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The Climate Change and Economic Impacts of Food Waste in the United States

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ABSTRACT

This study analyzes the climate change and economic impacts of food waste in the United States. Using loss-adjusted national food availability data for 134 food commodities, it calculates the greenhouse gas emissions due to wasted food using life cycle assessment and the economic cost of the waste using retail prices. The analysis shows that avoidable food waste in the US exceeds 55 million metric tonnes per year, nearly 29% of annual production. This waste produces life-cycle greenhouse gas emissions of at least 113 million metric tonnes of CO_2e annually, equivalent to 2% of national emissions, and costs $198 billion.

Keywords: food waste, climate change, greenhouse gas emissions, life cycle assessment (LCA)

1 Introduction

A recent study by the Food and Agriculture Organization (Gustavsson, et al., 2011) reported that one-third of all food produced for human consumption is lost or wasted globally, amounting to as much as 1.2 billion metric tonnes annually. Food waste is a global problem of staggering proportions, but the underlying reasons differ between countries. While food waste in industrialized countries is dominated by retail and consumer waste, developing countries have high losses at the post-harvest and processing stages due to spoilage in warm and humid climates resulting from the lack of modern transport and storage infrastructures. Gustavsson et al. (2011) estimated the magnitude of worldwide food losses, but did not assess the corresponding climate change or economic impacts.

Food waste is an issue in all of the major economies in the world. Japan's households and food industry together discard nearly 17 million metric tonnes of edible food annually, an estimated 30% of production (Morisaki, 2011; MAFF, 2012; Srinivas, 2010). In India, nearly 30% of the country's fruits and vegetables are lost due to lack of cold-storage facilities, and more than 30% of the grain supplied through the public distribution system is lost as well (Mukherji and Pattanayak, 2011). Food waste in China has increased rapidly and now accounts for about 70% of household and commercial waste (Xin et al., 2012).

Stenmarck et al. (2011) examined food waste from the retail and wholesale sectors in Nordic countries (Denmark, Finland, Norway and Sweden) and found that annual retail waste ranged from 40,000 to 83,500 metric tonnes in each of these countries. In comparison, the authors noted that retail and wholesale waste is orders of magnitude higher in larger economies such as Japan, the United Kingdom (UK) and the United States (US). This study looked at the causes and prevention of waste, but not the climate change or economic impacts.

A report from the Waste & Resources Action Programme (Chapagain and James, 2011) is one of the first country-level assessments of the environmental and economic impacts of food waste, focusing on household waste. It found that households in the UK waste 8.3 million metric tonnes of food and drink each year, with a value of at least $18.6 billion and responsible for about 3% of UK's domestic greenhouse gas (GHG) emissions.

In one of the earliest analyses of US food waste, Kantor et al. (1997) estimated that 27% of the available food was wasted in 1995. Food waste is now receiving increasing attention in the US, with major news organizations frequently covering it as an issue of interest (Barclay, 2011; Nassauer, 2012). The US Department of Agriculture regularly publishes data on food losses (USDA ERS, 2009). While US cities such as Portland are focusing on food waste recycling through composting (Walker, 2011), the food industry has launched an initiative to help reduce food waste at the source (EL, 2011). However, a comprehensive evaluation of the environmental and economic impacts at the national level has been lacking. Two recent studies have taken a first look at the larger environmental impacts of food waste in the US beyond just the disposal stage.

Hall, et al. (2009) used energy balance to calculate that nearly 40% of the food was wasted in the US as of 2003, accounting for more than one quarter of the total freshwater use and 4% of petroleum oil consumption. The water and energy estimates were based on the overall freshwater consumption by agriculture and the fossil energy used by the average farm to produce food containing 1 kcal of energy.

Cuellar and Webber (2010) used food loss data from the US Department of Agriculture for 1995 – which showed that 27% of edible food was wasted – and estimated that the energy embedded in wasted food represents about 2% of annual energy consumption in the US. The total energy required for food production (agriculture, processing, transportation and handling) at the national level was compiled from various literature sources. Agricultural energy use for 10 broad food categories was derived from the total energy used by agriculture using relative intensity factors and production mass.

Both of these studies used top-down methods (i.e., starting from an economy-wide estimate of energy used in agriculture and deriving from it a national average for the farm level or food category level) to estimate the energy needed to produce food that is ultimately wasted. While Hall, et al. (2009) discussed GHG emissions from the decomposition of wasted food (but not emissions from production or other upstream stages), neither of these studies directly addressed climate change, arguably the most pressing environmental problem of our times.

Garnett (2008) has pointed out that food waste contributes to GHG emissions in two ways: A relatively minor impact from decomposition of the wasted food after disposal in landfills, and a potentially far more significant impact from the embedded emissions associated with its production, processing, transport and retailing. This second impact requires a life-cycle view of the wasted food.

It should also be noted that the climate change impact of food waste – as quantified by life-cycle GHG emissions – is a more complete measure of environmental impact than embedded energy or barrels of oil: It includes not only the emissions from the burning of fossil fuels but also significant other GHG emissions that are not energy-related such as methane (in agriculture and waste disposal) and nitrous oxide (in agriculture).

Besides environmental impacts, food waste also imposes an economic cost on consumers and retailers. If quantified correctly, this could provide a unique incentive to simultaneously mitigate emissions and save money through waste reduction.

The motivation for the present study is to quantify in a comprehensive manner, for the first time, the annual climate change and economic impacts of the food wasted in the US using the most recent national data available (as of this writing). This is particularly important given the position of the US as the world's largest economy and a major consumer of resources. In conjunction, a secondary goal is to develop and demonstrate a robust food waste model and methodology – based on the principles of life cycle assessment (LCA) – that can be used to monitor the future impacts of food waste not only in the US but also in other parts of the world.

The approach adopted in this study is both bottom-up and life-cycle based: It analyzes 134 distinct food commodities accounting for most of the food consumed in the US, and then groups them into 16 food categories. Each of the 134 commodities is modeled using one or more representative production systems, based on detailed North American production data in most cases. Foods such as beef, chicken, pork and cheese are placed in their own separate categories because of their unique production characteristics and significant climate change impacts. Such an approach can provide a degree of precision and rigor that may not be possible with top-down methods.

The rest of the paper is organized as follows. We will first describe the methods used in our analysis including: the life-cycle food waste model; LCA standards, software and database used in the calculation of GHG emissions; the system boundary; important assumptions; and the how the economic impact is calculated. Following this, we will describe the food waste data used in this study, including a detailed summary of annual food production, consumption and waste in the US. We will then present detailed results for the climate change and economic impacts of US food waste, including a sensitivity analysis to test a critical subset of the assumptions used in this study. We will then close with concluding remarks and recommendations for further work on quantifying the full impacts of food waste.

2 Methods

2.1 Life-Cycle Food Waste Model

Figure 1 illustrates the life-cycle model of material flow from production to disposal for each of the food commodities. This model has been developed specifically to fit the loss-adjusted food availability data series from the US Department of Agriculture (USDA ERS, 2009).

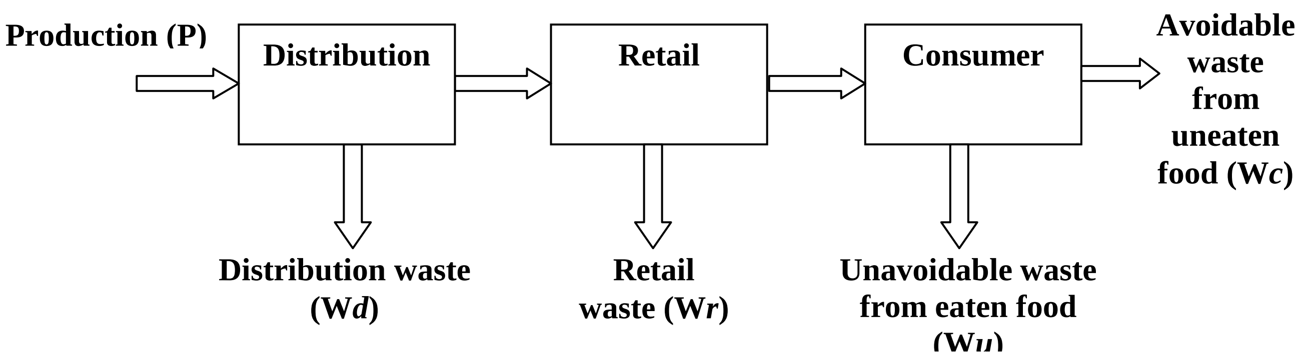

Figure 1. Life-cycle model of material flow from production to disposal

Equation 1 below defines the basic mass balance in the life cycle of a food commodity. The difference between production (P) and consumption (C) is the total gross waste made up of waste at the distribution (Wd), retail (Wr) and consumer (Wcg) levels. All quantities are product weights.

$$P - C = Wd + Wr + Wcg \qquad (1)$$

The food availability data series provides values for each of the terms in Equation 1 for all commodities on an annual basis from 1970 through 2009. This is described further in the Food Waste Data section below. Wcg is the gross consumer waste, the sum of avoidable and unavoidable consumer waste:

$$Wcg = Wc + Wu \qquad (2)$$

The avoidable consumer waste (Wc) – also referred to as "consumer waste" in this paper – represents uneaten food that is wasted at the consumer level and is defined in Equation 3. Wc excludes the unavoidable waste in consumed foods due to non-edible parts (such as skins and shells) as well as fat or moisture losses in cooking. N is the fraction of a food commodity that is non-edible, and L is the fraction that is lost as fat or moisture during cooking.

$$Wc = Wcg - \left(\frac{1}{(1-N)(1-L)} - 1\right)C \qquad (3)$$

The non-edible fraction N for each commodity is obtained directly from the food availability data. The fat or moisture lost in typical cooking is estimated from USDA ERS (1998) based on certain cooking assumptions as shown below. These estimates apply only to meats, fish, eggs and oils, all of which lose fat and possibly moisture during cooking. Vegetables may lose moisture in cooking, but we assume that this is compensated on average by added moisture during cooking. Since cooking methods and cooking losses can vary considerably, these typical loss estimates are subjected to a sensitivity analysis as described in the Results and Discussion section.

Table 1.
Estimated fat and moisture losses in typical cooking

Category	Cooking assumption	Fat/moisture loss fraction
Beef	Steaks	0.25
Pork	Chops	0.25
Chicken	All cooking	0.26
Turkey	All cooking	0.27
Lamb	Chops/Steaks	0.25
Shellfish	Boiled	0.24
Fish	Baked	0.19
Fats & Oils	All cooking	0.10
Eggs	Scrambled	0.08

The total avoidable waste Wa, then, is the sum of distribution waste, retail waste and avoidable consumer waste.

$$Wa = Wd + Wr + Wc \qquad (4)$$

The avoidable consumer waste is further adjusted for moisture and fat losses in cooking as follows in order to estimate the remaining solid waste that is actually landfilled. Although cooking is not explicitly included in this study, we assume that half of the consumer waste occurs after cooking. This assumption is necessary for calculating Wl, the quantity of waste sent to landfills after accounting for fat and moisture losses in the cooking of certain foods.

$$Wl = Wa - \frac{Wc}{2} L \qquad (5)$$

2.2 LCA Standards and Methodology

Life-cycle GHG emissions for the food commodities have been modeled and analyzed based on the PAS 2050:2008 standard (BSI Group, 2008), which in turn builds on ISO standards (ISO, 2006) by specifying additional requirements for the assessment of GHG emissions in the life cycles of products and services. Within this framework, GHG emissions from agricultural processes and waste disposal are modeled based on the IPCC tier 1 guidelines (IPCC, 2006). In the context of typical life cycle impact assessment methodologies used in the food sector (Amani and Schiefer, 2011), this study uses a single impact category: climate change, as quantified by life-cycle GHG emissions. The characterization step is included, but normalization and weighting are not. A sensitivity analysis on parametric uncertainties and an interpretation of the final results are presented in the Results and Discussion section.

2.3 LCA Software and LCI Database

FoodCarbonScope^{TM} (CleanMetrics, 2011b), a web-based LCA software tool for food and beverage products, was used to perform the detailed cradle-to-grave GHG emissions modeling and analysis of all the farming systems. FoodCarbonScope supports all of the LCA and GHG standards on which this study is based (BSI Group, 2008; ISO, 2006; IPCC, 2006).

FoodCarbonScope includes CarbonScopeDataTM (CleanMetrics, 2011a), which is a life cycle inventory (LCI) database. CarbonScopeData includes cradle-to-gate and unit process data for over 1100 products and processes in the food and agriculture sectors, covering a full range of crop and animal production systems, commercial food processing, commercial cooking appliances, packaging, and waste disposal. The majority of this data is for US and Canadian production and processing drawn from over a dozen major agricultural states and provinces. In addition, the database includes: food production data for Europe and other parts of the world; data for all energy sources including electricity by grid regions; all common freight transport modes used for food products, including refrigerated transport; and refrigerators/freezers used for food storage in distribution and retail locations. FoodCarbonScope and CarbonScopeData have been used previously in major LCA studies of North American food systems

(Hamerschlag and Venkat, 2011; Venkat, 2012).

Each of the 134 food commodities is mapped to one or more food production systems in the LCI database for the purposes of this study. Most of the high-volume commodities – including beef, pork, chicken, fish, some dairy, common nuts and legumes, and several fruits and vegetables – are modeled as the average of two or more representative production systems in North America. Most of the other commodities are modeled using the closest available North American production system in the database, with the exception of tropical fruits and tuna which are modeled using overseas production systems.

2.4 LCA Goal and Scope Definition

The goal of the LCA portion of this study is to assess the climate change impact of the food wasted in the US on an annual basis. The functional unit for the LCA of each food commodity is the actual annual quantity consumed in the United States as calculated from USDA ERS (2009). This in turn requires a higher quantity of production, and the difference between the two quantities determines the wasted food.

The spatial boundary for the LCAs of the food commodities is cradle to grave. This starts with extraction of raw resources from the ground and ends with the disposal of uneaten food. The system boundary includes the production, processing and packaging of food products, transport and storage through typical distribution networks, storage at retail locations, and landfilling of waste. Disposal methods are discussed further under Other Assumptions. Food production and processing are generally assumed to occur within the United States, except for specialty items such as tropical fruits and tuna which are imported. Food waste is considered at the distribution, retail and consumer levels for which data exist, but not at the farm or processing level (USDA ERS, 2009). Certain food processing steps are excluded where the data are in terms of the primary ingredients only, as explained further under Other Assumptions.

All energy used at the consumer level – including shopping trips, refrigeration and cooking – is excluded from this analysis because of uncertainties and lack of adequate data. Therefore, the total climate change and economic impacts of food waste as calculated in this study represent conservative lower bounds on the actual impacts.

The temporal boundary consists of one year of production and consumption based on 2009 data. The assessment period for the LCAs is 100 years, meaning that the climate change impact of one year's food waste is evaluated over the standard 100-year time horizon in this study. This is particularly important for the calculation of long-term emissions from landfills due to food waste deposited in any one year (BSI Group, 2008; IPCC, 2006).

2.5 Other Assumptions

The food waste analysis undertaken in this study considers the entire US food system, which necessitates a number of reasonable assumptions. These assumptions are listed below, and a critical subset of the assumptions is subjected to a sensitivity analysis as described in the Results and Discussion section.

- The vast majority of the food consumed in the US is assumed to be produced in North America, except as indicated below. This is justified by the fact that nearly 99% of GHG emissions from the provision of food in the US are due to domestic production and value chain activities (Stolaroff, 2009).
- All meat product weights are boneless-equivalent (edible) weights as specified in the food availability data (USDA ERS, 2009).
- All fish and shellfish are assumed to be produced in North America through aquaculture. Tuna is wild caught in Europe and imported to the US.
- Typical food processing is included for all commodities that are listed in their processed forms in the food availability data (USDA ERS, 2009). Examples of such processed foods include fruit juices, canned and frozen vegetables and fruits, canned tuna, various meats and fish, milled flour, etc. About half of the 134 commodities in this study are processed in some way before entering the distribution stage. On the other hand, some commodities are listed in the data only in terms of the primary ingredients – additional processing steps are excluded from our analysis in such cases. These commodities mostly include processed grain products such as breakfast cereals, pasta and bread, which are listed in terms of the primary grains and flour.
- All fresh foods are stored (in refrigerators, freezers or otherwise) in distribution centers and retail stores for an average of 7 days before purchase.
- All food commodities are assumed to be transported an average of 2400 km within North America from production or processing locations to typical retail locations. Out of this, 2240 km are through semi-trailer trucks and 160 km through single-unit trucks. Tropical fruits are transported an additional 5000 km by ocean, and canned tuna is transported an additional 10,000 km by ocean. All transport modes include refrigerator or freezer compartments as needed.

- Two-thirds of all meat and fish is distributed frozen and the rest is distributed fresh.
- Fresh meat, fresh fish, dairy, fruits and vegetables are assumed to require refrigeration throughout the distribution and retail stages. (While some fruits and vegetables may not be refrigerated for certain periods at the retail stage, almost all are refrigerated during distribution.)
- Food packaging materials and configurations for meat and fish products are based on commercial packaging information from Sealed Air (2011). All other commodities – including dairy, vegetables, fruits, nuts, grains, oils, and juices – are assumed to be packaged in typical materials and configurations as found in retail stores. In the case of grains, the food availability data (USDA ERS, 2009) are in terms of the primary grains and flour produced and consumed, but not in terms of final processed products such as breakfast cereals or pasta. In such cases, the packaging assumptions apply to the forms of the food commodities found in the data.
- All solid waste from wasted food is assumed to be landfilled under typical US conditions in anaerobic landfills, with 21% of the landfill methane flared and 23.25% of the methane recovered for electricity (EPA, 2006). The landfills are assumed to be distributed equally in Boreal temperate wet and dry climate zones as defined by the IPCC (2006). Long-term carbon storage in the waste matter present in landfills offsets a small portion of the final emissions. (Based on recent data from the US Environmental Protection Agency (EPA, 2010), it appears that about 87% of the US food waste is landfilled. As of 2009, only 2.5% of food waste was composted. While 10.7% of general municipal waste was incinerated in 2009 (EPA, 2010), there is no explicit data available on the portion of food waste incinerated. Given this lack of data and the dominant role of landfilling, we use landfilling to model all food waste disposals.)
- Fluid milk and juice products are assumed to be disposed through waste water which is then treated in an anaerobic reactor. Energy used in waste water processing comes from US average grid electricity.

2.6 Calculating the Economic Impact of Wasted Food

The economic impact of avoidable food waste is calculated in this study using current US retail prices for all the food commodities. The retail price of a commodity reflects all the value added throughout the value chain – including agriculture, processing, packaging, distribution and retail – and provides a very good measure of the total economic value embedded in the commodity as delivered to consumers. Therefore, retail prices are used to uniformly calculate the economic impact of all avoidable food waste occurring after the production/processing stages – specifically waste at the distribution, retail and consumer levels.

The US Department of Agriculture provides current national retail prices for most meats, eggs, vegetables and fruits (USDA AMS, 2011; USDA ERS, 2011). Prices for the other commodities are based on current advertised prices at a major online food retailer (Safeway, 2011). While the food waste data is for the year 2009, all retail prices used in this study are as of December 2011 because a complete set of 2009 prices is not readily available.

Most of the food waste is generally landfilled, as assumed in this study. The typical cost structure for municipal solid waste collection and disposal in North America is a flat rate for a fixed volume of waste (Rosenberg, 1996), which makes it difficult to quantify the real disposal cost of a marginal increase or decrease in the quantity disposed. Therefore, disposal cost is excluded from our calculation of the economic impact of food waste. It should also be noted that disposal costs are likely to be negligible compared to the retail prices of the wasted quantities.

3 Food Waste Data

The loss-adjusted food availability data series from the US Department of Agriculture (USDA ERS, 2009) is the basis for the food waste analysis in this study. The USDA maintains the sole national database of food availability and food loss data in the US. The data series provides annual per-capita food production, waste and availability data for a full spectrum of food commodities in the United States, adjusted for food spoilage and other losses to closely approximate per-capita intake. Food waste is further broken down into waste at the distribution, retail and consumer levels. The US population estimate for 2009 (US Census Bureau, 2011) is used to convert the annual per-capita data for all commodities into national aggregate data.

This study uses the most recent year in the food availability data series, which is 2009 as of this writing, and analyzes a total of 134 commonly consumed food commodities accounting for most of the food consumed in the US. These commodities include common meats, fish, shellfish, dairy products, oils and fats, eggs, sweeteners, nuts, legumes, grains, vegetables, fruits, and fruit juices. Note that this data is for a very recent year compared to the 1995 data used by Cuellar and Webber (2010).

Table 2 summarizes the annual aggregate food production, consumption and avoidable waste data for the major food commodity categories as derived from the food availability data (USDA ERS, 2009). Waste at the consumer level has been adjusted to remove the unavoidable waste in consumed foods as per the food waste model defined in the Methods section. The result is the *avoidable* consumer waste (defined by Equation 3) and includes both the edible and non-edible portions of foods available at the retail level that are not consumed.

All quantities in Table 2 are in millions of metric tonnes (MMT) per year. Using this data, our total estimate of avoidable food waste in the US is 55.41 MMT/year for 2009, which amounts to 28.7% of total annual production by weight. This translates to 180 kg/year of total avoidable waste on a per-capita basis – this is less than the 280-300 kg/year reported for Europe and North America by Gustavsson et al. (2011) because it excludes both production losses and the unavoidable consumer waste. Consumer waste dominates the total waste, accounting for just over 60% of the total avoidable waste. Per-capita consumer waste is 110 kg/year, which is within the 95-115 kg/year range estimated for Europe and North America by Gustavsson et al. (2011). Retail waste – including waste in institutional food service – amounts to 34% of the total. Figure 2 illustrates this in terms of absolute quantities (MMT), and Figure 3 depicts the same data as percentage of food wasted in each category.

Table 2.
US annual food production, consumption and avoidable waste in 2009 (MMT/year)

Category	**Production P**	**Consumption C**	**Distribution Waste** W_d	**Retail Waste** W_r	**Avoidable Consumer Waste** W_c	**Total Avoidable Waste** W_a
Beef	8.09	5.26	0.00	0.35	0.72	1.07
Pork	6.48	3.78	0.00	0.28	1.16	1.44
Chicken	7.80	4.50	0.00	0.31	1.42	1.73
Other Meats	1.95	1.27	0.00	0.08	0.14	0.21
Fish & Shellfish	1.98	1.29	0.00	0.17	0.25	0.42
Cheese	4.90	3.93	0.00	0.33	0.64	0.97
Milk & Yogurt	26.47	18.63	0.00	3.18	4.66	7.84
Other Dairy	5.70	4.18	0.00	0.62	0.90	1.52
Butter, Fats & Oils	10.88	7.23	0.00	2.08	0.87	2.95
Eggs	4.48	2.93	0.07	0.40	0.40	0.86
Sweeteners	18.00	12.82	0.00	1.98	3.20	5.18
Nuts	1.28	1.08	0.00	0.08	0.12	0.20
Legumes	0.96	0.81	0.00	0.06	0.09	0.15
Grains	27.02	18.89	0.00	3.24	4.89	8.13
Vegetables	37.60	21.91	1.95	2.96	8.72	13.63
Fruits & Juices	29.48	17.59	0.90	2.65	5.56	9.11
Total	193.10	126.13	2.92	18.76	33.73	55.41

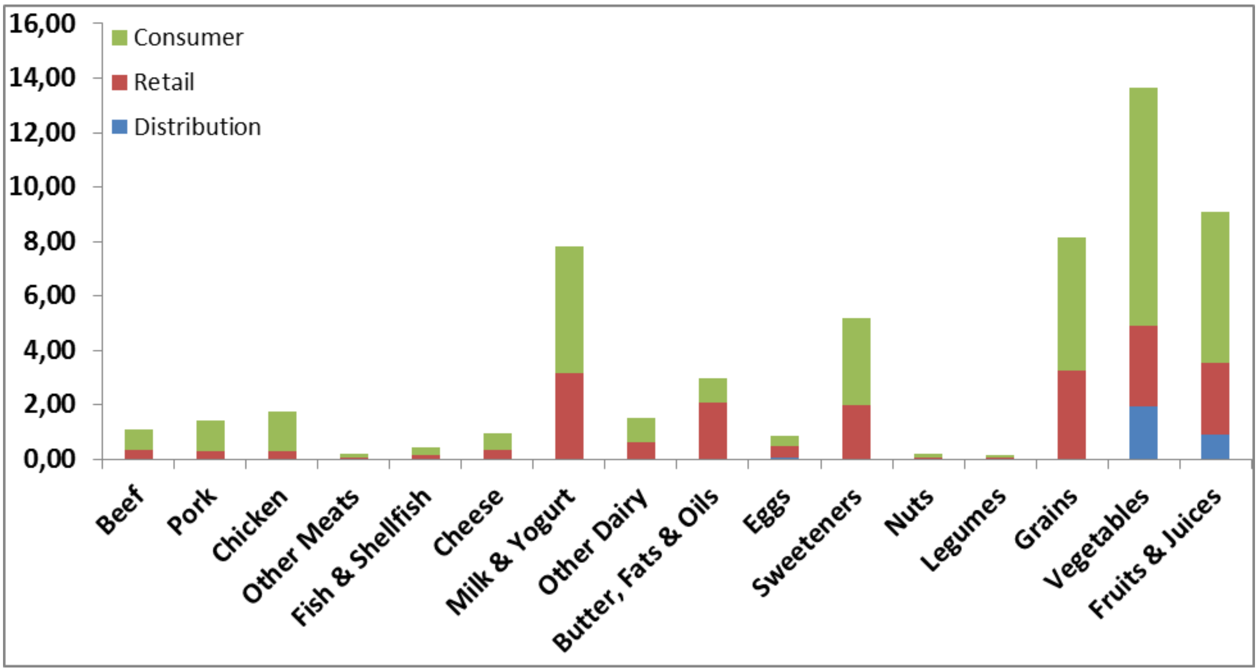

Figure 2. US annual avoidable food waste in 2009 (MMT/year)

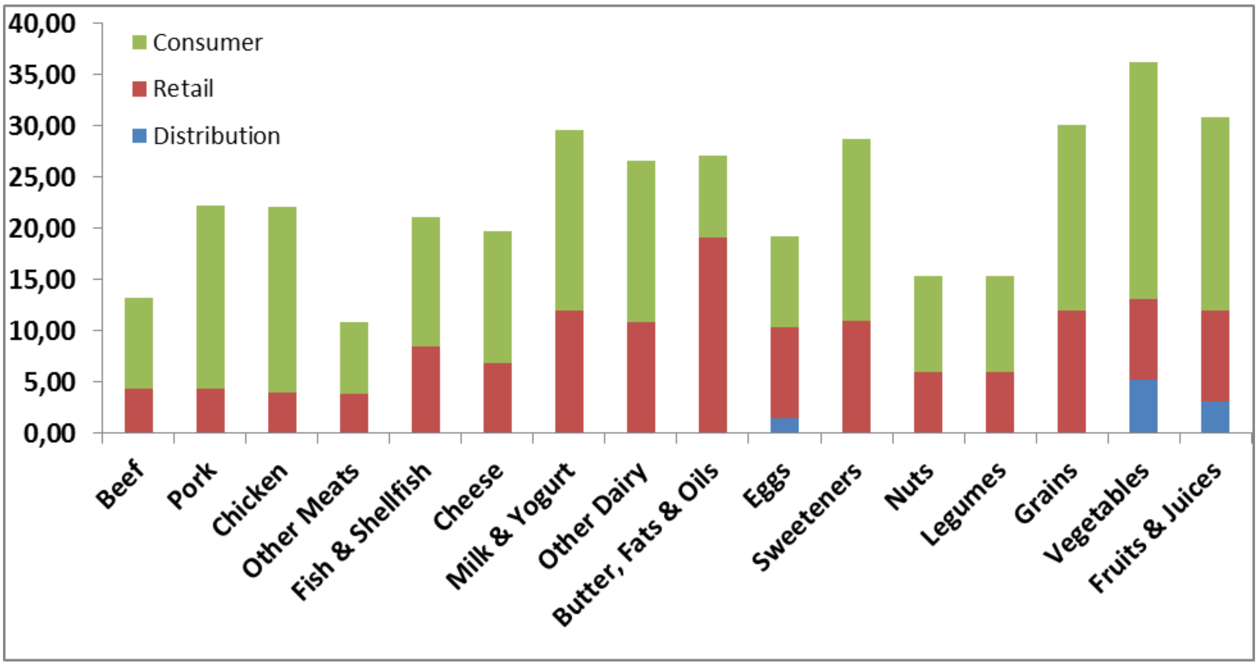

Figure 3. US annual avoidable food waste in 2009 as percentage of production

4 Results and Discussion

4.1 Climate Change Impact of US Food Waste

Table 3 summarizes the results of the LCA portion of this study and shows the GHG emissions due to avoidable waste throughout the life cycles of food commodities. The total emissions from all stages are presented as both aggregate national emissions and per-capita emissions. Figure 4 illustrates the national emissions graphically. The emissions are reported in carbon dioxide equivalents (CO2e).

Table 3.
GHG emissions from avoidable US food waste in 2009 (MMT CO2e/year for all emissions, except per-capita emissions in Kg CO2e/year)

Category	Production + Processing Emissions	Packaging Emissions	Distribution + Retail Emissions	Disposal Emissions	Total National Emissions	Total Per capita Emissions
Beef	17.27	0.10	0.32	0.34	18.03	58.74
Pork	7.12	0.13	0.43	0.45	8.13	26.49
Chicken	6.17	0.16	0.52	0.54	7.38	24.05
Other Meats	1.33	0.02	0.06	0.07	1.48	4.82
Fish & Shellfish	2.37	0.05	0.12	0.14	2.68	8.72
Cheese	8.60	0.23	0.24	0.34	9.40	30.63
Milk & Yogurt	6.89	1.72	1.89	0.20	10.70	34.84
Other Dairy	2.04	0.35	0.45	0.53	3.37	10.98
Butter, Fats & Oils	5.11	0.49	0.65	1.02	7.26	23.66
Eggs	1.82	0.14	0.21	0.29	2.47	8.03
Sweeteners	2.15	1.04	1.13	1.81	6.12	19.94
Nuts	0.20	0.01	0.04	0.07	0.33	1.06
Legumes	0.11	0.01	0.03	0.05	0.20	0.67
Grains	5.82	0.57	1.68	2.83	10.91	35.53
Vegetables	5.67	0.72	3.23	4.75	14.37	46.81
Fruits & Juices	4.79	0.50	2.11	2.68	10.08	32.84
Total	**77.46**	**6.23**	**13.12**	**16.11**	**112.92**	**367.82**

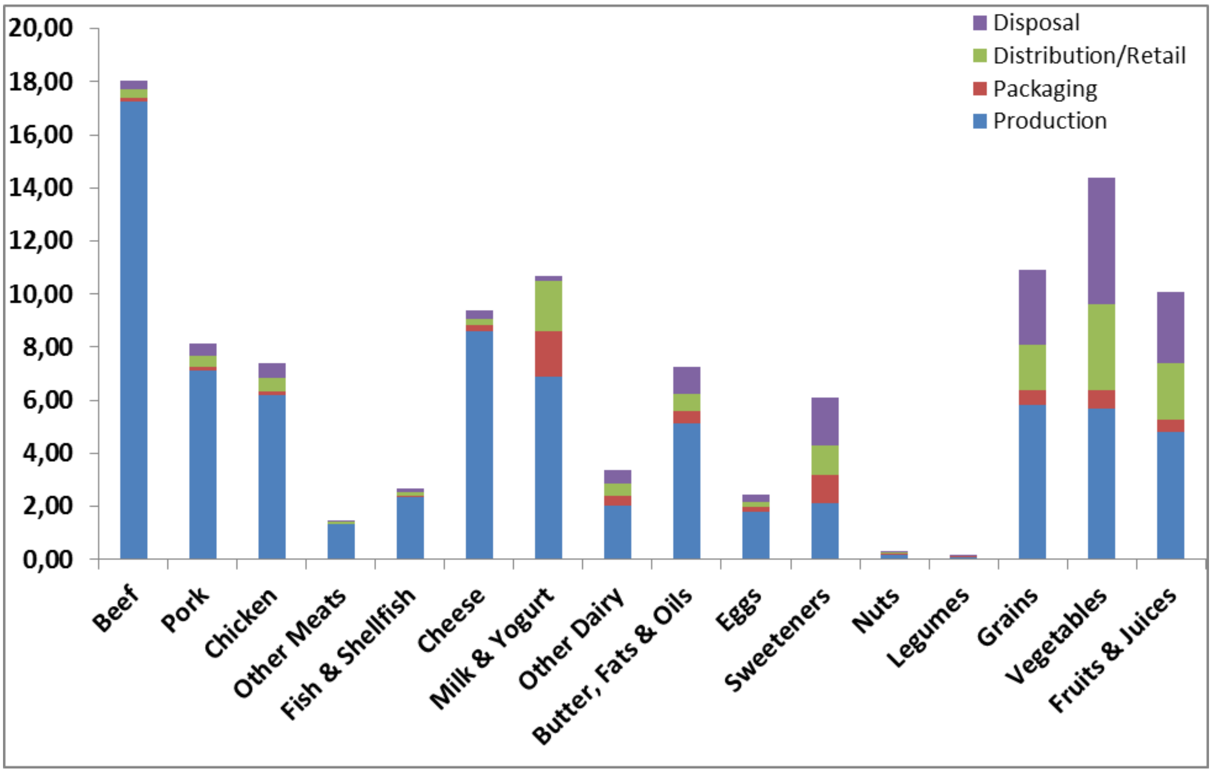

Figure 4. US national GHG emissions from avoidable food waste in 2009 (MMT CO2e/year)

Beef – accounting for 16% of the total emissions – is the single largest contributor to the emissions from wasted food, even though the quantity of beef wasted amounts to less than 2% of the total waste by weight. This is because of the high emissions intensity of beef (Hamerschlag and Venkat, 2011). Animal products have a disproportionate climate change impact because of their relatively high emission footprints. They make up about 30% of all wasted food by weight, but account for nearly 57% of the emissions. On the other hand, grains, vegetables and fruits make up 56% of the waste, but contribute just 31% of the emissions due to their relatively low emission footprints.

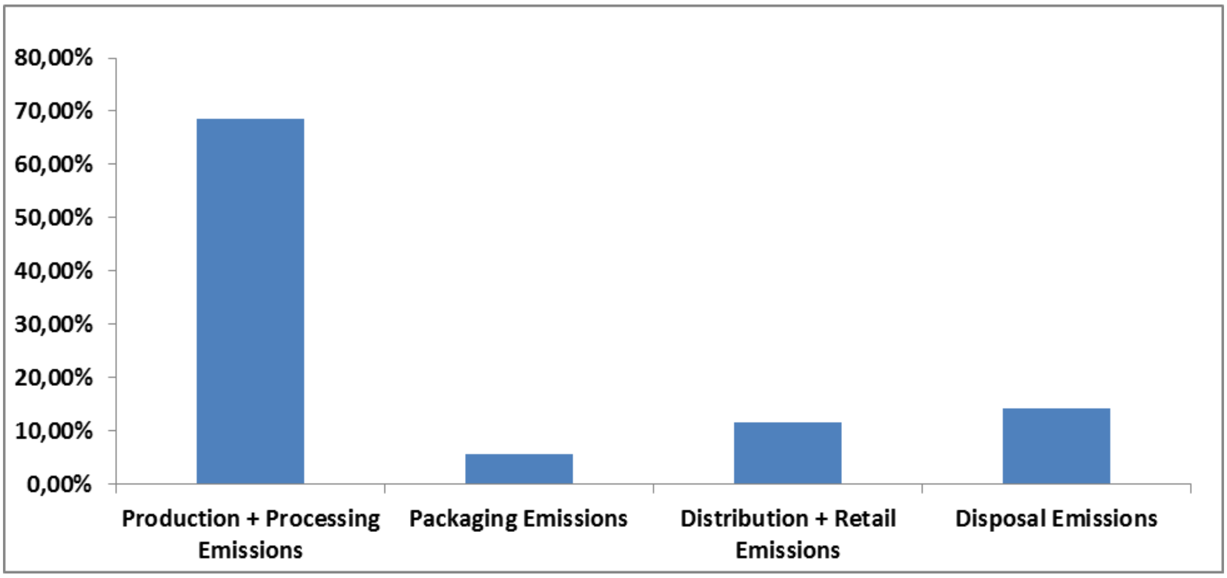

Figure 5. Components of US national GHG emissions from avoidable food waste in 2009

Figure 5 shows that the wasted GHG emissions are dominated by the production and processing emissions which account for 68.6% of the wasted emissions. The total emissions from the production, processing, packaging, distribution, retail and disposal of the avoidable food waste in the US amounts to 112.9 MMT CO2e per year. These emissions are equivalent to 2% of net US GHG emissions for 2009 based on the national emissions inventory published by the US Environmental Protection Agency (EPA, 2011). Note that these emissions represent a conservative lower bound on the actual emissions attributable to food waste, since all energy used at the consumer level – for example, in shopping trips, refrigeration and cooking – has been excluded from this analysis.

4.2 Economic Impact of US Food Waste

The economic impact of the wasted food is considerable. Using 2011 retail prices, the avoidable food waste (for the year 2009) has a total retail value of $197.7 billion, as shown in Table 4 and Figure 6. Out of this, the consumer waste alone amounts to $124.1 billion, which is nearly 63% of the total retail value of wasted food. Using the 2009 US population estimate of 307 million (US Census Bureau, 2011), the per-capita retail value of total avoidable waste is $643.95 per year. The avoidable consumer waste portion of this works out to about $1600 per year for a family of four. This suggests a promising opportunity to motivate consumers to reduce waste, which would yield additional dividends by way of lower emissions. Retail waste – including waste in institutional food service – is valued at $64.6 billion, which shows that businesses and organizations also have much to gain by reducing waste. The economic value reported here is a conservative lower bound because the cost of consumer-level energy use and the cost of waste disposal are not included.

Table 4.
Retail values of US avoidable food waste in 2009 using 2011 prices (billions of dollars per year for all waste, except per-capita waste in dollars per year)

Category	Value of Distribution Waste	Value of Retail Waste	Value of Avoidable Consumer Waste	Total National Value of Avoidable Waste	Total Per-capita Value of Avoidable Waste
Beef	0.00	3.45	7.09	10.54	34.35
Pork	0.00	2.57	10.53	13.10	42.66
Chicken	0.00	1.86	8.52	10.38	33.81
Other Meats	0.00	0.94	1.60	2.54	8.28
Fish & Shellfish	0.00	2.94	4.42	7.37	23.99
Cheese	0.00	3.44	6.64	10.08	32.82
Milk & Yogurt	0.00	3.46	5.07	8.54	27.80
Other Dairy	0.00	3.26	4.76	8.02	26.14
Butter, Fats & Oils	0.00	9.26	3.93	13.19	42.95
Eggs	0.06	0.36	0.36	0.78	2.53
Sweeteners	0.00	6.75	10.92	17.67	57.56
Nuts	0.00	1.07	1.68	2.76	8.98
Legumes	0.00	0.28	0.45	0.73	2.38
Grains	0.00	6.78	10.46	17.24	56.17
Vegetables	5.67	10.76	32.56	48.99	159.57
Fruits & Juices	3.24	7.42	15.12	25.78	83.96
Total	**8.97**	**64.62**	**124.11**	**197.70**	**643.95**

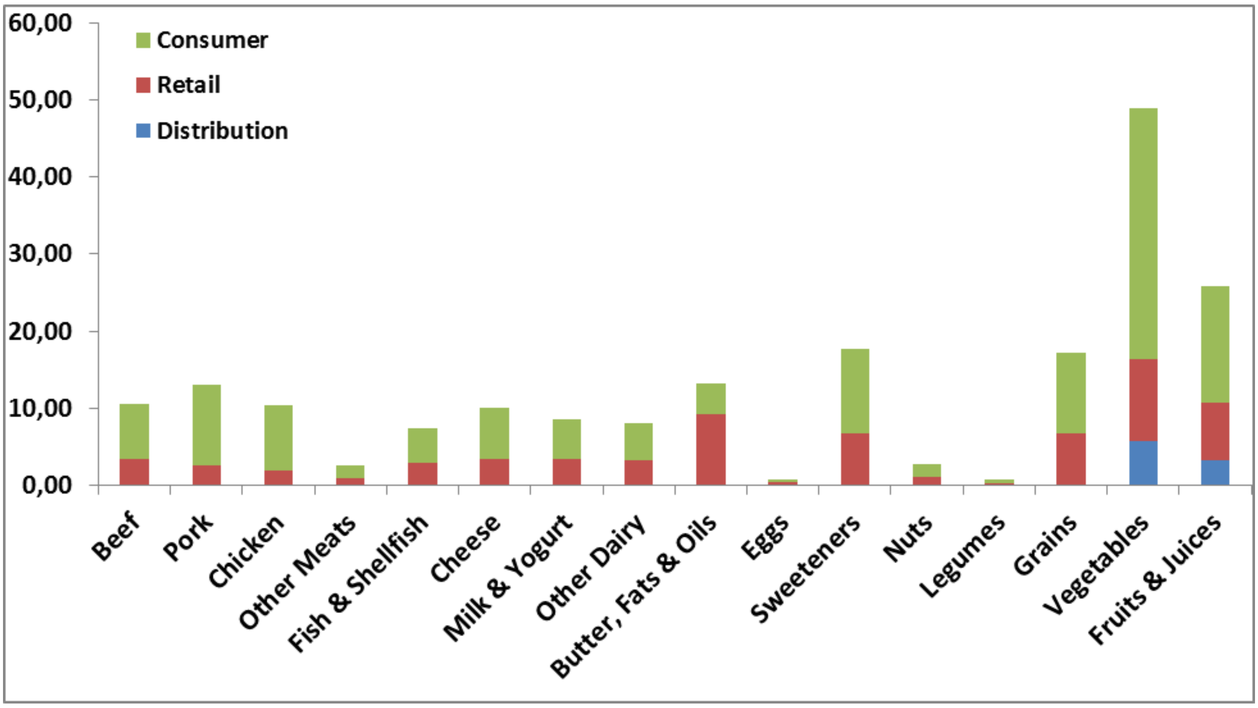

Figure 6. Retail values of US national avoidable food waste in 2009 using 2011 prices (billions of dollars)

Animal products have a more moderate influence on economic impact (in contrast to the climate change impact). They account for about 37% of the economic impact, only about seven percentage points above their contribution to the total waste. Grains, vegetables and fruits account for 47% of the economic impact, about nine percentage points below their contribution to the waste.

4.3 Sensitivity analysis

Sensitivity analysis is a necessary part of any modeling endeavor. It is used to test the robustness of conclusions to uncertainties in assumptions (Sterman, 2000). Of the different types of sensitivities that models exhibit, numerical sensitivity to parametric assumptions and estimates is important for LCA models and is routinely tested in LCA studies (Dalgaard et al., 2008; Pelletier et al., 2010).

The results presented in the previous subsections have been tested for sensitivity to parameters in four major areas: transport distances, storage time in distribution and retail, portion of consumer waste occurring after cooking (this is referred to in the following discussion as the post-cooking waste), and the fat/moisture losses in cooking. Baseline values for these parameters have been defined in the Methods section. The sensitivity analysis varies these four parameters uniformly one at a time (univariate testing) for all commodities as follows:

- Transport distance from production to retail: +50% and -50% relative to the baseline values of 2400 km domestic transport plus 5000-10,000 km of ocean transport for imported commodities
- Storage time in distribution and retail: +50% and -50% relative to the baseline value of 7 days
- Post-cooking consumer waste fraction: +50% and -50% relative to the baseline value of 0.5 (i.e., half of the consumer waste occurs after cooking)
- Fat/moisture loss fractions: +25% and -25% relative to the baseline values in Table 1

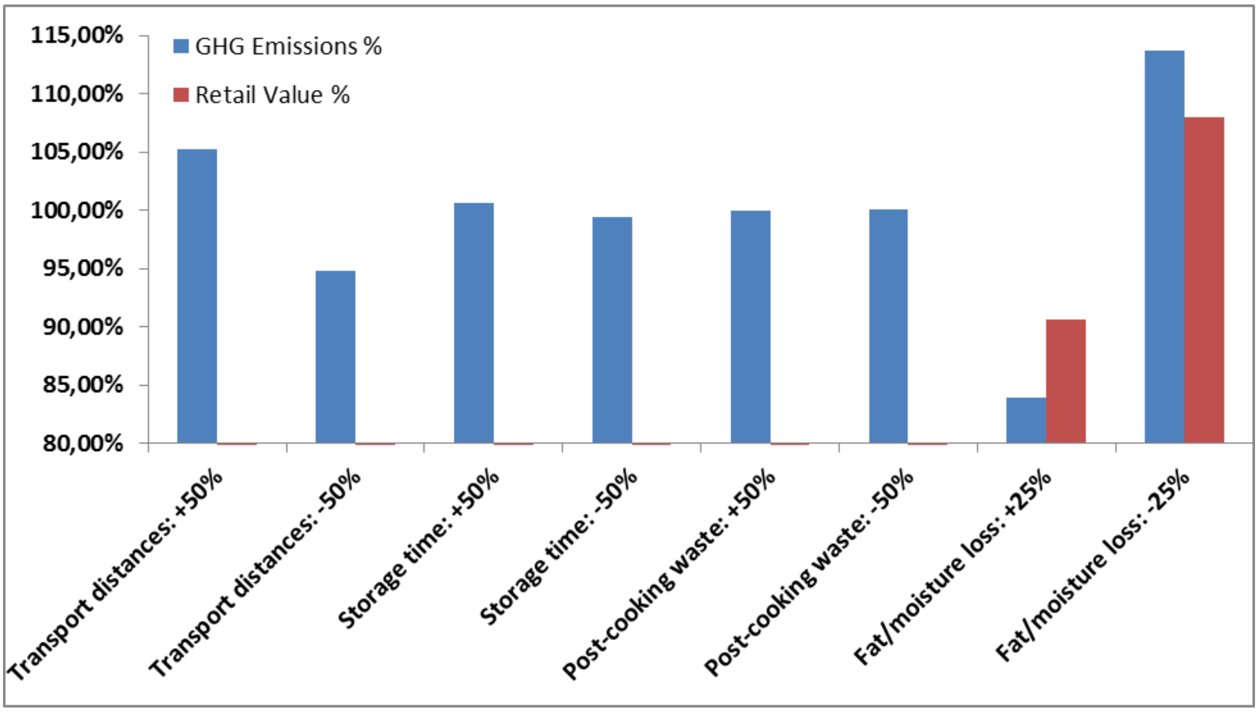

Figure 7. Sensitivities of results to parametric assumptions and estimates

Figure 7 summarizes the sensitivities to parametric variations of two key results: (1) total GHG emissions from all avoidable waste; and (2) total retail value of all avoidable waste. The sensitivity analysis considers the effect of all four selected parameters on total GHG emissions, and the effect of only the last parameter (fat/moisture loss fraction) on total retail value. While variations in transport distance and storage time will ultimately affect the retail price to some extent, those sensitivities could not be tested because economic values used in this study are not model-generated but instead taken directly from other sources (USDA AMS, 2011; USDA ERS, 2011; Safeway, 2011). In contrast, GHG emissions from all life-cycle stages have been computed based on the life-cycle model described in Section 2.1 and therefore amenable to a more complete sensitivity analysis.

As the transport distances are varied between +50% and -50% relative to baseline values, the total GHG emissions vary by +/-5.2%, indicating that the results exhibit only mild sensitivity to this parameter. For storage times and post-cooking consumer waste, as the parameters are varied in the +/-50% range, the GHG emissions vary by less than 1%, indicating virtually no sensitivity to these parameters.

As fat/moisture losses are varied in the +/-25% range, the total GHG emissions from avoidable waste vary between -16.1% and +13.7%. The total retail value of the waste varies between -9.4% and +8%. This suggests that sensitivity to the fat/moisture loss estimates is significant. As fat/moisture losses increase, correspondingly more of the consumer level waste must be attributed to the unavoidable waste from the cooking of consumed foods. The reverse is true as fat/moisture losses decrease. Since cooking methods for foods such as meats, fish and eggs – and the corresponding fat/moisture losses – can vary considerably, it is reasonable to expect that the GHG emissions attributable to avoidable waste might have an uncertainty of up to +/-20% and the retail value might have an uncertainty of up to +/-15%.

5 Conclusions

This study has presented, for the first time, a comprehensive analysis of both the climate change and economic impacts of food waste in the US. Using the loss-adjusted food availability data from the US Department of Agriculture (USDA ERS, 2009) for 2009, this study has applied a rigorous life cycle assessment methodology to calculate the annual life-cycle GHG emissions, which quantify the climate change impact of food waste. The annual economic impact of the waste has been calculated using recent retail prices for food commodities. The analysis is based on life-cycle modeling and analysis of 134 distinct food commodities accounting for most of the food consumption in the US, most of which are produced in North America (except for tropical fruits and tuna).

The food waste model – developed specifically to fit the USDA ERS (2009) food availability data – uses a mass balance method to account for all material flows and adjusts the waste at the consumer level so that only the avoidable waste due to uneaten food is considered in the final analysis.

The total avoidable food waste at the distribution, retail and consumer levels amounts to over 55 MMT/year, representing nearly 29% of annual production by weight. Over 60% of this waste occurs at the consumer level. The production, processing, packaging, distribution, retail and disposal of this wasted food results in GHG emissions of at least 113 MMT CO2e/year, which is equivalent to 2% of US national emissions. Beef is the single largest contributor to this, producing 16% of all wasted emissions, because of its high emissions intensity. All animal products together contribute 57% of the wasted emissions, even though they make up only 30% of the waste by weight. Over two-thirds of the emissions occur in the production and processing of food commodities.

There is a considerable economic cost to this waste. US businesses and consumers lose as much as $198 billion per year because of wasted food. Consumer waste alone amounts to $124 billion, or nearly 63% of the total value, which works out to about $1600 per year for a family of four. The annual cost to businesses and organizations at the retail level is nearly $65 billion. There is a promising opportunity here to show both consumers and businesses that they have much to gain by reducing waste. Waste reduction can save money as well as reduce emissions.

The total GHG emissions and economic value of food waste reported in this study represent conservative lower bounds, since the analysis ignores all energy used at the consumer level as well as the cost of waste disposal. These emissions are also subject to an uncertainty of up to +/-20% due to cooking assumptions. The economic value of the waste reported here is subject to an uncertainty of up to +/-15%.

The modeling and analysis presented here can be extended in the future in several areas using the analytical framework established in this study. By modeling cooking processes in more detail, the uncertainty bands can be tightened significantly. By including the consumer-level energy use attributable to food waste – due to shopping trips, refrigeration and cooking, using real-world data – the climate change and economic impacts can be made more realistic. Consideration of the water footprint, land use and other resource uses attributable to the wasted food would add further value to the analysis and results. Finally, the methodology developed in this study can be used to monitor the environmental and economic impacts of food waste on an ongoing basis, not only within the US but also for other regions of the world.

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