Shifting the Menu

Reducing the carbon footprint of fast-food consumption by switching to plant-based options

Prepared for World Animal Protection

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Disclaimer

About the authors

The Institute for Sustainable Futures (ISF) is a transdisciplinary research and consulting organisation within the University of Technology Sydney. ISF's mission is to create change toward sustainable futures.

The research team for this project have expertise across GHG & environmental assessments, resource efficiency, sustainable food systems and food market analysis and segmentation.

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Preface

The transition to a low emission, sustainable and cruelty-free food system will not happen without meaningful contributions from the fast-food sector. Estimates suggest that food-production accounts for over a third of all human-made greenhouse gas emissions, making it one of the largest contributors to climate change globally. Alarmingly, Australia has the highest per capita greenhouse gas emissions from the food sector of any G20 country – 60 per cent of which come from meat and dairy production.

The consumption of fast-food is increasing and a large proportion of it is meat and other animal products from low-welfare and high-emissions farming systems. If fast-food outlets in Australia want to ensure they are operating sustainably, they need to consider the environmental impact of the meat and dairy on their menus, and replace them with sustainable, plant-based meal options. The global warming impact of a plant-based beef burger is 90 per cent lower than a standard beef burger and requires much less land and water.

It's time to address the cow in the room and begin the necessary shift towards a plant-based food system.

This report demonstrates that by switching to more plant-based menu options, fast-food outlets could significantly reduce their climate and environmental footprint, as well as reducing the suffering of farmed animals. By offering more sustainable menu options, they would also make it easier for consumers to reduce their carbon footprint. A quick and tasty take-away meal shouldn't cost the planet.

Ben Pearson

Country Director

World Animal Protection

Executive summary

Food production is one of the largest contributors to climate change – estimated at over a third of all human-made greenhouse emissions (GHGs). Within the food sector, meat and dairy production contribute the largest share. This is primarily due to methane emissions from cattle and sheep, in addition to manure, feed production, fertiliser production and use, farm machinery, food waste and other post-farm gate emissions. Australia has pledged to reduce methane emissions by 30% by 2030, together with 129 other countries who are signatories to the Global Methane Pledge.

This means that our food choices at home – and away from home – can collectively have an enormous impact on reducing GHG emissions.

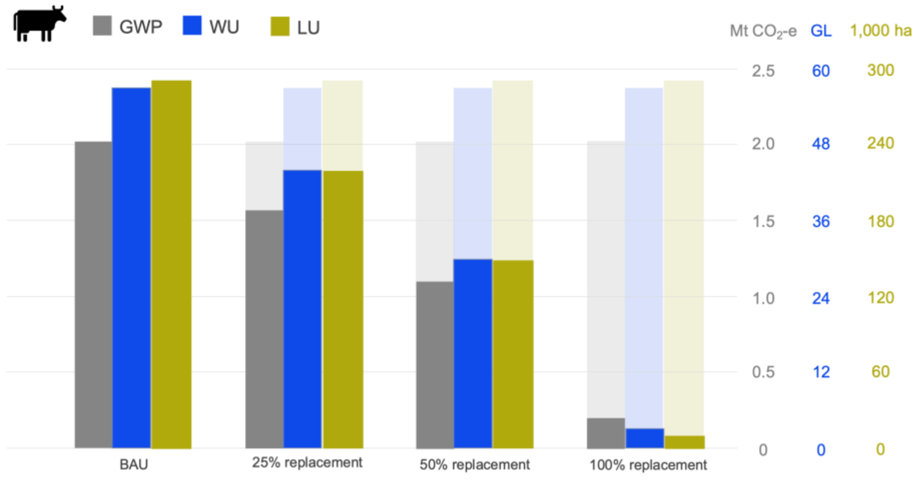
This report reviews and synthesises 12 life cycle assessment (LCA) studies to estimate the impact of fast-food choices across various meat types, cheese, and plant-based alternatives. The LCA studies incorporate measurements of GHG emissions, water use and land use.

Our findings are that by ordering a plant-based beef patty instead of a beef patty at a fast-food outlet, Australian consumers can reduce the global warming potential of their burger by 90%. If they replace a chicken patty with a plant-based option, it reduces that burger's global warming potential by 60%. This is especially significant given that three-quarters of all Australians over the age of 14 eat at fast-food restaurants and convenience store outlets.

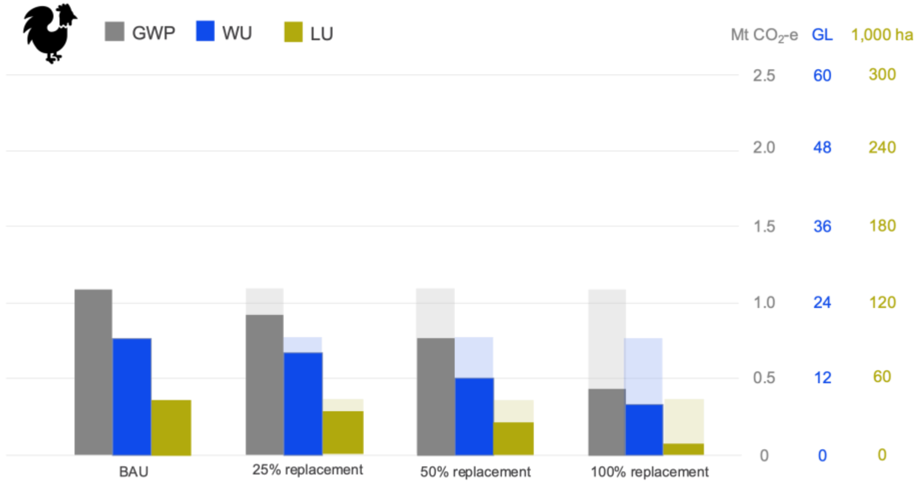
Australia has the highest per capita GHG emissions from the food sector of all G20 countries. Australians also consume meat at one of the highest rates in the world, well above dietary guidelines. There are huge potential benefits associated with reducing the consumption of animal product-based food within the fast-food sector, including a reduction in GHG emissions, water use and land use requirements. Due to the potency of methane as a GHG, and its relatively short lifetime in the atmosphere, shifting diets enables a relatively quick win to reduce the global warming potential of Australia's emissions.

In this report, we assess reduction scenarios for GHG emissions, water use and land requirements in Australia, based on a 25%, 50% and 100% rate of substitution

Environmental impacts of replacing beef with plant-based alternatives in Australia's fast-food sector



Environmental impacts of replacing chicken with plant-based alternatives in Australia's fast-food sector



of meat-based fast-food offerings with plant-based options. For example, we estimate that by replacing just 25% of beef with plant-based options in fast-food restaurants, GHG emissions from the beef industry sector in Australia would reduce by 0.45 Mt CO_2-e (equivalent to taking 150,000 cars off the road). Similarly, replacing merely 25% of chicken with plant-based options in fast-food restaurants would reduce GHG emissions from the chicken sector in Australia by 0.15 Mt CO_2-e (equivalent to taking 52,000 cars off the road).

While the fast-food sector has begun to offer some plant-based alternatives, there is an urgent need to address the significant benefits associated with reducing the consumption of meat and animal products. These benefits also need to be reflected in policies, guidelines and communication on diets and consumer choices.

The findings from existing studies (including this report) are clear enough to make a compelling case for reducing meat consumption to reduce climate impacts. However, the food GHG emissions data in Australia is currently fragmented, patchy and predominantly funded by the respective industries themselves. More research is needed to develop and support comprehensive, consolidated, independently generated or verified data on GHG emissions that extend across the whole food sector value chain, from pre-farm gate (including manufacturing of farm inputs) and land use change, all the way through to post-farm gate impacts (like food processing and food waste).

Abbreviations and glossary

Abbreviation	Description
ACT	Australian Capital Territory
CH_4	Methane
CO_2	Carbon dioxide
CO_2-e	Carbon dioxide equivalent
F	Fluorine
FSR	Full-service restaurant
GHG	Greenhouse gas emissions
GWP	Global warming potential
ha	Hectare
IPCC	Intergovernmental Panel on Climate Change
kg	Kilogram
L	Litre
LCA	Life cycle assessment
LU	Land use
LULUC	Land Use & Land Use Change
m^2	Square metre
ML	Megalitre
Mt	Megaton
N_2O	Nitrous oxide
NDGs	National Dietary Guidelines
OECD	Organisation for Economic Co-operation and Development
QSR	Quick-service restaurant
UN	United Nations
WU	Water use

Contents

1 Food – especially meat – has an enormous climate impact

Food production is one of the largest contributors to climate change – estimated at over a third of all human-made greenhouse gas (GHG) emissions [1]. Within the food sector, GHG emissions from meat and dairy production contribute the largest share (around 60%), while plant-based foods contribute around 30%, and remaining agricultural products (fibre, etc.) contribute 13% [2]. Sources of food sector GHG emissions vary widely, from methane produced in the stomachs of ruminant livestock like cattle and sheep and in their manure, to land-clearing to grow crops (see Section 2).

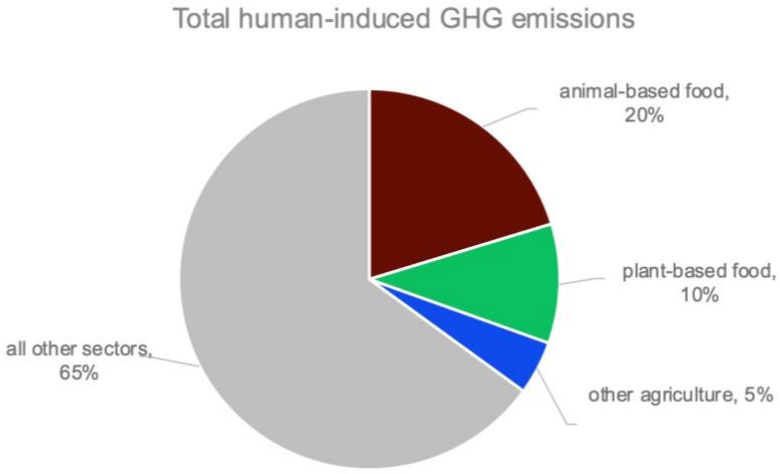


Figure 1: Total human-induced GHG emissions, indicating the contributions from the food sector: animal-based food production (brown); plant-based food production (green). Data: [2]

Methane is a GHG that is more than 25 times as potent as carbon dioxide at trapping heat in the atmosphere [3]. Over the last two centuries, methane concentrations in the atmosphere have more than doubled, due largely to human-related activities.

This means that our food choices at home – and away from home – can collectively have an enormous impact on reducing GHG emissions, if we shift our food consumption towards foods with lower carbon footprints.

Australia has pledged to reduce methane emissions by 30% by 2030, together with 129 other countries who are signatories to the Global Methane Pledge [4].

Compared to diets rich in animal foods, plant-based diets are more sustainable because they are less taxing on the environment overall [5]. Practices and policies that favour the global adoption of plant-based diets can simultaneously help to optimise food supply, health and environmental outcomes.

> "Livestock is estimated to contribute around 15-20% of total human-induced GHG emissions [2] [6] [7] [8] [9].

1.1 Meat consumption trends in Australia's fast-food sector

Australia currently has one of the world's highest levels of meat consumption. We consume approximately 90 kilograms per capita annually, compared to the global average of around 35 kilograms per capita annually [10] (see Section 3).

Poultry is the most widely consumed meat in Australia (44 kilograms per capita annually), followed by beef/veal (22 kilograms) and pork (20 kilograms) (Figure 2) [10]. Over time, there has been a shift from red meat consumption to white meat consumption (Figure 2) [11] for reasons linked to perceived health benefits [12]. The increasing popularity of chicken in Australia is also linked to its lower price relative to red meats [13], and it being considered a more versatile ingredient to cook with [14].

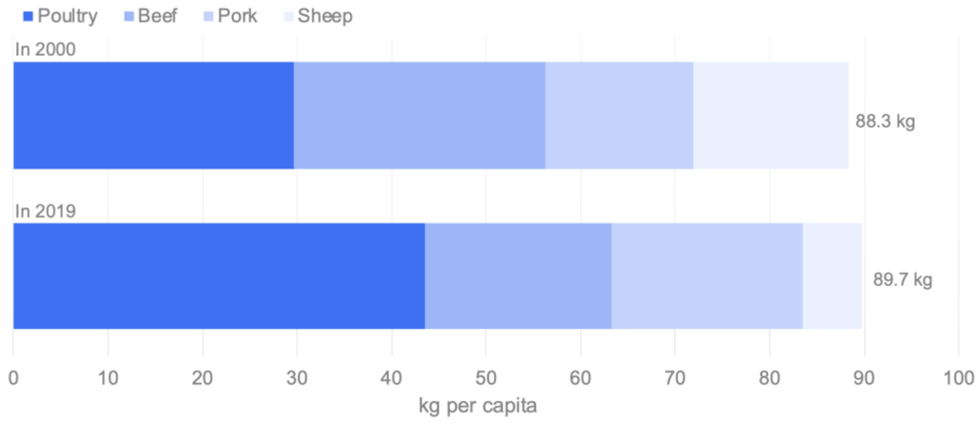


Figure 2: Changing meat consumption trends in Australia 2000-2019: poultry consumption is now double beef consumption [15].

Key factors contributing to high meat consumption in Australia include the widespread and influential marketing of meat, the Australian public's perception that meat is crucial to health and/or nutrition, the sensory appeal of meat-based foods, and meat's symbolic association with masculinity in modern Australian culture [11] [16] [17] [18].

Research shows that three-quarters of all Australians aged over 14 eat at fast-food[1] restaurants and convenience store outlets [19]. Almost 1 in 5 Australians consume fast food more than 10 times, on average, across a period of four weeks.

In 2021, the size of the Australian foodservice market (which consists of food and beverages consumed outside the home)[2] was estimated to be $50 billion [20]. Fast-food restaurants have the highest value share of the Australian foodservice market. In terms of sales by cuisine types or food formats in Australia, burgers ($6 billion), pizzas ($2.5 billion) and chicken-based foods ($2.2 billion) sold through fast-food outlets generate the highest value in sales [21].

The biggest players in Australia's fast-food and takeaway-food services are McDonald's, Competitive Foods Australia, Domino's Pizza Australia and Yum! Restaurants Australia [22]. While Fast-food restaurants like McDonald's have recently begun to offer plant-based foods [23], meat-based products still dominate their menus. McDonald's Corporation is said to serve more beef than any other restaurant chain on the planet – between 1 to 2% of the world's total.

Australia's Department of Health notes that more than $550 million is spent on advertising annually by food companies in Australia [24]. Influential meat advertising campaigns have used catchy sayings or jingles (such as "We love our lamb", "You never lamb alone" [25], and "Get some pork on your fork" [26]) to encourage and entrench meat-eating norms. These advertisements also nod to the fact that the pressure to consume meat and dairy products may often come from an individual's own social networks (their family members, friends, teachers, or the wider community).

> "Three-quarters of all Australians aged over 14 eat at fast-food restaurants and convenience store outlets [19].

Scholars also argue that more needs to be done to incorporate the connection between food and environmental sustainability into current Australian National Dietary Guidelines (NDGs) [27].

A recent report from the EAT–Lancet Commission is the world's first to propose guidelines that integrate individual nutritional needs and environmental sustainability, thus forming a single set of global dietary recommendations that can also be customised for regional cultural preferences [28].

[1] Note: The categories of 'fast-food and takeaway food tend to be combined and/or used interchangeably in both market analysis reports [22] and in peer-reviewed research on consumer behaviour in relation to the fast-food and takeaway food sector [86] [87] [88] [89]. However, 'takeaway foods' tend to encompass meals made-to-order and food commonly consumed off-premises, whereas 'fast foods' commonly refer to food offerings from large national and multinational fast-food chains (such as McDonalds, Competitive Foods, Yum! Brands and Dominoes Pizza) and can include dining-in [22]. The terminology in this report has been maintained to represent the subtle differences between these two categories.

[2] Key channels within the Australian foodservice market include full-service restaurants, fast-food restaurants, pubs, clubs & bars, coffee & tea shops, accommodation, retail, leisure, workplaces, travel, ice-cream parlours, and mobile operators

A subsequent Australian study aimed to develop a sustainable food basket modelled on these EAT–Lancet Commission guidelines. The study's authors measured the affordability of such a diet across various urban socio-economic groups nationwide, and compared this to the typical current Australian diet [29]. Their findings are encouraging: a sustainable diet is – potentially – feasible financially for metropolitan-dwelling Australian households, regardless of socio-economic status or location [29]. However, they note that more needs to be done in terms of food promotion, nutrition literacy, and developing cooking skills to help Australians transition towards a healthier and more environmentally sustainable diet [29].

1.2 Climate impact of beef patties vs plant-based patties

Meat burgers represent the largest share of the $22 billion fast-food and takeaway-food services in Australia (38% share). This segment has been in decline over the past five years [22] and to maintain demand and cater to changing consumer diets and preferences, some fast-food burger vendors have been expanding their product range to include plant-based burgers.

In this report, we estimate the climate impact of a meat-based burger patty – and plant-based alternatives. The results indicate that the GHG emissions from a beef burger are 10 times greater than emissions from a plant-based beef burger (Figure 3).

These estimates are based on a synthesis of 12 Life Cycle Analysis (LCA) studies (see Appendix 1 for methodology). The scope of the LCA data includes impacts generated from farming, food processing, retail, and distribution. While the average burger is 113 g, some burgers in the fast-food industry are offered as a larger serve (double patties weigh half a pound, or 226 g), which would double the GWP measured in Figure 3.

Some of the LCA studies have shown a decrease in GHG emissions from Australian beef production over the past decades. This decrease is predominantly due to efficiency gains from heavier slaughter weights, improved cattle survival rates, and using grain as feed. Over the same time period, however, the increase in supplementing grain as feed on farms resulted in a twofold increase in fossil fuel energy demand for beef production [30].

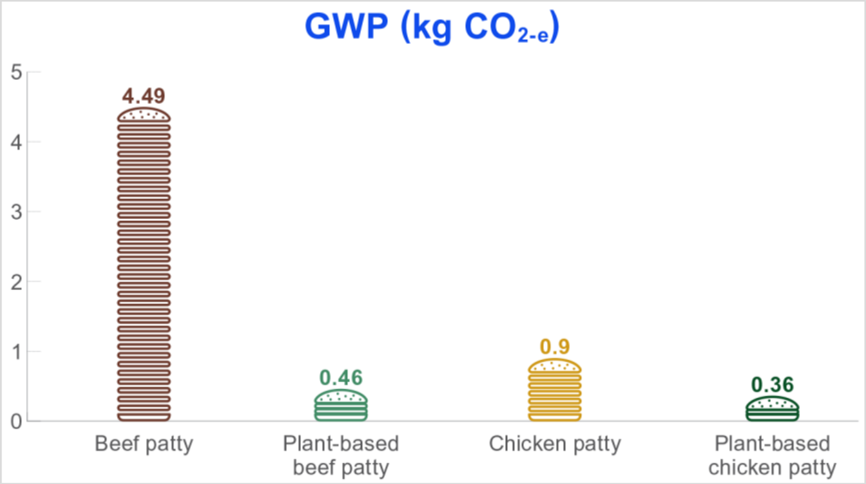


Figure 3: Estimated Global Warming Potential (GWP) in kg CO_2-e for a 113 g burger beef patty and its replacements: plant-based beef patty, chicken patty, and plant-based chicken patty. Source: Authors.

If consumers replace beef patties with plant-based beef patties in their burgers, on average a **90% reduction** in global warming potential could be achieved (Figure 4). The LCA literature on reported GWP reductions from making this switch range from 74% to 98% (Appendix 1). This variation is attributed to a range of factors, including the variety of ingredients used in plant-based patties (pea-based vs soy-based) and processing technologies (low moisture extrusion vs high moisture extrusion). Soy-based burger patties, for instance, have lower environmental impact than pea-based patties. Mycoprotein-based burger patties have an environmental impact in the middle of this range; however, they are rarely used as a substitute because they have less favourable sensory properties [31].

Unique supply chain characteristics from different parts of the world also contribute to this variance [31]. A significant portion of the carbon footprint of a beef patty comes from the agricultural stage [32] (see Figure 6), largely attributed to the enteric fermentation[3] process of ruminant livestock.

[3] Enteric fermentation produces methane gas and occurs during the digestion of grass and plants by cows and other ruminants.

> “Methane has a much shorter lifespan in the atmosphere (and is far more potent than CO_2) – it ‘lives fast, dies young’[4]. Because meat is the single largest source of methane [7], this means we can reduce global warming potential much faster by shifting diets away from methane-intensive animal proteins.

By replacing a chicken patty with a plant-based chicken patty, consumers could achieve a **60% reduction** in the GWP of their burgers (Figure 4). The GWP of an individual chicken patty is far less than for a beef patty (80% lower GWP than a beef patty – see Figure 3). However in total, Australians consume twice as many tonnes of chicken than beef annually (Figure 2). The environmental impacts of chicken meat production in Australia also vary based on location. For example, lower impacts are observed for fossil fuel energy, greenhouse gas emissions, land use, land change, and freshwater consumption in South Australia than in Queensland [33]. Feed production is the largest contributor to all impact categories [33], highlighting the importance of geographically specific data on emissions from different kinds of feed. Surprisingly, there is not much reported difference in environmental impacts between different chicken housing arrangements (conventional versus free-range production) [33].

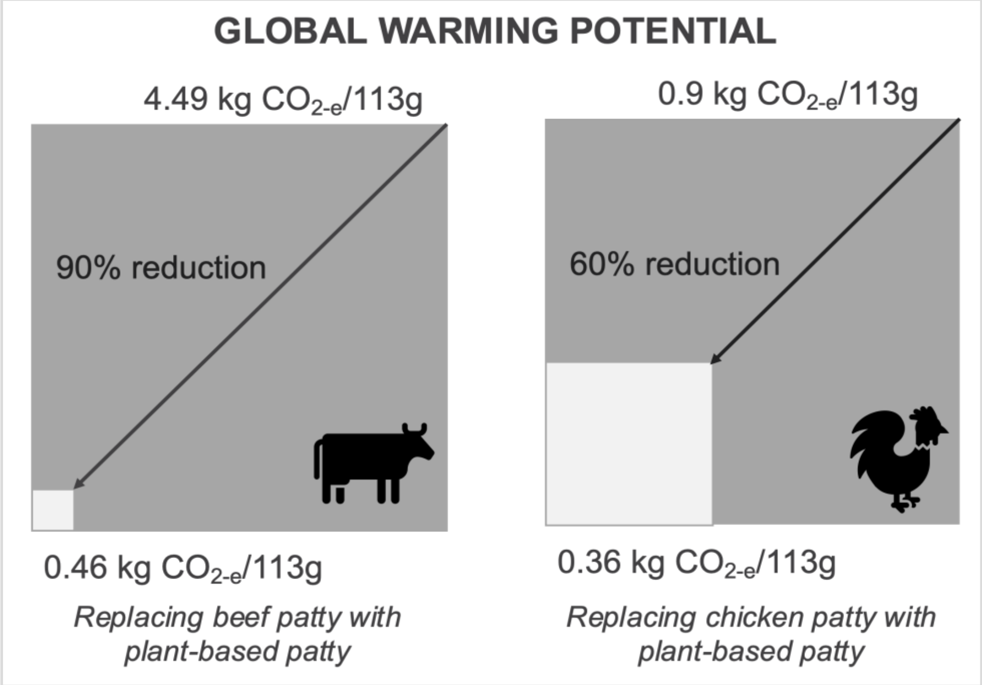


Figure 4: Reductions in global warming potential (GWP) by replacing a burger’s beef and chicken patty with a plant-based patty. Source: Authors.

[4] Methane is 28-100 times more potent than CO_2, and has a lifespan of around a decade in the atmosphere [85].

1.3 Climate impact of dairy cheese vs vegan cheese on pizza

Pizza represents 16% of the revenue from fast-food and takeaway-food services in Australia [22]. Cheese is heavily used in many fast-food products and is a core ingredient in making pizzas. Consumer preference is shifting towards higher quality woodfired pizzas [22], which are often topped with mozzarella or buffalo mozzarella cheese. LCA studies report that half of the GHG emissions in the production of a margherita pizza come from the cheese, and that replacing mozzarella with fresh buffalo mozzarella doubles the carbon footprint [34]. On average, 75% of cheese's GWP is attributed to the production of ingredients for cheese, with packaging, transport, distribution and consumption playing a smaller role [35].

The estimated GWP impact of mozzarella cheese used on a pizza, according to existing LCA studies [36] [37] [38] [39] [40], is shown in Figure 5. This impact is based on a 12-inch pizza containing 8 ounces (226 g) of cheese, however this pizza size and cheese amount varies somewhat in the LCA studies (see Appendix 1).

By replacing dairy cheese with plant-based cheese, consumers can achieve on average a **79% reduction** in GWP (mainly due to avoiding the climate impacts of intensive dairy-farming, including the generation of methane by livestock). Across all cheese types, the estimated GWP reduction has been estimated in the range of 59% to 79% [36]. This variation is due to the different ingredients used in plant-based cheeses, and to differences in supply chain characteristics.

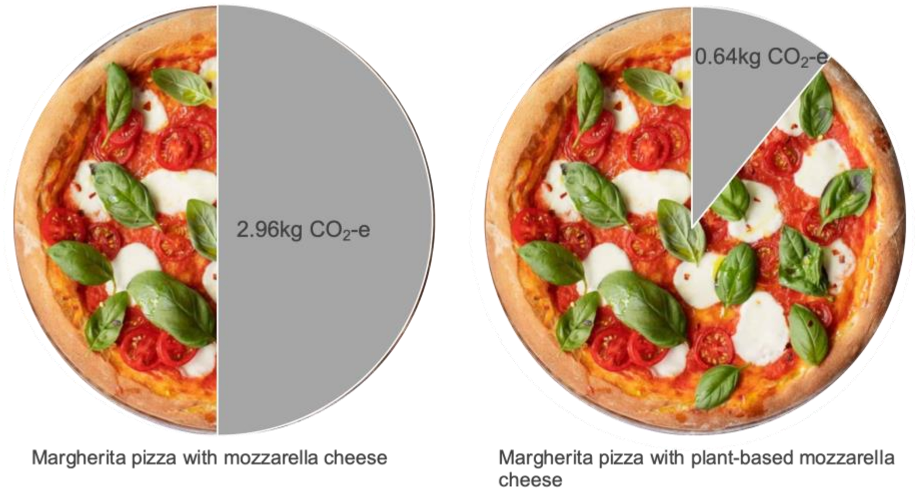


Figure 5: Comparison of the estimated GWP for a typical 12-inch pizza containing 8 ounces (226 g) of mozzarella cheese vs plant-based mozzarella cheese. Source: Authors.

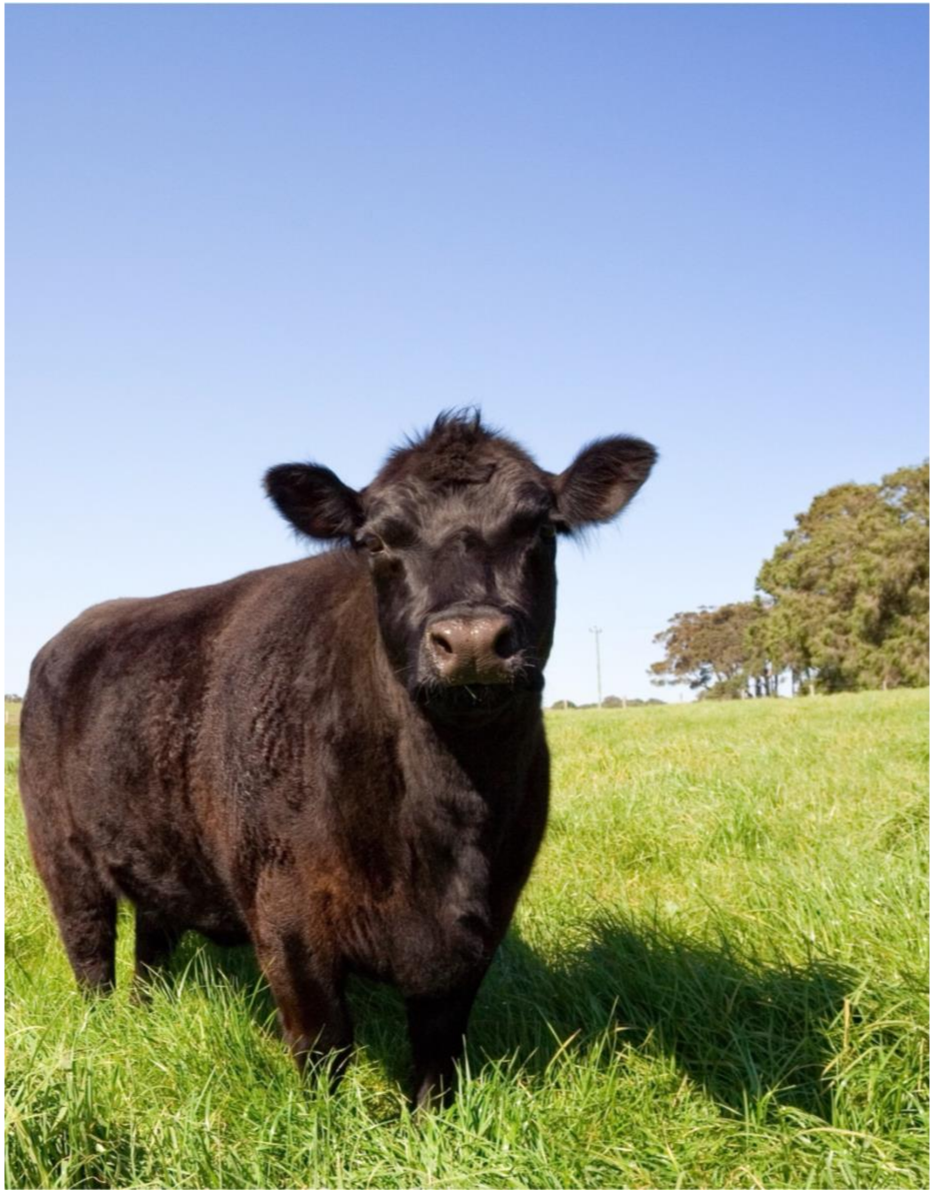
2 Why does meat have such a big climate impact?

2.1 Emissions across the whole meat value chain

Australia is the world's 14th largest emitter of GHG emissions. Within Australia, livestock is the 3rd largest source of GHG emissions [37], after the energy and transport sectors [38]. Methane (CH_4) accounts for around 35% of food system GHG emissions (broadly the same for both developed and developing countries), and livestock-raising is a key contributor. Most of this methane is produced by the digestive processes of ruminant livestock, and about 10% is released from manure management [37].

Where do the other meat-related emissions impacts come from? While many studies do not include all key emissions across the meat-based value chain [39], important sources of emissions (in addition to methane from the digestive system of ruminants), include emissions from manure, feed production, fertiliser application, and operating machinery with fossil fuels (see Appendix 2). Land-use changes – such as clearing forests for farms and ranches – are also a significant source of emissions, as are pre- and post-farm gate value chain activities (such as mining or manufacturing fertilisers) (see Figure 6).

> "In Australia, pasture-fed livestock typically requires grazing cows and sheep on pastures that have been land-cleared and fertilised, releasing significant amounts of CO_2 and the GHG nitrous oxide.



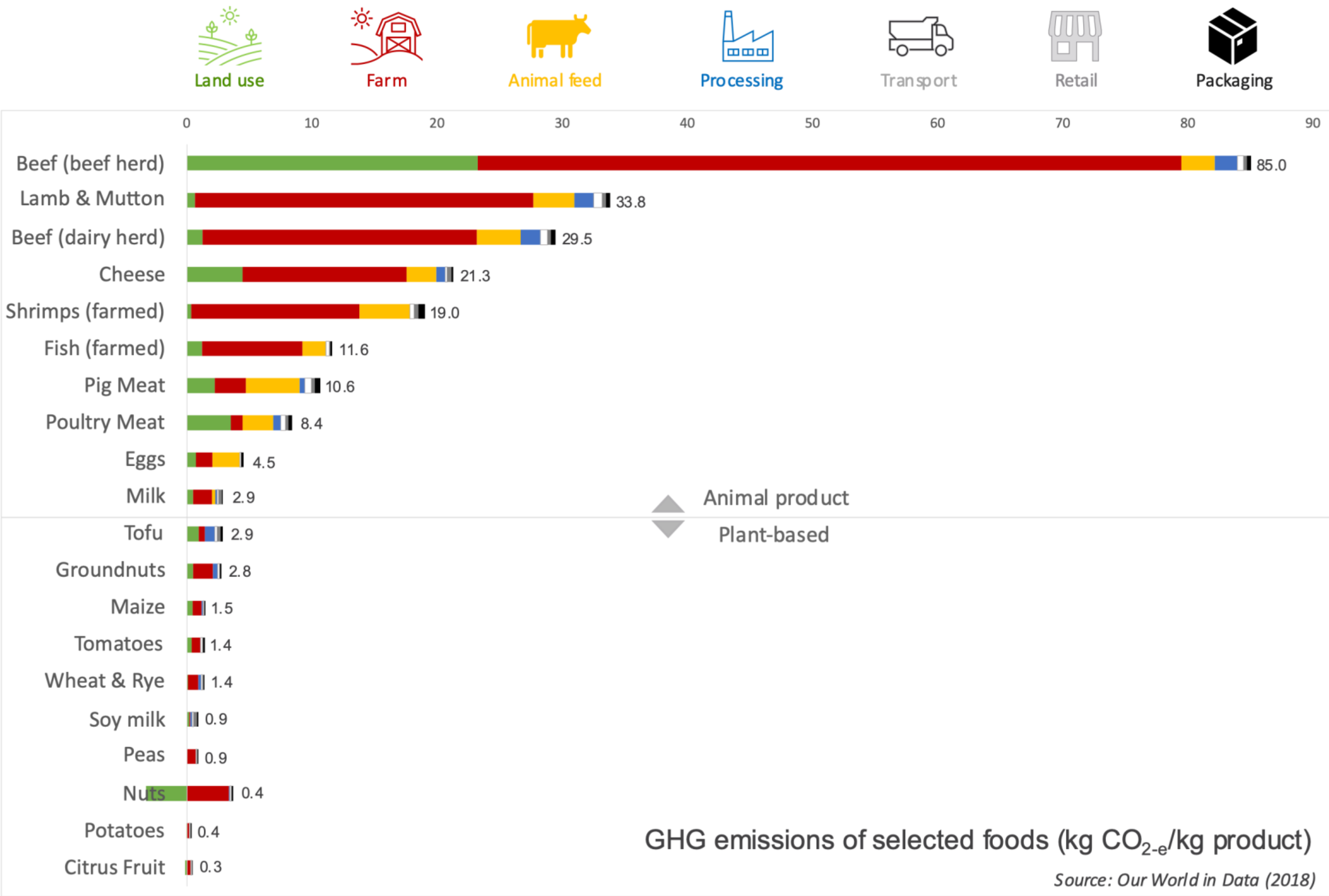


Figure 6: GHG emissions impacts along the whole food value chain. Animal-based foods are far more emissions-intensive than plant-based foods. Adapted from: [40]

2.2 Food-related GHG emissions data is fragmented and under-reported

The total GHG emissions embodied in food value chains are often difficult to identify. They are distributed across sectors and hence under-reported in most life cycle assessments of agriculture and food [41]. In part, this is because the GHG data and inventories for food supply chain emissions are often accounted for within different sector categories. The IPCC categories, for instance, are Land-based (which includes Agriculture and LULUC[5]), Energy, Industry, and Waste [1] (Figure 7). According to this classification, fossil fuel emissions associated with on-farm agricultural machinery are accounted for in the Energy sector, rather than in the Agriculture sector [42]. Land use change associated with land-clearing to grow crops is typically reported within the Land Use Change sector; and CO_2 and NO_2 emissions from fertiliser production are accounted for in the Industry sector. This fragmentation makes it more difficult to communicate the full GHG impact of food.

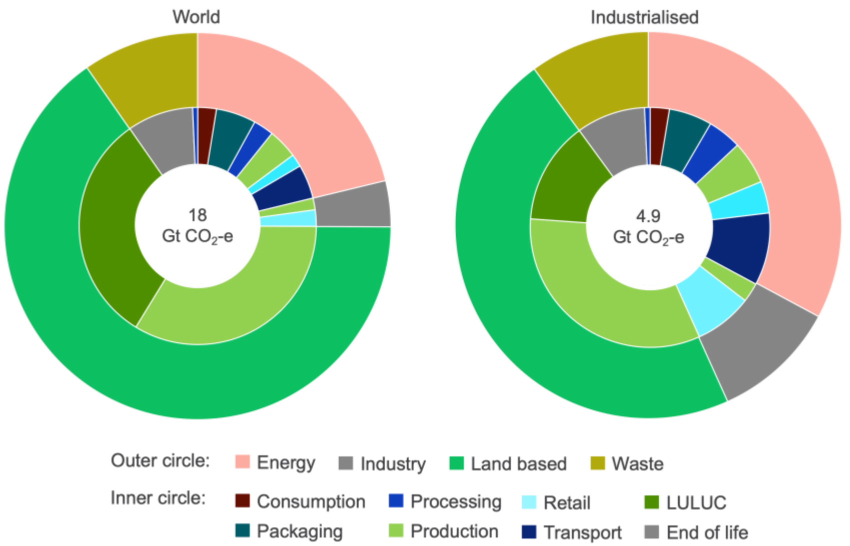


Figure 7: GHG emissions from the food system spread across different sectors: Energy, Industry, Land-based and Waste. Note: Total GHG emissions (including CO_2, CH_4, N_2O and F-gases) are expressed as CO_2-e calculated using GWP100 values used in the IPCC AR5, with a value 28 for CH_4 and 265 for N_2O. Source: adapted from [1].

A further complicating factor is that 'food' is often erroneously equated with 'agriculture' in terms of climate impacts. In reality, food system activities extend far beyond the agricultural sector, and include many production and consumption sectors before and after the farm gate (ranging from fertiliser manufacture to food waste).

New research by the UN Food and Agriculture Organisation [43] indicates that GHG emissions in the pre- and post-farm gate stages are collectively significant – currently more than a third of total food-related emissions – and growing (note the *Pre & Post Production* category in Figure 8). Post-farm gate emissions are dispersed across a wide range of sub-sectors, including food processing, packaging, food retail, food transport, household consumption, and food waste (see Figure 8).

Land use is also a large contributor to food-related emissions in the form of land-clearing for cropping or pastures, yet these emissions are often excluded from LCA studies [1].

Several new major international studies have sought to improve modelling and emissions accounting across major food system categories to include land use, farming, and pre- and post-farm gate emissions [1] [2] [41].

> " GHG emissions pre- and post-farm gate are together very significant – around a quarter of total food-related emissions [43] [44].

Most of the LCAs of meat and plant-based alternative products we reviewed for this report (see Appendix 1) varied in their coverage of different sectors across the value chain. 'Cradle-to-gate' was the most widely used LCA system boundary in these studies, which means that many consumption and waste-related emissions were overlooked or omitted.

[5] Land Use & Land Use Change

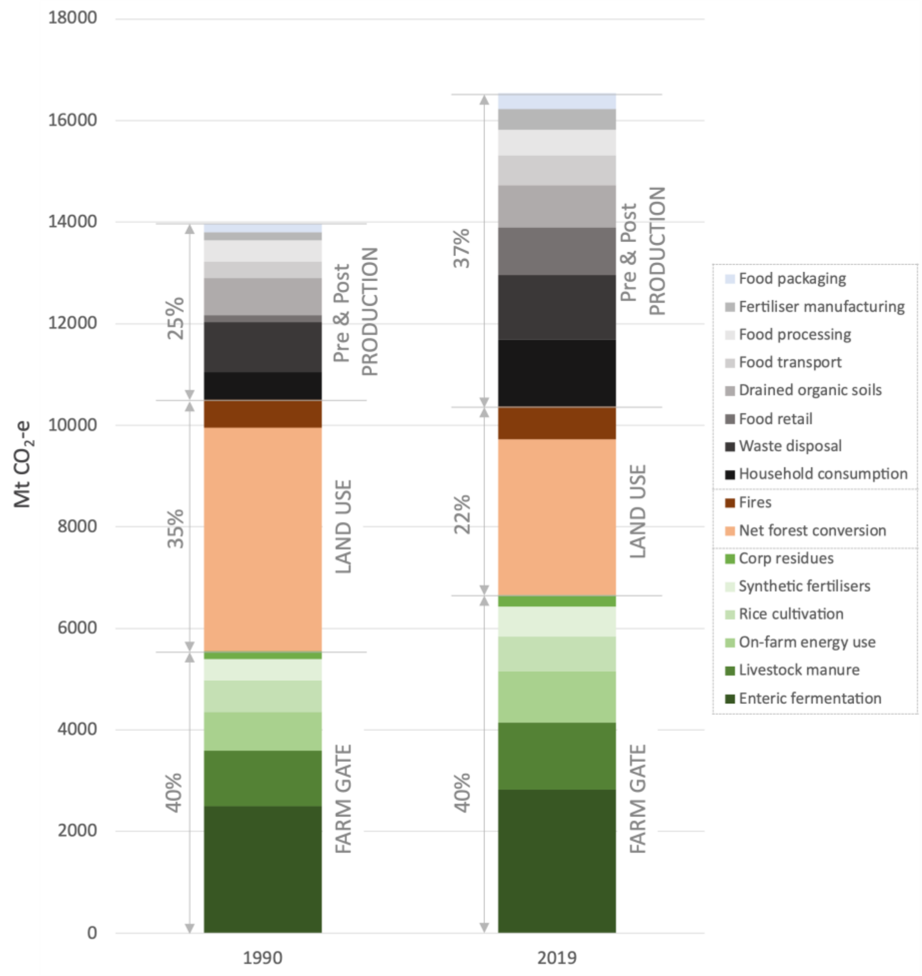


Figure 8: GHG emissions by agri-food system component (farm gate, land use and pre & post production) and process (Mt CO_2-e). Data sourced from [44].

Currently, comparative LCA studies of plant-based and animal-based foods across the full food value chain are fairly rare, and have mainly been conducted for foods distributed within European countries and the United States (see Appendix 1).

There is an urgent need for more comprehensive LCA assessments of Australian-produced and consumed products, since Australia has a unique agricultural and food processing supply chain. Different brands of plant-based alternatives are distributed and consumed within Australia, and cannot be directly compared to other products distributed in other countries. We also need independently verified studies, as most product-based LCAs are funded by the meat or plant-based alternatives industry (see Appendix 1).

3 Australia has the highest GHG emissions from food consumption in the world

An analysis of per capita GHG emissions from food consumption shows Australia to be the highest among G20 countries (see Figure 9). Across all G20 countries, there is a common trend towards increased prevalence of unhealthy diets characterised by overconsumption of red meat, dairy, sugar and highly processed foods, and underconsumption of healthy foods [45].

Food consumption patterns that align with current National Dietary Guidelines would reduce total GHG emissions for most G20 countries [28]. If NDGs were universally followed in each country, GHG emissions would be reduced by approximately 19%. Further, adopting the Planetary Health Diet would reduce food-related emissions in G20 countries by nearly 46%. These reductions could mainly be achieved through reductions in red meat and dairy consumption [45].

> “We over-consume protein in our diets (in Australia and all other regions), mainly from eating excess meat.

All regions, including Australia, currently overconsume protein, mainly in the form of animal protein (see Figure 10). In 2019, daily consumption of meat in Australia was about 246 g/person/day [10]. Australian dietary guidelines recommend a maximum 65 g/day for Australian adults [46]. Shifting to plant-based protein doesn't have to mean replacing all the equivalent kilos of animal protein – we can reduce the total amount of protein we eat too. [47]

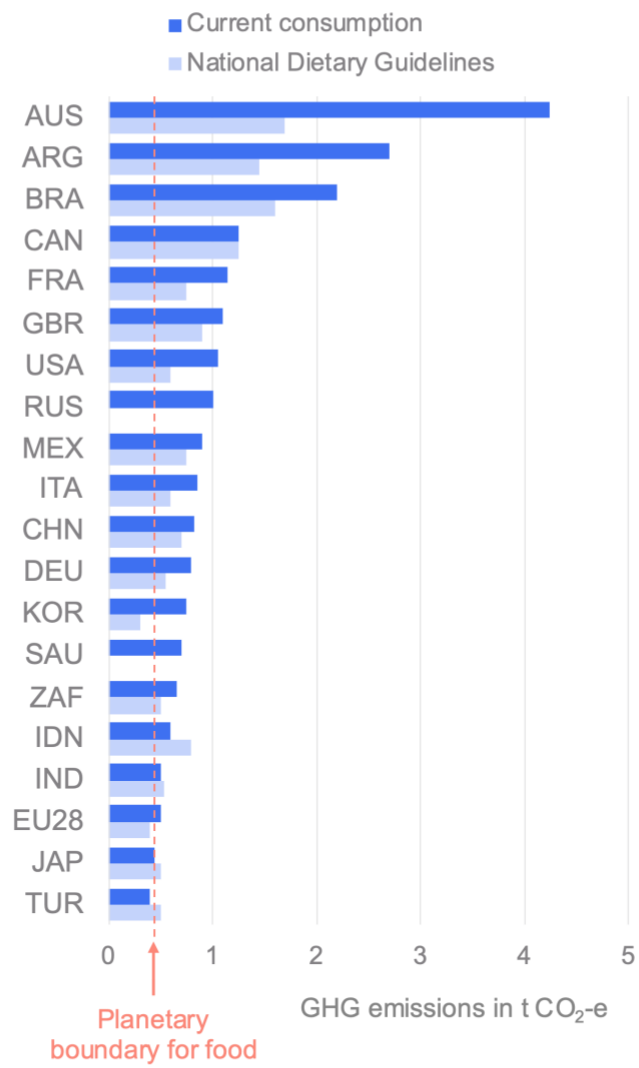


Figure 9: GHG emissions per capita from food consumption in G20 countries, based on National Dietary Guidelines. Redrawn from [45].

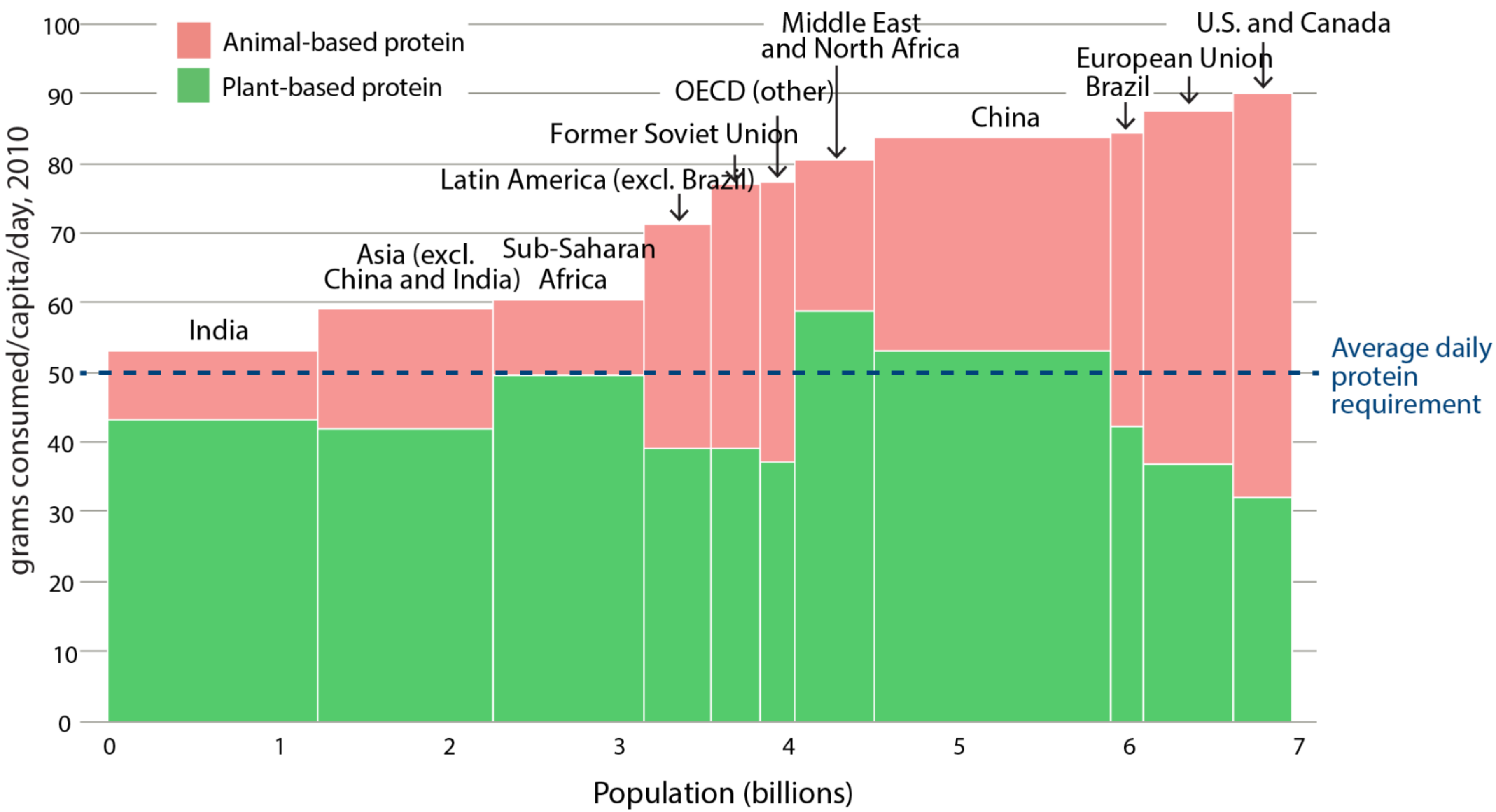


Figure 10: Average protein consumption greatly exceeds average estimated daily requirements, especially in the world's wealthier regions. Image reproduced from WRI (2019) [41]. Note: the width of the bars is proportional to each region's population. Australia is included in 'OECD (other)'. Average daily protein requirement of 50 g per day is based on average adult body weight of 62 kg [48] and recommended protein intake of 0.8 g/kg body weight/day [49]. Individual energy requirements vary depending on age, sex, height, weight, pregnancy/lactation, and level of physical activity.

Current consumption of red meat in G20 countries is more than 200% above National Dietary Guidelines [50], and more than 400% above the Planetary Health Diet[6] recommendations [45].

Figure 11 indicates the total consumption of meat (beef and chicken) and dairy (cheese) in Australia, including the fast-food service sub-sector. In 2021, 866 thousand tonnes of beef and veal were consumed in Australia [10], and 50,940 tonnes of beef were consumed in fast-food service [51]. Almost double amount of chicken (1.3 million tonnes) was consumed in 2021 [10], of which 142 thousand tonnes are estimated to have been consumed in fast-food services [51]. Australians consumed 324,800 tonnes of cheese in 2021. Of that total, 45,472 tonnes was used on pizzas [52].

> “Two of the biggest options to reduce GHG emissions in the food system are shifting diets to more plant-based foods, and reducing food waste and loss [41] [53].

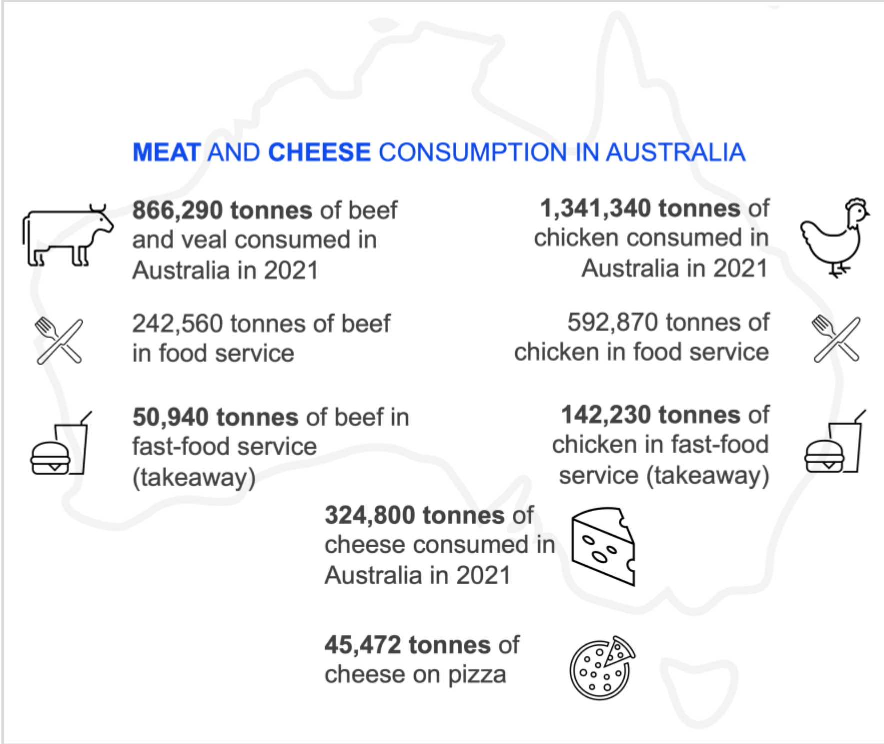


Figure 11: Consumption of meat, poultry and cheese in Australia: total consumption, and consumption within the food service and takeaway sub-sector. Data sources: [10] [51] [52] [21].

Recent research in Australia indicates that meat continues to be perceived by a large sector of the public as necessary for a healthy diet [54], and that meat tends to be positively associated with terms such as “iron,” “protein,” and “staple dietary requirement” [55]. Meat-eating is often linked symbolically with Australian masculinity [56] [57], and with power, strength and virility [58] [59]. For many Australians, meat-eating is also strongly associated with social occasions [55], such as enjoying a meat-based meal with friends and family [60]. It has been claimed that Australians tend to “treat cheap meat as an entitlement” [61].

[6] The Planetary Health Diet is a healthy *and* environmentally sustainable diet that keeps food consumption within planetary boundaries (created by the EAT-Lancet Commission) [28].

4 Meat has a large resource footprint in terms of water, land use and fertilisers

Meat consumption – especially of beef – is highly resource-intensive. Each kilogram of meat consumed requires significantly more water, land, energy and fertilisers to produce than any other food type [41]. This is because converting biomass to animal mass for human food protein/calories is a very inefficient and wasteful process.

4.1 Water and land-use impact of meat

Australia is one of the two largest exporting nations for beef [62]. Fresh water consumption for Australian beef production has dropped by almost two thirds (from 1,465 L/kg live weight in 1981, to 515 L/kg live weight in 2010). This is due to an increase in competitive demand for irrigation water[7], an initiative to cap free-flowing artesian bores in the rangelands, and a decline in water available for agriculture (compared to industrial and domestic uses) [30].

Our analysis shows that the impacts of water consumption and land use to produce a beef burger patty are significantly higher than for plant-based alternatives (see Figure 12). An inventory indicates a sevenfold increase in land requirements for feed production for Australian beef [30]. Our analysis shows that if consumers replace a beef patty burger with a plant-based beef patty burger, **94% of land use could be avoided**. We estimate a reduction of **94% in water use** by replacing beef burger patties with plant-based options (see Figure 12).

When plant-based chicken is consumed instead of beef, further water use and land use reductions become possible. If a chicken patty is replaced with plant-based chicken: **47% less water and 73% less land is used** (see Figure 12).

We estimate that by replacing 226 g of mozzarella cheese with plant-based cheese (on a typical 12-inch pizza), **47% of water use** and **77% of land use** could be saved (see Figure 13).

Higher land and water use for beef patties and dairy cheese (compared to plant-based options) is due to the requirements of producing feed crops, as well as land requirements for grazing [63]. It should be noted that varying supply chain characteristics across different countries can affect the land and water use of certain food products due to unique farming practices, technologies and regulations [64].

[7] This has led to a shift from using pasture for cattle to other uses/industries (such as horticulture).

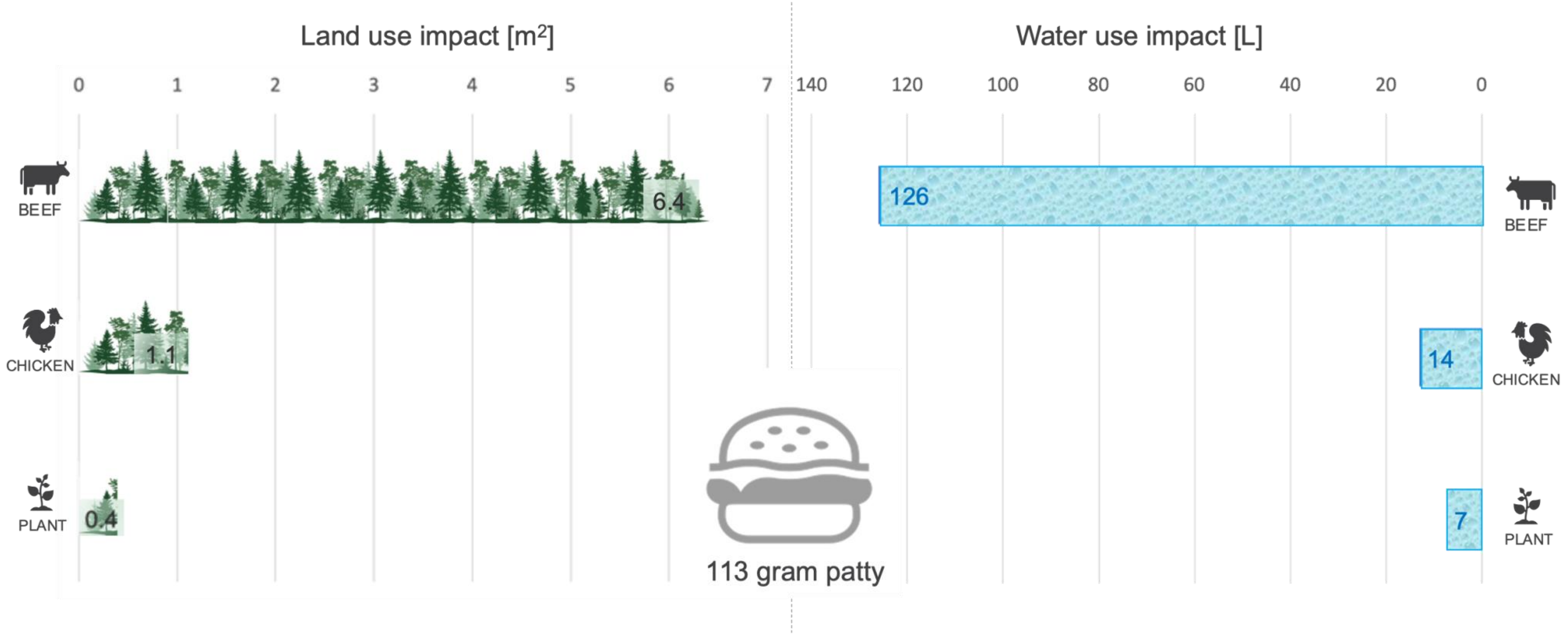


Figure 12: Estimated land use impact [m^2] and water use impact [L] for a 113 g beef burger patty, chicken patty and plant-based patty. Source: Authors. Note: values were estimated based on the literature LCA studies [32] [65] [64] [63] [31]. See Appendix 1 for methodology.

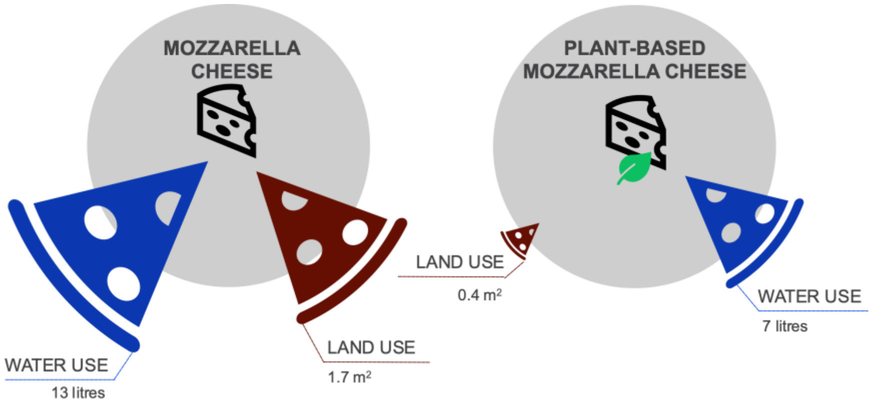


Figure 13: Estimated water use and land use impact of 226 g of mozzarella cheese on a typical 12-inch pizza, compared with 226 g of vegan mozzarella cheese. Source: Authors. Note: Values were estimated based on literature LCA studies [66] [67] [68] [69] [36].

4.2 Australia's phosphorus footprint

Meat (especially beef) also has a significantly higher phosphorus footprint than plant-based foods [70]. While the sustainability concerns around phosphorus are lesser-known than for water and land-use, phosphorus is an essential ingredient in fertilisers that has no substitute in food production. Yet the world's main source, mined phosphate rock, is finite and becoming increasingly scarce. All farmers need access to phosphorus, yet just 5 countries control 85% of the world's remaining phosphate rock reserves (Morocco, China, Egypt, Syria and Algeria) [71].

Australia is the world's 5th largest importer of phosphate fertilisers, and has the largest phosphorus footprint per capita in the world (see Figure 14). Despite having naturally phosphorus-deficient soils, we have invested in phosphorus-intensive export industries like beef and dairy [72]. The major share of Australia's phosphorus use is to fertilise pastures for livestock [72].

Phosphorus runoff from poorly-managed farms and outdated wastewater treatment plants can also lead to widespread nutrient pollution of water, from the Murray-Darling river system to the Great Barrier Reef [73].

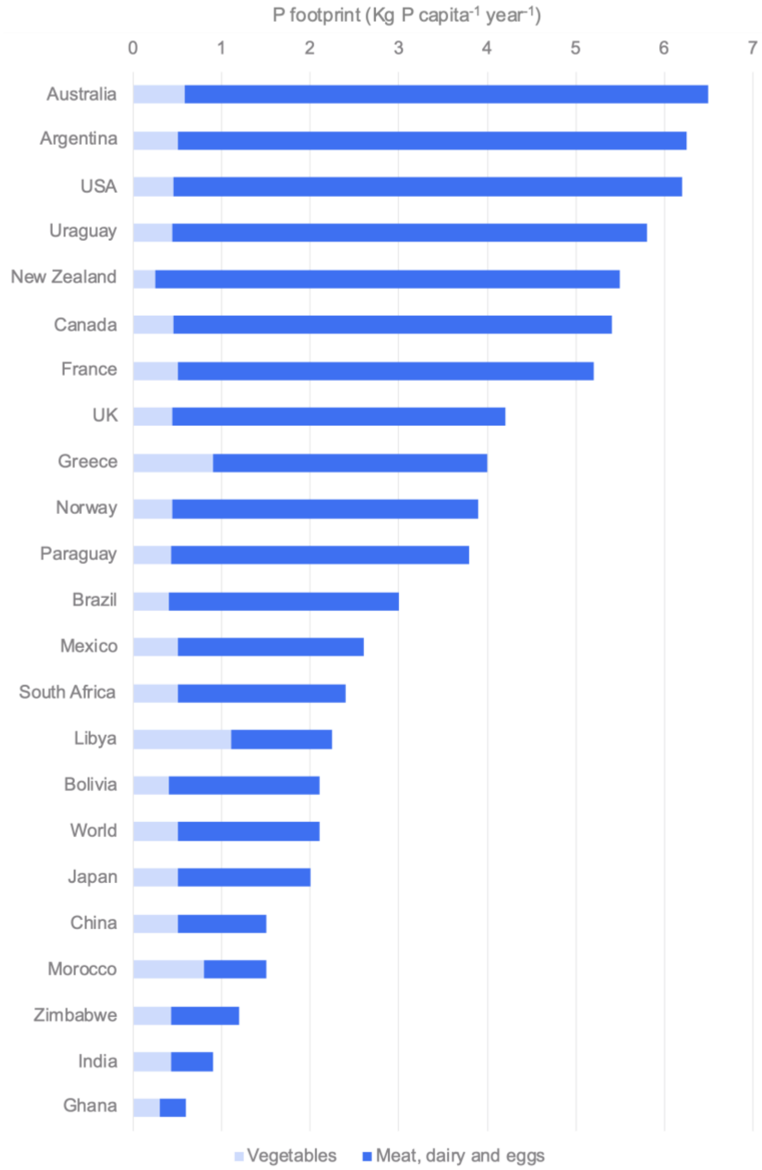


Figure 14: Phosphorus footprint of diets in selected countries, due largely to the consumption of animal-based products. Reproduced from [70].

5 Australia's fast-food sector can significantly reduce its' climate impact by replacing meat with plant-based alternatives

This report assesses reduction scenarios for GHG emissions, water use, and land use requirements in Australia based on a 25% and 50% substitution of meat-based fast-food products with plant-based options.

The estimate of GHG emissions from beef used in the Australian fast-food sector for 2021 is 2 Mt CO_2-e per year; water use is 57,000 ML per year; and land use is 290,000 ha (Figure 15). For chicken consumed in the Australian fast-food sector in 2021, the estimate for GHG emissions is 1.1 Mt CO_2-e, water use is 18,000 ML and land use is 43,000 ha (Figure 15).

Our findings show that by replacing **25% of beef** with plant-based alternatives (Figure 16) in the fast-food sector, GHG emissions from beef would be reduced in a year by 0.45 Mt CO_2-e (equivalent to taking 150,000 cars off the road). Replacing 50% of beef with plant-based options in the sector would achieve a reduction in GHG emissions of up to 0.91 Mt CO_2-e (equivalent to taking more than 300,000 cars off the road). Replacing **25% of chicken** with plant-based alternatives (Figure 16) in fast-food sector would reduce GHG emissions by 0.15 Mt CO_2-e (equivalent to taking 52,000 cars of the road). If 50% of the chicken consumed in fast food sector was replaced with plant-based options, up to 0.31 Mt CO_2-e would be saved (or equivalent to 110,000 cars of the road).

There are massive potential water savings, too. If **25% of beef** is replaced with plant-based options in the fast-food sector, 13 billion litres (GL) a year would be saved (equivalent to nearly 5,200 Olympic swimming pools) (Figure 16). Replacing 50% of beef with plant-based options would save 27 billion litres (GL) of water a year (enough to fill 11,000 Olympic swimming pools). Big potential water savings can be achieved when **25% of chicken** is replaced with a plant-based alternatives: 2 billion litres (GL) a year – equivalent to 800 Olympic swimming pools, and if 50% of chicken would be replaced a saving of 5 GL would be saved.

Similarly, replacing beef with plant-based options in the fast-food sector would result in much lower land use requirements (Figure 16). Replacing 25% of beef with plant-based options would reduce land use by 70,000 ha, while replacing 50% of beef with plant-based options would reduce land use by 140,000 ha (equivalent to the size of the 70,000 Melbourne Cricket Grounds). Replacing chicken with plant based options would also result in lower land use requirements. When replacing 25% of chicken with plant-based options would reduce land use by 9,000 ha, or 17,000 ha when 50% of the chicken in fast-food sector is replaced with plant-based alternative (equivalent to 9,000 Melbourne Cricket Grounds).

If a quarter of all beef and chicken consumption across Australia[8] was replaced with plant-based alternatives, this could save the meat sector around 10 Mt CO_2-e GHG emissions. This represents a 2% reduction of Australian's total GHG emissions (489 Mt CO_2-e as of March 2022 [74]), which is equivalent to the total GHG emissions arising from the waste sector [74].

> "There are a wide range of technical mitigation options to reduce GHG emissions in the meat supply chain, and Australia's red meat industry has set a goal to be carbon neutral by 2030 [75].

Measures to reduce methane and other GHG emissions in the meat supply chain include diverse options like anaerobic digestion of manure, soil carbon sequestration, and livestock feed inhibitors like Asparagopsis seaweed [76] [53]. However, these only fractionally contribute to reducing the overall global warming

[8] i.e. including at home consumption and other food service consumption in addition to fast-food.

potential of meat value chains compared to changing diets, which can significantly - and quickly - reduce or eliminate GWP along the whole supply chain [41] [75].

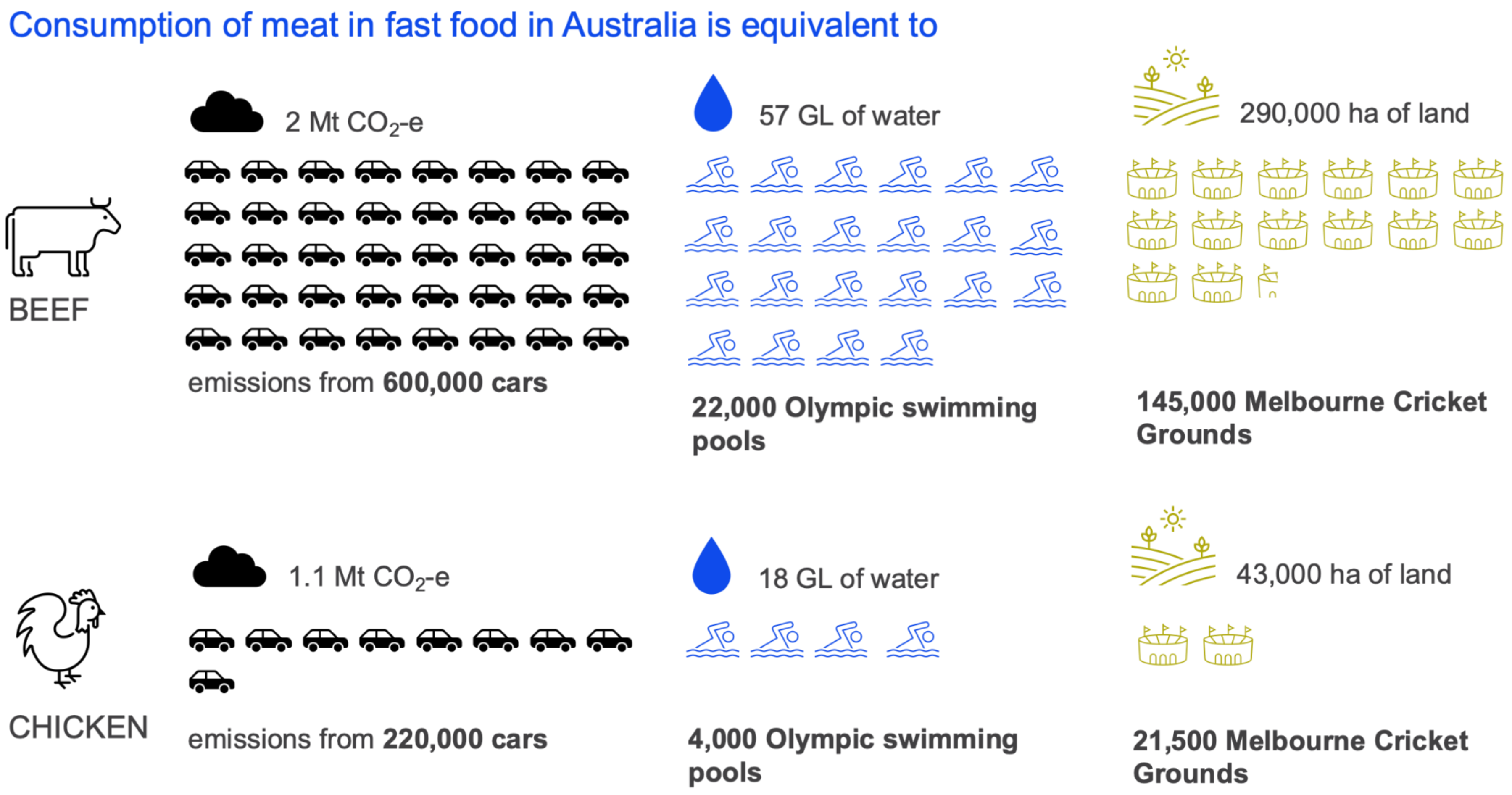


Figure 15: Environmental impact of beef and chicken consumption in the fast-food sector: GHG emissions, water use and land use. Source: Authors.

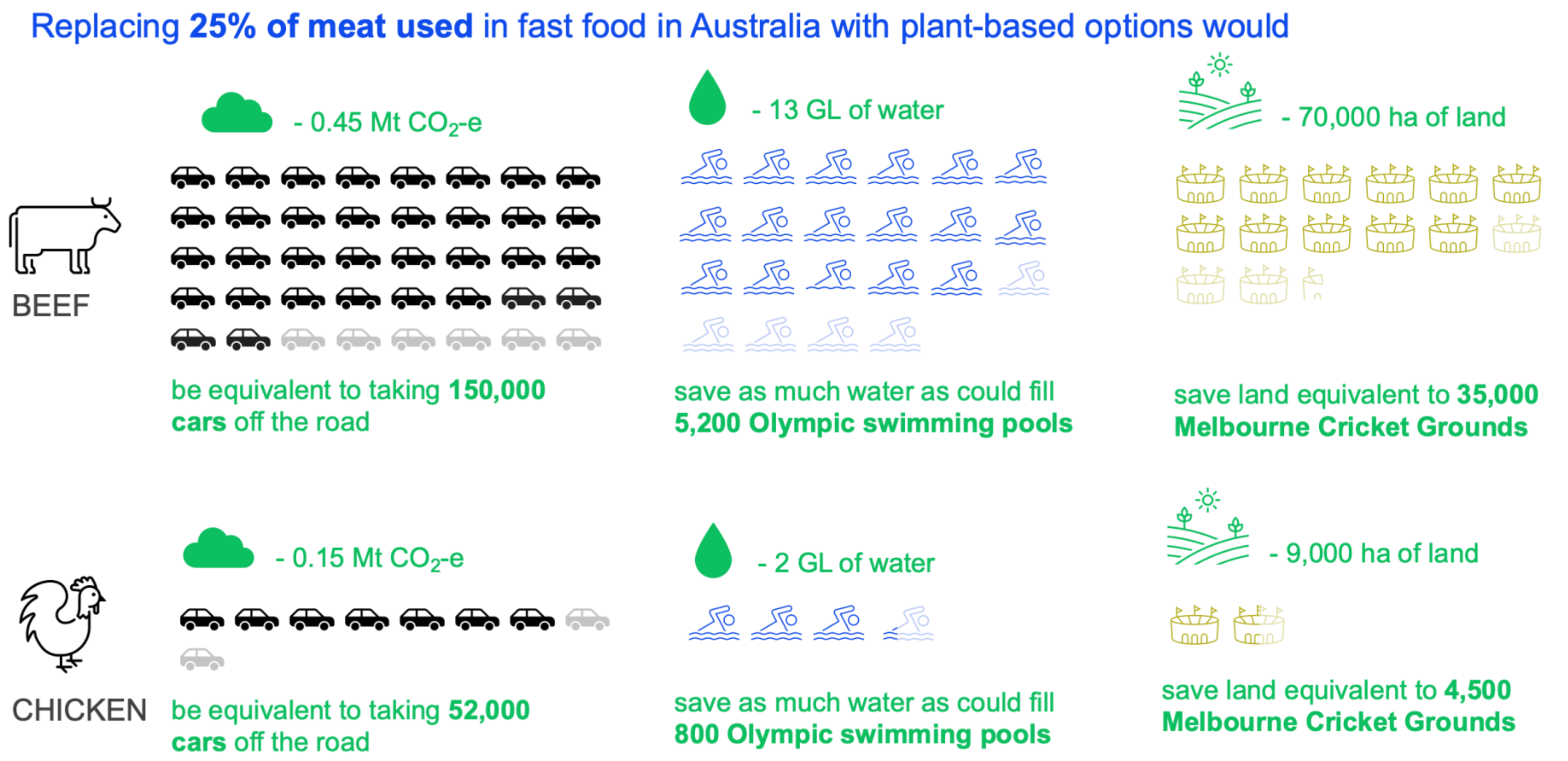


Figure 16: Environmental impact of replacing 25% of beef and chicken in the fast-food sector with plant-based alternatives: emissions reduction, water saved and land saved. Source: Authors.

Reducing the environmental impact of food is critical in our fight against climate change [45]. Improving the efficiency of food production, distribution and consumption, and minimising food waste, are key factors.

Shifting diets is also crucial. Choosing healthy and sustainable food is one of the single most powerful actions an individual can take to combat climate change [45]. Many countries have already taken positive steps towards promoting plant-based diets (and achieved reductions in food-related climate impacts), but others – including Australia – are lagging behind on this front.

There are exciting opportunities for the plant-based meat replacement industry in Australia (Figure 17), given recent changes in dietary patterns (towards consuming less meat). The plant-based meat sector has already shown significant market growth, both in Australia and overseas.

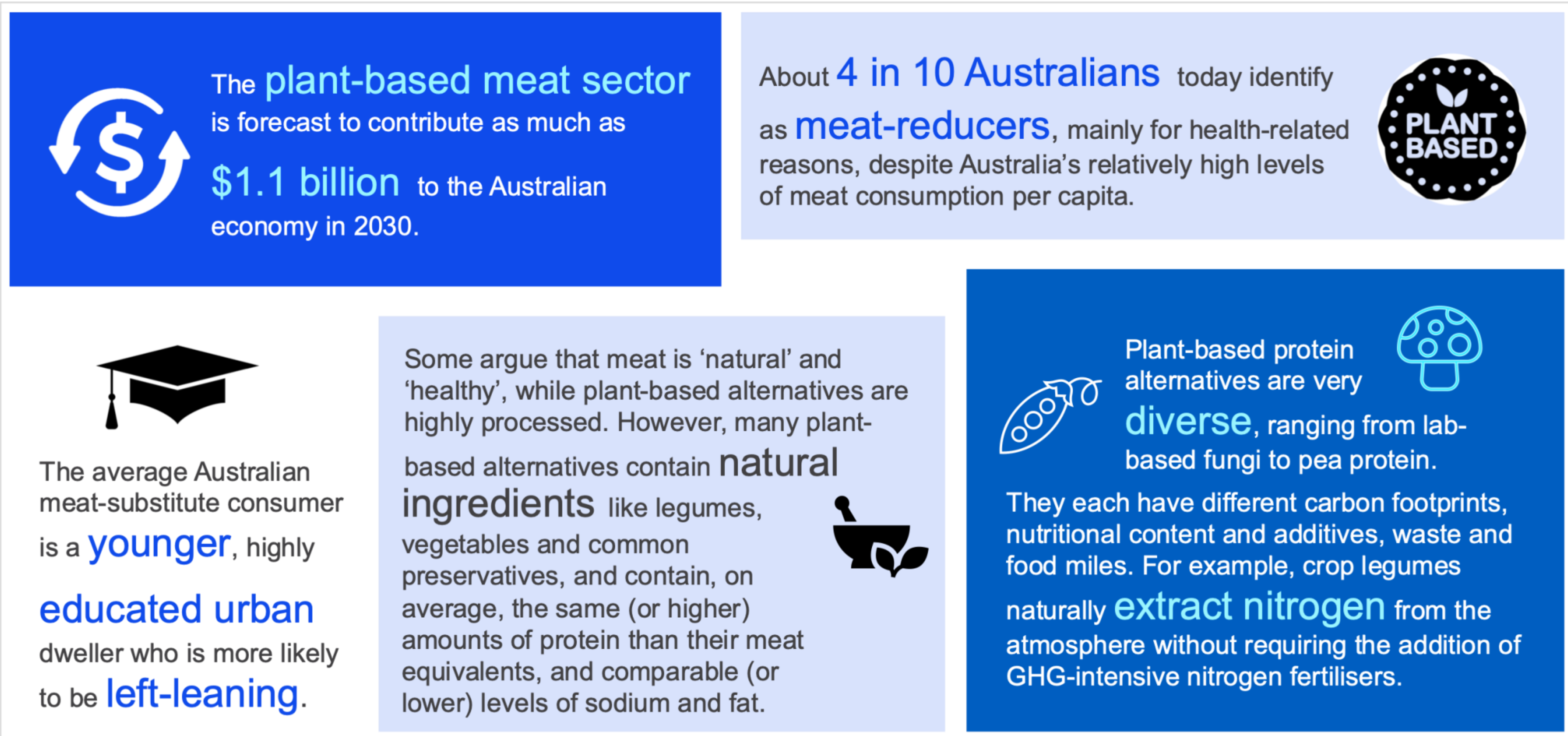


Figure 17: Plant-based meat industry in Australia is growing rapidly and will be soon worth $1.1 billion. Sources: [77] [78] [79] [80] [81] [27].

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APPENDIX 1 – Methodology of estimating embedded GHG emissions in the fast-food sector

This study used a literature review of published life cycle assessments and life cycle analyses to synthesize comparative data on the carbon footprints and other environmental impacts of animal-based foods and their plant-based alternatives. We included the scientific literature from scholarly databases, online LCA databases, Google Scholar and industry reports.

Fast-food value chains are long, starting with the production of farm inputs, land use change, on-farm activities ranging from grazing livestock to growing crop feed to manure management, and post-farmgate activities like cold storage, transport, food retail, cooking and food waste management. However the most common LCA system boundary in the studies reviewed were limited to 'cradle-to-gate', which excludes post-farmgate activities [44]. However some studies also use cradle-to-grave, with key assumptions for the consumption and disposal stages. Due to limited data availability, the scope of LCA studies incorporated into this analysis includes both of these boundary definitions. While on-farm agricultural activities typically have the highest impact (due to enteric fermentation in the stomachs of cattle and sheep), the impacts from the consumption and waste management stages are becoming increasingly significant [44] [32].

This study used three important indicators to compare the impacts of animal-based and plant-based foods in the fast-food sector, including global warming potential (GWP), land use (LU), and water use (WU). The impact values retrieved from the literature were standardised (where different units of measurement had been used in the original research). The impact values of particular products (such as plant-based beef patties) shared in this report were obtained by estimating the average values in each impact category across different studies as outlined in Table 1. Please note that not all of the literature we examined covered all three of our selected impact indicators.

Our scenario analysis looked at the environmental impacts (GWP, land use and water use) of replacing beef and chicken consumption (by 25% or 50%) with plant-based alternatives in fast-food and takeaway-food sector in Australia (including fast-food restaurants, sandwich bars, and independent takeaways). There was no existing, overall emissions data for the fast-food sector.

We estimated the GHG emissions for the sector by extrapolating the average GWP per kilogram to the amount of beef sold in the takeaway sector. Beef consumption data was gathered from various sources, including OECD Agricultural Outlook data [10] and Foodservice market analysis [51]. We used real-life comparisons for the potential reduced climate impacts in beef consumption reduction scenarios (such as number of cars that could be taken off the road for GWP; Olympic swimming pools for WU; and total land area of the ACT for LU).

Table 1: Scope, impacts and assumptions used in estimating carbon footprints and climate impacts in this report

Product	Region	Scope	Impacts per kg	Notes	Reference
Plant-based beef patty	United States	Cradle-to-gate: from raw material to distribution to retail	GWP: 3.5 kg CO_2-e WU: 28.9 litres LU: 2.7 m^2	• Geographical assumptions of ingredient supply and costs according to the specific company's supply chain (not mentioned in detail). • The patty is assumed to be distributed frozen. Refrigeration assumption for distributor with energy consumption of 40 kWh per m^3 and a storage time of 4 weeks; or for supermarket with energy consumption of 2,700 kWh per m^3 and a storage time of 4 weeks.	[65]

Product	Region	Scope	Impacts per kg	Notes	Reference
				• Cooking times of beans required to produce plant-based products vary according to the cooking instructions for different types of beans. • No significant difference in waste generation was assumed between plant-based beef patty and beef patty. • 5% losses in ingredients were assumed during the pre-treatment and final processing stages.	
Plant-based beef patty	United States	Cradle-to-gate: from crop production to the final product being ready for shipment	GWP: 3.1 kg CO_2-e WU: 28.9 litres LU: 4 m^2	• Ingredients supplied from the Philippines, Canada, Indonesia, and other countries. • After packaging, stored for an average of 1.5 weeks at −10°F (23.3°C). • Plant-based beef patty and beef patty share the same distribution and packaging approach.	[63]
Plant-based beef patty	United States	Cradle-to-gate: all activities necessary to produce frozen packaged burger patty from "cradle to manufacturer's gate"	GWP: 3.5 kg CO_2-e WU: 106.8 litres LU: 2.5 m^2	• All databases and key reports are from 2013 and later, and efforts were made to better represent current production process (based on updated equipment, processes and market conditions). • Chemical ingredients representing less than 1% by weight are modelled using generic chemical organic or inorganic datasets when the exact chemical ingredient match is unavailable. • For the processed ingredients, when data is unavailable for the final product, and if they represent less than 1% of the total weight, raw materials data are used in the model instead. • All refrigerants are assumed to be recharged every 8 years with a 0.1% leak at end-of-life.	[64]
Plant-based beef patty	Germany	Cradle-to-gate: from raw materials production to processing and forming	GWP: 1.5 kg CO_2-e LU: 3.9 m^2	• Consumer transportation, product storage and product packaging stages were excluded. • Did not identify any important differences in packaging of burger patties, nor in the approaches to their transportation and cooking.	[31]

Product	Region	Scope	Impacts per kg	Notes	Reference
				• The analysis was done for a specific recipe (variations in ingredients are not accounted for).	
Plant-based chicken patty	United States	Cradle-to-grave, but the study provided breakdowns of each stage of the supply chain. Thus, cradle-to-gate impact values were obtained from raw materials to retail and distribution	GWP: 5.8 kg CO_2-e WU: 76.7 litres LU: 1.8 m^2	• Ingredients are supplied by different countries according to the company's supply chain, and costs and emissions from transport are calculated based on distance. • Cooking time of beans required to produce plant-based product vary according to the cooking instructions for different types of beans. • Refrigeration assumption of distributor with energy consumption of 40 kWh per m^3 and a storage time of 4 weeks; or for supermarket with energy consumption of 2,700 kWh per m^3 and a storage time of 4 weeks. • No significant difference in waste generation was assumed between plant-based beef patty and beef patty. • 5% losses in ingredients were assumed during the pre-treatment and final processing stages.	[32]
Plant-based chicken patty	The Netherlands	Cradle-to-gate	GWP: 0.6 kg CO_2-e WU: 40 litres LU: 2.6 m^2	• The origins of included legumes are based on the countries that produce the most legumes for processing in the Netherlands. • Legumes exist in the form of flour, protein concentrate, and protein isolate. Different conversion factors were used for these forms. • Environmental data about fortifications is not available and assumed to have a relatively high environmental impact. • Environmental impacts from the processing stage are estimated based on energy use, natural gas use, and water consumption.	[82]
Beef patty	United States	Cradle-to-gate: from raw material to distribution to retail	GWP: 32.7 kg CO_2-e WU: 1932.7 litres LU: 33.6 m^2	• A typical beef cattle operation was assumed to be in the Midwest and Great Plains of the United States.	[65]

Product	Region	Scope	Impacts per kg	Notes	Reference
				• Consideration of dairy beef and grass-fed beef in the LCA model.	
Beef patty	United States	Cradle-to-gate: from crop production to the final product being ready for shipment	GWP: 32.7 kg CO_2-e WU: 853.1 litres LU: 61 m^2	• Comparable impacts within the distribution and transportation stages of a beef patty and plant-based patty. • Some beef is sourced from dairy farms and ground beef patties are packaged for retail and pre-portioned. • Beef patty processing follows the United States standard process of 80% lean meat and 20% fat.	[63]
Beef patty	United States	Cradle-to-gate: all activities necessary to produce a frozen packaged burger patty from “cradle to manufacturer’s gate”	GWP: 30.6 kg CO_2-e WU: 850.1 litres LU: 62 m^2	• Impacts of supporting herd are assigned to cow-calf operations. • Manure and enteric emissions are calculated according to the Tier 2 IPCC (2006) and WFLDB v3.3 (2017) guidelines. • No significant difference in carcass yield and revenue between European and U.S. cattle market. • 22% of beef comes from dairy operations. • Beef patty production shares similar production and packaging practices with plant-based options. • 5% loss during manufacturing.	[64]
Beef patty	United States	Cradle-to-grave, but the study provided breakdowns of each stage of the supply chain. Thus, cradle-to-gate impact values were obtained from raw materials to retail and distribution	GWP: 63 kg CO_2-e WU: 778.3 litres LU: 68.3 m^2	• Ingredients are supplied by different countries according to the company’s supply chain, and costs and emissions from transport are calculated based on distance. • Refrigeration assumption of distributor with energy consumption of 40 kWh per m^3 and a storage time of 4 weeks; or of supermarket with energy consumption of 2,700 kWh per m^3 and a storage time of 4 weeks. • No significant difference in waste generation was assumed between a plant-based beef patty and a beef patty.	[32]

Product	Region	Scope	Impacts per kg	Notes	Reference
				• 5% meat loss factor was assumed during the pre-treatment and final processing stages. • Burger production and packaging occurred within the slaughtering plant, thus no transportation occurred during these processes. • Waste disposal was assumed to be the same for plant-based alternatives.	
Chicken patty	United States	Cradle-to-grave, but the study provided breakdowns of each stage of the supply chain. Thus, cradle-to-gate impact values were obtained from raw materials to retail and distribution	GWP: 9 kg CO_2-e WU: 125.7 litres LU: 11.2 m^2	• Ingredients are supplied by different countries according to the company's supply chain, and costs and emissions from transport are calculated based on distance. • Refrigeration assumption of distributor with energy consumption of 40 kWh per m^3 and a storage time of 4 weeks; or of supermarket with energy consumption of 2,700 kWh per m^3 and a storage time of 4 weeks. • No significant difference in waste generation was assumed between a plant-based beef patty and a beef patty. • 5% meat loss factor was assumed during the pre-treatment and final processing stages. • Chicken production includes transport of chickens to slaughtering plants and the slaughtering process to produce chicken meat.	[32]
Chicken Patty	Germany	Cradle-to-gate: from raw material extraction to ending at production	GWP: 6.1 kg CO_2-e LU: 19.8 m^2	• Packaging material, packaging process and method of distribution were assumed the same for all burger patties studied. • Meat-based burger patties production was modelled based on the inventory data for raw meat available in the LCA Food DK database. • Other ingredients include potato starch (4%), water (4-7%), and salt (1-2%).	[83]
Mozzarella	Europe	Cradle-to-grave: from farming to consumer	GWP: 10.6 kg CO_2-e WU: 58 litres	• The mozzarella is grated.	[36]

Product	Region	Scope	Impacts per kg	Notes	Reference
		use and packaging end-of-life	LU: 10.1 m^2	• Data was compiled for different recipes, ingredients sourced from different countries, location of production, energy mixes, packaging designs, transportation, and end-of-life scenarios. • Geospatially differentiated agricultural life cycle inventory was generated, as well as land use change emissions from ingredients in all markets.	
Mozzarella	Europe	Cradle-to-grave: from farming to consumer use and packaging end-of-life	GWP: 10.2 kg CO_2-e WU: 54 litres LU: 10 m^2	• The mozzarella is in the form of a block. • Data was compiled for different recipes, ingredients sourced from different countries, location of production, energy mixes, packaging designs, transportation, and end-of-life scenarios. • Geospatially differentiated agricultural life cycle inventory was generated, as well as land use change emissions from ingredients in all markets.	[36]
Mozzarella	United Kingdom	Cradle-to-grave: from farming to consumer use and packaging end-of-life	GWP: 10.3 kg CO_2-e WU: 54 litres LU: 9.3 m^2	• The mozzarella is in the form of a block. • Data was compiled for different recipes, ingredients sourced from different countries, location of production, energy mixes, packaging designs, transportation, and end-of-life scenarios. • Geospatially differentiated agricultural life cycle inventory was generated, as well as land use change emissions from ingredients in all markets.	[36]
Mozzarella	United States	Cradle-to-grave: from agricultural production to consumer use and waste management	GWP: 11.9 kg CO_2-e	• Transportation powered by gasoline vehicles. • Per capita annual consumption of mozzarella is estimated to be 3.95 kg. • Assumed home refrigeration and dishwashing during consumer use stage as well as post-consumer waste disposal.	[66]
Mozzarella	The Netherlands	Cradle-to-consumer: from agricultural production to consumer use stage	GWP: 8.5 kg CO_2-e WU: 68 litres LU: 3.3 m^2	• Not disclosed by the publisher	[69]

Product	Region	Scope	Impacts per kg	Notes	Reference
Mozzarella	Italy	Cradle-to-gate: from milk production to manufacturing processes at the dairy plant	GWP: 33.9 kg CO_2-e	• Buffalo mozzarella was used in this study. • Methane (CH_4) emissions at farm level were calculated according to Tier 2 of the IPCC with updated conversion factors. • CH_4 from enteric fermentation, based on DM intake of the herd, was calculated by using a CH_4 conversion factor of 6.0% for dairy buffaloes, heifers, bulls and calves. • Fuel and electricity used in the agricultural phase were estimated based on the invoices.	[68]
Mozzarella	Italy	Cradle-to-grave, but breakdowns of each stage were provided, and cradle-to-gate value was calculated from the agricultural stage to the retail stage.	GWP: 6.3 kg CO_2-e LU: 4.4 m^2	• The transport impact is calculated by distance travelled by refrigerated trucks. • Loss of milk during manufacturing was estimated by the difference in milk solids entering the plant and the raw milk and milk solids delivered by the plant with the mozzarella and co-products. • Mozzarella was stored for 1 day at the dairy plant and then delivered to a distribution centre. The distribution, retail, consumption and disposal phases abroad were assumed to be the same as the equivalent Italian phases due to the low percentage of exported mozzarella and the limited data. • In distribution centres and retail, mozzarella was stored at 2 to 4°C with a maximum period of storage of 10 days.	[67]
Plant-based mozzarella	Europe	Cradle-to-grave: from farming to consumer use and packaging end-of-life	GWP: 2.6 kg CO_2-e WU: 30 litres LU: 1.8 m^2	• The mozzarella is grated. • Data was compiled for different recipes, ingredients sourced from different countries, location of production, energy mixes, packaging designs, transportation, and end-of-life scenarios. • Geospatially differentiated agricultural life cycle inventory was generated, as well as land use change emissions from ingredients in all markets.	[36]

Product	Region	Scope	Impacts per kg	Notes	Reference
Plant-based mozzarella	Europe	Cradle-to-grave: from farming to consumer use and packaging end-of-life	GWP: 2.2 kg CO_2-e WU: 26 litres LU: 1.6 m^2	• The mozzarella is in the form of a block. • Data was compiled for different recipes, ingredients sourced from different countries, location of production, energy mixes, packaging designs, transportation, and end-of-life scenarios. • Geospatially differentiated agricultural life cycle inventory was generated, as well as land use change emissions from ingredients in all markets.	[36]
Plant-based mozzarella	United Kingdom	Cradle-to-grave: from farming to consumer use and packaging end-of-life	GWP: 2.2 kg CO_2-e WU: 26 litres LU: 1.6 m^2	• The mozzarella is in the form of a block. • Data was compiled for different recipes, ingredients sourced from different countries, location of production, energy mixes, packaging designs, transportation, and end-of-life scenarios. • Geospatially differentiated agricultural life cycle inventory was generated, as well as land use change emissions from ingredients in all markets.	[36]
Plant-based mozzarella	Canada	Cradle-to-grave: from farming to consumer use and packaging end-of-life	GWP: 3.1 kg CO_2-e WU: 29 litres LU: 1.8 m^2	• The mozzarella is grated. • Data was compiled for different recipes, ingredients sourced from different countries, location of production, energy mixes, packaging designs, transportation, and end-of-life scenarios. • Geospatially differentiated agricultural life cycle inventory was generated, as well as land use change emissions from ingredients in all markets.	[36]
Plant-based mozzarella	United States	Cradle-to-grave: from farming to consumer use and packaging end-of-life	GWP: 4.2 kg CO_2-e WU: 37 litres LU: 1.8 m^2	• The mozzarella is grated. • Data was compiled for different recipes, ingredients sourced from different countries, location of production, energy mixes, packaging designs, transportation, and end-of-life scenarios. • Geospatially differentiated agricultural life cycle inventory was generated, as well as land use change emissions from ingredients in all markets.	[36]

Product	Region	Scope	Impacts per kg	Notes	Reference
Plant-based mozzarella	Japan	Cradle-to-grave: from farming to consumer use and packaging end-of-life	GWP: 2.8 kg CO_2-e WU: 37 litres LU: 1.7 m^2	• The mozzarella is sliced. • Data was compiled for different recipes, ingredients sourced from different countries, location of production, energy mixes, packaging designs, transportation, and end-of-life scenarios. • Geospatially differentiated agricultural life cycle inventory was generated, as well as land use change emissions from ingredients in all markets.	[36]

APPENDIX 2 – Categories and classification of food-related emissions

GHG emissions associated with food occur across the whole food value chain. In addition to agriculture, this includes land use and sectors before and after the farm gate. The United Nations Food and Agriculture Organisation (FAO) groups these activities into the following categories: land use, farm gate, and pre- and post-production (see Figure 18).

FAO Groupings			Food system activity	GHG		
				CH_4	N_2O	CO_2
Food systems	Agriculture land	Land use	Net forest conversion	x	x	x
			Tropical forest fires	x	x	x
			Peat fires	x		x
		Farm gate	Drained organic soils	x	x	x
			Burning: crop residues	x	x	
			Burning: savanna	x	x	
			Crop residues		x	
			Enteric fermentation	x		
			Manure management	x	x	
			Manure applied to soils		x	
			Manure left on pasture		x	
			Rice cultivation	x		
			Synthetic fertilizers		x	
			On-farm energy use	x	x	x
	Pre and post production		Transport	x	x	x
			Processing	x	x	x
			Packaging	x	x	x
			Fertilizer manufacturing	x	x	x
			Household consumption	x	x	x
			Retail: energy use	x	x	x
			Retail: refrigeration	x	x	x
			Solid food waste	x		
			Incineration			x
			Industrial wastewater	x	x	
			Domestic wastewater	x	x	

Figure 18: Categories of food system activities and their GHG emissions. Source: [84]

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