Estimating Energy and Greenhouse Gas Emission Savings through Food Waste Source Reduction

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ABSTRACT

To help advance the source reduction of food waste in the U.S. municipal solid waste (MSW) stream, ICF International is working with the U.S. Environmental Protection Agency to develop life-cycle energy and greenhouse gas (GHG) emission factors for food waste to compare the impacts of source reduction and disposal options for common food waste types in the U.S. MSW stream. ICF has developed cradle-to-retail source reduction energy and GHG emissions factors as part of EPA's Waste Reduction Model (WARM) for four food waste types: grains, bread, fruits and vegetables, and dairy products. These factors are expected to have broad appeal across the food service, restaurant, and materials management industries and governmental organizations and are expected to be used as part of EPA's Food Recovery Challenge to encourage reduction and recovery of food waste.

Keywords: food waste, greenhouse gases, source reduction, organics

1. Introduction

In 2012, food waste was the largest single component in the U.S. municipal solid waste (MSW) stream, comprising over 21% of MSW discards my mass (U.S. EPA 2014a). The U.S. Environmental Protection Agency's (EPA) food recovery hierarchy identifies source reduction as the most preferred method for addressing food waste (U.S. EPA 2014b). In the context of MSW, source reduction is defined as the reduction of waste generation at its source by means of altering the waste generation source (e.g., via more efficient consumer use of materials, reuse, or improved product design). In the case of food waste, source reduction refers to upstream reductions in food production. It can result from any activity (e.g., lowering consumption, reducing food spoilage, avoiding disposal of uneaten food) that reduces the amount of an agricultural input needed and therefore used to make food. As a result, there is demand for a simple tool allowing waste managers, food service managers, and other stakeholders to estimate the energy and greenhouse gas (GHG) emissions avoided through food waste source reduction. To help meet this demand, ICF International worked with EPA to develop life-cycle energy and GHG emission factors for food waste to compare the impacts of source reduction and other disposal options for common food waste types in the U.S. MSW stream using EPA's Waste Reduction Model (WARM).

EPA created WARM to help solid waste planners and organizations track and voluntarily report GHG emissions reductions from several different materials management practices. WARM calculates and totals the relative GHG emission and energy impacts of baseline and alternative materials management practices—source reduction, recycling, combustion, composting, and landfilling—using GHG emission factors that EPA has developed based on a materials life-cycle approach. ICF has provided EPA with ongoing support for the development of life-cycle emission factors and in the development of and updates to WARM since its creation.

WARM currently models life-cycle GHG impacts for over 50 material types. Prior to the development of the energy and GHG factors described in this paper, WARM included a general "food scraps" waste category representative of national average food waste composition. For the "food scraps" category, WARM modeled energy and GHG impacts from three end-of-life pathways—landfilling, combustion, and composting—but did not consider GHG emissions associated with raw materials acquisition, transportation, and processing of food products before they enter the U.S. MSW stream. Therefore, it was not possible to use WARM to estimate the energy and emissions avoided through reduced production of food, also known as source reduction.

To better understand and reduce the impacts from this growing waste stream, ICF worked with the EPA to expand WARM by developing life-cycle energy and GHG emission factors for food waste to include cradle-to-retail upstream energy and emission factors for four of the largest food waste types in the U.S. MSW stream (bread, grain products, dairy products, and fruits and vegetables) and a weighted average for mixed food waste. This paper summarizes the methods and results for developing the factors for these food waste types suitable for inclusion within the existing scope and boundaries of WARM.

2. Methods

When a food product is source reduced, GHG emissions associated with producing and transporting the product and managing the production and post-consumer waste are avoided. Consequently, source reduction of food waste provides GHG emission benefits by: (1) avoiding the "upstream" GHGs emitted in the raw material acquisition, manufacture, and transport of the source-reduced material; and (2) avoiding the downstream GHG emissions from waste management. This paper describes the development of energy and GHG emission factors to estimate the avoided upstream GHG emitted in the raw material acquisition, manufacture, and transport of source-reduced food waste using a methodology consistent with existing WARM factors.[1]

2.1. Scope and Boundaries

Food waste types to be modeled in WARM were selected based on: (1) their usefulness and practicality to WARM users; (2) the share of total U.S. food waste the materials would individually and collectively comprise; (3) the availability of relevant, high-quality LCI data; and (4) the practicality of emission factor development. U.S. Department of Agriculture (USDA) Economic Research Service (ERS) loss-adjusted food availability data from 2010 were used to determine the food types constituting the largest share of the U.S. MSW stream (USDA 2012b). As summarized in Table 1, ICF evaluated the share of food waste generated in the United States for five food groups: grain products, fruits and vegetables, red meat, poultry, and dairy products. For each of these groups, ICF chose to model one or more food types that would cumulatively represent at least half of the waste generated for that group. This paper presents the methods for developing source reduction factors only for the basic categories of grains, fresh fruits and vegetables, and dairy. Future work will address source reduction factors for beef and chicken.

Table 1. Share of Total 2010 U.S. Food Waste Stream Represented by Materials Modeled in WARM.

Food types modeled in WARM		**Share of U.S. food waste in 2010**	**Share of weighted average food type in WARM**
Grains	Wheat	5.3%	68.3%
	Corn	1.3%	16.8%
	Rice	1.2%	14.9%
	Total	*7.8%*	*100%*
Fruits and vegetables	Potatoes	8.1%	27.5%
	Tomatoes	7.9%	27.0%
	Citrus	6.1%	21.0%
	Melons	2.7%	9.3%
	Apples	2.4%	8.2%
	Bananas	2.0%	6.9%
	Total	*29.3%*	*100%*
Red meat	Beef	5.5%	100%
Poultry	Chicken	6.5%	100%
Dairy	Fluid milk	7.3%	60.3%
	Cheese	1.2%	12.0%
	Yogurt	0.6%	5.4%
	Other dairy	1.6%	22.3%
	Total	*10.9%*	*100%*
All food materials modeled in WARM		61.4%	

Source: USDA 2012b.

The scope of the food waste source reduction energy and emission factors included in WARM is cradle-to-retail, meaning that the factors include the upstream impacts of all unit processes prior to retail storage and consumer use. The main GHG emission sources considered in the source reduction factors include: (1) the upstream production of agricultural inputs, such as fertilizer, irrigation, livestock feed, and fuel; (2) on-farm energy use; (3) on-farm non-energy emissions, including fertilizer application, manure management, and enteric fermentation; (4) some energy from food processing, depending on food type; (5) energy use and fugitive emissions from refrigeration during processing and transport of some materials; and (6) retail transportation energy. In order to

[1] Full documentation for existing WARM factors is available at http://www.epa.gov/warm.

maintain consistency with other material categories in WARM, the impacts of consumer transport and material use are not included. Furthermore, these downstream emissions are outside the scope of "source reduction" as defined by the U.S. EPA.

Several key exclusions from the scope include: (1) infrastructure and capital equipment; (2) induced land-use change; (3) production, use, and end-of-life management of packaging materials; (4) energy use, fugitive refrigerants, and food loss rates at retail locations; and (5) consumer transport, refrigeration, and energy use for cooking. In most cases, these exclusions were made to ensure consistency with existing WARM energy and GHG emission factors or because impacts were considered negligible. WARM includes energy and GHG emission factors for the production and disposal of most common food packaging materials, including corrugated cardboard, other paper types, plastic resins, and glass. Packaging material wastes and food wastes are commonly managed using different waste management pathways (e.g., recycling of paper, plastics, and glass). Therefore, this aspect of the food life cycle was excluded from the food waste energy and GHG emission factors in order to avoid redundancy between the food waste factors and existing packaging material factors available within WARM and to more-accurately capture the end-of-life impacts from management of packaging materials.

Due to data limitations, certain differences in boundaries exist between the factors for different food waste types in addressing food processing. The dairy material type includes energy and GHG emissions associated with all processing steps for the main dairy-based products consumed in the United States, include additional upstream processing to freeze or otherwise modify the flavor or texture prior to sale. The boundaries of the grains material type includes energy used for grain drying prior to product-specific processing, but exclude processing steps such as milling, packaging and cooking due to unavailability of national average grains processing data for wheat, rice, and corn. However, ICF has developed a separate source reduction factor for wheat-based bread to account for the energy and emissions associated with milling and baking. Similarly, because all of the components included in the fruits and vegetable factors can be consumed as fresh fruits and vegetables and due to the lack of data on fruit and vegetable processing, ICF has assumed that all fruits and vegetables enter the waste stream as fresh fruits and vegetables.

The material-specific food waste source reduction factors in WARM are linked to existing end-of-life factors for landfilling, combustion, and composting of general food waste to cover the full cradle-to-grave life cycle of food products. While future updates to WARM will include the development of material-specific food waste disposal factors for landfilling, combustion, and composting, the development of such factors was outside the scope of the effort described in this paper. Future updates to WARM will also include modeling the energy and GHG emissions from anaerobic digestion of food waste.

2.2. Functional Unit

The functional unit for all food waste material types is one tonne of food at end-of-life.

2.3. Data Sources and Representativeness

ICF gathered LCI data for primary and secondary inputs to production of grains, bread, fruits and vegetables, and dairy products from industry, academic, and government sources, including LCI databases. ICF assessed the scope and boundaries of each data source to identify any smaller data gaps requiring secondary data and to determine appropriate boundaries for the upstream food waste factors that are both consistent across all food waste types and consistent with existing WARM methodology. A summary of the key primary LCI data sources is provided in Table 2.

Table 2. Key Primary LCI Data Sources for Food Types Modeled in WARM

Food types modeled in WARM		Data Source
Grains	Wheat Corn Rice	USDA Undated.
Bread	Wheat	USDA Undated; Espinoza-Orias 2011
Fruits and vegetables	Potatoes	Ecoinvent Centre 2007.
	Tomatoes Citrus Melons Apples	UC Davis 2013.
	Bananas	Luske 2010.
Dairy	Fluid milk Cheese Yogurt Other dairy	Thoma et al. 2010.

In developing food waste energy and GHG emission factors for WARM, ICF sought to use data sources that were most representative of current, national average practices with a goal of representing the main components of the U.S. MSW stream. All primary data sources are based on data collected in 2001 or later, with most based on data from 2008-2012. In order to develop national average source reduction energy and emission factors, several key assumptions were made. First, ICF assumed that all of food types modeled would be produced in the United States, with the exception of bananas[2], and would be produced using conventional (i.e., non-organic) farming practices. Secondly, the differences in production impacts across different breeds, varieties, or types components of each food waste category were not considered in the analysis. For example, LCI data for the production of Fuji apples were assumed to be representative of all apple production in the United States. Likewise, LCI data for the farming of oranges was assumed to be representative of all citrus production due to lack of data for production of other citrus fruits and food consumption data showing that oranges comprise 65% of citrus fruits consumed in the United States in 2012 (Boriss 2013).

2.4. General Methodology

A similar methodology was applied for developing the energy and GHG emission factors for all food waste categories. Any differences in methodology are identified in each of the material-specific subsections below. In general, the emissions were calculated in two separate stages: first, energy-derived emissions were calculated by determining the cumulative energy demand for producing one kilogram of each food type. Secondly, non-energy emissions were estimated and added to the fossil fuel-derived emissions.

To estimate the energy-derived emissions, ICF calculated the cumulative energy demand for each dataset within SimaPro through the Ecoinvent version 2 cumulative energy demand impact assessment method provided in the software. This method calculated the total life-cycle energy in MJ required to produce one unit of food product and then separated the total into several categories, including: petroleum, nuclear power, biomass, natural gas, coal, and renewables. Each energy source's contribution to the total energy demand was then multiplied by the fuel-specific carbon coefficients used in WARM for all materials to determine the total energy-derived emissions associated with the production of one unit of food product. The caloric biomass energy embedded in the food products themselves were excluded from the analysis because they did not contribute to the energy-related emissions associated with their manufacture.

Non-energy emissions were calculated using a variety of methods, depending on the emissions source, the food type, and the LCI data available. A summary of non-energy emissions methodology is provided in each material-specific subsection below. For all food types, ICF utilized the IPCC Tier 1 method for managed soils to calculate the total amount of N_2O and CO_2 released from fertilizer application, run-off, volatilization, and leaching (IPCC 2006).

[2] Foreign-grown bananas were included within this assessment because they are one of the largest sources of fruit and vegetable waste within the U.S. waste stream. They were assumed to be produced in Central America using conventional farming practices due to the lack of suitable climate for their cultivation on a large scale within the United States.

Additional detail on the methodology for developing food waste source reduction energy and GHG emissions factors is provided as part of the WARM Version 13 documentation chapter for Food Waste, available at http://epa.gov/epawaste/conserve/tools/warm/SWMGHGreport.html.

2.5. Grains and Bread Methodology

The grains energy and GHG emission factors includes milling of wheat into flour but assumes that wheat flour, corn, and rice can be purchased as dried grains without further processing or cooking. The emission factor for grains may understate the upstream emissions associated with corn and rice products that have undergone further processing. Therefore, ICF developed the bread factors to supplement the grain factors by including the additional energy used to process wheat flour into bread, which is the predominant use for wheat flour (USDA 2012a).

ICF identified recent LCI data for the three grain products—wheat, corn, and rice—available in the USDA National Agricultural Library's LCA Digital Commons database. The Digital Commons database is intended to provide LCI data for use in life-cycle assessment (LCA) of food, biofuels, and a variety of other biological products. All datasets in the LCA Digital Commons database are specific to grain production in U.S. states. The LCI data from the Digital Commons datasets only provide material inputs, outputs and, processes in units of magnitude per unit of agricultural product produced without any estimates of the energy or GHG impacts associated with production. For example, the LCI data include estimates of the amount of fertilizers needed for grain production but do not include data on the energy needed to for fertilizer production or the direct GHG emissions from fertilizer application. In order to translate these values into the actual energy demand and emissions associated with agricultural production, ICF identified matching unit processes and corresponding LCI data for those materials and processes within the life-cycle software, SimaPro. The unit processes within the database are taken from the Swiss Ecoinvent version 2 database and the U.S. LCI Database. Several life-cycle unit processes from Ecoinvent use European electricity grid assumptions. Therefore, ICF updated the LCI data for these unit processes within SimaPro to utilize U.S. electricity grid assumptions using the updated US-EI database update for SimaPro prepared by EarthShift.

ICF identified the most representative and recent state-level datasets for winter wheat, corn, and rice within the Digital Commons database. Representativeness of state-level data in the Digital Commons database was determined through a National Agriculture Statistics Survey (NASS) commodity data search of the production levels of each grain on a state by state basis. Arkansas and Kansas datasets were chosen for rice and winter wheat production, respectively, because they were the largest producers of those grains. For corn, due to the similarly large shares of corn produced by both Iowa and Illinois, ICF created a weighted average from datasets from both states.

The Digital Commons LCI data assumes that the production of each of the three grains included in WARM leads to the production of one or more co-products. These co-products include corn silage, corn stover, wheat straw, and rice straw. The amount of each of these co-products produced per ton of grain ranges from 0.04 tonnes for corn silage to 0.58 tonnes for wheat straw. Rather than be treated as a waste, each co-product has an economic value and therefore should be allocated some percentage of the total energy and emissions required for grain production. In keeping with ISO 14044 standards, ICF first investigated avoiding allocation by expanding the system analyzed to include the impacts from co-product use and disposal (ISO 2006). However, due to the prohibitive time and data requirements for system expansion, ICF chose to allocate impacts to co-products in proportion to the economic value of the products. Using data from the USDA ERS Commodity Costs and Returns database, ICF determined the economic value per acre of production for corn, corn silage, rice, wheat, and wheat straw for each of the LCI data years (USDA 2013a). This provided sufficient data to determine economic allocation percentages for wheat and wheat straw. Supplementary data from a 2009 study by van der Voet et al. provided prices for corn stover, allowing us to estimate the allocation percentages for corn, corn silage, and corn stover. However, ICF was unable to find a reliable source for the economic value of rice straw. An anecdotal article cited rice straw's value at approximately \$10 to \$20 per acre, which would translate to allocation of 1 to 3% of rice production energy and emissions to rice straw (Smith 2004). Due to the lack of reliable data and the likely low economic value of rice straw, ICF allocated 100% of energy and emissions to rice grain. These allocation calculations are summarized in Table 3.

Table 3. Allocation Assumptions for Grains Co-Products

Grain	Primary Product/Co-Product(s)	Weighted Average Economic Value across LCI Data Years
Wheat	Primary product: wheat grain	96.1%
	Co-product: wheat straw	3.9%
	Total	100%
Corn	Primary product: corn grain	85.8%
	Co-product: corn silage	0.6%
	Co-product: corn stover	13.6%
	Total	100%
Rice	Primary product: rice grain	100%
	Co-product: rice straw	0%
	Total	100%

The final results for each grain were calculated by summing the energy emissions and non-energy emissions and then combining each grain into a weighted emission factor based on production in the selected states during their respective data years. From there, the three grain emission factors were combined into a final weighted emission factor based on the relative shares of each within the U.S. municipal solid waste stream. Retail transport energy and emissions were estimated with the Bureau of Transportation Statistics commodity flow survey, consistent with other materials in WARM, and are equal across the three types of grains.

Energy and GHG emissions from bread production were estimated by taking an estimate of bread production energy intensity from Espinoza-Orias et al. 2011, which contained LCI data characterizing the energy use associated with producing bread. For the purposes of this analysis, white bread was chosen as it is more common than wheat bread. The study found that wheat milling and baking, respectively, had energy demands of 0.059 kWh and 0.600 kWh per loaf of bread, which was assumed to be 0.8 kg. This equated to 2.66 MJ of cumulative energy demand to prepare one tonne of bread, of which the entirety was assumed to be taken from the national average electricity grid. To estimate the total farm-to-retail energy associated with bread, ICF summed the bread production energy emissions with those for wheat flour, but did not include corn or rice. Corn and rice were excluded from this process because the energy use data for milling and baking were based on wheat bread production and because wheat-based bread is the predominant bread category in the United States (USDA 2012a).

2.6. Fruits and Vegetables Methodology

LCI data used to develop the energy and emission factors for fresh fruits and vegetables in this memo came primarily from three sources. Data for the production of apples, melons, tomatoes, and oranges came from the University of California Cooperative Extension's (UCCE) sample cost production studies (Fake et al. 2009, O'Connell et al 2009, Stoddard et al. 2007, Wunderlich et al. 2007). These studies are intended as hypothetical guides for farmers to produce crops, and include yield projections and sample requirements for fuel, fertilizers, irrigation, and plant protection products. Data for the production of bananas was acquired from a 2010 LCA conducted by Soil and More International, on request of the Dole Food Company (Luske 2010). The banana LCA study characterizes the cradle-to-retail GHG emissions associated with banana production in Costa Rica and retail in Western Europe. In developing the source reduction energy and emission factors, ICF used supplementary data to model international shipping and retail transport to the United States. Lastly, the data for potato production was acquired from the Ecoinvent version 2 database, available within the SimaPro LCA Software.

In assessing energy and GHG emissions from production of bananas, ICF supplemented the primary data source with secondary data and applied a different methodology to maintain consistency with the other fruits and vegetables within the weighted emission factor and with the scope of WARM. First, to narrow the scope of the data to cradle-to-retail, ICF did not assess the impacts of retail storage at the destination country. Secondly, to make the dataset more relevant to bananas sold within the United States, ICF assumed an average transportation distance from Central American banana plantations to U.S. ports, acquired from a separate study on fruit transportation distances (Bernatz 2009).

Unlike the other components of the fruit and vegetable energy and emission factors, bananas are shipped internationally in specially-made, refrigerated cargo containers to prevent over-ripening prior to sale. The average transportation distance to the United States was multiplied by a separate factor for emissions per ton-kilometer of refrigerated ocean cargo transport (BSR 2012). Additionally, due to the role of refrigeration in the ocean transport of bananas, ICF incorporated Luske 2010's estimate of fugitive refrigerant emissions during processing and transport.

For this analysis, distribution of fruits and vegetables to their final point of sale was assumed to have two components: the energy and GHG emissions associated with fossil fuel combustion from vehicle operation in addition to the GHG impact of fugitive refrigerants emitted from refrigerated vehicles. The GHG emissions from vehicle operation were a product of diesel fuel combustion. Fugitive emissions of refrigerants consisted of a mix of 1,1,1,2-Tetrafluoroethane (R-134a), Chlorodifluoromethane (HCFC-22), Monochloropentafluoroethane (R-155), and 1,1-Difluoroethane (HFC-152a). Due to lack of data for fruit and vegetable-specific transportation, the fugitive emissions associated with refrigerated vehicle transport were assumed to be the same as for refrigerated dairy delivery via a medium-sized truck (Thoma et al. 2010). In the Thoma et al. 2010 study, estimates of fugitive emissions of refrigerants during the transport phase were estimated via a sales-based approach, which equated purchases of refrigerants for the truck fleet to fugitive refrigerants released via leakage.

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Retail transport of perishables such as fruits and vegetables also results in losses due to spoilage and physical damage to the produce that would render it unfit for sale. Loss rates for the transport of fresh fruits and vegetables from production to retail were derived from USDA Economic Research Service (ERS) loss-adjusted food availability data (USDA 2012b). Loss rates for each fruit and vegetable in the analysis were compiled from USDA (2012b) and then re-weighted based on each product's share of the waste stream. The loss rates were specific to losses incurred strictly during the transport of fresh fruits and vegetables instead of a weighted mix of fresh and processed fruits and vegetables in order to maintain consistency with the scope and methodology of the analysis. The calculated weighted loss rate of 7.1 percent was applied to both production and transportation emissions of all fruits and vegetables in the study.

Impacts from co-products were not included in this analysis due to data limitations. For apples, oranges, melons, and tomatoes, the datasets did not include any information about co-products. However, differences between the amount of fruits and vegetables harvested in these scenarios and the final amount available for sale indicates that a portion of the production was unsalable for a variety of reasons. Due to a lack of data on the pathways for these fruits and vegetables and their assumed value, ICF determined that the impacts from any possible co-products from apples, oranges, melons, and tomatoes are outside the scope of this effort. Luske 2010 determined that approximately 10% (by mass) of the bananas produced within the scope of its assessment were unsuitable for international sale and sold to a separate distributor for a much lower price for local distribution. Relative to the price of the bananas destined for international sale, these bananas had approximately 0.3% of the value of the entire yield. Because of the low value and lack of distribution to the United States, ICF deemed that impacts from this co-product were outside of the scope of analysis. The LCI data used to develop included a co-product of potato leaves; however, in the dataset, it was allocated at 0.0% due to its low economic value. Consequently, it was not included in this analysis.

2.7. Dairy Methodology

The LCI data for dairy production used for developing the energy and emission factors in WARM are provided by the Innovation Center for U.S. Dairy, an industry group. The Innovation Center conducted its own LCA for dairy production (Thoma et al. 2010). The study followed the ISO 14040 protocols for LCA and was subject to external review. The Innovation Center's LCA's scope is larger than the scope used to develop the WARM energy and emission factors, covering the cradle-to-grave life-cycle of dairy products including retail storage, consumer use, and disposal. Therefore, ICF removed portions of the unit processes in the LCI data set that were outside the scope of the analysis, such as retail storage, consumer transport, packaging, and consumer use (e.g., cooking and consumer food loss).

The broad category of dairy foods includes a wide variety of products with differing inputs and processing stages. This made it necessary for ICF to develop weighted average energy and emission factors based on the Innovation Center's LCI data that reflect the relative contribution of different products to the total U.S. waste stream. ICF used the USDA Economic Research Service (ERS) loss-adjusted food availability data from 2010 to determine the relative shares of various dairy products within the U.S. waste stream. This dataset includes a variety of more granular product categories than the products addressed in the Innovation Center's LCI data, such as sub-categories of milks and cheeses. In order to make the USDA food loss dataset more consistent with the more general LCI data, ICF consolidated several product categories into more general categories. For example, ICF consolidated a variety of Italian-style cheeses into the Mozzarella category and categorized flavored milk (e.g., chocolate milk) and buttermilk as "generic milk".

In the Innovation Center's LCA, dairy production is linked to several other systems that produce products outside the scope of the WARM food waste source reduction factors, including feed co-products (e.g., dried distillers' grains) and beef. In the data set from the Innovation Center, impacts for most co-products are allocated economically. However, causal allocation is used for both beef based on feed nutrient content and for corn silage based on crop nitrogen requirements determined from reported yield. Causal mass balance is used for different fat-content milks during production (Thoma et al. 2010). Because the Innovation Center's data set already allocated impacts to co-products, ICF did not further modify the data to account for impacts from products outside the scope defined in this memorandum.

ICF analyzed retail transportation of dairy products as a separate unit process and assumed it applied to all dairy products equally. The Innovation Center dataset includes complete LCI data on the retail transportation process for dairy products including energy and emissions from onboard refrigeration equipment to prevent spoilage. This approach differs from the methodology used for estimating retail transport for other materials currently in WARM, which rely on average commodity retail transportation distances provided by the U.S. Census Bureau data. As for dairy production, ICF estimated the energy-derived emissions from transport by calculating the cumulative energy demand within the software. Non-energy emissions in the form of fugitive refrigerants were evaluated with the non-fossil-derived GHG emissions impact assessment method within the software.

3. Results

Using the methodology described in Section 2, ICF developed energy and GHG emissions factors for source reduction of grains, fruits and vegetables, and dairy products. The GHG emissions factors and energy factors are presented in Table 4 and Table 5, respectively, for each category. These factors are integrated into WARM Version 13, available at http://epa.gov/epawaste/conserve/tools/warm/index.html.

Table 4. GHG Emission Factors for Food Waste Categories in WARM

Category	Component	Energy emissions ($MTCO_2e$/tonne)	Non-energy emissions ($MTCO_2e$/tonne)	Total emissions ($MTCO_2e$/tonne)
Grains	Wheat flour	0.27	0.34	0.61
	Corn	0.48	0.20	0.67
	Rice	0.66	0.34	1.00
	Weighted average	0.37	0.31	0.68
Bread	Wheat bread	0.40	0.34	0.74
Fruits and vegetables	Potatoes	0.29	0.06	0.35
	Tomatoes	0.46	0.09	0.55
	Oranges	0.53	0.07	0.59
	Melons	0.32	0.06	0.37
	Apples	0.52	0.02	0.54
	Bananas	0.38	0.12	0.51
	Weighted average	0.41	0.07	0.48
Dairy	Weighted average	0.94	0.98	1.92

Note: $MTCO_2e$ = Metric tons of carbon dioxide equivalent.

Table 5. Energy Factors for Food Waste Categories in WARM

Category	Component	Process and transport energy (GJ/tonne)
Grains	Wheat flour	4.98
	Corn	8.42
	Rice	11.54
	Weighted average	6.54
Bread	Wheat bread	7.57
Fruits and vegetables	Potatoes	4.67
	Tomatoes	7.05
	Oranges	8.01
	Melons	4.75
	Apples	7.98
	Bananas	5.51
	Weighted average	5.90
Dairy	Weighted average	16.61

For grains, wheat has the smallest upstream GHG and energy footprint but constitutes the largest share of the three grains in the waste stream and therefore has the largest impact on the final emission factor. Though the total emissions from rice are significantly higher than both corn and wheat, its smaller share of the overall waste stream reduces its impact on the final weighted emission factor. The largest contributors to the emission factors for all three grains were irrigation, fertilizer production and application, and grain drying—though irrigation was a much lower contributor for wheat production than both corn and rice. The remaining unit processes contributed, on average, less than 10% of the remaining life-cycle impacts.

For bread, roughly one-third of the total energy demand comes from bread baking, leading to an increase in upstream GHG footprint relative to wheat.

For fruits and vegetables, the largest components of the total emission factor are process emissions from cultivation, including on-farm fuel use and upstream production of inputs such as fertilizer. Fertilizer application emissions did not constitute as large a share for these crops as they did for grains, likely due to lower fertilizer application rates for perennial crops. As expected, banana production had the highest life-cycle emissions of all of the fruits and vegetables assessed due to relatively higher fertilizer inputs and a substantial international transport component.

For dairy products, the largest components of the total emission factor are process emissions from dairy agriculture, including both fermentation and fertilizer. Interestingly, one of the largest contributors to energy demand is the production of feed for dairy cattle.

4. Discussion and Conclusion

The results show that the dairy products are both more energy and GHG emissions intensive than grains, bread, and fruits and vegetables. However, the grains and fruits and vegetable factors likely underestimate the GHG emissions associated with grains and fruits and vegetables due to the unavailability of national average LCI data for the processing of those food types into food products. Therefore, in future efforts, ICF will seek to estimate the additional energy and GHG emissions associated with some common processed food types, such as pasta and ketchup.

ICF is currently engaged in the development of similar factors for poultry and red meat. Future efforts will also involve the development of food type-specific end-of-life management factors for all relevant waste pathways in WARM, including composting, landfilling, combustion, and anaerobic digestion.

ICF expects that the streamlined energy and GHG emission factors for food products in WARM will have a broad appeal to parties who manage food waste with an interest in waste reduction. The factors are intended to expand the resolution of food waste modeling in WARM while keeping the tool streamlined, user-friendly, and appropriate for users without a technical background in LCA. EPA expects to apply these factors in a number of existing and future tools and programs. For example, the WARM factors are expected to be used as part of EPA's Food Recovery Challenge, a voluntary program for commercial, governmental, and non-commercial organizations. Food Recovery Challenge participants will use the source reduction factors to estimate the GHG emissions savings from food waste reduction efforts over the past calendar year.

5. References

Bernatz, G. (2009) Apples, Bananas, and Oranges: Using GIS to Determine Distance Travelled, Energy Use, and Emissions from Imported Fruit. Volume 11, Papers in Resource Analysis. 16 pp. Saint Mary's University of Minnesota Central Services Press. Winona, MN.

Bernatz, G. (2013) Personal email correspondence with Nikita Pavlenko, ICF. July 12th, 2013.

Boriss, H. (2013) "Citrus Profile." Agricultural Marketing Resource Center. Retrieved from: http://www.agmrc.org/commodities__products/fruits/citrus/citrus-profile/.

BSR (2012) Clean Cargo Working Group Global Trade Lane Emissions Factors. Business for Social Responsibility (BSR). August 2012. Retrieved from: https://www.bsr.org/reports/BSR_CCWG_TradeLaneEmissionsFactorsReport.pdf.

Bureau of Transportation Statistics (2013) "Commodity Flow Survey". Retrieved from: http://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/publications/commodity_flow_survey/index.html.

Ecoinvent Centre (2007) Ecoinvent data v2.0. Ecoinvent reports No.1-25, Swiss Centre for Life Cycle Inventories, Dübendorf, 2007. Retrieved from: www.ecoinvent.org.

Espinoza-Orias, N., H. Stichnothe, and A. Azapagic (2011) "The Carbon Footprint of Bread". International Journal of Life Cycle Assessment, (2011) 16:351–365.

Fake, C., K.M. Klonsky, and R.L. De Moura (2009) Sample Costs to Produce Mixed Vegetables. University of California Cooperative Extension. VM-IR-09. Retrieved from: http://coststudies.ucdavis.edu/files/MixedVegIR09.pdf.

International EPD System (2013) Product Category Rules: Arable Crops (Multiple CPC-Codes). June 12, 2013. Retrieved from: http://www.environdec.com/en/PCR/Detail/?Pcr=8804#.UrIW9NJDuSo.

International EPD System (2012) Product Category Rules—Fruits and Nuts. Version 1.0. August 23rd, 2012. Retrieved from: http://www.environdec.com/en/PCR/Detail/?Pcr=8235.

IPCC (2006) "IPCC Guidelines for National Greenhouse Gas Inventories: N2O Emissions from Managed Soils, and CO2 Emissions from Lime and Urea Application". Retrieved from: http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_11_Ch11_N2O&CO2.pdf.

ISO (2006) International Standard 14044: Environmental management – Life Cycle Assessment – Requirements and guidelines. International Organization for Standardization. First edition. July 7, 2006.

Kim, D., G. Thoma, D. Nutter, F. Milani, R. Ulrich, and G. Norris. (2013). "Life cycle assessment of cheese and whey protein in the USA." International Journal of Life Cycle Assessment; 18:1019-1035.

Luske, B. 2010. Comprehensive Carbon Footprint Assessment Dole Bananas. Soil and More International. Retrieved from: http://dolecrs.com/uploads/2012/06/Soil-More-Carbon-Footprint-Assessment.pdf.

Miller, D. and Y. Wang, eds. (2013). "Carbon and Water Footprint of U.S. Milk, From Farm to Table." International Dairy Journal; 31 (Supplement 1): S1-S100.

National Agriculture Statistics Service (NASS) (2013) "NASS Quick Stats: Grain Yield and Production by State". Retrieved from: http://www.nass.usda.gov/Quick_Stats/.

Nemecek, T., and Kagi, T. (2007) Life Cycle Inventories of Agricultural Production Systems. Ecoinvent Report No. 15. Retrieved from: http://www.upe.poli.br/~cardim/PEC/Ecoinvent%20LCA/ecoinventReports/15_Agriculture.pdf.

O'Connell, N.V., C.E. Kallsen, K.M. Klonsky, and R.L. De Moura (2009) Sample Costs to Establish an Orange Orchard and Produce Oranges. University of California Cooperative Extension. OR-VS-09. Retrieved from: http://coststudies.ucdavis.edu/files/orangevs2009.pdf.

Piers Industry Blog (2013) "U.S. Banana Imports Jump 12% in Q1 2013." Retrieved from: http://content.piers.com/blog/us-banana-imports-rise-sharply.

Smith, C. (2004) "New Market for Baled Rice Straw." American Agriculturist. Retrieved from: http://farmprogress.com/story-new-market-for-baled-rice-straw-9-2951.

Stoddard, C.S., M. LeStrange, B. Aegerter, K.M. Klonsky, and R.L. De Moura (2007) Sample Costs to Produce Fresh Market Tomatoes. University of California Cooperative Extension. TM-SJ-07. Retrieved from: http://coststudies.ucdavis.edu/files/tomatofrmktsj07.pdf.

Thoma, G., J. Popp, D. Shonnard, D. Nutter, R. Ulrich, M. Matlock, D.S. Kim, Z. Neiderman, C. East, F. Adom, N. Kemper, and A. Mayes (2010) "Global Warming Potential of Fluid Milk Consumed in the US: A Life Cycle Assessment." Innovation Center for U.S. Dairy and University of Arkansas.

U.S. EPA (2014a) Municipal Solid Waste Generation, Recycling, and Disposal in the United States: Facts and Figures for 2012. Office of Solid Waste and Emergency Response, United States Environmental Protection Agency. EPA-430-F-14-003.

U.S. EPA (2014b) Food Recovery Challenge. United States Environmental Protection Agency. Retrieved from: http://www.epa.gov/smm/foodrecovery/.

USDA (2013a) Commodity Costs and Returns. U.S. Department of Agriculture Economic Research Service. Retrieved from: http://www.ers.usda.gov/data-products/commodity-costs-and-returns.aspx#.UqtabtJDuSp.

USDA (2013b) National Agricultural Statistics Service Quick Stats. Retrieved from: http://www.nass.usda.gov/Quick_Stats/.

USDA. (2012a). “Estimating Wheat Supply and Food Use”. U.S. Department of Agriculture Economic Research Service. Retrieved from: http://www.ers.usda.gov/topics/crops/wheat/estimating-wheat-supply-and-use.aspx#.U5HRAHJdX1Y

USDA (2012b) “Food Availability (per Capita) Data System – 2010”. U.S. Department of Agriculture Economic Research Service. Retrieved from: http://www.ers.usda.gov/data-products/food-availability-(per-capita)-data-system.aspx#.UqoMEtJDvy4.

USDA (Undated) LCA Digital Commons. Retrieved from: https://www.lcacommons.gov/.

Van der Voet, E., G. Huppes, and H.A. Udo de Haes (2009) Allocation Issues in LCA Methodology: A Case Study of Corn Stover-Based Fuel Ethanol. International Journal of Life Cycle Assessment, 14, 529-539. Retrieved from: https://openaccess.leidenuniv.nl/bitstream/handle/1887/15394/chapter%202.pdf?sequence=14.

Wunderlich, L., K.M. Klonsky, and R.L. De Moura (2007) Sample Costs to Establish and Produce Apples. University of California Cooperative Extension. AP-IR-07. Retrieved from: http://cecentralsierra.ucanr.edu/files/60510.pdf.

This paper is from:

Proceedings of the 9th International Conference on Life Cycle Assessment in the Agri-Food Sector

LCA Food 2014

8-10 October 2014 - San Francisco

Rita Schenck and Douglas Huizenga, Editors
American Center for Life Cycle Assessment

The full proceedings document can be found here:
http://lcacenter.org/lcafood2014/proceedings/LCA_Food_2014_Proceedings.pdf

It should be cited as:

Schenck, R., Huizenga, D. (Eds.), 2014. Proceedings of the 9th International Conference on Life Cycle Assessment in the Agri-Food Sector (LCA Food 2014), 8-10 October 2014, San Francisco, USA. ACLCA, Vashon, WA, USA.

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ISBN: 978-0-9882145-7-6