An assessment of individual foodprints attributed to diets and food waste in the United States

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Abstract

This paper assesses the environmental impacts of the average American’s diet and food loss and waste (FLW) habits through an analysis of energy, water, land, and fertilizer requirements (inputs) and greenhouse gas (GHG) emissions (outputs). We synthesized existing datasets to determine the ramifications of the typical American adult's food habits, as well as the environmental impact associated with shifting diets to meet the US Department of Agriculture (USDA) dietary guideline recommendations. In 2010, FLW accounted for 35% of energy use, 34% of blue water use, 34% of GHG emissions, 31% of land use, and 35% of fertilizer use related to an individual's food-related resource consumption, i.e. their foodprint. A shift in consumption towards a healthier diet, combined with meeting the USDA and Environmental Protection Agency’s 2030 food loss and waste reduction goal could increase per capita food related energy use 12%, decrease blue water consumption 4%, decrease green water use 23%, decrease GHG emissions from food production 11%, decrease GHG emissions from landfills 20%, decrease land use 32%, and increase fertilizer use 12%.

1. Introduction

To reduce the environmental impact of the food system and to improve food security and human health, the United States (US) can consider reducing food loss and waste (FLW) within the food system and encouraging a shift to healthier diets. This work seeks to inform that opportunity by assessing a typical American's ecological footprint associated with dietary behavior, defined herein as foodprint. A foodprint is the resource and environmental impact associated with an individual's eating habits and choices. The components of an individual’s foodprint examined in this paper are energy, water, land, and fertilizer inputs and greenhouse gas (GHG) emission outputs. An individual’s foodprint will vary with composition of diet, shopping venue, type of food purchased (conventional, processed, local, organic, seasonal, etc), quantity of food consumed, caloric needs, quantity of food wasted, food availability, and food access. In this paper, foodprints are calculated for the average adult American diet, using average calorific intake, calorific requirement, and food habits. The total individual foodprint is calculated using per capita retail level food availability. The term ‘foodprint’ is meant to convey the idea that food choices are inextricably linked with all ‘footprints’ and singular footprints do not adequately assess the holistic impact of food habits.

There are a number of studies that examine the environmental impacts of food waste or the environmental impacts of changing diets [1, 2]. A 2010 study found that at least 2% of annual energy consumption is thrown out with FLW [3]. Additionally, food waste is responsible for more than 25% of consumptive fresh water use and 300 million barrels of oil annually [4]. The general consensus is that animal-based products are more resource intensive than plant-based products, with beef being the largest overall consumer [5, 6]. And although there are arguments to reduce...
consumption of animal-based foods, this diet shift might lead to an increase in total per capita food-related resource consumption [7, 8].

This study quantifies the anticipated change in an individual’s foodprint associated with a shift in diet to meet the US Department of Agriculture (USDA) dietary guidelines for the average American adult. It is assumed that consumer behavior regarding the levels of FLW stays proportionally the same. This study is novel, as the results distinguish resource and environmental impacts of consumption, FLW, and nonedible consumer loss for a shift in diet for nine food categories and six foodprint components. Additionally, this study calculates the benefits of reducing per capita food waste to meet the USDA and Environmental Protection Agency (EPA) 2030 food loss and waste reduction goal.

1.1. Food loss and waste
The World Resource Institute defines food loss and waste as ‘food and/or associated inedible parts removed from the food supply chain [9].’ Within this definition, measurement of FLW begins when crops are ripe in the field, animals are ready for slaughter, and milk has been drawn [9, 10]. For the purpose of this text, food waste is defined as edible food that is not consumed for any reason (e.g. cosmetic imperfections, spoilage, and cooking loss). Nonedible food loss refers to parts of food not intended for human consumption but produced along with the edible parts (e.g. peach pits and watermelon rinds), and are included in the following foodprint calculations as a discrete measurement.

FLW occurs along every step of the food chain. During production, crops are left in the field and fish are thrown back because they do not meet certain standards. Losses occur during handling and storage due to pests and disease and during processing and packaging from spilled and damaged products. Food is thrown out during distribution due to displeasing aesthetics or because it does not sell before the ‘best by date’. Food is lost during consumption, when consumers do not eat all of a purchased product [10, 11]. In 2010, 10% percent of produced food was lost at the retail level and 21% at the consumer level [12]. This report focuses on the FLW that occurs at the retail and consumer levels, as these are the areas individuals can most directly influence.

In 2015, the USDA and EPA set the first national FLW reduction goal. The partnership aims to reduce the US’s FLW 50% by 2030, using 2011 EPA estimates of food sent to landfills (32 billion kg) and 2010 USDA estimates of FLW at the retail and consumer levels [13]. Estimates of how much food is wasted vary from 27%–40% of total food production [3, 4, 12, 14–16]. Food waste is equivalent to 141–150 trillion calories per year or approximately 60 billion kilograms [4, 10, 12]. Food waste is a growing problem, as per capita food waste has increased by approximately 50% since 1974 [4].

The quantity of food wasted and the notable increase in food waste is significant, as producing food that will enter landfills is a waste of resources. Agriculture can be resource intensive, with current agricultural production accounting for 10%–15% of US energy use, 80% of consumptive water use, and 51% of land use [3, 17–19]. Additionally, agricultural production is responsible for 8% of US greenhouse gas (GHG) emissions and uses 20 million metric tons of nutrients annually [20, 21]. Resources are wasted and agricultural outputs are exacerbated through FLW. A reduction in FLW would lead to a smaller foodprint per person, enabling more people to be fed with less.

1.2. Influence of nutrition on health
Food habits also influence consumer health, and as nutrition is the main reason to consume food, nutritional factors should be addressed when assessing life cycle environmental impacts [5]. For the last 25 years, more than half of American adults have been considered overweight or obese [22]. In 2012, 73% of adult males, 65% of adult females and 32% of children aged two to 19 were overweight or obese [22, 23]. The increase in obesity is largely attributed to an increase in caloric consumption [24, 25]. Per capita food consumption in the United States has increased since the 1970s [24–29]. Although the precise increase in caloric values vary across studies, they consistently conclude that Americans have increased caloric consumption between 175–300 calories per person per day over the last four decades [24, 25, 29].

In addition to overconsumption, increasingly poor diets have seen a surge in obesity and diet related diseases [27, 29, 30]. Americans are eating more carbohydrates and less protein and fat [29]. From 1971 to 2006, Americans increased energy from carbohydrates from 44% to 48.7%, while decreasing energy from fat from 36.6% to 33.7% and from protein from 16.5% to 15.7% of daily caloric consumption [29]. These trends were found to be the same across people of all BMIs [29], indicating a cultural shift in what Americans like to eat.

2. Methodology for assessing the foodprint
The impacts of the American diet and FLW are calculated using existing methods for energy use, water use, GHG emissions, land use, and fertilizer requirements, as well as 2010 datasets [3, 8, 21, 26, 31–36]. Foodprints consist of production-level inputs of energy, water, land, and fertilizer and outputs of GHG emissions from food production and disposal based on the amount of food available, consumed, and wasted at the retail and consumer levels. Foodprints are based on an average adult consumption of 2390 calories per day and a recommended consumption of 2190 calories per day, consistent with the 2015 USDA
Dietary Guidelines for Americans [22]. The average American consumption is based on the Economic Research Service (ERS) Loss-Adjusted Food Availability (LAFA) dataset, which estimates the type and quantity of food available per person per day in the United States [37]. For the purpose of this paper, the foodprint is based solely on an individual’s diet, however foodprints will vary with shopping venues and types of food purchased (conventional, processed, local, organic, seasonal, etc), both of which are beyond the scope of consideration for this paper.

In the following sections, per capita resource use is broken into nine food categories, rather than the USDA’s six ‘MyPlate’ food groups [38]. The nine food categories are based on the US Department of Health and Human Services and the USDA’s Dietary Guidelines for Americans report [22]. The Dietary Guidelines report provides recommended serving sizes of each food category based on gender, activity level, and caloric needs. The Dietary Guidelines report was utilized to provide a more detailed analysis of the foodprint results than would be achieved if using MyPlate.

2.1. Consumption methodology
This report curates data from existing databases and dietary studies to approximate the average American adult’s caloric needs to determine the environmental impacts of current food habits. The two databases used are the ERS LAFA datasets and the Centers for Disease Control and Prevention (CDC) National Health and Nutrition Examination Survey (NHANES) datasets [37, 39].

The ERS publishes estimates of per capita food availability in their LAFA datasets by determining the original produced quantity of individual food items and adjusting for FLW. The data differentiates between production level loss, retail level loss, and consumer level edible and nonedible loss [37]. In 2010, the ERS reported that after accounting for FLW, the per capita food availability was 2547 calories per day. Buzby et al also state that the food availability estimate is too large; that is, the average American consumes less than 2547 calories per day and that there are more unaccounted losses in the system or other errors with the calculations [12]. To more accurately represent the impacts of food waste on the environment and the benefits of reducing food waste, the ERS consumption estimates were adjusted based on the work of multiple studies [7, 40–42].

Tom et al used information from the CDC NHANES datasets to calculate the average American’s caloric intake and required caloric intake for healthy weight [7]. The study found that in 2010, the average American adult consumed 2390 calories per day, while requiring 2190 calories per day. These results are similar to other studies estimated caloric consumption, estimated caloric requirements, and estimated overconsumption related to weight gain [40–42].

Using Tom et al’s estimates, each food category in the ERS LAFA dataset is scaled down by maintaining the ratio of calories in each category, to reduce the estimated food availability of 2547 calories per person per day to the estimated per capita consumption of 2390 calories per day [7, 37]. The results are shown as ‘US Consumption’ in figure 1. It is assumed that the difference between the estimated food availability and ‘US Consumption’ is additional unaccounted FLW and is included in the food loss and waste calculations in later sections. This additional FLW is included in calculations pertaining to FLW in an attempt to accurately model the impacts reducing food waste has on resource use.

The ‘US Consumption’ values are compared to the USDA dietary guidelines for each food category, shown as ‘USDA Dietary Guideline Recommendations’ in figure 1. Food types are classified as overconsumed if Americans are receiving more calories from that category than the USDA recommends. The results find that Americans are overeating in four

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**Figure 1.** The average American diet (US Consumption) is compared to the USDA recommendations, showing Americans overconsume in four food categories and underconsume in five. Data sources: ERS LAFA [37] and USDA Dietary Guidelines [22].
areas: (a) meat, poultry, eggs, (b) nuts, (c) oils, and (d) solid fats and added sugars. In the other five categories, (a) fruit, (b) vegetables, (c) grains, (d) seafood, and (e) dairy, Americans are underconsuming, consuming less than the recommended number of daily calories.

2.2. Food loss and waste methodology

The data used for food availability and FLW in this report come from the ERS LAFA database [37]. This paper focuses on the consumer and retail levels due to data availability. The LAFA database does not calculate losses that occur at the primary level (on the farm) [37]. Additionally, losses between the primary level and the retail level are not differentiated between edible loss and inedible loss. Therefore, the FLW environmental impacts are underestimates; accounting for losses on the farm and between the primary and retail levels might result in substantially higher estimates.

There is one difference between the data used to calculate impacts of FLW in this paper and the data found in the ERS LAFA database [37]. This paper includes ‘additional unaccounted loss’ in the calculation of FLW, which is the difference between the ERS food availability estimate and the estimated average adult consumption, calculated as ‘US Consumption’ in the consumption section. Our calculations, shown in table 1, find that the per capita retail and consumer level loss is 259 kg per year, or 1449 calories per day, 200 calories higher than the ERS estimate [12]. Instances of FLW are the highest with dairy products, which have a relatively short shelf life, and the lowest with nut products, which have a relatively long shelf life.

A study on European Union (EU) consumer food habits found that the average per capita consumer FLW is 123 kg per year, of which 97 kg is edible [43]. Thus, EU residents waste approximately 66 kg less per year than the average American. This is likely due to differences in consumer behavior and attitudes.

Resource requirements for the FLW associated with the USDA recommended diet are predicted using values on the percent of retail loss, consumer loss, and nonedible consumer loss for each food item in the ERS dataset, assuming percentages of FLW are maintained at current levels. A weighted average for each type of loss is calculated for each of the nine food categories, based on food weight. Food weight is used rather than calories, as the ERS data on food consumption is provided in units of weight. The FLW associated with the USDA recommended diet is calculated assuming the percentages of FLW along each step of the food chain are held constant. Changes in per capita FLW are based on the differences in consumption between the current average American adult’s diet of 2390 calories and the USDA recommended diet for a healthy American adult of 2190 calories. Thus the results represent not only a shift in types of food consumed, but in quantity as well.

We also calculate the resource requirements and environmental impacts associated with reducing FLW for the average American adult following the USDA recommended diet. The current retail level food waste values are adjusted to reduce waste by 0%–60% in each food category. This analysis is conducted to determine the impact of the USDA and EPA 2030 food loss reduction goal.

2.3. Per capita resource use methodology

The per capita energy use is found through an extrapolation of Cuellar et al’s study on the total energy input for agricultural production [5]. The energy analysis includes energy use for all steps of the food chain. The green water use and the blue water use is calculated using Mekonnen and Hoekstra’s meta-analysis of the life cycle water requirements for different food items [31, 32]. This water use represents the life-cycle water consumption for individual food items. The water requirements for plant and animal products are based on average country data when available and global water data when not. The GHG data for food production is taken from the meta-analysis by Heller et al on GHG emissions for different

| Table 1. Per capita retail and consumer level food loss and waste equated to 229 kg per year in 2010. |
|---------------------------------------------------------------|
| **Retail and consumer level** | **Retail level** | **Consumer level** | **Nonedible consumer loss** |
| **(kg person yr\(^{-1}\))** | **(kg person yr\(^{-1}\))** | **(kg person yr\(^{-1}\))** | **(kg person yr\(^{-1}\))** |
| Fruit | 8.6 | 31.3 | 13.8 |
| Vegetables | 10.5 | 40.3 | 13.5 |
| Grain | 10.6 | 16.9 | 0.5 |
| Protein Seafood | 0.6 | 2.2 | 0.0 |
| Meat, Poultry, Eggs | 4.6 | 21.1 | 1.6 |
| Nuts | 0.3 | 0.4 | 0.0 |
| Dairy | 15.4 | 25.9 | 0.0 |
| Oils | 5.1 | 3.1 | 0.0 |
| Solid fats, added sugar | 10.2 | 22.2 | 0.0 |
| Total | 65.9 | 163.5 | 29.4 |

Data: ERS LAFA [37].

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The amount of fertilizer and blue water applied to crops depends on the quality of the land and quantity of green water. Additionally, energy use is a direct determinant of GHG emissions. This study could benefit from addressing the connections between resources. The relationships between resource uses are becoming increasingly interlinked, as the best hope for increasing food production to meet growing demand is by increasing yield per acre [46].

The foodprint analysis can be improved by accounting for the GHG emissions related to land use change and by focusing on unique food processing and storage approaches, such as canning and freezing, to determine the food types that contribute the most to an individual’s foodprint. A closer examination of FLW on the farm and between the farm and retail levels would more accurately represent the environmental impacts and individual foodprints.

3. Results

This section synthesizes the datasets identified in section 2 to quantify per capita food related energy use, water use, land use, GHG emissions, and fertilizer use at the retail and consumer levels. These inputs and outputs are evaluated for consumption, FLW, and nonedible consumer losses for the current average American diet of 2390 calories and for a diet of 2190 calories following the USDA guidelines. The USDA proposed diet, shown as ‘USDA Habits’ in figure 2, represents a healthy diet for the average American adult. It is assumed the percentage of FLW for each food category is held constant at current levels. Shifting the typical diet to meet the dietary guidelines will result in a per capita increase of consumption from 393 kg to 540 kg, of FLW from 227 kg to 296 kg, and of nonedible consumer loss from 29 kg to 59 kg each year. Overall consumption will increase even as caloric consumption decreases, as healthier diets consist of more fruit and vegetables which have fewer calories per kilogram than animal-based products. These values might not hold true if current FLW habits shift, but they are used as a baseline for establishing the impacts of shifting to the USDA recommended diet.

3.1. Energy component of foodprint

The energy calculations include the energy required for agricultural processes, transportation, food handling, and food processing [3]. The total per capita energy use for retail level food production is 23 GJ per year for the current diet and 31 GJ per year for the USDA based diet, shown in figure 3. Shifting diets will result in a 34% increase in energy use. Dairy is the largest contributor to an individual's energy component of the foodprint in both scenarios, at 4.9 GJ per year for the

![Figure 2. Comparison of consumption, FLW, and nonedible consumer loss associated with the current average adult American diet and with a diet of 2190 calories following USDA dietary guideline recommendations. Data sources: ERS LAFA [37] and USDA Dietary Guidelines [22].](image-url)
current diet and 8.2 GJ per year for the USDA based diet. The second largest energy consumer for the current diet is the meat, poultry, seafood category at 4.5 GJ. The second largest consumer for the USDA based diet however, is fruit at 7.0 GJ.

Shifting to the lower calorie recommended diet will increase the energy used to produce, process, and transport FLW and nonedible consumer food from 7.9 GJ to 10.2 GJ and from 0.9 GJ to 1.8 GJ, respectively. In both scenarios edible food waste makes up approximately one third of the total energy used to produce, process, and transport food. If Americans were to shift diets without reducing food waste, the energy used to create and transport edible dairy FLW (2.7 GJ) is more than the current energy used for consumed fruit, vegetables, grains, eggs, nuts, oils and solid fats, and added sugar.

These results are similar to other studies in this field. Tom et al found that shifting from the current average American diet to the lower calorie USDA recommended diet results in a 38% energy increase [7]. A second study found that 2030 trillion Btu of energy were consumed for food waste in 2007, equivalent to 6.9 GJ per person [3].

3.2. Blue water component of foodprint

There are three types of water used for agricultural production: blue, green, and gray [47]. Blue water is surface and groundwater removed from the original source and not returned. Green water is precipitation that is stored in the soil or stays on vegetation and does not lead to run-off or groundwater recharge. Gray water is the quantity of water required to dilute pollutants to ensure the water quality remains above water standards. Blue and green water are required for agricultural production, while gray water is a theoretical quantity.

The total blue water component of the current average American diet is 162,000 liters of water per year,
as shown in figure 4. If Americans were to shift diets to meet the recommended dietary guidelines, the per capita water foodprint would increase 15% to 186 000 liters of water per year. Although the water use associated with the meat, poultry, eggs category would decrease from 37 000 to 28 000 liters per year, the dairy category would increase from 16 000 to 27 000 liters per year. Additionally, water consumption for fruit and vegetables would increase by 44 000 liters per year.

Approximately one third of the blue water used to produce crops and livestock is wasted through edible FLW. Water used to produce FLW would increase from 54 000 to 60 000 liters of water per person per year with a shifted diet. The least water is wasted with nuts, where only 20% of water used to produce nuts is wasted with the current American diet. The least efficient food category is oil, where 44% of water is associated with FLW.

Comparatively, a study by Kummu et al found the per capita blue water use from 2005–2007 to be 120 000 liters per year in North America and Oceania [48], whereas this study found average per capita blue water use to be 161 000 liters per year. Kummu’s study also found that 35% of water was used to produce food that was eventually lost or wasted [48], similar to our results of 34%. There are three major differences between the studies. Kummu’s calculations do not include the FLW for meat-related food products, which accounts for 23% of blue water use in our study. Additionally, our results are based on a higher number of food items and Kummu’s analysis includes agricultural losses, while our calculations begin at retail level food availability [48]. A study conducted on the EU water consumption found that shifting diets from current eating habits to a healthy diet reduced blue water use by 18% [49]. The EU likely experienced a decrease in blue water consumption due to differences in eating habits and water requirements for food production.

3.3. Green water component of foodprint

A shift in diet would decrease total annual green water use by 7% from 1171 000 to 1090 000 liters of water per person. The decline is due to significant changes in green water use for the meat, poultry, eggs category and the oils, and solid fat, added sugar categories, which decline by 128 000, 41 000, and 88 000 liters per year, respectively. The dairy category will experience the largest increase in green water consumption, increasing 70%, or 116 000 liters per year.

The largest green water FLW component of an individual’s foodprint is the meat, poultry, eggs category. At 167 000 liters of water per year, the meat, poultry, eggs category wastes more water than any other food category uses to produce consumed food. Green water use is not necessarily bad, as green water is rainfall that would not recharge groundwater or surface water.

3.4. Greenhouse gas (GHG) emission component of foodprint

To quantify the GHG emissions from food production, all GHGs are considered in terms of the global warming potential by use of CO2-equivalent (CO2e). These calculations include all GHG associated with the life-cycle of each food category, with the exception of the emissions related to food disposal and landfill. The emissions related to landfilling food waste are calculated separately, below.

The results in figure 6 show that the average American adult diet in 2010 generated 2020 kg CO2e from food production and transportation. If Americans were to meet the USDA dietary guideline recommendations, while maintaining current FLW habits, a diet of 2190 calories would result in a 7% increase to 2169 kg CO2e. The largest contributor of GHG in the average diet is the meat, poultry, eggs category, which accounts for 53% of the average American output. A shift in American diets would
lower meat, poultry, eggs emissions to 38% of total per capita emissions.

FLW emissions from the meat, poultry, eggs category, 329 kg CO₂e, are larger than total emissions from every other category with the exception of dairy. A shift in diets would decrease the FLW meat emissions by 20% to 264 kg CO₂e. The alternate consumption scenario would more than double the GHG emissions associated with fruit and seafood FLW, counteracting the benefits of reducing meat, poultry, eggs consumption.

Additional GHG emissions are created when FLW is sent to the landfill. Landfills are the second largest source of methane emissions in the US, responsible for 23% of total methane emissions in 2007 [11]. At the consumer level, 95% of the food thrown away ends up in landfills or combustion facilities [50]. Analyzing the 2010 food waste data using the EPA’s WARM model, finds that the per capita annual emissions from landfilling food waste is 132 kg CO₂e, similar to Heller et al’s estimate of 135 kg CO₂e per year, using the same calculator [33]. A shift in diets and decrease in caloric consumption would increase GHG emissions from landfills by 34%, to 177 kg CO₂e. This is mainly because a caloric decrease in the meat, poultry, eggs category results in a much smaller weight decrease in consumption compared to the weight increase of the additional consumed produce. Additionally, produce has a significant amount of nonedible consumer loss at the retail and consumer level. In the ERS LAFA datasets, it is assumed that meat and poultry are de-boned prior to the retail level [37]. Figure 7 shows the contribution of different food groups to overall emissions. Under current habits, vegetables are the largest source of landfill methane, responsible for 25% of total emissions for the current diet and 30% of emissions for the adjusted diet. Edible FLW makes up 87% of landfill

![Figure 6](image-url) The average adult American’s greenhouse gas (GHG) emissions food production foodprint in 2010 was 2020 kg CO₂e. Shifting to meet the USDA based diet would result in per capita GHG emissions of 2169 kg CO₂e per year. Notes: (1) ’CH’ = Current Habits, ’UH’ = USDA Habits, (2) the data for this figure can be found in table S4. Data sources: ERS LAFA [37] and Heller et al [33].

![Figure 7](image-url) The average adult American’s greenhouse gas (GHG) emissions landfilling foodprint in 2010 was 132 kg CO₂e. It is assumed that all liquid dairy products are poured down the drain and are not included in these calculations. Shifting to meet the USDA based diet would result in per capita GHG emissions from landfills of 177 kg CO₂e per year. Notes: (1) ’CH’ = Current Habits, ’UH’ = USDA Habits, (2) the data for this figure can be found in table S5. Data sources: ERS LAFA [37], Heller et al [33], EPAWARM [34].
emissions for the typical American and 80% of emissions for the USDA based diet.

3.5. Land component of foodprint

Figure 8 shows the land component of the foodprint for an average American diet in 2010. These numbers are underestimates of land use impacts, as there is limited data on land use requirements for seafood, dairy, fats, and oils. Additionally, the data from FAOSTAT regarding land use does not account for all the food products included in the LAFA dataset and only provides data on acres harvested, rather than planted [36].

The biggest land requirements for overconsumption and FLW occur for the meat, poultry, eggs category, as land is required to feed and house the animals [26]. The total per capita land use is 3400 m² per year. A shift to the USDA based diet would result in a 19% land use reduction, to 2765 m² per year. This is mainly due the reduction of animal products. It is important to note that land use for agriculture is good for the environment in many ways. Using land to grow crops and produce livestock, if properly maintained, allows for groundwater recharge and can improve soil quality.

Although farmland can be good for the environment, it is a waste of land to produce food that rots in the field or is sent to landfills. Currently, 30% of land is used to produce FLW. If diets are changed to be healthier, FLW land use could increase to 32% of total farmland. The largest contributor to the FLW foodprint component is the meat, poultry, eggs category, accounting for 89% of land use for the current diet and 85% of land use for the adjusted diet. Much of the land used for the meat category is low quality pastureland, which might be a better use for the land than urbanization.

Peters et al conducted a land use study on ten diets produced entirely in the US. The results of their study found per capita land use requirements vary from 1300–10 800 m² [51]. Our results fall on the lower end of Peters et al’s range, which seems accurate as our calculations do not account for seafood, dairy, fats, and oils. Another study found that the average American household land footprint for all material goods is 23 000 m² [52]. Our results of 3 400 m² represent nearly 15% of total household land use.

3.6. Fertilizer component of foodprint

Figure 9 shows the per capita fertilizer use for an average American adult as nearly 50 kg per year. Consumed food uses 29 kg per year, 60% of total use, with FLW accounting for 35% and inedible food loss for 5%. Grain production accounts for 59% of all
fertilizer use. The calculations in this study do not account for fertilizer used to produce feed for animals. Using Capper's 2011 paper and assuming animals consume a diet of corn, fertilizer for animal feed could add another 60 kg per person per year [53]. Changing the American diet could increase fertilizer use to 65 kg per year, with 33% used to produce FLW.

Kummu et al calculated the average annual per capita fertilizer use for 2005–2007 by averaging the total amount of fertilizer applied across all harvested cropland [48]. They found the total per capita fertilizer use was 31 kg per year, 17 kg per year less than our calculations for the current American diet [48]. The differences in the results are due in part to different estimates for food availability, consumption, and waste. Additionally, our study includes a greater number of food items. Neither Kummu et al’s study nor our results reflect the fertilizer requirements for meat-related products.

4. Conclusions and discussion

An individual’s foodprint is the combination of resource and environmental impacts linked with food choices and food supply chain management. For the typical American adult, overconsumption and FLW comprise a significant portion of one’s foodprint. As shown in figure 10, based on food weight, in 2010 the average US adult consumed 60% of per capita food available at the retail level and discarded 35% of edible food and 5% of food due to being inedible. Reducing FLW leads to a reduction in an individual’s foodprint.

Table 2, representing the current and the USDA recommended average adult American’s foodprint, shows that shifting diets to the USDA dietary guideline recommendations would result in an increase in energy use by 34%, blue water use by 15%, GHG emissions from food production by 7%, GHG emissions from landfills by 34%, and fertilizer use by 34% if consumer behavior remains consistent with current habits. The recommended diet would consume 7% less green water and 19% less land. The table also shows that FLW uses approximately one-third of all resources in the US food system. Although the recommended diet could potentially increase resource use, it is important for people to consume a nutritionally balanced diet.

If the USDA and EPA’s 2030 food waste and loss reduction goal is met, FLW could be reduced by 50%, potentially mitigating the increased resource use associated with consuming a balanced diet. Table 3 shows adjusted resource use for the USDA Habits with reduced FLW. The baseline for the current typical diet

Table 2. The average adult American’s resource use in 2010 for a diet of 2390 calories and theoretical resource use following the USDA recommended diet of 2190 calories.

|                  | Energy (GJ yr⁻¹) | Blue water (thousand l yr⁻¹) | Green water (thousand l yr⁻¹) | Production GHG (kg CO₂ yr⁻¹) | Landfill GHG (kg CO₂ yr⁻¹) | Land (m² yr⁻¹) | Fertilizer (kg yr⁻¹) |
|------------------|-----------------|------------------------------|------------------------------|----------------------------|---------------------------|----------------|---------------------|
| **Consumed**     | 14              | 102                          | 756                          | 1307                       | 0                         | 2282           | 29                  |
| **Current Habits** |                |                              |                              |                            |                           |                |                     |
| FLW              | 8               | 54                           | 397                          | 673                        | 114                       | 1051           | 17                  |
| Nonedible        | 1               | 6                            | 17                           | 40                         | 18                        | 66             | 2                   |
| **Consumer loss**|                |                              |                              |                            |                           |                |                     |
| Total            | 23              | 162                          | 1172                         | 2020                       | 132                       | 3399           | 48                  |
| **USDA**         |                |                              |                              |                            |                           |                |                     |
| FLW              | 10              | 60                           | 368                          | 724                        | 142                       | 800            | 21                  |
| Nonedible        | 2               | 12                           | 23                           | 62                         | 35                        | 65             | 5                   |
| **Consumer loss**|                |                              |                              |                            |                           |                |                     |
| Total            | 31              | 186                          | 1090                         | 2169                       | 177                       | 2765           | 65                  |

Figure 10. The average adult American wasted 35% of food (by weight) available at the retail and consumer level. Data sources: USDA ERS LAFA [37].
Table 3. Reduction of FLW can help improve resource requirements and environmental impacts. These results assume that diets have shifted to meet the USDA dietary guidelines, with the baseline analysis representing current FLW behavior.

| Food waste reduction (%) | US Data Habits foodprint | Energy (GJ yr⁻¹) | Blue water (thousand 1 yr⁻¹) | Green water (thousand 1 yr⁻¹) | Production GHG (kg CO₂e yr⁻¹) | Landfill GHG (kg CO₂e yr⁻¹) | Land (m² yr⁻¹) | Fertilizer (kg yr⁻¹) |
|--------------------------|--------------------------|-----------------|------------------------------|-------------------------------|-------------------------------|--------------------------|-----------------|-------------------|
| 0%                       |                          | 31              | 186                          | 1090                          | 2169                         | 177                      | 2765            | 65                |
| 10%                      |                          | 30              | 180                          | 1053                          | 2097                         | 163                      | 2676            | 62                |
| 20%                      |                          | 29              | 174                          | 1017                          | 2204                         | 149                      | 2587            | 60                |
| 30%                      |                          | 28              | 168                          | 980                           | 1952                         | 134                      | 2498            | 58                |
| 40%                      |                          | 27              | 162                          | 943                           | 1880                         | 120                      | 2409            | 56                |
| 50%                      |                          | 26              | 156                          | 906                           | 1807                         | 106                      | 2320            | 54                |
| 60%                      |                          | 25              | 150                          | 870                           | 1735                         | 92                       | 2231            | 52                |

is 23 GJ per year of energy, 162,000 liters per year of blue water, 1172,000 liters per year of green water, 2020 kg CO₂e per year from food production, 132 kg CO₂e per year from landfills, 48 m² per year of land, and 3399 kg per year of fertilizer. Successfully meeting the 2030 goal of reducing FLW would result in an energy increase of 12% rather than 34%, would decrease blue water consumption by 4% rather than increase by 15% and would reduce green water use by 23% rather than 7%. Additionally, GHG emissions from food production would decrease 11% rather than increase 7% and GHG emissions from landfills would decrease 20% rather than increase 34%. Land use would decrease 32% rather than 19% and fertilizer use would only increase 12% rather than 34%. The increase in resource use from a healthier diet is not a reason to continue eating poorly. Instead, the US can focus on an existing goal of reducing FLW to mitigate the consumption of resources related to the US food system.

Food waste is unique from other components of the foodprint because there is a significantly higher degree of control by the individual and the changes required to reduce each are relatively less intrusive on consumer lifestyle and do not require a significant shift in decision making at the point of purchase [54, 55]. These two components require relatively small shifts in shopping, meal preparation, and dining habits and are not subject to price sensitivity such as changes in where to shop or types of food to purchase might be [24, 25, 56, 57]. While the potential environmental benefits are rather grand, there are also personal financial benefits through cost savings to be reaped from reducing food waste and overconsumption that are less prevalent in changes to other foodprint factors.

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