Economic and Environmental Costs of Agricultural Food Losses and Waste in the US

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***Abstract*—According to the Food and Agriculture Organization (FAO), approximately 30% of agricultural production (1.6 billion tons of food) is lost every single year [1]. Food wastage is linked to economic and environmental losses occurring in the production chain from the farm to the table. While many studies address the problem of food waste by analyzing consumption patterns, little research has been done on the economics of food waste and sustainability of agricultural production related to agricultural and food losses and waste. This paper seeks to address this question by monetizing resource losses (e.g. energy, water, agricultural land), environmental impacts (i.e. methane emissions), and by contributing to the discussion on biodiversity loss in the food production process in the US. The presented analysis and results can help raise awareness and incentivize households and governments to design and implement cost-effective measures for food waste reduction.**

***Index Terms*—food waste, food loss, agriculture, economics, environment**

I. Introduction- Food Waste and Losses, and Impacts on Natural Resources

Approximately a third of food produced in the world is wasted each single year which translates to 1.6 billion tons [1]. In the US, almost 40% of food is lost in the production chain from farm to landfill [2].

In agricultural production, food losses occur in the production chain on farm, after harvesting, during food processing, and through wholesales/supermarkets. On the contrary, food waste occurs through domestic consumption (in households and restaurants) (Table I).

TABLE I. Estimated Total Food Loss in the usin 2010

	Losses from food supply* (billion pounds)		
Commodity	**Retail**	**Consumer**	**Total**
Dairy products	9.3	16.2	25.4
Vegetables	7.0	18.2	25.2
Grain products	7.2	11.3	18.5
Fruit	6.0	12.5	18.4
Added sugar & sweeteners	4.5	12.3	16.7
Meat, poultry, fish	2.7	12.7	15.3
Added fats and oil	5.4	4.5	9.9
Eggs	0.7	2.1	2.8
Tree nut and peanuts	0.2	0.3	0.5
Total	**43.0**	**89.9**	**132.9**

* Totals might not add due to rounding.
Source: [3]

Although food waste and loss has been a growing problem worldwide, it has been reported unwieldly in developed countries characterized by high incomes and consumption rates. According to the UN Environmental Program, consumers in industrialized countries waste 222 million tons of food annually, which corresponds to almost as much food as the entire net food production of sub-Saharan Africa (230 million tons) [4]. This issue in the industrialized world at large is even more pronounced in the US in particular. Bringing food from the farm to an American's fork requires 10% of the US energy budget, 50% of the US land area, and 80% of all freshwater consumption in the country [4]. In the end, 40% of those energy, land, and water resources are wasted. In economic terms, food waste costs generate monetary losses in households. On average, food waste costs a family of four at least $589-$1,600 annually [5], while it amounts to more than 20 pounds of wasted food per person [4].

The depicted situation is disturbing as approximately one in six Americans lacks a secure food supply - in 2010, 48.8 million Americans lived in food-insecure households [2]. Accordingly, reducing food waste by 15% could help feed more than 25 million Americans every year.

Beyond the loss of resources, food waste also generates methane emissions and negatively impacts biodiversity in some densely agricultural areas. The Food Recovery Initiative by the Environmental Protection Agency (EPA) estimated that approximately 13% of GHG emissions in the US are associated with growing, manufacturing, transporting, and disposal of food. According to NRDC [4], over 97% of food waste ends up in landfills, while less than 3% is recovered and recycled (composted). The cost of landfill disposal amounts to ~$1.3 billion annually [2], [5]. Landfills (with organic waste being the second highest component) are the single largest source of methane emissions, and generated 18% of the total methane emissions in the US in 1990-2013. Methane emissions are the more harmful, as the comparative impact of methane on climate is 25 times greater than carbon dioxide (CO_2) over a 100 year period. In 2013, total methane emissions in the US equaled to 6,673 million m^3 of CO_2 equivalent (End Food Waste Now, 2015). Every ton of food waste ultimately results in about 3.8 tons of GHG emissions [2], while the emissions vary depending on the geographic region (Fig. 1).

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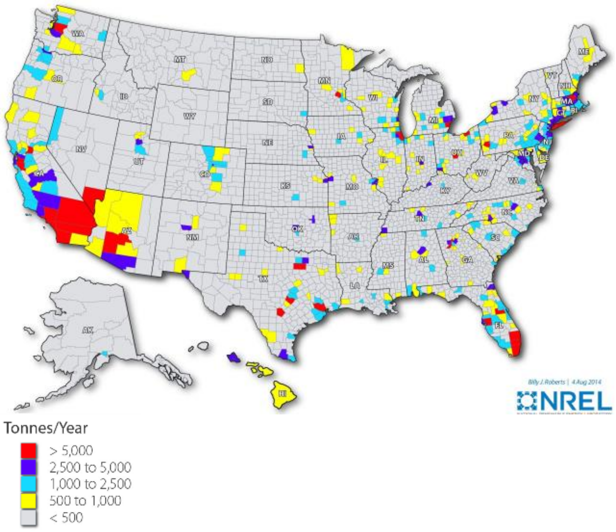

Figure 1. Methane generation potential from industrial, institutional & commercial organic wastes in 2014.
Source: [6]

Because of the significant environmental, economic, and social impacts of food waste, many agencies (like EPA and United States Department of Agriculture - USDA) emphasized the importance of reducing and recycling food waste. For instance, the US EPA recommended a Food Recovery initiative that prioritizes actions organizations can take to prevent and divert wasted food. Each tier of the Food Recovery Hierarchy is focused on different management strategies for wasted food, while the top levels of the hierarchy are considered to be the best ways to prevent and divert wasted food as they create the most benefits for the environment, society and the economy (Fig. 2).

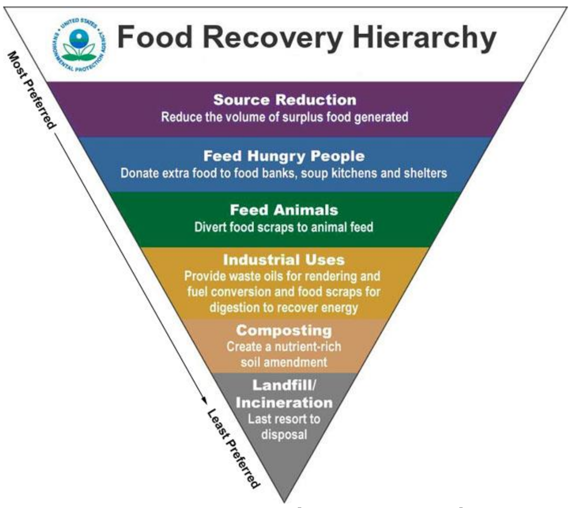

Figure 2. US EPA Food Recovery Hierarchy.
Source: [7]

Beyond the involvement and interest of government agencies in this issue, many nonprofit organizations invested their resources in reducing food waste triggered by their goal of curtailing hunger in the country and feeding families in need. For instance, the Food Waste Reduction Alliance (FWRA) is dedicated to feeding the hungry with donated food that would otherwise end up in landfills [8]. ‘Feeding America’ is a member of the FWRA striving to divert safe, edible food away from landfills and to the households. Decisive and sustainable measures are needed to involve each market participant in the process of food waste reduction goal, starting with national goals for waste reduction, businesses streamlining their operations and reducing losses, and consumers planning their shopping, willing to purchase cosmetically unattractive produce, and eat leftovers.

Research on food waste and loss is still limited, which is reflected in most studies providing a descriptive analysis and evaluation of the problem at hand in different countries [9]-[14]. For instance, Dai *et al.* [15] evaluated underlying reasons for food waste and recycling incentives in Shanghai, while Schimdt [16] discussed ways of promoting food waste prevention in households in Germany. In recent years, many studies have addressed ways and approaches of food waste reduction [17], [18], including stakeholders’ engagement [19], [20]. Moreover, an increasing number of studies address environmental impacts of food waste generation [21] and approaches to mitigate them [22]. For a comprehensive analysis of food waste impacts, life cycle analysis (LCA) has been recommended by Saraiva et al. [23]. Ahamed *et al.* [24] analyzed food waste management strategies, while Cristóbal *et al.* [25] conceptualized a 3-stage methodology combing Data Envelopment Analysis (DEA), Life Cycle Analysis, and process retrofit to assess and retrofit different technological options for food waste management. Also, the question of date labels and packaging has been addressed by Wilson *et al.* [26] to emphasize the impact on predicted food waste. Several studies pointed out the economic value of food waste recycling [27], [28]; however economic and environmental evaluations of food waste impacts expressed in monetary values are still limited [29], [30]. This research adds to the discussion in this field and attempts to monetize economic and environmental impacts of food waste, based on data and examples from the US.

II. Problem Setting and Research Objective

Currently, consumers and food services are the largest source of food waste, which leads to the realization that concerted actions are needed to improve consumer awareness and reduce food waste in the short and long term. The process of food production, processing, distribution, and disposal require large inputs of energy, water, and land, while generating GHG emissions, and negatively impacting biodiversity. While those impacts have been acknowledged by many as a results of food waste, assessing the scope and extent of food waste and loss is challenging, as economic analyses are missing that would allow for quantifying monetary costs of this problem. At the same time, an economic evaluation of this kind is needed as it could effectively support the process of raising awareness and educating the public about the need to reduce food waste/loss. Accordingly, it is arguably more convincing and significant to an individual, household or a government to realize direct food waste costs impacting their budgets and expenses, rather than convincing those groups about negative impacts on water scarcity or air pollution. This paper evaluates and analyzes the monetary value of natural resource losses in the US, and corresponding impacts on energy, water, agricultural land resources, methane emissions, and biodiversity. The study aims at raising awareness and providing a quantitative basis to incentivize households and governments to create cost-effective measures for food waste reduction.

III. Methodology and Data

To calculate economic impacts of food waste, data was collected primarily from USDA, research journal articles, and nonprofit organizations. The monetized values of food waste are approximate (indicative), but not definitive for decision-making, as long-term knowledge and statistics are missing that would be required for a more comprehensive analysis. Due to missing data in this field, the variable values included in this analysis might represents different years; while an assumption is made that annual changes in resource use for food production are relatively miniscule. The estimated monetary values of food waste are based on the percent of resources used/wasted and their respective prices.

The cost of energy losses was calculated according to the following formula (eq. 1):

$$\textit{Cost of lost energy (\$)} = \Sigma\ [\textit{energy lost (BTU)} * \%\ \textit{of energy source used} * \textit{price for energy source (\$/BTU)}] \quad (1)$$

The calculations were based on the existing information that ~63% of energy used in food production in 2011 was derived in the form of “direct” energy, while 37% came in the form of “indirect” energy. Direct energy sources include diesel (27%), gasoline (9%), LP gas/propane (5%), natural gas (4%), and electricity (21%). Indirect energy sources are: fertilizers (28%) and pesticides (6%) [31]. Direct energy consumes twice as many BTUs [1] as indirect energy, yet indirect energy accounts for 9-10% of farm expenditures, while direct energy accounts for only 5-7% of these expenditures [31]. The prices for the respective energy sources included in this analysis were as follows (\$/million BTU): diesel - \$15.49, gasoline - \$17.81, LP gas/propane - \$13.28, natural gas - \$5.69, electricity - \$26.31, and coal - \$1.32 [32]. In addition, the total expenditures on pesticides equaled \$27 million in 2011. The US applied 12.5 million tons of fertilizer to crops in 2008, while each ton required an average of 32.5 million BTUs to produce, and used 73% natural gas and 27% coal in production [33]. According to Cuellar and Webber [34], the total amount of energy lost due to food waste in 2007 was between 1,870 and 2,190 trillion BTU. These amounts were multiplied by the types of energy used and their corresponding prices and summed up to evaluate a range for the cost of the energy loss due to food waste (\$25.2-29.4 billion).

Calculating water used for irrigation and food production was more challenging as prices have varied drastically across states and regions. Many farmers own water rights on their lands and therefore accrue no water fees. Water expenses for farmers purchasing water have varied subject to farm size and location (\$26-\$71/acre in 2008) [35]. Furthermore, farmers do not pay the “shadow price” (actual price) of water as a resource. According to Ziolkowska [36], the shadow price for crops in the US High Plains varied considerably, depending on the region, and the planted crop. For instance, the shadow price of water for corn production in 2010 in the Texas Northern High Plains amounted to \$92/af (acre foot), while 971,853 af (316.6 bil gallons) of water were used for irrigation that year in that region. According to the USGS, 128,000 mil gal of water were used for the total food production in the US per day, which equals to 144,000 thousand af/year in 2005 [37]. For irrigated farmland, the total amount of water used was 88.5 million af in 2013 [35].

The cost of water loss due to food waste was calculated using the equations 2-3 and knowledge that farmers paid between \$26 and \$71 per acre for water in 2008. In aggregate, farmers paid between \$1.443 billion to \$3.941 billion for water that year. Given that the US wastes 30-40% of its food, around \$433 mil - \$1.576 bil of water was wasted. Importantly, this number would be much higher if the shadow price of water was accounted for.

$$\textit{Cost of water for food production (\$)} = \textit{price of water/ac (\$/ac)} * \textit{irrigated acres (ac)} \quad (2)$$

$$\textit{Cost of wasted water (\$)} = \%\ \textit{of food waste} * \textit{cost of water for food production (\$)} \quad (3)$$

Regarding land use for food production, in 2007 around 3.5 billion acres of land globally (an area larger than Canada) was cultivated to grow food or support livestock and dairy production that were never consumed. In the US, 44.7% of land areas is used for agricultural purposes [38]. Cropland makes 408 million acres, which is 18% of the country’s total land area, while 55.3 mil acres are irrigated [35]. Livestock requires 614 mil acres of grassland, pasture, and rangeland, which makes 27% of the US land area [39]. In 2014, the average value of US cropland (irrigated and non-irrigated) was \$4,100/ac. At the state level, the average rental rates for cropland range between \$32.5-\$313/acre. Irrigated cropland costs \$64-405 to rent, while non-irrigated land cost varied from \$14 to \$206 in 2014 [40]. As of 2014, the average value of US pastureland was \$1,300/ac, while regional variations were reported for the rental cost/ac from \$1.80 to \$50 [40]. Therefore, on average producers paid \$57.5 billion of rent for cropland annually and \$7.4 billion for rent of pastureland. Since 30-40% of food produced in the US is ultimately wasted, monetary losses in conjunction with land use equate to \$17.3-23.0 billion for

[1] BTU - British thermal unit. 1 BTU = 1055 joules

cropland and \$2.2-3.0 billion for pastureland (equation 4-6).

Cost of land use (\$) [irrigated cropland] = land rent (\$)% of food waste* (4)

*Cost of land use (\$) [non-irrigated cropland] = land rent non-irr (\$) * % of food waste* (5)

Cost of land use (\$) [pastureland] = land rent pastureland (\$)% of food waste* (6)

Another cost variable in the food waste calculations was methane emissions. If global food waste was a country, it would be the third largest generator of greenhouse gases in the world behind China and the US [1]. In the US, organic waste is the second largest component of landfills that are the single largest source of methane emissions in the country generating 18% of total emissions [41], [42]. In 2013, methane emissions in the US were equivalent to 6,673 million metric tons of CO_2 equivalent, which takes into account the fact that methane is 25 times more potent than carbon dioxide. A representative cost for methane pollution can be derived from the British Columbia (CAN) market that has the most stringent carbon tax in the Western hemisphere charging \$30 per ton of CO_2 as of 2008 [43]. If the US had the same carbon tax as British Columbia, its 2013 methane emissions would have cost \$200.2 billion. Since 18% of methane emissions come from landfills, those emissions would translate to \$36.0 billion. Further, assuming that ~40% of methane emissions from landfills are generated by rotting food waste, then the cost of methane emissions produced by food waste was approximately \$14.4 billion in 2013 (eq. 7):

Cost of methane emissions (\$) = carbon tax (\$)CH_4 emissions (mil m^3 of CO_2 equiv.) * % of landfill emissions (18%)* (7)

IV. Results and Discussion

The data analysis and results show that \$59.5-\$71.4 billion dollars could be saved annually by reducing food waste in the US. The cost of energy loss is the greatest, followed by rents for cropland. Water appears to be the least costly, but it needs to be emphasized that if water was priced more uniformly across the country and reflected its true value (i.e., shadow price) and water scarcity, this cost would be much higher (Table II).

TABLE II. Food Waste Related Costs

Resource	Food waste costs (billion US\$)
Energy	25.2 - 29.4
Water	0.4 - 1.6
Land Use (Cropland)	17.3 - 23.0
Land Use (Pastureland)	2.2 - 2.9
Methane Emissions	14.4
Sum	**59.5 – 71.4**

In addition to the factors discussed above, the cost of biodiversity loss cannot be overlooked, although it is very difficult to monetize. The current situation of the excessive food waste means that the US engages in much more industrial agricultural production than is needed to satisfy consumption demands, while food resources are not evenly distributed among different societal groups. Industrial agriculture diminishes biodiversity in the agricultural landscape, mainly though excessive manure, nutrients, and pesticide runoffs from industrial and plant agriculture that might negatively impact ecosystems and biodiversity. Many examples of nutrient runoffs and eutrophication of water bodies have been reported in recent years, causing fish and other aquatic wildlife die-offs. Also, examples of bird eradication in the second half of the 20th century are known as a result of the DDT insecticide use [44].

Furthermore, water use affects both flora and fauna, while the agricultural sector consumes about 70% of the Earth's accessible freshwater, compared to the industry's consumption of 23% and municipal use of 8% [45]. The problem of unsustainable water use in agriculture can be directly linked to inefficient irrigation systems, and the cultivation of irrigation intensive crops not always suited to the given natural environments. While unsustainable water use depletes groundwater resources, excessive irrigation can increase soil salinity and wash pollutants and sediments into rivers. This chain reaction can damage freshwater ecosystems and species directly in the effected region, as well as further downstream, including coral reefs and coastal fish breeding grounds [45].

Moreover, in case of converting habitable lands to farmland, habitat loss can occur. Around 50% of the world's habitable land has already been converted to farming land. Farmland covers 38% of the world's land area and is still expanding. In fact, 120 million hectares of natural habitat is expected to be converted to farmland to meet food demands by 2050, including land with high biodiversity value. This is especially problematic because oftentimes natural habitats are converted to monocultures, while unsustainable agricultural practices cause 12 million hectares of land to be lost each year to desertification [45]. Reducing food waste would eliminate the need to increase the land area for food production.

V. Conclusions

The analysis shows a wide range of costs as a result of food waste in the US equal to \$59.5-\$71.4 billion annually and related to wasted water, energy, land resources, and GHG emissions. Due to the high annual food waste costs in the US, raising awareness through media, government agencies, and environmental groups is an important measure to reduce food waste. The USDA alone has 33 different agencies and offices working on approaches to reduce, recover, and recycle food waste. While local initiatives are necessary, including restaurants to measure their food waste to help them curtail loss, also governmental regulations are anticipated to help address the problem. This includes, for instance, standards for "sell by", "best by", and "use by" dates that currently urge consumers to throw away food prematurely.

Moreover, the United Nations Sustainable Development Goals define 'Zero hunger' as the second most important goal of global development efforts. This initiative can facilitate reduction of food waste through improved effectiveness of food allocation, which could further reinforce efficient agricultural production and sustainable resource (water, energy, land) use.

Furthermore, implementation of new technologies in food production (e.g., biotechnology, nanotechnology) is anticipated to change the food market to some extent in the years to come. On the one hand, those technologies would allow for reduced fruits and vegetable bruising, prolonged freshness and improved visual appearance of fresh produce, thus reducing food loss in the food production chain. On the other hand, however, potential negative health and environmental issues have been emphasized by scientists that need to be investigated in more detail to exclude any potential risks for humans and ecosystems resulting from the application of those technologies.

Also, more research is needed to determine the true value of water that would allow for setting a standard for its worth, as well as a global standard for the cost of greenhouse gas emissions. Evaluating economics of food waste and loss is crucial and would allow for tracking progress in reducing food waste in the short, mid and long term.

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