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The greenhouse gas profile of a "Hungry Planet"; quantifying the impacts of the weekly food purchases including associated packaging and food waste of three families

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Abstract: The United Nations Food and Agricultural Organisation (FAO) have estimated that 1.3 billion tonnes of food is wasted across the supply chain, while food security emerges as one of the leading challenges facing a growing global population. Life cycle assessment (LCA) can illustrate the environmental implications of food production, consumption and waste. In 2005, Peter Menzel and Faith D'Aluisio presented a photographic study in "Hungry Planet – What the World Eats" documenting what thirty families across twenty-four countries ate during the course of one week. The weekly food purchasing inventories of three of these families have been combined with LCA data to report the greenhouse gas intensity of these food purchases. The greenhouse gas emission profile including those of 128 varieties of fresh food, along with data on packaging material production and household food waste, have been used in the calculations. The paper will present the findings illustrating the contribution each component has: food, packaging and food waste; and will also discuss the implications for food packaging design.

Keywords: food packaging design, food purchases, greenhouse gas, life cycle assessment, LCA, packaging.

1 Introduction

Packaging LCA's have historically been completed in isolation of the food stuff they aim to protect, however there is a need to broaden this understanding of the environmental impacts to include those associated with food production, and food waste. This is appropriate due to packaging's potential causal relationship to food waste. In 2001 using five food categories, Packforsk documented with the use of LCA, the contribution of energy to food production and consumption and the packaging materials. It was reported that packaging's contribution was less than 10% (Erlov et al., 2000). This was further supported by INCPEN in 2009 with the release of their publication *Table for One* that expanded upon food categories and documented the energy contribution across the whole supply chain. For an average European's weekly food consumption over 50% of the life cycle energy impacts are associated with farm operations, home storage and cooking contributing 31% and packaging 10% (INCPEN, 2009).

In recent years there has been significant activity to document and report food loss and waste through the global supply chain (Gunders, 2012, Gustavsson et al., 2011, Institution of Mechanical Engineers, 2013, Quested et al., 2013b, Lipinski et al., 2013). This has been estimated to be in the range of 1.3 billion tonnes globally (FAO, 2013). In developed nations the majority of the loss occurs between farm and sale due mainly to inadequate infrastructure and packaging (Kummu et al., 2012), while in developed nations the majority is at retail and consumption (Institution of Mechanical Engineers, 2013, Kummu et al., 2012) due to factors including excessive consumption.

Everyday across the world households consume and waste food that has crossed local neighbourhoods, states and countries as it moves from the farm or sea, through to processing and manufacturing, distribution, retail, purchase, storage, preparation and cooking and eventually into our stomachs, or partly disposed of into landfill, incinerators or compost. There are however, stark differences amongst households in what they purchase, how much they purchase, how the food is packaged, how much they cook and consume, and how much they waste. These differences were captured on film by Peter Menzel and Faith D'Aluisio in their 2005 photographic study

Hungry Planet – What the World Eats that documented what thirty families across twenty-four countries ate during the course of one week (Menzel and D'Aluisio, 2005). The images are powerful as they depict the abundance of food and beverages overflowing on tables of households in developed western countries compared with counterparts in developing countries where a sack of rice and a couple of other staples are all that can be purchased.

The aim of this paper is to explore the relational complexity and environmental impacts of diet, food waste and packaging. We are curious to find out what food, packaging and waste configurations contribute to a household's weekly greenhouse gas (GHG) profile. We propose to study three family's GHG profile from three different countries and discuss the implication of the findings for food packaging design.

In this paper we take the food and packaging inventory of three families from *Hungry Planet* – the Molloys from Australia, the Manzos from Italy and the Baintons from the United Kingdom, and combine these with LCA GHG emission profiles for the production of the food and packaging materials. These LCA values are combined with household food waste statistics to arrive at a profile illustrating the contribution of each component: food, packaging and food waste. The LCA waste treatment used in the model assumes similar landfilled treatment of food waste for each family; however, the transport and infrastructure impacts are calculated specifically for each country's energy grid. Considering the LCA results for each family, the paper then discusses the implications and directions for packaging designers to ameliorate the impacts via food packaging design, in accord with the intent of this conference.

2 Background

In this section we provide a background on the three main data sources: (i) LCA of food and packaging materials, (ii) household food waste statistics and (iii) the family food and packaging inventories.

2.1 LCA of food and packaging materials

GHG inventories for the production of dairy, fresh fruits, vegetables, nuts, grains, other starchy foods, meat, fish and eggs were estimated by coupling the mass and type of food to GHG profiles for the individual food types. The GHG profiles were adopted from data from Clune et al. (under review 2014), which are averages based on approximately 100 life cycle assessment studies. The system boundary of the studies underpinning Clune et al. varied, but always included farming operations. Inventories for beverages, condiments, prepared food, snacks and deserts were based on input-output modelling, which relate economic flows to environmental flows. The input-output databases were modified to exclude impacts from packaging. The Australian Input Output 2008-09 GHG (Grant, 2013a) and the EU & DK Input Output 2003 LCA databases were used. Prices were adjusted to the year of the original publication year by applying inflation factors, based on Australian (ABS, 2014) and European Union (EC, 2014) averages. Great British pound prices were converted to Euro prices based on historical exchange rate data from www.oanda.com. The impacts of packaging production was estimated by determining or approximating the mass and type of packaging used for each food item, and then coupling this data with existing life cycle inventories for packaging materials from ecoinvent 2.2 (Hischier, 2007, Hischier, 2004), PlasticsEurope (Boustead, 2005), and the Australasian Unit Process Life Cycle Inventory (AUPLCI, Grant, 2013b).

The end of life for all *wasted* food and beverages was assumed to be landfill. Degradation of food and paper/board waste in landfill was determined by calculating the dry mass from moisture contents for each flow. Moisture contents were from the United States Department of Agriculture's National Nutrient Database. The dry mass was then modelled using default values from IPCC waste landfill models (IPCC, 2006), which accounts for the generation of biogenic carbon dioxide and methane through anaerobic and aerobic degradation. The fate of landfill methane was based on region-specific rates for fugitive emissions, flaring and energy capture. No credits were applied for avoided electricity or heat generation, as these were assumed to be part of the next life cycle.

The end of life of packaging waste was split between landfill and recycling. Recycling rates for Italy and the United Kingdom were based on historical recycling rates (EC, 2014), while Australian recycling rates were linearly interpolated from 2003 and 2011 data (APC, 2011). Landfill and recycling models for packaging were adopted from AUPLCI (Grant, 2013b) with energy inputs modified to account for the different regions. Credits for avoided production stemming from recycling were excluded from the assessment. Inventories for the collection and transportation of waste (recycled and landfill) was adopted from AUPLCI (Grant, 2013b), with energy inputs modified to account for the different regions. Energy models for the United Kingdom and Italy were taken from ecoinvent 2.2 (Frischknecht et al., 2007).

Life cycle impact assessment (LCIA) was undertaken using global warming potentials from the IPCC Fourth Assessment report for a 100 year time horizon (IPCC, 2007). The global warming potential for biogenic methane was adjusted to account for carbon sequestered within methane. Carbon uptake and sequestration in soil were excluded from the assessment. GHG was selected as the focus of this paper, as this is the most common environmental impact category where consistent data is available across food types, packaging and end of life. Other environmental indicators, such as water use and eutrophication, can also be of importance, but available impact data on this is often inconsistent on impact assessment methodology.

2.2 Household food waste statistics

The number of studies regarding food waste has increased in recent years. They include studies that have been experimentally or statistically achieved (Sibrián et al., 2006, Lebersorger and Schneider, 2011, Knudsen, 2009, Hall et al., 2009, Monier et al., 2010), documenting the reasons for household food waste (Evans, 2011, Baker et al., 2009) or with both amounts and reasons (Koivupuro et al., 2012, Williams et al., 2012, Ventour, 2008). In industrialized countries more than 40% of the food waste occurs in retail and households (Gustavsson et al., 2011). Of this 40%, the per capita waste in North America and Oceania has been estimated at 115kg/a, compared with the per capita figures from sub-Saharan Africa and South/Southeast Asia at 6-11 kg/a. In the EU, the average household waste is 76 kg/capita/a, in Italy it is 46 kg/capita/a and in the UK 49 kg/capita/a (Monier et al., 2010). Australian households waste an estimated $239/capita/a worth of food (Baker et al., 2009). However methods on how to calculate and interpret food waste data between studies is still ambiguous (Lebersorger and Schneider, 2011).

There are various studies that have quantified food waste percentages and Figure 1 presents a graphical perspective of key food categories and their associated waste percentages (combining results from two studies). Vegetables, prepared food, dairy, fruit and berries and breads and grains are the key food categories that have the highest waste percentages.

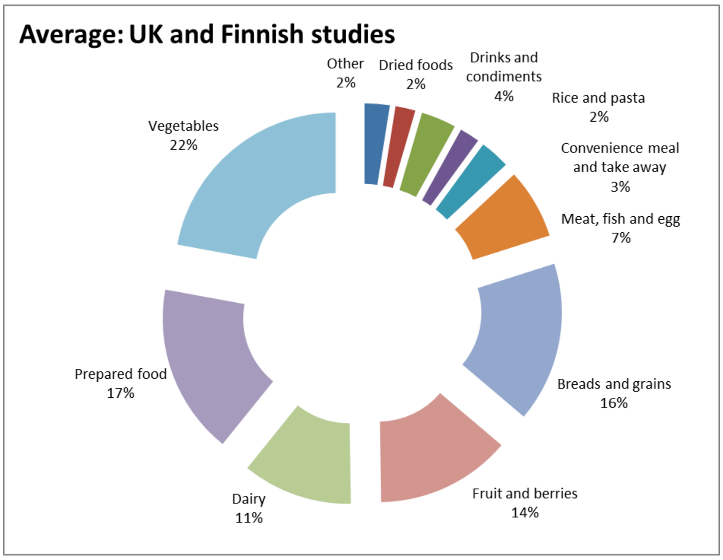

Figure 1 An example of what food categories are wasted (combining findings from the UK and Finland)

Notes: Study 1: 2138 UK households with collection and sorting of waste from waste bins +interviews with 2715 households. 70 kg/capita of avoidable food waste (Ventour, 2008). (Avoidable waste means food that at some point prior to disposal was edible; not peals and bones). Study 2: 380 Finish households filling in food waste diary with weighting and questionnaire, 23 kg/capita of avoidable food waste (Katajajuuri et al., 2012).

In this paper, food waste figures for Australia were aggregated from FAO figures (Gustavsson et al., 2011) and proxy data sourced from the UK's Waste Resource and Action Programme (WRAP) publications on *Household Food and Drink Waste* (Quested and Johnson, 2009, Quested et al., 2013a); for the UK it came in a disaggregated form (Quested and Johnson, 2009, Quested et al., 2013a), where given inputs for food waste data was on single products within a group of foods; while data for Italy was in an aggregated form on the summarized level presented in this study e.g one single data for meat, fish and egg (BCFN, 2012). Assumptions for food waste percentages for each food type and region are presented in Table 1.

Table 1: Regional food waste assumptions (%)

Food type	Region		
	Australia	United Kingdom	Italy
Grains and starchy foods	27.8	17.7	10.7
Dairy	15	6.5	35.0
Meat	18.2	10.4	18.3
Fruit and vegetables	26.3	17.6	10.6
Condiments	13.3 (Proxy – UK data)	13.3	13.3 (Proxy – UK data)
Snacks and deserts	8.8 (Proxy – UK data)	8.8	8.8 (Proxy – UK data)
Prepared foods	22.7 (Proxy – UK data)	22.7	22.7 (Proxy – UK data)
Beverages	7.6 (Proxy – UK data)	7.6	7.6 (Proxy – UK data)
Data sources: (BCFN, 2012, Gustavsson et al., 2011, Quested and Parry, 2011, Quested et al., 2013b)			

Household's food practices and routines are many, separated in space and time and therefore complex (Quested et al., 2013b). The main reasons for wasting food include food left on plate or cooking too much, food that has passed its best before or use by dates or spoiled (Ventour, 2008). Household planning and shopping routines are important for the amount of food waste (Stefan et al., 2013). Households who shop more regularly for smaller amounts of food waste significantly less than households that shop once a week (Williams et al., 2012). Food safety issues are also important to households and uncertainty about date labels contribute to food waste (Cox and Downing, 2007, Evans, 2011, Broad Leib et al., 2013). In a Swedish study, packaging that was too large or difficult to empty contributed to 10% of the food waste (Williams et al., 2012). Studies also reveal a lack of knowledge about how to store food at home leading to incorrect or inappropriate food storage may cause the shelf-life of food to be reduced (WRAP, 2007, Plumb et al., 2013).

2.3 The families

The *Hungry Planet* (Menzel and D'Aluisio, 2005) families provide a rich and diverse inventory of food and packaging items from 24 countries. Inventory items in *Hungry Planet* are more detailed than the generic data that can be extrapolated from national databases such as the Household Expenditure (ABS, 2008) and National Nutrition Surveys, in that specific food types, brands and packaging amounts can be estimated.

Three families were selected and modelled for this paper from Australia, the United Kingdom and Italy. The composition of each household varied slightly. The Molloys from Australia were composed of three adults and a child, the Manzos from Italy two adults and three young children, while the Baintons from the United Kingdom had two adults and two teenagers. The selection of families for this paper was based on countries where sound consumer food waste data was available in a disaggregated form. The co-location of authors to the selected countries also enabled packaging to be weighed accurately. Recycling data from the selected countries was also readily available (Quested and Johnson, 2009, Quested et al., 2013a).

The food each family purchased when converted to US dollars was of a similar quantum (see Table 2). However the diet of each family had subtle differences. A detailed overview of the diet of each family is provided in Table 2. The key differences between the families are:

- The Bainton family (UK) consumed by far the largest amount of dairy products 21.0kg compared to 12.3kg in the Molloy household (AU) and 6.5kg in the Manzos (IT), as well as the highest amount of beverages (15L).
- The Bainton family (UK) consumed the least amount of fruit and vegetables. 12.1kg of fruit and vegetables in comparison to 17.0-17.3kg for the Molloy's and Manzos respectively.
- The Molloy household (AU) had the highest amount of meat consumed at 8.9kg, the Manzo household 3.6kg, and the Bainton household 3.4kg. The percentage of ruminant meat (beef and lamb) consumed in the Molloy household was also higher.
- The Molloy household also purchased the least amount of snacks and desserts by weight (2.4kg in comparison to 5.2-5.4kg for the Manzos and Bainton households).

Table 2: The weekly food inventories of the Australian (Molloy), United Kingdom (Bainton) and Italian (Manzo) households

THE MOLLOYS (Australia)	THE BAINTONS (Great Britain)	THE MANZO (Italy)
Grains and Other Starchy Foods		
White russet variety potatoes; white bread; sliced, 2 loaves; bread rolls, 10; *Dick Smith Bush* foods breakfast cereal; *San Remo* spaghetti; *San Remo* penne; white rice; sweet chili twist (savory bread).	White potatoes; *Kingsmill Gold* soft white bread, slices, 2 loaves; *Hovis* crusty white bread; *Weetabix* whole-grain cereal; new (young) potatoes; *McDougall's* self-raising flour; *Saxby* puff pastry; *Seeds of Change* tagliatelle; *Waitrose* porridge oats; *Kellogg's* Coco Pops; *Waitrose* corn flakes; *Waitrose* garlic baguette, organic; *Jacob's* TUC crackers	*Poiatti* spaghetti, rotini, orzo, margherite, macaroni; bread; bread crumbs; white potatoes; *Kellogg's* Frosties Chocos cereal; *Mulino Bianco* fette biscottate, 1 loaf; *Mulino Bianco* white bread, sliced, 1 loaf; white flour
Dairy		
Pura Light Start milk, *Pauls* milk, whole, cheese, *Pauls* Greek yoghurt, natural set, *Pauls* thickened cream, *Woolworths* sour cream, butter *Dairy purchased = 21.0kg*	Semi-skim milk; full cream milk (whole); *Waitrose* strawberry yoghurt; *Muller Corner* strawberry yoghurt; *Waitrose* custard mild English cheddar; *Philadelphia* cream cheese; *Waitrose* rhubarb yoghurt; *Waitrose* toffee yoghurt; *Country Life* butter; *Cropwell Bishop* cheese: *Dairy purchased = 12.3kg*	*Granarolo* whole milk; *Da Cucina* cooking cream; *Galbi* yoghurts; *Grandi Pascoli* butter; parmesan cheese, grated *Dairy purchased = 6.5kg*
Meat, Fish and Eggs		
Chicken, whole; tuna, canned; *Woolworths* beef; *Woolworths* chicken breast; *Woolworths* lamb; sea perch; *Woolworths* pork; eggs; ham; salami: *Meat, Fish and Eggs purchased = 8.9kg*	*Waitrose* British pork; *Waitrose* eggs (12); *Waitrose* pork escalopes; *Waitrose* tuna, canned in brine; honey roasted ham; *Waitrose* unsmoked British bacon; *Waitrose* large prawns, frozen: *Meat, Fish and Eggs purchased = 3.6kg*	Fish sticks, frozen; sometimes a fresh fish; eggs (12); beef, ground; sausage; veal *involtini* (meat rolls); clams; tuna; wurstel (German hot dog); ham and cheese, sliced; anchovies: *Meat, Fish and Eggs purchased = 3.4kg*
Fruits, Vegetables and Nuts		
Watermelon, seedless; *Sundowner* variety apples; oranges; yellow bananas; plums; green grapes; lemons; nectarines; *Heinz* baked beans; avocados; *Iceberg* lettuce, 2 heads; cucumbers; *Val Verde* peeled tomatoes, canned; tomatoes; white onions; carrots; sweet corn, 4 ears; asparagus; Silverbeet; celery; *Master Foods* tomato sauce; mushrooms; broccoli; beetroot, canned; Italian flat beans; tomato paste; snow peas; red bell peppers; garlic	*Coxes* variety apples; *Braeburn* variety apples; yellow bananas; oranges; *Granny Smith* variety apples; green grapes, seedless; *Del Monte* pineapple chunks, canned; *Heinz* baked beans, canned; *Waitrose* Brussel sprouts, fresh; *Birds Eye* garden peas, frozen; white cabbage, organic, 1 head; white mushrooms; cauliflower, 1 head; carrots; parsnips; iceberg lettuce, 1 head; tomatoes; broccoli; cucumber; red onion; runner beans; mange tout peas (snow peas); sugar snap peas	Red grapes; yellow bananas; lemons; pears; persimmons; *Vitale* crushed tomatoes, canned; *Star* tomato sauce, bottled; broccoflower (hybrid of broccoli and cauliflower), 1 head; chard; peas, frozen; tomatoes; *Comal* olives; corn, canned; garlic
Prepared Food		
Heinz spaghetti, canned; beef Stroganoff mix	*New Covent Garden Food Co* vegetable and lentil soup; *Waitrose* five cheese and pepperoni pizza; *Loyd Grossman* four cheese pasta sauce; *Heinz* cream of tomato soup, canned; *Waitrose* cheese and onion flan; *Waitrose* chicken and mushroom flan; *Dairylea* ham Lunchables; *Bisto* granules gravy mix, roast vegetable flavoured; *Waitrose* carbonara sauce	*Star* Gran ragù sauce; *Star* vegetable bouillon cubes; school lunch, lasagne or pasta and juice, 6 days for two children

Table 2 continued

THE MOLLOYS (Australia)	THE BAINTONS (Great Britain)	THE MANZO (Italy)
Condiments		
Coconut milk; peanut butter; *Kikkoman* less salt soy sauce; *Lea & Perrins Worcestershire* sauce; *Master Foods* BBQ sauce; *Nutella* chocolate spread; *Master Foods* seeded mustard sauce; *Viva* olive oil; red chili peppers; basil; ginger; *Capilano* honey; parsley, 1 small bunch; balsamic vinegar; coriander (cilantro), 1 small brunch; *Master Foods* horseradish; jam; Mayonnaise; *Master Foods* tomato and chili pickle (salsa); mint, 1 small bunch; oregano; *Tonkatsu* sauce; *Vegemite*; cumin; mustard seeds; rosemary, 4 sprigs; turmeric; black pepper; curry leaves (20); salt; thyme, 1 small bunch;Bay leaves (5)	*I Can't Believe It's Not Butter* spread; *Heinz* ketchup; *Hartley's Best* raspberry jam; *Heinz* salad cream; *Hellmann's Real* mayonnaise; *Waitrose* smooth peanut butter, organic; *Waitrose* blend olive oil; *Tate Lyle* white sugar; *Waitrose* dark-brown muscovado sugar; waldorf salad topping; paprika; black pepper; *Maldon* sea salt; *Saxa* table salt; basil, 1 bunch; parsley, 1 bunch; *Sweetex sweetener*, 80 tablets (they are very small)	*Tevere* vegetable oil; olive oil; white wine, used only for cooking; *Bonanno* white vinegar; mayonnaise; cherry jam; pine nuts and raisins; Italia white sugar; salt; tomato paste, 1 tube; bicarbonate of soda (baking soda); pepper
Snacks and Desserts		
Ice blocks (popsicles), 24 pk; sultana raisins; *Cadbury* Milk chocolate bar; *Uncle Tobys* strawberry muesli bars; *Uncle Tobys* fruit twists; *SAKATA* crackers; *Arnott's* shortbread cream biscuits; *Smith's* chicken flavoured potato crisps	*McCain* oven chips, frozen; *Mars* candy bars, multipacks; *Waitrose* savory wedges, frozen; *Waitrose* milk chocolate digestive biscuits; *Waitrose* treacle tart; *Cadbury* twirls; *Trebor* softmints; *Haribo* Maoam Stripes; *Waitrose* rich tea biscuits; *Golden Wonder* Nik Naks; *Walker's* BBQ crisps; *Walker's* prawn cocktail crisps; *Waitrose* caramel surprise; *Waitrose* chocolate surprise; *Onken* chocolate hazelnut mousse; strawberry laces; *Waitrose* mini jelly babies; *Dairylea* Double Dunker nachos; Flying Saucers candy	*Kinder* milk chocolate; biscotti; *Nutella* chocolate spread; *Kinder* paradiso chocolate; *Buondí* (packaged cream cakes); baby biscuits; *Kinder* Brioss (packaged cream cakes); *Mulino Bianco* flauti (packaged cream cakes with chocolate); *Pavesini* biscuits; candies, assorted
Homemade food		
	Savoury pancakes, made with flour, milk and eggs, listed above	
Beverages		
Water; fruit juice; red wine, 3 bottles (each); *Just* juice poppers (juice boxes); *Mateus* rose wine; *Cascade* light beer, 6 bottles (each); *Nescafe* gold blend coffee; *Nestle* milo (instant chocolate drink); *Twinings* of London English breakfast tea, 10 teabags	*Capri Sun* fruit juice, 12 6.8 fl oz pkg; *Somerfield Pennine Valley* Water; *Wadworth* beer, 12 16.9 fl oz cans; *Waitrose* pineapple juice; *Waitrose* press apple juice; *Waitrose* pure orange juice; *Tesco* mountain spring water; *Cadbury* drinking chocolate; *James Herrick* red wine; *Douwe Egberts Continental Gold* Coffee; *PG Tips* tea, 40 teabags; tap water, for drinking and cooking	*Pepsi*, 2 bottles (each); ginger soda; peach juice, 12 mini bottles (each); *San Benedetto* iced tea; *Spuma* (light cola drink); *Top* cola; *Espresso Bar* coffee; tap water for drinking and cooking

Table 2 continued

THE MOLLOYS (Australia)	THE BAINTONS (Great Britain)	THE MANZO (Italy)
Total weight of food purchased		
40.6 kg solid food 25.3 kg liquid (milk and beverages)	38.6 kg solid food 33.2 kg liquid (milk and beverages)	50.42 kg solid food 12.92 kg liquid (milk and beverages)
Food expenditure for one week (excluding medicines, tobacco and pet food)		
AU$387.73, equivalent to US$303.37	£138.59, equivalent to €208.62/ US$225.55	€164.44, equivalent to US$199.44
Notes: Family food purchases were captured during the period of 2001-2004, and subsequently published in 2005. Input output modelling for the United Kingdom was based on Euro prices		
Source: (Menzel and D'Aluisio, 2005)		

3 Results

The central focus of this paper is on the relationship between purchased food type, packaging and food waste. The GHG profile related to food purchases of each household is not the focus of comparison. The differing number of family members renders that comparison inconsistent; however for completeness the total GHG profile for the weekly food purchases was 158.9 kg $CO_{2\text{-eq}}$ for the Molloy household, 169.0 kg $CO_{2\text{-eq}}$ for the Manzo household and 178.1 kg $CO_{2\text{-eq}}$ for the Bainton household. The remainder of the results are presented as broken down percentages of the above result, to show the relationship between food types, packaging and food waste.

3.1 Consumed food

The GHG profile of the consumed food, as a percentage of the total amount of food purchased in one week, for each food category for the Molloy, Bainton and Manzo families over one week is presented in Figure 2.

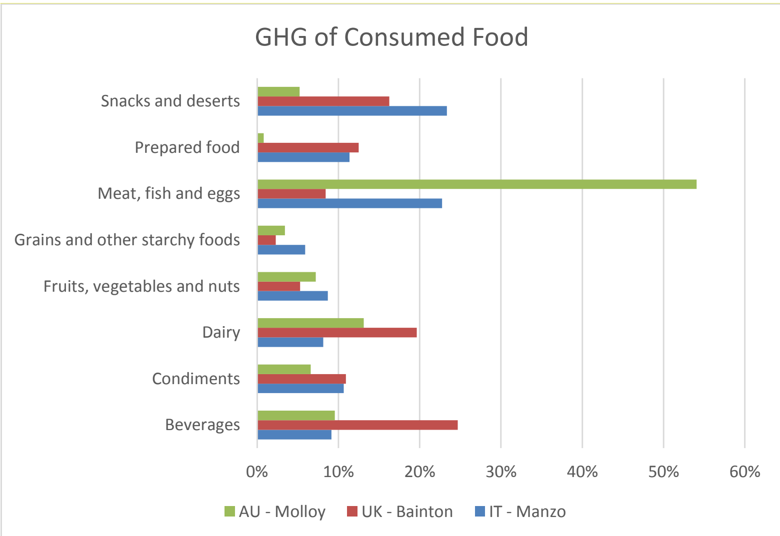

Figure 2: The greenhouse profile, as a percentage, of the Australian (Molloys), United Kingdom (Bainton), and Italian (Manzo) households

The GHG results illustrate distinct differences amongst the three households, for example the higher meat, fish and eggs consumption of the Molloy household; high dairy and beverages in the Bainton household; and high snacks and desserts in the Manzo household. The results track the variation of products highlighted in the previous section, and presented in Table 2.

The majority of the GHG profile of the weekly purchased food, food waste and packaging for the Molloy household is associated with the embedded GHG of the purchased food and beverages (73%). This is followed by 15% associated with the wasted food component, while packaging materials contributed 10%.

The following sections will present values for the Molloy (Australian) household for the four top food categories, based upon the GHG profile for the consumed food: meat, fish and eggs; dairy; beverages; and fruits, vegetables and nuts.

3.2 Meat, fish and eggs (Molloy – Australian household)

The GHG profile of the meat, fish and egg category for the Molloy (Australian) household is presented in Figure 3 where the majority is associated with the embedded GHG of the meat, fish and eggs (80%), followed by 18% or 14 kg $CO_{2\text{-eq}}$ associated with the wasted food component, while packaging materials only contribute 2%.

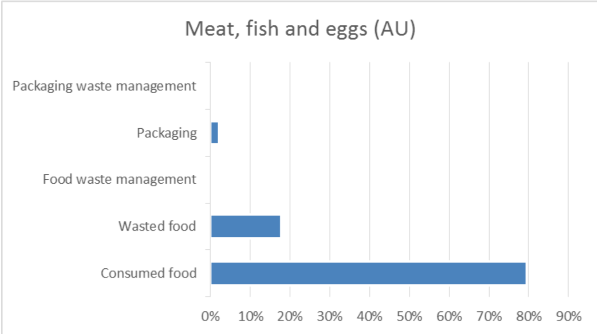

Figure 3: The greenhouse profile for meat, fish and eggs for the Molloys – Australian household

3.3 Dairy (Molloy – Australian household)

The GHG profile of the dairy category for the Molloy (Australian) household is presented in Figure 4, where the majority is associated with the embedded GHG of the dairy products (75%), followed by 13%, or 2.6 kg $CO_{2\text{-eq}}$ associated with the wasted food component, while packaging materials contribute 10%.

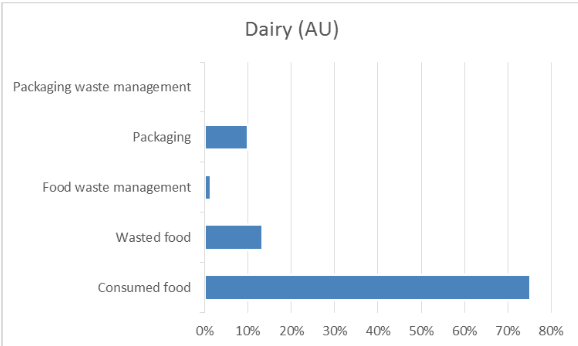

Figure 4: The greenhouse profile for dairy for the Molloys – Australian household

3.4 Beverages (Molloy – Australian household)

The GHG profile of the beverages category for the Molloy (Australian) household is presented in Figure 5, where majority is associated with the embedded GHG of the beverages (56%), followed by 38% associated with the packaging materials (dominated by glass) and the wasted beverage component only contributes 5% or 1 kg $CO_{2\text{-eq}}$.

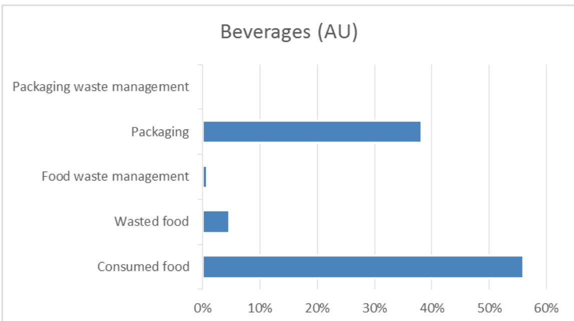

Figure 5: The greenhouse profile for beverages for the Molloys – Australian household

3.5 Fruit, vegetables and nuts (Molloy – Australian household)

The GHG profile of the fruit, vegetables and nuts category for the Molloy (Australian) household is presented in

Figure **6**, where the majority is associated with the embedded GHG of the fruits, vegetables and nuts (62%), followed by 22% associated with the wasted food component, while packaging materials only contribute 12%.

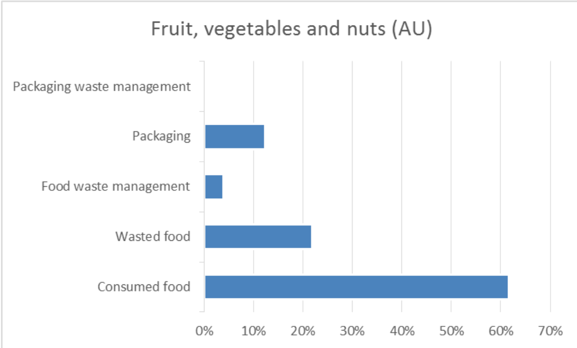

Figure 6: The greenhouse profile for fruit, vegetables and nuts for the Molloys – Australian household

4 Discussion

In this section we discuss the results in relation to the role of packaging design for efficient food containment and protection while minimizing food waste.

4.1 Food waste

The Love Food Hate Waste fact sheet provided by the New South Wales (NSW) Environment Protection Authority in Australia (DECCW, 2009, p.2) highlights a number of broad reasons why food is wasted by households (percentages refer to the proportion of respondents who indicated each cause): (i) Buying: I think I need more than I do (61%) and I'm tempted by special offers (44%); (ii) Cooking: I prefer to serve too much rather than too little (48%) and I find it hard to estimate how much to cook per person (32%); and (iii) Storing: I'm unsure about the best way to store different types of food (60%) and I forget about leftovers (63%)

Within the causes of waste identified above, the perishable food groups of meat, fish, eggs, dairy, fruit and vegetables, food waste contributes between 13-22% of weekly greenhouse gas impacts. The climate impact of wasted meat, fish and eggs are higher than the impact of all purchased fruit and vegetables.

Helping consumers buy and cook the correct amount of food by designing and selling a larger diversity of packaging sizes at retail is one possible development in tackling food waste. Other packaging attributes that need to be considered include: containing the desired quantity; mechanical protection; resealability; accessibility including easy to open, grip, dosing and emptying; containing the correct quantity; food safety/freshness information and facilitating sorting of household waste (Wikstrom et al., 2014). Smarter packaging with better atmospheres and coatings aimed at elongating shelf life may also assist to reduce this food waste (Verghese et al., 2013).

The UK has made a broad, considered effort to reduce food waste, from industry through to consumers. For packaging designers, the WRAP packaging design and food waste checklist suggests resealable/ recloseable packaging, portion packaging, shelf life extension packaging and better on-pack consumer communication as a means to address food waste (WRAP, 2009). They have also implemented initiatives between packaging designers and retailers, for example "WRAP, The Co-operative and VionFoods (UK), Giraffe Innovation Ltd who investigated the opportunity to reduce meat waste through a packaging solution" (Holdway, 2011, p.1). The partnership resulted in packaging that separated individual portions to facilitate freezing. WRAP has indicated that since the launch of the program, food waste within the UK has declined (Quested et al., 2013b), however it is not possible to establish efficacy of each program initiative to this decline.

4.2 Packaging design

These reasons for food waste listed in Section 4.1, provide insights where packaging design can contribute to overcoming food waste. Opportunities for packaging design to reduce or eliminate food waste can include better facilitation or communication around portioning, special offers that link to appropriate food requirements rather than bulk sales, assistance in per person cooking requirements, expiry date/ best before extension or better clarification, and left over storage solutions.

Moreover, focusing packaging designs on waste reduction for areas of particularly high food category waste impacts can also be a strategy of climate impact reduction. In the case of the Molloys, solutions to reduce the waste for either high climate impact foods per kg (and subsequently relatively high total waste impacts for related food waste) such as wasted meat, fish and eggs, or high climate impact foods for total waste (not necessarily high climate impact foods per kg, however relatively high climate impact when accumulated waste is considered for related food waste) such as fruit and vegetables, could start to address the impacts of food waste.

The relationship between packaging, product and waste impacts should also be part of any strategy to reduce waste impacts of product-packaging systems. As an example of a particular food category for the Molloys, the beverage category results reveal that packaging has more than 7 times higher climate impact than of food waste. This indicates a challenge for industry when these products with low environmental impacts are to be packed. For this specific Australian family the impact from beverage packaging has half the climate impact from wasting meat, fish and eggs, the drivers of food waste impacts. The high impact is driven by the use of glass packaging for that particular beverage (based upon the photographic image from Hungry Planet), though this needs to be put into context and also compared against the other packaging attributes this type of packaging material delivers in the containment and protection of the product to the consumer. Packaging material selection and design needs to focus upon appropriate material use, not just light weighting, whereby the right combination of the amount of and appropriate choice of material is used, ensuring packaging integrity and stability through the supply chain – that it is 'fit-for-purpose'.

The variations evident across the food categories in Section 3 illustrates that the contribution of product and packaging are always different and that the relationship between packaging and product impacts is not a one size fits all approach. Detailed investigations within food categories and packaging formats is required to understand the implications for various combinations of product and packaging, linked to consumer preferences and use. This research, along with attention to packaging attributes listed above in Section 4.1 will ensure that each product-packaging system is designed to minimise food waste and packaging impacts, while catering for consumer preferences, and the requirement to protect and preserve products in the process.

4.3 Data assumptions

Food waste figures for the UK were calculated using data from the UK's WRAP publications on Household Food and Drink Waste (Quested and Johnson, 2009, Quested et al., 2013a). Waste percentages from 2012 were used where possible, with more comprehensive data from 2007 being utilised to complete the waste estimates.

There are some differences in how aggregated data was used for food waste among the three countries. Packaging data was compiled with estimates and direct measurement of packaging formats and combined with existing LCA data. This data aggregation derived from observations of the *Hungry Planet* family photos and food purchasing lists. Packaging recycling data is derived from information governments collect for different materials which is often transparent and coherent.

It is important to remember that the data used in this study are estimates of three families in three different regions, and that it does not apply to the broader population. Also we have taken food waste figures and assumed these were directly applicable for the three families, while this may not have been the case. The research is aimed at understanding the difference between environmental impacts of food type, packaging and food waste in particular case contexts, rather than a generalizable set of results. This is made in order to inform the direction of further research that may indeed start to broaden the scope of this new knowledge to a constituent, national or global level.

5 Conclusions

Brandowners and packaging manufacturers have a critical role to play in reducing food waste and thus the GHG emission profile of consumers such as the three families from *Hungry Planet* explored in this paper. Although these three families had similar absolute GHG emissions from their weekly food shop, differences amongst food GHG emission impact, packaging and food waste are clear from the results generated. Data are complex and no single rule for waste reduction can be used in all types of food categories. However, it is important to minimise waste from food items with high GHG emission impacts, or from food items that may have lower GHG emission intensity per kg yet are wasted in high amounts leading to a large absolute GHG emissions.

Packaging designs can help to facilitate this saving of resources. Further research is required to understand the role packaging may play from a functional perspective. This could involve ethnographic and action research tracking the uptake or success of designed packaging instruments aligned to the themes in the discussion section of this paper. The current paper could also be expanded upon to investigate the trends and differences across all three families in regards to similarities and differences between packaging and food waste contributions to GHG emissions for all food item categories. An assessment on a larger population could inform more comprehensively packaging design in relation to reducing waste for particular food types. Primarily, this interaction between packaging and product in saving food, and where the sweet spot lies in this phenomenon at a food item level, provides researchers with an opportunity to articulate how packaging design can contribute to a more sustainable supply chain.

References

ABS 2008. 6535.0.55.001 - Household Expenditure Survey, Australia: Detailed Expenditure Items, 2003-04 (Reissue). Canberra: Australian Bureu of Statistics.

ABS 2014. 6401.0 - Consumer Price Index, Australia. Australian Bureau of Statistics.

APC 2011. The National Packaging Covenant: 2010 Annual Report. Australian Packaging Covenant Council.

BAKER, D., FEAR, J. & DENNISS, R. 2009. What a Waste. An Analysis of Household Expenditure on Food. Banbury UK: The Australian Institute.

BCFN 2012. Food waste: causes, impacts and proposals. Barilla Food Center for Food & Nutrition.

BOUSTEAD, I. 2005. Eco-profiles of the European Plastics Industry. Brussels: PlasticsEurope.

BROAD LEIB, E., GUNDERS, D., FERRO, J., NIELSEN, A., NOSEK, G. & QU, J. 2013. The Dating Game: How Confusing Food Date Labels Lead to Food Waste in America. New York: Natural Resources Defense Council.

CLUNE, S., CROSSIN, E. & VERGHESE, K. under review 2014. Analysis of greenhouse gas emissions for different fresh food categories: a review. *Journal of Cleaner Production*.

COX, J. & DOWNING, P. 2007. Food Behaviour Consumer Research: Quantitative Phase. Banbury UK: Waste & Resources Action Programme.

DECCW. 2009. *Food Waste Avoidance Benchmark Study 2009* [Online]. Sydney: Department of Environment, Climate Change and Water NSW. Available: http://www.lovefoodhatewaste.nsw.gov.au/portals/0/kit/print/10242FWAFactsheetCMYK_print.pdf [Accessed 12/10/2010 2010].

EC. 2014. *eurostat: http://ec.europa.eu/eurostat* [Online]. Brussels: European Commission. [Accessed 23/04/2014.

ERLOV, L., LOFGREN, C. & SORAS, A. 2000. PACKAGING - a tool for the prevention of environmental impact. Kista, Sweden: Packforsk.

EVANS, D. 2011. Beyond the Throwaway Society: Ordinary Domestic Practice and a Sociological Approach to Household Food Waste. *Sociology,* 46**,** 1841-56.

FAO 2013. Food wastage footprint. Impacts on natural resources. Summary Report. Rome: Food and Agriculture Organisation of the United Nations.

FRISCHKNECHT, R., TUCHSCHMID, N., FAIST EMMENEER, M., BAUER, C. & DONES, R. 2007. Strommix und Stromnetz. In: Sachbilanzen von Energisystemen: Grundlagen fuer die oekolischen Vergleich von Energiesystemen und den Einbezug von Energiesystemen in Oeobilanzen fuer die Schweiz (ed. Dines, R.). ecoinvent report No. 6 v2.0. Villigen and Duebendorf: Paul Scherrer Institut and Swiss Life Cycle Centre for Life Cycle Inventories.

GRANT, T. 2013a. Australian Input Output 2008-09 GHG database. Published by Life Cycle Strategies Pty Ltd, Melbourne.

GRANT, T. 2013b. Australasian Unit Process Life Cycle Inventory. Published by Life Cycle Strategies Pty Ltd, Melbourne.

GUNDERS, D. 2012. Wasted: How America is Losing up to 40 Percent of its Food from Farm to Fork to Landfill. New York: Natural Resources Defense Council.

GUSTAVSSON, J., CEDERBERG, C. & SONESSON, U. 2011. Global food losses and food waste: extent, causes and prevention. Rome: Swedish Institute for Food and Biotechnology for the Food and Agriculture Organization of the United Nations.

HALL, K. D., GUO, J., DORE, M. & CHOW, C. C. 2009. The pro- gressive increase of food waste in America and its environmental impact. PLoS ONE 4.

HISCHIER, R. 2004. Life Cycle Inventories of Packagings and Graphical Papers. ecoinvent-Report No. 11. Part III Paper and Board. Dübendorf: Swiss Centre for Life Cycle Inventories.

HISCHIER, R. 2007. Life Cycle Inventories of Packaging and Graphical Papers. ecoinvent-Report No. 11. Part II, Plastics. Duebendorf: Swiss Centre for Life Cycle Inventories.

HOLDWAY, R. 2011. Final report: Packaging design to reduce household meat waste. Oxon: WRAP and Giraffe Innovation.

INCPEN 2009. Table for one. Reading: The Industry Council for Packaging and the Environment.

INSTITUTION OF MECHANICAL ENGINEERS 2013. Global food waste not want not. London.

IPCC 2006. 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Volume 5. Waste. *In:* EGGLESTON, S., BUENDIA, L., MIWA, K., NGARA, T. & TANABE, K. (eds.). Kanagawa: Intergovernmental Panel on Climate Change.

IPCC 2007. *Climate Change 2007: The Physical Science Basis,* Cambridge, Cambridge University Press.

KATAJAJUURI, J. M., SILVENNOINEN, K. H., HARTIKAINEN, H., JALKANEN, L., KOIVUPURO, H. K. & REINIKAINEN, A. Food waste in the food chain and related climate change impacts. LCA Food, 2012 St Malo

KNUDSEN, M. L. C. 2009. In Danish: Affaldsforebyggelse i husholdninger - muligheder og barrierer for Danmark. Roskilde University: Roskilde University.

KOIVUPURO, H. K., HARTIKAINEN, H., SILVENNOINEN, K., KATAJAJUURI, J.-M., HEIKINTALO, N., REINIKAINEN, A. & JALKANEN, L. 2012. Influence of socio-demographical, behavioural and attitudinal factors on the amount of avoidable food waste generated in Finnish households. *International Journal of Consumer Studies,* 36**,** 183-191.

KUMMU, M., DE MOEL, H., PORKKA, M., SIEBERT, S., VARIS, O. & WARD, P. 2012. Lost food, wasted resources: Global food supply chain losses and their impact on freshwater, cropland and fertiliser use. *Science of the Total Environment,* 438**,** 477-489.

LEBERSORGER, S. & SCHNEIDER, F. 2011. Discussion on the methodology for determining food waste in household waste composition studies. *Waste management* 31**,** 1924-33.

LIPINSKI, B., HANSON, C., LOMAX, J., KITINOJA, L., WAITE, R. & SEARCHINGER, T. 2013. Reducing Food Loss and Waste. Working Paper, Installment 2 of Creating a Sustainable Food Future. Washington DC: World Resources Institute.

MENZEL, P. & D'ALUISIO, F. 2005. *Hungry planet - what the world eats,* New York, Random House Inc.

MONIER, V., MUDGAL, S., ESCALON, V., O'CONNOR, C., ANDERSON, G., MONTOUX, H., REISINGER, H., DOLLEY, P., OGILVIE, S. & GARETH MORTON, G. 2010. Preparatory study on food waste across the EU 27. Final report. *In:* C-INDUSTRY, D. (ed.). European Commission (DG ENV).

PLUMB, A., DOWNING, P. & PARRY, A. 2013. Consumer Attitudes to Food Waste and Food Packaging.

QUESTED, T., INGLE, R. & PARRY, A. 2013a. Final Report Household Food and Drink Waste in the United Kingdom 2012. Oxon: Waste & Resources Action Programme.

QUESTED, T. & JOHNSON, H. 2009. Household Food and Drink Waste in the UK. *Final Report.* Oxon: Waste & Resources Action Programme.

QUESTED, T. & PARRY, A. D. 2011. New estimates for household food and drink waste in the UK : A report presenting updated estimates of food and drink waste from UK. Oxon: Waste & Resources Action Programme.

QUESTED, T. E., MARSH, E., STUNELL, D. & PARRY, A. D. 2013b. Spaghetti soup: The complex world of food waste behaviours. *Resources, Conservation and Recycling,* 79**,** 43-51.

SIBRIÁN, R., KOMOROWSKA, J. & MERNIES, J. 2006. Estimating household and institutional food wastage and losses in the context of measuring food deprivation and food excess in the total population. *Working Paper Series.* Rome, Italy: Statistics Division.

STEFAN, V., VAN HERPEN, E., TUDORAN, A. A. & LÄHTEENMÄKI, L. 2013. Avoiding food waste by Romanian consumers: The importance of planning and shopping routines. *Food Quality and Preference,* 28**,** 375-381.

VENTOUR, L. 2008. *The Food We Waste,* Banbury UK, WRAP.

VERGHESE, K., LEWIS, H., LOCKREY, S. & WILLIAMS, H. 2013. The role of packaging in minimsing food waste in the supply chain of the future. Sydney: CHEP Australia and RMIT University.

WIKSTROM, F., WILLIAMS, H., VERGHESE, K. & CLUNE, S. 2014. The influence of packaging attributes on consumer behaviour in food-packaging LCA studies - a neglected topic. *Journal of Cleaner Production*.

WILLIAMS, H., WIKSTRÖM, F., OTTERBRING, T., LÖFGREN, M. & GUSTAFSSON, A. 2012. Reasons for household food waste with special attention to packaging. *Journal of Cleaner Production,* 24**,** 141-148.

WRAP 2007. Food Storage and Packaging. Retail Programme-Food Waste: Final Report. Banbury UK: Waste & Resources Action Programme.

WRAP 2009. Packaging design & food waste checklist. Oxon: Waste & Resources Action Programme.