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Assessing U.S. Food Wastage and Opportunities for Reduction

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Abstract

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Keywords

food loss, food waste, food wastage, food security, sustainable food system, food supply chain

Disciplines

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ABSTRACT

Reducing food wastage is one of the key strategies to combat hunger and sustainably feed the world. We present a comprehensive analysis of available data, despite uncertainties due to data limitation, indicating that the U.S. loses at least 150 million metric tonnes (MMT) of food between farm and fork annually, of which about 70 MMT is edible food loss. Currently, <2% of the edible food loss is recovered for human consumption. A reasonably-attainable goal of food waste reduction at the source by 20% would save more food than the annual increase in total food production and would feed millions of people. This is an opportunity of significant magnitude, offering food security and resource and environmental benefits with few negatives. Seizing this opportunity requires technological innovation, policy intervention, and public outreach. This U.S.-based analysis is pertinent to other mid- to high-income countries.

1. Introduction

A Chinese proverb that originated over 2000 years ago states *min yi shi wei tian*, meaning “food is a basic necessity of man”. Yet today, providing enough food to meet the basic needs of 7.3 billion people remains a difficult challenge, as one in nine people do not have enough food to lead a healthy active life (World Food Programme, https://www.wfp.org/hunger/stats). That challenge can worsen as the world population is expected to exceed 9 billion by 2050 with projected food demand increasing by 60% (Alexandratos and Bruinsma, 2012). Parallel to the growing food challenge are the widely recognized problems of dwindling natural resources, continued environmental degradation, and climate change. Agriculture, a significant contributor to these problems, will also face escalating constraints.

Various strategies have emerged to address the pressing need to feed the world sustainably. Enhancing agricultural output through scientific and technological innovation appeals to many; examples include closing yield gaps, exploiting genetic resources, and extending the Green Revolution in Africa, etc. (AGRA, 2015; Mueller et al., 2012; Pradhan et al., 2015; Rahman et al., 2012). However, tradeoffs associated with agricultural intensification will be more difficult to address going forward. Other strategies focus on curbing the demand for food via achieving sustainable population growth (Searchinger et al., 2013) or dietary modification (Godfray et al., 2010). The demand-side strategies, worth debating, are politically sensitive and subject to moral and philosophical scrutiny. Without doubt, sustainably feeding the growing population is a daunting challenge; we need to consider all possible strategies to tackle it.

Here, we present a new opportunity that is attracting much attention, that is, a *waste-less-to-feed-more* movement burgeoning worldwide in recent years. This movement is largely kindled by the FAO report (Gustavsson et al., 2011) that one-third of food produced for human consumption is lost, amounting to 1.3 billion tonnes annually. According to that report, the extent of food loss (i.e. about one-third of food never reaches a human stomach) is similar across the globe but the stages and causes differ. In low-income countries food loss takes place prior to the consumer stage because of infrastructural deficiencies, whereas in mid- to high-income countries consumer food wastage is the single largest component. The severity of consumer food wastage in developed countries is also reflected in several recent reports, e.g. 109 kg per capita per year of household food wastage in the UK (Parry et al., 2015), and 132 kg per capita in the U.S. in the consumer sector including both households and food-service entities (Buzby et al., 2014). Clearly, reducing food wastage represents an opportunity of significant magnitude, serving food security and sustainability purposes with few negatives or conflicts. Toward this end, developed countries have a critical role to play given their large capacity in both food supply and their great potential to reduce food wastage.

The U.S. stands out among developed economies in this regard. Annually, it produces 766 million metric tonnes (MMT) of food

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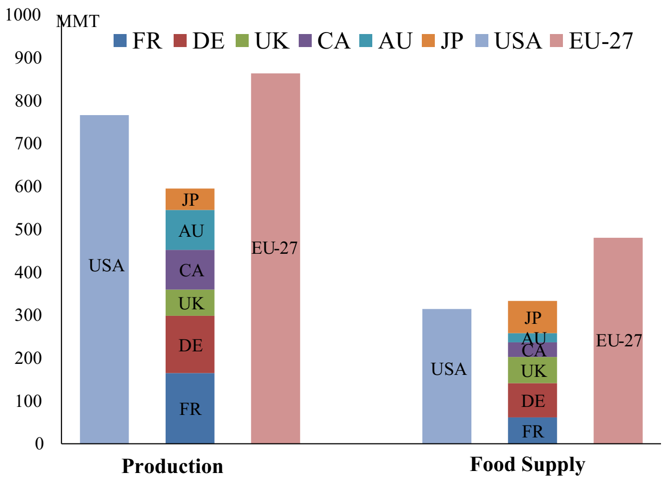

Fig. 1. Comparison of U.S. annual food production (Production) and domestic human food supply (Food Supply) with that of EU-27 and selected countries (France, Germany, United Kingdom, Canada, Australia, and Japan). FAO defines food supply as primary commodities available for human consumption, adjusted for imports and exports, seed and livestock feed use, and losses in storage and transportation. Data include fruit, vegetable, grain, nuts and oilseed crops primary production, and animal products including fisheries catch and aquaculture; grain and oilseed production includes all uses (food, feed, biofuel and exports); data exclude manufactured fruit and vegetable products, fiber crops, animal hides, wool, and forages and fodder for animals. Data source: FAO (2015; data for 2011).

(Fig. 1; FAOSTAT, 2011 data), which is more than that of France, Germany, UK, Canada, Japan, and Australia combined (595 MMT) or about 89% of EU-27. Annual food availability for domestic human consumption has a pattern reflecting similar significance (Fig. 1). Moreover, the U.S. is the third most populous country (behind China and India), and its per capita food supply is among the highest in the world (FAO, 2015). Given its population and food production and consumption significance, it is necessary to better understand the source and magnitude of food loss and waste in the U.S. food system, and to assess the opportunities that reduction in food wastage may have on global trends and the related potential contribution to global food security.

In this paper, we examine where and how much food wastage occurs across the U.S. supply chain, assess food waste reduction and recovery potential, and discuss data gaps and critical needs for the nation to move toward a more sustainable food system.

2. Definition, data sources

A variety of terminologies and phrases have been used when discussing food loss and waste problems. Often the meaning or implication is content-specific or depends on an author's opinion. For example, some may consider it wasteful to give food that humans could eat to animals (e.g. Stuart, 2009), while others (Smil, 2004) describe over-nutrition as another type of food wastage. Furthermore, the conventional sense of food loss or waste refers to the disappearance of food mass in its natural state (as-is), but some researchers choose to study the subject in a different light, for example, on a dry-matter (Cheng, 2015) or caloric basis (Hall et al., 2009). In general, the phrases "food loss", "food waste", or "food loss and waste" have been used interchangeably. In some cases (e.g. HLPE, 2014), "food loss" is used to refer to the decrease in food quantity associated with harvest, handling, processing, and transport, while "food waste" refers to that related to consumer food behavior, with the latter conveying a negative connotation resulting from human choices.

In this paper, we conform to the principle definition of FAO (1981) and refer to food loss and/or waste as "decrease in mass of wholesome food material intended for human consumption that is lost, degraded, spoiled, or discarded at any stage of the food system". We use various phrases interchangeably (e.g. food loss, food waste, food wastage, wasted food); we make no distinctions among them because of data limitation.

Our primary sources of information for assessing U.S. food wastage at the national level include: (i) the report of Buzby et al. (2014) for edible food loss at the retail and consumer levels, which is based on the Loss Adjusted Food Availability (LAFA) databases maintained by the U.S. Department of Agriculture Economic Research Service (USDA-ERS, 2015b); (ii) our own calculation of food loss for the processing, handling, and manufacturing stages of the supply chain, derived from the LAFA databases; (iii) the results from surveys conducted by the Food Waste Reduction Alliance (FWRA, a food industry coalition) assessing food losses in the manufacturing and wholesale-retail sectors, as reported by BSR (2012, 2013, 2014); and (iv) supplementary information derived from local or organization-based reports for estimating on-farm food loss.

3. Magnitude of food wastage

In this analysis, we quantify three major food-loss streams across the U.S. supply chain based on data availability: (i) the food handling/processing/manufacturing sector (industry), (ii) the retail sector (retail), and (iii) the consumer sector (consumer). See Table 1.

Industry-sector food loss calculated from the LAFA databases amounts to 35.9 MMT (79 billion lbs.) annually. This consists of three food groups (vegetables, fruit, and meat/poultry/fish; Table 1). For the vegetables or fruit groups, much of the loss is probably unavoidable due to processing losses, for example, water evaporation and volume shrinkage when fresh tomato (*Solanum lycopersicum* L.) is processed into canned products. There would also be food remnants (e.g. trimming or peels or pulp) that cannot be made into saleable products. For the meat/poultry/fish group, the 12.0 MMT loss refers to inedible parts such as bones, because it is carcass weight for meat and poultry (and boneless fillets for fish) that enter the LAFA databases as food supply. It must be noted that loss estimates for dairy, grain products, fats and oils, and sweeteners were left blank, due entirely to how the LAFA databases were structured (where grain products refer to post-milling for flour or after manufacturing; dairy refers to fluid milk and

Table 1
Estimated food loss and wastage across the U.S. supply chain.

Food Group	Industry[a]	Retail[b]	Consumer[b]
	Million metric tonnes		
Vegetables	17.4 (31%)[c]	3.2 (8%)	8.3 (22%)
Fruit	6.4 (19%)	2.7 (9%)	5.7 (19%)
Dairy	–[d]	4.2 (11%)	7.3 (20%)
Meat poultry fish	12.0 (32%)	1.2 (5%)	5.8 (22%)
Grain products	–	3.3 (12%)	5.1 (19%)
Eggs	0.07 (2%)	0.3 (7%)	1.0 (21%)
Fats and oils	–	2.4 (21%)	2.0 (17%)
Sugar and sweeteners	–	2.0 (11%)	5.6 (30%)
Tree nuts and peanuts	0.01 (1%)	0.1 (6%)	0.1 (9%)
SUM	35.9 (15%)	19.5 (10%)	40.8 (21%)

[a] Our own calculations based on USDA ERS Loss Adjusted Food Availability (LAFA) databases; 2012 data.
[b] Buzby et al. (2014); calculations were based on USDA ERS LAFA databases; 2010 data.
[c] Values in parentheses represent percent of food entering each of the supply chain sectors that is lost and wasted by food group within that sector.
[d] For some food groups, processing losses were zero in the LAFA tables. Refer to Food Availability tables for details (USDA-ERS, 2015a).

other dairy products after their manufacture). Two additional sources can help fill this data gap. One is the survey result of U.S. food manufacturers indicating a total of 20.1 MMT (44.3 billion lbs.) of food loss (BSR, 2013; Table 1). The type of food loss (grain vs. vegetable products, for example) was not specified but the survey indicated that 69% of the 20.1 MMT of waste was recovered for animal feeding. The other source of data comes from the national records of food byproducts fed to animals (2012 data; see a summary by Ferguson, 2016), totaling 43.9 MMT (including oilseed meals 30.4 MMT, mill products 10.9 MMT, and animal proteins 2.5 MMT). It is likely that the national records encompass much of the industry survey volume. (Note that byproducts from ethanol or brewers used in animal feeding are not included here.) Considering various factors, the amount of food exiting the industry sector is likely to exceed 80 MMT, including recoverable (e.g. byproducts for animal feeding) and non-recoverable losses.

For the retail sector, food loss derived from the LAFA databases by Buzby et al. (2014) totaled 19.5 MMT (43 billion lbs.), while the survey reported an order of magnitude less (1.7 MMT; 3.8 billion lbs.). The latter figure was derived and extrapolated from 10 retailer and 3 wholesaler survey respondents, whose collective revenue was 30% of the entire sector in the nation. That extrapolation was considered by the authors to be representative (BSR, 2013). However, it is not clear whether the numerical answers to the questionnaire were based on company records or involved guesswork. There are indications that some guesswork was likely, because the respondents were more confident about the accuracy of their food donation and food waste recycling data (self-reported confidence level 7.5 and 7.7; 10 is most confident) than that of food waste disposal data (5.0) (BSR, 2013). Assuming that survey respondents recognized food wastage to be socially and environmentally undesirable, an underestimation is probable. On the other hand, the far greater retail food loss derived from the LAFA statistical databases (19.5 MMT, as compared to the survey result of 1.7 MMT) can be subject to system error as well, although none is known at present. In fact, Buzby et al. (2014) argue that their overall results on food loss are likely to be underestimated (see below).

At the end of the supply chain, i.e. in the consumer sector, food wastage approximates 41 MMT (90 billion lbs.; Table 1). This, together with the retail food loss, totaling 60 MMT (133 billion lbs.), is the official number on national food loss that has been widely cited. Note that the 60 MMT food loss figure refers to *edible food*, since the waste factors embedded in the LAFA tables were developed for edible-food loss explicitly (USDA-ERS, 2015a). Buzby et al. (2014) believe that the 60 MMT is likely to be a *conservative estimate*. Most compellingly, estimated daily food consumption by an average American, calculated by subtracting the estimated food loss from the amount of supply in the LAFA tables, would contain 2547 cal, which is higher than the energy requirements of most age cohorts determined by the Institute of Medicine (U.S. DHHS, 2005), even considering the prevalence of obesity. This means that the estimated edible food loss is on the low side.

For on-farm food loss (i.e. prior to entering the supply chain), nationally representative data are lacking, but a few reports of limited scope provide a glimpse of the magnitude of the problem. Based on interviews with 16 growers and packing houses in central California, NRDC (2012) reported that 15% of tree fruit, 5% of head lettuce (*Lactuca sativa* L.), and 13% of broccoli (*Brassica oleracea* L.) were left un-harvested; packing culls accounted for a further 13% of tree fruit and 3% of lettuce. Another piece of information is food rescued through field gleaning by volunteers from hunger-relief organizations. The Society of St. Andrew reports that approximately 13,620 t (30 million lbs.) of food is rescued annually through its gleaning network spanning the 48 contiguous U.S. states (www.endhunger.org). Feeding America, the largest charitable organization in the U.S. focusing on hunger relief, reports an annual recovery of 266,500 t (587 million lbs.) of fresh produce (www.feedingamerica.org), presumably through gleaning and other recovery efforts. If we assume on-farm loss of vegetables and fruit to be 10% on the low side and 20% as an upper estimate, nationwide on-farm vegetable and fruit losses would amount to 9–18 MMT (U.S. domestic production for human consumption totals 56 MMT vegetables and 34 MMT fruit, respectively).

To summarize, on an annual basis approximately 150 MMT or more of food exits the U.S. supply chain, with 80 MMT being largely unavoidable (but recoverable as byproducts) from the industry sector and 70 MMT as edible food loss. The latter includes 9–18 MMT on farms, nearly 20 MMT at retail, and 41 MMT at the consumption stage. To put the amount of edible food loss in perspective, the domestic annual food supply for human consumption ranges from 20 to 80 MMT in France, Germany, Australia, Canada, Japan, and the UK, whereas most of the African nations had annual food supply of less than 25 MMT per country (FAO, 2011 data). Clearly, reducing U.S. food wastage offers a significant potential to combat hunger and enhance food security.

4. Opportunities for reducing food wastage

4.1. Characteristics of food waste

The food waste reduction hierarchy developed by the U.S. EPA (Fig. 2) prioritizes different endpoints for food through various reduction, recovery, and recycling efforts. The priority is obvious, moving from source reduction to feeding people, feeding animals, industrial conversion, composting, and landfill disposal (preferably with gas recovery) or incineration. Naturally, all food waste is not equal; the most appropriate endpoints depend, first and foremost, on the characteristics of the food being considered.

Upstream of the supply chain in the industry sector, food waste materials can be considered in three broad types. First is the waste associated with the meat/poultry/fish food group (12.0 MMT, Table 1), primarily as bones or trimmings, which is not salvageable for humans but may be suitable for industrial use or processed into byproducts such as rendered fat and bone or blood meals to

Fig. 2. Food waste reduction, recovery, and recycling hierarchy. Source: U.S. Environmental Protection Agency, http://www2.epa.gov/sustainable-management-food/food-recovery-hierarchy.

be used for animal feeding. The second type includes food remnants that cannot be converted into consumer products, such as mill byproducts, orange rind and pulp. Such food residues, unavoidable and unpalatable to humans, would have animal feeding as the most desirable end use. The third type of waste results from manufacturing mishaps (e.g. mislabeling), overruns or operational changes. For example, if a manufacturer changes the recipe of a frozen entrée or discontinues a product line, it may find itself with massive amounts of un-needed ingredients. While suddenly unsaleable, such food materials are safe to eat; therefore, they could be best directed to human uses.

Mid-stream at the retail sector, food waste materials are entirely different from those in the industry sector. Here, much of the waste involves finished food products that are removed from the distribution channel for various reasons. For example, damaged packaging renders some items unsaleable. Blemished produce, day-old bread, or grocery items nearing sell-by dates are routinely removed from shelves. Such food materials, while unsuitable for sale, are generally safe to eat when handled properly.

Downstream in the supply chain at the consumer level, food waste is generated by individuals in homes or food-service places for numerous reasons, e.g. poor planning, over-sized portions, food safety concerns, etc. (Buzby et al., 2014). Here, wasted food can be in any form, cooked or uncooked, wholesome or spoiled. At this last stage of the food system, waste prevention (i.e. source reduction) is the best and practically the only viable option. Once wasted, few opportunities exist for recovery for human consumption purposes, or even for animal feeding because of regulatory and technical specifications (see discussion later). Capture for energy production through anaerobic digestion is possible but costly due to lack of significant volume per location. Composting is feasible but also logistically challenging, particularly for dispersed household food waste.

Waste streams at the industry, retail, and consumer sectors also differ in the pattern of distribution. In the industry sector, large volumes of food residues excluded from the supply chain are concentrated at a relatively small number of processing/manufacturing sites. Such concentration allows for greater economies of scale when food residues are recovered for animal feeding, or mishandled food ingredients or products are recovered for human use (BSR, 2013). In contrast, wasted food at the retail or consumer sectors is scattered across numerous locations, making it logistically challenging to divert the waste away from landfill for higher uses. To put the relevant distribution characteristics in perspective, there are roughly 27,400 locations for the processing/manufacturing sector in the U.S. (Census Bureau, 2015) generating about 80 MMT of food waste annually, compared to nearly 180,000 wholesale and retail stores dealing with 19.5 MMT of food waste, and approximately 117 million households plus nearly one million restaurants across the country accounting for 41 MMT of food waste. In essence, industry food waste resembles *point sources* whereas consumer food waste resembles *non-point sources*. Differences in compositional and physical /distribution attributes, together with human management decisions, determine the fate and ultimate destination of the food that is lost from the nation's supply chain.

4.2. Current efforts

Efforts to raise awareness and address food waste issues have grown rapidly in recent years. Media coverage of the topic is increasing. Countless individuals are engaged in food-rescue activities. Various charity organizations work in partnership with food establishments to re-purpose unsaleable but safe-to-eat food for food-insecure families. The food industry has also mobilized to better understand and address food waste issues; examples include the FWRA initiatives (www.foodwastealliance.org) and the Food Waste Challenge led by USDA and EPA (www.usda.gov/oce/foodwaste/index.htm).

Quantitative information on food waste reduction, recovery, and recycling at the national level is best documented with the aforementioned survey report (BSR, 2013). As shown in Fig. 3a, of the 20.1 MMT of food materials that exit the manufacturing sector, about 1.6% (320,000 t) is recovered for human consumption through donation, 69% (13.9 MMT) is re-directed for animal feeding, 26% (5 MMT) is recycled through land application, composting, etc., and the remaining 5.4% (1.1 MMT) is disposed of in landfills or by incineration. Notably, the survey data on the quantity of food donation for humans is in line with the report of Feeding America (370,000 t, or 815 million lbs. from food industries in 2012). Feeding America is the umbrella organization for receiving and re-directing donated food for domestic hunger-relief. In addition, the amount of documented food byproducts used in animal feeding is more than half of the total estimate of industry food loss, as discussed earlier.

A different pattern is shown for the 1.7 MMT food materials reportedly exiting the wholesale-retail sector (BSR, 2013; Fig. 3b). Compared to the industry food waste diversion pattern, a considerably higher portion (17.9%) is recovered for human use; the portion for animal feeding is much less (6%), while composting or other recycling is substantial (31%). Still, disposal through landfill or incineration accounts for the greatest portion (44.7%). The different endpoints of food waste at retail versus the manufacturing sector are primarily determined by their composition and physical attributes, as discussed earlier. Finished and packaged food products in the wholesale-retail sector enable donation; but the dispersion and diversity of wasted food material add complexity to the option of animal feeding. Notably, the amount of donated food from the retail sector as reported by Feeding America (410,000 t or 895 million lbs. in 2012) is considerably greater than that in the survey report.

No comparable data are available for the reduction, recovery, or recycling of the 41 MMT (90 billion lbs.) of food waste in the consumer sector. Conceivably, opportunities exist to recover food for humans from restaurants, cafes, etc. but the capacity may be small (see Box 1 as an example). On the other hand, household food waste is generally beyond the point of recovery for feeding people because of health and food-safety concerns. Even feeding animals is not widely practiced, due in part to health-related stipulations (e.g. wasted food must be heated to 100 °C for 30 min before being fed to pigs; Swine Health Protection Act, U.S. Congressional Record (96th Congress), 1980). Another major hindrance is that wasted food from restaurants or homes varies a great deal in composition and nutritional attributes, making it incompatible with the precision feeding of today's animal production systems for maximal efficiency (Banhazi et al., 2012). As for other beneficial uses, composting is probably the only viable option. We postulate that, of the 41 MMT food wasted by American consumers, the amounts recovered for humans or any other beneficial uses are negligibly small (Fig. 3c).

In summary, current food recovery for human consumption approximates 1 MMT (2 billion lbs.), based on major estimates (BSR and Feeding America reports), including 320,000–360,000 t (700–800 million lbs.) industry donation, 300,000–410,000 t (670–900 million lbs.) wholesale-retail donation, and roughly 250,000 t (550 million lbs.) fresh produce presumably from gleaning efforts. The amount rescued/recovered is less than 2% of edible food loss. On the other hand, of the 80 MMT industry sector food loss, about 55% is recovered for animal feeding.

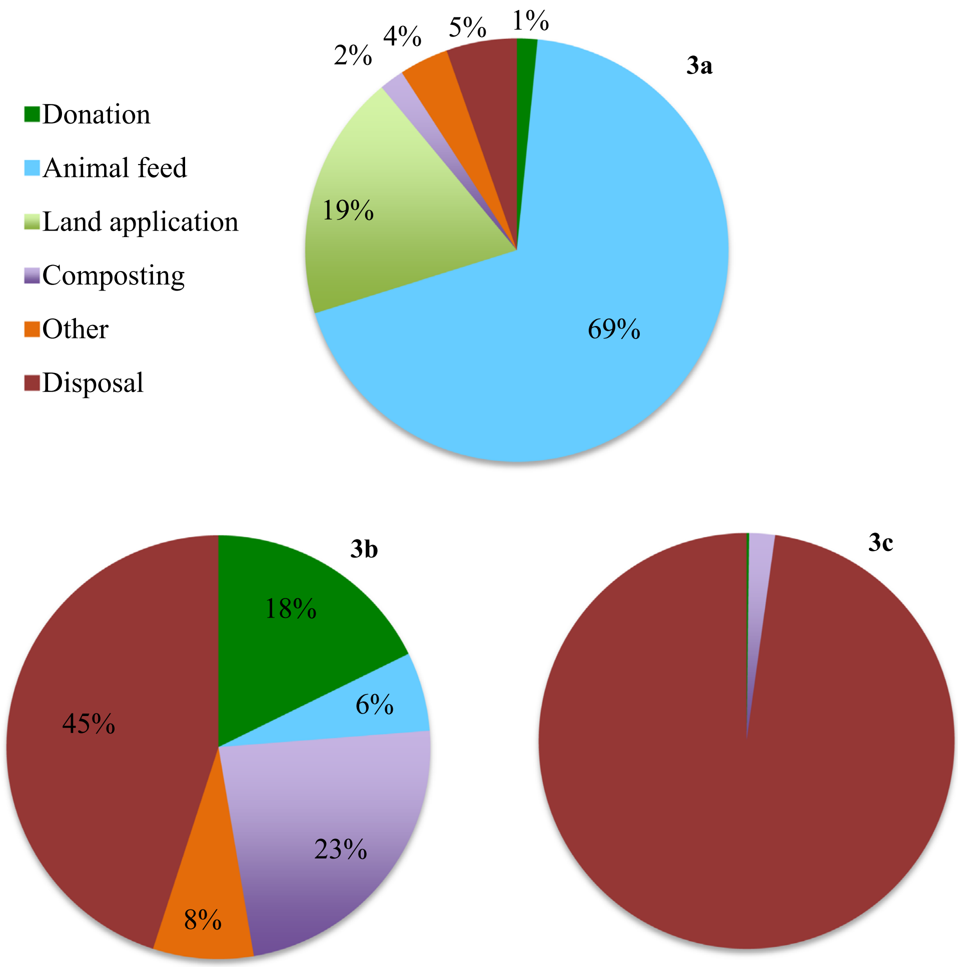

Fig. 3. Recovery and diversion of wasted food in food manufacturing (3a), retail-wholesale (3b), and consumer sectors. Data adapted from survey reports (3a and 3b; BSR, 2013), or estimates based on various reports for the consumer sector (3c).

4.3. Prevention versus diversion

Food waste reduction has two dimensions (Buzby et al., 2014): one is the *prevention* of food from being wasted in the first place (i.e. source reduction), and thus directly serves food security purposes; the other is the *diversion* of wasted food from landfills for beneficial non-human uses, providing environmental services. Different opportunities exist at the various stages of the food supply chain for waste prevention and diversion.

Opportunities for food waste prevention exist on farms (9 to 18 MMT fresh produce annually), in the retail sector (nearly 20 MMT finished food products), and in the consumer sector (41 MMT consumer food products). Certainly not all edible food loss can be prevented considering the perishability of most foods, the complexity of consumer behavior, the costs of collecting, handling, and distributing food, and the need for ensuring food safety. Nevertheless, a 20% reduction at these sources would amount to 14 MMT (30 billion lbs.) of edible food saved annually for human consumption. This should be an attainable goal within a short timeframe given the UK experience where a nationwide reduction of 21% in avoidable food waste in households was achieved, made possible by a five-year intense campaign and concerted efforts (Quested et al., 2013). (Note that the recently announced U.S. food waste-reduction goal calls for a *50% reduction of food going to landfills* by 2030. This is different from source reduction for food security purposes.)

Food waste prevention and food rescue for hunger relief has traditionally relied on volunteers and charitable organizations in partnership with farmers and food enterprises (see Box 2 as a case study). Participants in such collaboration will continue to be at the front line for saving food, fighting hunger, serving the community, and benefiting the environment. Meanwhile, innovative policies that can further incentivize the participation of relevant stakeholders by addressing their concerns, overcoming barriers, and strengthening partnerships are critical to substantially advance food-rescue and waste-prevention campaigns.

Certainly, food waste prevention at the consumer level is most challenging, since consumer food behavior can be influenced by numerous internal and external factors. An individual's food habits can be knowledge- or skill-related, e.g. how to handle leftover food, how to use certain food ingredients, and how to store different perishable items for prolonged freshness. Parental and peer influence is important in shaping children's food behavior (Savage et al., 2007; Wang et al., 2011). Examples of external factors include packaging, marketing, and labeling. As various factors intertwine to exert influence on individuals' attitudes about food, finding effective ways to change consumer food behavior will not be easy, but it is not impossible. The UK's achievement of 21% reduction in avoidable food waste in households was achieved by carefully-planned and well-coordinated campaigns and concerted efforts by multiple stakeholders (Quested et al., 2013). Success stories exist in the U.S. as well. One example is the Food-Too-Good-To-Waste program, whereby 50–60% reduction of kitchen food discards has been realized among participating households (O'Donnell, 2016).

For wasted food that is beyond recovery for humans, diversion

Box 1–Food waste audit at a University dining hall.

A pilot study was conducted by a group of students at the University of Pennsylvania to quantify food waste streams at an all-you-can-eat dining hall. Four waste streams were identified: (i) kitchen trimmings during food preparation, (ii) cooked but unserved food, (iii) service station remains, and (iv) plate waste discards. These waste streams were weighed and recorded daily after a single meal (dinner) for 10 weekdays over a two-week period.

Plate waste was the single largest stream, averaging 63 kg (138 lbs.) per day-meal (standard deviation 10 kg), whereas the other three streams averaged 6-8 kg (13–17 lbs.) each. On a percentage basis, plate waste accounted for 76% of the total food waste. Diners' self-reported plate waste was 205 g (0.45 lbs.) per meal per person, compared to an average of 290 g (0.64 lbs.) as measured. Notably, only the "cooked but unserved" stream qualifies as recoverable for humans, averaging 7.7 kg (17 lbs.) per day-meal, which would feed 14 hungry people. Food thrown away by every two diners (plate waste) was enough to feed a third person, equivalent to 115 meals per day-meal. Unfortunately, such wasted food is not recoverable for humans. The important messages are:

- Although a considerable amount of food is recoverable to help feed hungry people, 84% of the wasted edible food is currently non-recoverable for humans.
- From a food security and sustainability standpoint, finding ways to change consumer food wasting behavior is paramount.

See Cirone et al. (2016) for more details of the study.

Box 2–Rescuing food and serving communities.

Rolling Harvest Food Rescue (RHFR) is a not-for-profit organization in Bucks County, Pennsylvania dedicated to rescuing food from area farms and farmers markets (food donating partners) and delivering it to food pantries, soup kitchens, low-income senior housing, etc. (hunger-relief sites).

On a typical day, RHFR volunteers carry out 2-3 *scheduled truck pickups* pre-arranged with donating partners to minimize any inconvenience. Volunteers also respond to many last-minute calls, emails or texts from growers who have leftover produce from previous day's markets or harvested excess food that they will not be able to sell. A large donated walk-in cooler helps keep the donated food fresh until delivery, reducing post-donation wastage.

With about 80 volunteers, RHFR has established partnerships with 27 farms and markets and nearly 50 hunger-relief sites, serving over 14,000 food-insecure families in the community. Scheduled weekly food pickups account for 40% of the annual food volume, another 40% comes from last-minute opportunities and the remaining 20% comes from RHFR's gleaning program.

See more details at: http://www.rollingharvest.org/.

for animal feeding is the next priority in the hierarchy (Fig. 2). In fact, this option can contribute to food security: Wasted food recovered and fed to animals can replace feed grains, which can then be added to the human food supply; animals fed by recovered food waste enrich the food supply for humans by providing meat, milk, and eggs. As shown earlier, the food industry has successfully diverted large volume of food-processing byproducts to animal feed, driven by profit and favored by the economies of scale. Nevertheless, large amounts of wasted food are not recovered across the supply chain. To divert more of the wasted food from landfill to animal feed will require technological innovation. For example, technologies that can effectively dehydrate, sanitize, and homogenize food waste materials would help surmount the current barriers concerning animal health as well as the nature of wasted food being high in water content and variable in nutrient content. Toward this end, support policies, coupled with public education and creative interventions are essential to change the current waste-management regimens.

Diversion of wasted food to composting, although not directly contributing to food security, is preferable over landfill disposal. Currently, there are nearly 400 composting facilities in the U.S. that include food waste as part of the feedstock, which together handle about 5% of wasted food in the nation (Goldstein, 2016). Another viable option is anaerobic digestion (AD), a process that converts organic waste into energy. Food waste can be the main feedstock at standalone AD facilities or added to farm or wastewater organics at co-digestion facilities (Moriarty, 2013). About 150 AD facilities in the U.S. accept food waste, while overall AD capacity is expected to increase more than fourfold by 2017 (EREF, 2015). The growing interest in composting and AD could contribute substantially to the national goal of 50% food waste reduction at landfills by 2030.

4.4. Food for thought

Substantially reducing food wastage is no small task. There can be any number of opinions, obstacles, strategies, and approaches. Detailed discussion on how this goal may be achieved operationally is beyond the scope of this paper. Recommended public and private interventions can be found elsewhere (Dou et al., 2016). Nonetheless, we believe that meaningful progress in reducing food waste nationwide requires some fundamental measures, outlined below.

- ***Engage and educate consumers.*** Consumers collectively contribute the most to the total volume of edible food loss. Despite growing awareness, the American public is yet to be significantly engaged, as the scope and scale of food waste have not yet registered with the average consumer (Neff et al., 2015). Recognizing the problem is a prerequisite to fixing it. UK consumers, too, were initially in denial (Exodus Market Research, 2007; Lee and Willis, 2010), but they were persuaded to address the problem when they were presented with evidence generated through actual measurement and data recording (Quested et al., 2013). In particular, early intervention involving the education of K-12 children is important because this demographic represents 16% of the population and their food habits, knowledge, and attitudes will determine not only their own food behavior over long life-spans but also affect future generations.
- ***Mobilize stakeholders and foster innovation.*** Many external factors influence consumer food behavior. Reforming certain business practices can drive positive changes in the way consumers handle food. For example, retailers adopting a "buy-one-get-one-free" *in the next purchase* instead of now could help consumers minimize spoilage. Furthermore, inconsistent and ambiguous date labeling ("sell by", "best by", etc.) has been frequently blamed for causing confusion among consumers and contributing to food discards (Newsome et al., 2014). Reforming the labeling system is needed in concert with consumer education. Technological advances have always played a central role in changing the way we live our lives in modern society. New technologies and improved food processing practices, such as better preservation methods, employment of nanotechnology in food packaging, and in particular, innovative techniques for recovering and re-purposing wasted food for feeding animals

will help reduce food losses over time. Toward this end, support policies and incentive programs must be created to empower entrepreneurship and enable technological development.

- ***Invest in building a sustainable food system***. Like the soil conservation program that helps safeguard the primary base of agricultural production, we need a food conservation program to maximize the use of food already produced and foster sustainable food consumption. Similar to combatting pollution or climate change, governments have the responsibility to lead the fight against food wastage for food security and sustainability. Relying solely on the market economy is unlikely to resolve the food waste problem. In fact, in many cases, food is wasted because it is a cheaper option; for example, vegetables are left unharvested or truckloads of produce are dumped when dictated by labor or market conditions (Bloom, 2010; NRDC, 2012). Policy interventions with research initiatives, government-coordinated campaigns, education, and new mechanisms to reward food waste reduction actions and outcomes, plus additional changes in laws and regulations are indispensable and can offer the greatest potential to reduce food loss for short- and long-term benefits.

5. General discussion and conclusions

The inefficiency of our current food system is appalling. The quantity of edible food loss in the U.S. (about 70 MMT) is more than half (54%) of the amount that is consumed by Americans (129 MMT, calculated from LAFA tables) on an annual basis. Enhancing the use of what is already produced by cutting down wastage deserves attention in the endeavor to address the growing food security challenge. For comparison, U.S. total food production increased from 380 MMT to 766 MMT in the past five decades (1961–2011), averaging a net gain of 7.7 MMT per year. If the nation can reduce its edible food loss by 20%, a reasonably attainable goal, the amount of food saved each year (about 14 MMT) would equate to two-years of growth in production. Globally, average annual increase of total food production during the same time span was 122 MMT (2900 MMT in 1961 and 9000 MMT in 2011, FAOSTAT); a 20% reduction of the 1.3 billion tonnes of food loss would mean 260 MMT saved annually. This is a magnitude of great significance. Enhanced efficiency of food usage by reducing waste would also help improve the resilience of local and global food systems, which is increasingly important in the face of climate change. To forgo the low-hanging fruit of reducing food waste to strengthen food security would be irresponsible.

Food security relies on sustainable use of natural resources such as land, water, nutrients, fossil fuel, etc. Wasted food is wasted resources. In the U.S., the annual edible food loss in the retail and consumer sectors is associated with 16 million ha cropland, 3.9 MMT fertilizer nutrients, and 17 billion m^3 irrigation water which are utilized to produce that amount of food (Toth and Dou, 2016). These resources are spent in vain when the food is never eaten but lost, not to mention other environmental impacts associated with the food production processes, such as soil erosion, greenhouse-gas emissions, and pollution of water bodies with agricultural nutrients. Saving food and reducing wastage by 20% would mean conservation of the resources in a similar proportion.

Our analyses of the magnitude and pattern of U.S. food loss between farm and fork and our summary of opportunities to reduce that loss are pertinent to other developed economies because food systems in these economies have shared similarities. For example, food is relatively cheap, abundant, and convenient in these societies. The vast majority of consumers in the highly urbanized economies are increasingly separated, conceptually and physically, from the processes of growing and harvesting food. Our food systems are increasingly sophisticated with supply chains from farm to table intrinsically extended, food processing more complex, products more diverse, and the “food-print” spread far beyond national borders. In essence, the U.S. food system is connected to, and an integral part of, a vast global network involving both developed and developing countries, as are the food systems of other nations, particularly in the developed world. Reducing food wastage in the U.S. and other developed economies can contribute substantially to local and global food security and sustainability.

The analysis of U.S. food loss in this study is based primarily on the nation's food-supply inventory coupled with waste factors as maintained by the USDA Economic Research Service. The robust, statistically based data enable us to see the big picture at the national level. Yet, evidence-based data from ground-up measurements are critically needed to help us better understand consumer food behavior and contributing factors. Such understanding is key to finding practical solutions and interventions for change. Furthermore, the food loss assessment expressed in weight in its natural (as-is) state is crude, as different types of food (e.g. vegetables, cereals, dairy products) differ dramatically in nutrient density per unit weight. On the other hand, different waste streams have different biological–physical attributes, which in turn determine their endpoints. For example, industry food waste largely comprises processing residues that are unpalatable for humans; animal feeding would be the most desirable endpoint. Nevertheless, the caloric and retail values for the edible food loss in the U.S. retail and consumer sectors have been reported (Buzby et al., 2014).

In conclusion, tremendous opportunities exist to reduce food wastage across the supply chain for multifaceted benefits of combating hunger, enhancing food supply, improving resilience of the food systems, and improving resource and environmental performance. Importantly, these opportunities are not limited to the U.S. but extend across the globe as well.

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