cropland biodiversity footprint (CBF), and cropland malnutrition footprint (CMF).

The average CSF in Australia exceeds the global target (7.1 m^2 year-e $person^{-1}$ day^{-1} compared to 6.1 m^2 year-e $person^{-1}$ day^{-1}) [35]. However, given the diversity of diets, in terms of overall energy intake and the types of foods consumed, many adults are below the target. If all Australian adults consumed the food choices evident in the high dietary quality-low cropland footprint (HDQ-LCF) dietary pattern (see Table 1), the CSF would decrease by around 20% and CBF (CBF) by 21%. On the other hand, for Australian adults whose diet conforms to the food choices and portion sizes recommended by the current ADG (i.e. increased core food intake and reduced discretionary foods), the CSF would increase by 0.3 m^2 year-e per day, representing an overall increase of 4% [35]. Therefore, the estimated CSF still exceeds the global target.

In Australia, discretionary foods contribute the highest percentage share to the Ecological Footprint (35%) [25] and to cropland footprints (36%) [35], compared to other food groups. Ridoutt et al. [35] found that the second largest contributor to cropland footprints was the meat and alternatives group (23.9–27.4%), with poultry (9.5–11.7%), and beef and lamb (7.3–8.8%) being the main contributors within this food group. The third highest contributor was the grain (cereals) food group, with approximately 12% contribution to total cropland footprint.

Within the discretionary food category, the percent contribution to the Ecological Footprint was highest for processed meats and fattier/salty sausages (17.5%), followed by alcohol (7.0%), condiments, confectionary, food additives, and prepared meals (3.0%) and cakes, biscuits, puddings, and related products (2.9%) [25]. A similar pattern was seen for discretionary food product categories and contribution to CSF and CBF. The highest contributors to CSF were processed meat products (12.5%), alcoholic beverages (6.0%) and biscuits, cakes, waffles (3.3%) and muesli bars, confectionary, and chocolate (2.5%). For CBF, the contributions were similar, namely, processed meat products (10.1%), alcohol (5.5%), muesli bars, confectionary and chocolate (4.7%) and biscuits, cakes, and waffles (4.3%) [35].

Discussion

There was a range of approaches used to assess the environmental impacts of food and/or diets in the studies we reviewed. We have observed that the researchers tended to choose a single environmental indicator to assess the environmental impact of food and/or diets such as GHGe, cropland footprint, or water footprint. Aldaya et al. [42••] reported similar findings in their recent review which highlighted the most frequently used indicators and approaches for assessing sustainable healthy diets.

Interestingly, we were still able to see clear trends. For example, discretionary foods are consistently one of two highest contributors to environmental impacts across multiple metrics: GHGe, cropland footprints, ecological footprint, and water scarcity footprint [22•, 25, 27, 28, 33•, 35]. The meat and alternatives group also had a high environmental impact across multiple metrics although the water scarcity footprint was lower for this group compared to dairy products, cereals, grains, and fruit and vegetables [18, 20••, 22•, 28, 31, 33•, 35]. Fruits and vegetables generally had a low environmental impact in other metrics. However, as fruit and vegetable intake currently falls below recommendations in both Australia and NZ [22•, 28], this is unlikely to be the case when actual intake meets recommendations.

In Australia, most consumers sourced their food domestically in 2020 with only 11% of food consumption by value from imported food [41], a reduction from 15.4% in 2015–2016. The majority of these foods are processed products (9.6%) such as beverages and frozen vegetables. These imported foods play an important role in meeting consumer preferences for taste and variety and may not always have a higher environmental impact compared to domestically produced alternatives. Farmery et al. [23] found that imported seafood does not necessarily have a higher carbon footprint than domestically produced seafood. Imported foods can also provide supply when domestic production is impacted by drought, such as in the case of rice in 2019–20.

Poore and Nemecek [8] reported that moving from current diets to a diet that excludes animal products would reduce the food-related GHGe globally by 6.6 billion metric tonnes of CO_2e. In the studies reported above which modelled different dietary patterns, this benefit was not clearly observed. Wilson et al. [36] estimated that the GHGe of a vegan diet in NZ was approximately 0.6 kg CO_2e person^{-1} day^{-1} higher compared to a dietary pattern which minimised GHGe whilst achieving nutrient levels. In comparison, Candy et al. [20••] found that a plant-based diet in Australia had lower GHGe compared to other modelled diets. As the recommended diets for the two countries differed until recently (i.e. NZ recommended three serves of vegetables compared with Australia's five serves), it could explain the difference in results. Additionally, NZ has low carbon emissions per kg of beef and lamb produced compared to the rest of the world; around 25% of the global average which could impact on the variation [43]. The dietary pattern modelling indicates there are alternative ways to reduce GHGe than just eliminating animal products such as meat, eggs, and dairy. For example in NZ, a 4% reduction was observed in GHGe when the eating pattern was shifted to meet the minimum recommendations of the NZ Dietary Guidelines [22•]. Therefore, rather than eliminating particular foods from a diet, a more realistic goal would be to aim to meet the dietary recommendations and choose mostly sustainable options.

The choice of metric used (or combination thereof) is important to consider as it may under-represent the environmental impacts of foods. Only four groups of researchers used metrics which accounted for multiple environmental impacts [21, 25, 32, 35]. One such metric is the Ecological Footprint. This tool is described as a useful resource-accounting tool that measures how fast individuals, groups of people, or activities consume energy and resources (including plant-based food products, livestock and fish products) compared to how fast nature can absorb our waste (carbon emissions) and generate new resources to replenish those that have been used [44]. The Ecological Footprint tracks the use of productive surface areas such as cropland, grazing land, and fishing grounds and is measured in global hectares (gHa). In contrast, the cropland footprint does not include grazing land for livestock and therefore may not accurately represent the environmental impacts from meat and dairy. Furthermore, not all water footprint calculations consider environmental relevance especially for Australia where variation in local water stress is extreme between regions [45]. The water scarcity footprint is a much more useful metric in Australia and could be a useful tool to identify appropriate regions for crop growing in the future.

Furthermore, some of the metrics used in the cited studies do not allow for differences in agricultural practices and the use of renewable energy. Lifecycle assessments (LCA) are commonly used for analysing the environmental impacts of agricultural products and consider metrics such as resource use, pollutant emissions, and land use. However, van der Werf, Knudsen, and Cederberg [46•] recently highlighted that the LCA method often does not account for alternative production methods and can misrepresent less intensive farming systems such as organic agriculture. Regenerative animal farming methods can have positive environmental impacts such as the integration of livestock into agricultural crops for manure, reduction or elimination of tillage and cover crop leading to improved soil health, increased sequestration of carbon, and increased biodiversity [47].

Another potential problem with using an LCA is the availability of specific country data as there are multiple factors that contribute to the difference between GHGe between countries and within locations in a country. The authors of the two NZ studies stated that there is a lack of available food-related GHGe and waste data and LCA analysis in NZ which resulted in both Drew et al. [22•] and Wilson et al. [36] utilising data estimates from the UK. This may have misrepresented the emissions from NZ's food system particularly as Australia has the largest share of NZ's food imports (and vice versa).

This rapid review synthesises the latest evidence on associations between dietary exposures and environmental outcomes in Australia and NZ. This evidence is highly relevant in the context of dietary guideline development. To inform the next iteration of the ADG, the findings of this review could be used as a starting point to summarise the environmental impact associated with current food consumption behaviours, and against which to make comparisons with alternative dietary patterns. Comprehensive modelling is required to investigate the nutritional adequacy of food substitution effects of more sustainable food choices [48]. For example, reductions in the recommended number of serves of meat could be balanced by increases in the recommended number of serves of legumes or nuts. Undoubtedly, to promote both health and environmental sustainability, dietary guidelines should continue to recommend reduced consumption of discretionary foods.

Conclusions

The results of this rapid review demonstrate that there is context-specific evidence available that describes the environmental impacts associated with food consumption in Australia and NZ. Most of the articles included in this review provided evidence related to the consumption of individual foods, food groups, or dietary patterns on GHGe. Whilst there are commonalities between different environmental indicators such as the impact of discretionary food consumption on CSF, WSF, and GHGe, there is wide variation in these indicators for other foods such as fruit. Modelling of current food consumption data to those dietary patterns recommended as being optimal for health does not necessarily result in an improvement in all environmental indicators. Thus, it is essential that environmental sustainability is considered in the revision of Australia's Dietary Guidelines, as has been recently done for NZ, in order to ensure that the foods and dietary patterns that are recommended are associated with both positive health and environmental outcomes.

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Compliance with Ethical Standards

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