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Krista L. Thyberg  
*SUNY Stony Brook*, krista.thyberg@stonybrook.edu

David J. Tonjes  
*SUNY Stony Brook*, david.tonjes@stonybrook.edu

Jessica Gurevitch  
*SUNY Stony Brook*, jessica.gurevitch@stonybrook.edu

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Quantification of Food Waste Disposal in the United States: A Meta-Analysis

Krista L. Thyberg† *
David J. Tonjes†
Jessica Gurevitch‡

†Department of Technology and Society, Stony Brook University, Stony Brook, New York 11794-3760, USA
‡ Department of Ecology and Evolution, Stony Brook University, Stony Brook, NY 11794-4245, USA.

Food waste; municipal solid waste; meta-analysis; quantification; waste characterization

Food waste has major consequences for social, nutritional, economic, and environmental issues, and yet the amount of food waste disposed in the U.S. has not been accurately quantified. We introduce the transparent and repeatable methods of meta-analysis and systematic reviewing to determine how much food is discarded in the U.S., and to determine if specific factors drive
increased disposal. The aggregate proportion of food waste in U.S. municipal solid waste from 1995 to 2013 was found to be 0.147 (95% CI 0.137-0.157) of total waste, which is lower than that estimated by USEPA for the same period (0.176). The proportion of food waste increased significantly with time, with the western U.S. region having consistently and significantly higher proportions of food waste than other regions. There were no significant differences in food waste between rural and urban samples, or between commercial/institutional and residential samples. The aggregate disposal rate for food waste was 0.615 pounds (0.279 kg) (95% CI 0.565-0.664) of food waste disposed per person per day, which equates to over 35.5 million tons (32.2 million tonnes) of food waste disposed annually in the U.S.

**Introduction**

Food waste has been identified as a significant social, nutritional, economic, and environmental problem and interest in preventing food waste and diverting it from disposal has grown rapidly in the U.S. and abroad, as reflected in federal and state policies. Multiple states and cities in the U.S. have recently enacted legislation banning the disposal of food waste in landfills to encourage waste prevention and treatment through alternative technologies, such as anaerobic digestion and composting. However, currently large quantities of food waste, which is biodegradable and some of which is edible, is still commingled with regular trash and disposed of in landfills or incinerators. It has been estimated that one quarter of the produced food supply is lost within the food supply chain; the production of this lost and wasted food globally has been estimated to account for 24% of total freshwater resources used in food production, 23% of global cropland, and 23% of global fertilizer use. As the global population continues to quickly grow, urbanize, and become wealthier, leading to a diversification of dietary patterns and an increase in demand for land, resources, and greenhouse gas intensive foods, it will be essential that changes be made to food
systems to increase sustainability. In addition to reducing the impact of food systems on the environment, reduced food waste and proper waste management can also save economic resources, contribute to food security, and minimize negative impacts of food waste on waste management systems, while obtaining increased benefits, such as energy or compost production.

However, because of considerable gaps in both data and methods for analyzing extant data, no reliable and repeatable information exists on the actual proportion of food lost and wasted nationally or globally. There is a scarcity of data on food waste all throughout North America\(^4\), Europe\(^5\), and the rest of the world\(^6\), and available data tend to be incomplete and outdated.\(^7\) Few peer-reviewed or major studies estimating quantities of food waste have been conducted,\(^8\) and those that have been done utilize different methodologies,\(^9\)\(^10\) making it difficult to compare findings across studies or aggregate findings. In particular, definitional issues\(^11\), the absence of sound quantification methods, and a general lack of political will have led to a deficit of information with regard to food waste disposal quantities in the U.S.\(^6\) These data gaps have led to recent calls for further research on wasted and lost food.\(^5\)\(^12\)\(^13\)

Food waste disposal data are essential for the development of effective, well-planned food waste management policies\(^11\), and can be used to determine if future food waste recovery and prevention efforts considerably change the composition of the residual waste stream. Examining the amount of waste that is currently being disposed shows the amount of waste that has yet to be recovered from the disposal stream, thus indicating how much waste is available for prevention or alternative treatments. Recycling programs are well-established and usually mandatory, so it is reasonable to assume these efforts will continue. Analyzing materials that are still being disposed defines areas where improvement can be achieved. A better understanding of the municipal solid waste (MSW) stream (wastes from residential, institutional, and commercial sources)\(^14\) also allows for
improvements to key inputs for waste models, such as life cycle assessments (LCA), and better
data-driven policy development and decisions.

Recent interest in implementing policies targeting food waste (e.g., disposal bans, pay-as-you-
throw volume based pricing systems to reduce waste disposal, educational campaigns, regulatory
mandates for diversion) indicate that understanding food waste disposal quantities is particularly
timely. Policies have been recently implemented at the state level in the U.S. to encourage or
mandate diversion of food waste, including food waste disposal bans in Vermont, Rhode Island,
Connecticut, Massachusetts, and California. Some cities have also implemented policies targeting
food waste (e.g., San Francisco, New York, Seattle). BioCycle magazine found 198 communities
in 19 states offered residential food waste collection in 2013 and 2014, an increase from prior
years; in 2005, 24 municipalities offered collection.\textsuperscript{15}

**Inadequacies of current data on food waste**

The primary source of municipal waste disposal estimates in the U.S. is the U.S. Environmental
Protection Agency’s (USEPA) annual Facts and Figures reports which are ubiquitously relied upon
when discussing U.S. MSW (e.g.,\textsuperscript{16,17}). The methods used to develop these estimates are flawed,
however. The USEPA estimates are generated using a materials flow model which makes specific
adjustments to industrial production data, such as for imports/exports and product life spans.\textsuperscript{18}
However, materials flow concepts are inappropriate for food waste.\textsuperscript{19} Food waste is not generated
by industrial processes where the kinds of materials used to create the materials are known and
counted, the outputs are tracked, and product lifespans are understood.\textsuperscript{20} So, data on food sales
bear little relation to the generation and disposal of food waste.\textsuperscript{21} USEPA has acknowledged this,
stating that ‘quantities of MSW components such as food scraps and yard trimmings can only be
estimated through sampling and weighing studies.’\textsuperscript{18} It indicates that these wastes are accounted
for by compiling data from a variety of waste sampling studies in combination with demographic
and other data (e.g., population, grocery store and restaurant sales). However, there is no detail
provided on exactly which reports and data are included, the criteria for data selection and
inclusion, or specifically how the data are used to generate food waste estimates, so it is impossible
to assess assumptions, sampling error, or accuracy of estimates. Furthermore, results were
routinely revised after they are posted. It is unclear exactly how studies are selected for inclusion
and it cannot be determined if there were any biases involved in the study selection.

We propose and implement a more formal, systematic, and transparent analytical approach for
quantifying food waste and use it to estimate U.S. food waste disposal (waste sent to landfills or
incinerators). Specifically, we used meta-analysis and research synthesis, powerful statistical
approaches which employ scientific methodology for data gathering and analysis developed
specifically for generalizing results across studies, to analyze data on food waste from waste
categorization sort studies. Waste categorization sorts involve the representative sampling,
sorting, and weighing of wastes to determine the proportion of waste types in samples of waste.
Numerous waste categorization studies have been completed in the U.S., thus creating an
extensive dataset, and studies have been assessed as consistent, comparable, and reliable,22 in part
because most follow the widely-cited ASTM method for waste categorization (ASTM D 5231-
08).23-24 The standard outlines details on: (1) determining the number of samples needed to achieve
reasonably low levels of errors for the mean composition estimates; (2) selecting representative
distribution of incoming trucks containing wastes from the targeted waste shed; (3) obtaining a
representative sample of waste from tipped loads; (4) sorting the samples into individual material
categories and weighing the relative contribution of each constituent to the overall samples; and
(5) calculating the mean, standard deviation, and confidence intervals for the sample data.24 Waste
characterization studies have not previously been collated or statistically analyzed. Most sort data
are available online, although they are not always easily found. Multiple recent waste
characterization studies in the U.S. have indicated large quantities of food waste in the MSW
stream, and results have been found to be different from USEPA estimates. The definitive
data generated here can serve as a compelling test of the accuracy and applicability of the heavily
relied upon USEPA dataset and the methods detailed here can be applied in related fields.

Two other studies have collated waste characterization studies, although the specific methods,
scales, and overall objectives differ considerably from this study. The U.K.’s Waste and Resources
Action Programme (WRAP) collated and analyzed data from waste composition studies in the
U.K. that focused on disposed food waste. The waste characterization collation findings for
households were averaged and combined with estimated disposal tonnages to generate overall
disposed food waste quantities for 89 local authorities in the U.K. Staley and Barlaz combined
11 state waste sorts using the sample arithmetic mean to create an approximation of the wastes
discarded in landfills. The data were used to estimate landfill gas emissions that would result from
particular organic wastes.

Methods

Meta-analysis and research synthesis were used to analyze U.S. waste characterization data. In
meta-analysis, standardized effect sizes are used to compare, on the same scale, the results of
multiple studies in which a common effect of interest has been measured. After an effect size is
calculated for each study, an aggregate (or pooled) effect size across all studies is determined by
weighting the precision of each individual effect value so that studies with greater precision are
given higher weight than those where effect sizes are estimated with lower precision.
Waste characterization data from state, county, and regional studies were found using the Google search engine. Primary search terms were ‘waste sort’, ‘waste characterization study’ and ‘waste composition study’. The search also targeted websites listing waste characterization studies.\textsuperscript{30} \textsuperscript{31}

After an initial selection using search terms and study titles, the methodology and results sections were carefully reviewed to determine if studies met inclusion criteria.

Selection criteria for inclusion were developed prior to choosing or discarding studies. All studies not meeting all selection criteria were excluded and the reason for exclusion was noted (see Supporting Information). Inclusion criteria were: (1) followed general principles and methods outlined by ASTM for waste characterization studies; (2) contained compositional data for food waste based on weight and enabled percentage (by wet weight) of food waste to be determined; (3) performed at a municipal scale (e.g., city, county, state); (4) performed post-recovery of recyclables; (5) involved sampling at the disposal (or transfer) site rather than at the generation point; (6) examined only MSW (residential, institutional, and commercial waste); (7) involved primarily manual sorting of samples (not visual); (8) provided confidence intervals and sample sizes; (9) used a standard, comparable definition of food waste; (10) conducted in the U.S; and (11) conducted between 1989 and 2013, thus capturing a 25-year span.

An important selection criterion was that studies focused only on MSW. Some food waste and loss are not included as MSW food waste (Figure 1). Industrial food loss (agriculture, production and processing) is not considered MSW, and it is generally not managed with MSW. The industrial sector faces particular circumstances and regulations making industrial food waste management different than food waste in MSW. Considerable amounts of industrial food waste are diverted from disposal; one estimate was 95 percent of food waste from manufacturers did not go to landfills, with 70 percent used for animal feed.\textsuperscript{32} MSW food waste data do not include wastes that
escape through pathways other than MSW systems, such as home composting, food disposals, or
food fed to animals. This approach is consistent with how USEPA quantifies U.S. MSW.\textsuperscript{18} The
present analysis includes avoidable (food that was edible prior to disposal), possibly avoidable
(food that some people eat and others do not), and unavoidable (food that is not edible under
normal circumstances) food waste.

Information coded for each study were: study ID number, name, author(s), year, publication
date, scale (county, state, region), state, region, population of study area, sectors included (all
MSW, residential, commercial/institutional), residential type (single –family, multi-family),
geographical classification (urban, rural), sampling season, number of samples, average sample
weight, and the proportion of food waste as determined from sampling and its 95% confidence
interval. Data on waste shed disposal quantities were recorded as reported in each individual study.
These tonnages allow for the determination of the total food waste disposed annually in the waste
shed and for the calculation of pounds of food waste disposed per person per day.

Food waste disposal tonnages and daily disposal rates were determined for each sample (see
Supporting Information). The effect size calculated for each study was a function of the proportion
of food waste in the total waste. The approximation method was used with a variance stabilizing
transformation (arcsine transformation); this transformation is a standard means to minimize
potential bias associated with the approximation method (equations are provided in the Supporting
Information).\textsuperscript{33} The aggregate (pooled) mean effect size across studies was determined by
weighting each individual effect size by a term that represents its precision, the inverse variance
weight.\textsuperscript{29} Variance stabilizing transformations yielded summary proportions that were back-
transformed to the raw proportion scale using the inverse transformation.
In addition to using the proportion as an effect size, the per capita food waste disposal rate was aggregated for the sample group of studies surveying all MSW, where possible. This rate represents all food waste disposed in the MSW stream from residential, institutional, and commercial sectors, consistent with the USEPA’s estimates of per capita wastes. Per capita rates allow comparisons to be made across waste sheds and to rates estimated by USEPA. The sample mean, which was based on a large sample size, was assumed to be approximately normally distributed and sample size was used as a proxy for variance. This was based on the assumption that sampling variances were equal, which is probably not valid because variances are almost never equal across studies. Therefore the meta-analysis outcomes could be biased to an unknown extent. However, the statistical technique was used as a tool to assess if disposal rates showed similar trends across time and region as proportions, and focus was placed on confidence intervals, rather than point estimates.

A continuous random effects model was used to determine aggregate mean effect sizes. An assessment of overall heterogeneity (variation in study outcomes between studies) was then performed using Cochran’s Q, calculated as the weighted sum of squared differences between individual study effects and the pooled effect across studies, with the weights being those used in the pooling method. When a significant level of overall heterogeneity was found, a linear meta-regression was performed using a mixed effects model to determine if specific moderators explained any of the heterogeneity. Mixed effects models are random models which allow for the inclusion of moderators to determine if the moderators account for heterogeneity in the effects. The specific estimator used in the meta-regression was the restricted maximum likelihood estimator. Tests for the amount of heterogeneity explained in the model by the moderators and for the amount of residual heterogeneity were calculated in the meta-regression, along with tests of
each coefficient’s individual effect on the proportion (or rate). The calculations were performed using the open-access meta-analysis software Open Mee.\textsuperscript{36}

Study samples were grouped based on characteristics of the samples (samples of total MSW, samples differentiating between residential and commercial/institutional sectors, samples differentiating between rural and urban areas, samples of total MSW that enable per capita rate calculations) to ensure effect sizes for each group were independent (no more than one effect size from any subject sample), ensure equitable comparability within a group, facilitate moderator assessment, and allow for valid statistical modeling. Each group was meta-analyzed separately, yielding a total of four meta-analyses.

Estimates of food waste disposal from the USEPA’s ‘MSW in the U.S.: Facts and Figures’ quantification reports were collected.\textsuperscript{20} Pounds of food waste disposed per person per day were calculated from these data. The USEPA explicitly states that its waste assessments describe wastes from residences, businesses, and institutions, and the accounting does not include hazardous wastes, dedicated construction and demolition debris, sewage sludge, and industrial wastes.\textsuperscript{14} This is consistent with the waste streams analyzed by the waste characterization studies included here for the total MSW and per capita groups so it is possible to compare the aggregate findings from the waste characterization studies to USEPA estimates.

**Results and Discussion**

We found and assessed 107 waste characterization studies; 45 of these were eliminated because they did not meet the pre-defined selection criteria. Sixty-two waste characterization studies were included in the meta-analyses, representing over 20,000 samples of sorted refuse (waste remaining after recycling and composting), with a total sample weight of more than four million pounds (1.8 million kg) (see Supporting Information). Food waste was found to make up a considerable
proportion of the disposed waste stream from 1995 to 2013 (0.147, 95% Confidence Interval [CI] 0.137-0.157) (Table 1), and this proportion has been increasing significantly with time (β=0.005, z=4.112, p<0.001). There was significant heterogeneity among studies, with the proportion of food waste in samples including all MSW ranging from 0.071 to 0.228 (Q=144.014, p<0.001). The western U.S. had consistently higher proportions than the eastern or central U.S. (Table 1). A meta-regression model with year and region as covariates explained a significant amount of the total heterogeneity ($R^2=45.69\%$, $Q_M=19.809$, $p<0.001$). There also was significant residual heterogeneity ($I^2=46.12\%$, $Q_E=77.991$, $p=0.002$), indicating that other moderators may also influence food waste proportion. The mean effect size for the food waste disposal rate in terms of pounds of food waste disposed per person per day (ppd) from 1995 to 2013 was 0.615 ppd (95% CI 0.565-0.664) (0.279 kg per person per day) (Table 1). This is equal to 225 pounds (100 kg) per person per year, and equates to over 35.5 million tons (32.2 million tonnes) of food waste disposed annually in the U.S. The per capita disposal rate per day had an upward trend with time, although this was not significant (β=0.005, z=1.089, p=0.276). Region, however, was significant, with the west having higher per capita food waste disposal rates (β=0.233, z=4.549, p<0.001) (compared to eastern and central regions).

A meta-analysis of total MSW disposal rates was performed to better understand waste system dynamics. The aggregate mean total MSW disposal rate from 1995 to 2013 was 4.249 pounds (1.927 kg) of MSW disposed per person per day (95% CI 3.938-4.561). This equates to over 245.4 million tons (222.6 million tonnes) of MSW disposed in landfills or incinerators each year in the U.S. There was a decrease in MSW disposal rate with time, but this was not significant. Region, however, was significant, with the west having higher rates of MSW disposal (β=0.857, z=2.424, p<0.05).
The aggregate proportion of food waste disposed in the U.S. from 1995 to 2013 as determined from waste characterization studies (0.147) was four-fifths of that estimated by USEPA for the same period (0.176) (Table 2). If over 245.4 million tons (222.6 million tonnes) of MSW is disposed annually in the U.S., this percentage difference represents a difference of over seven million tons of food waste disposed annually. This substantial difference can have considerable effects on management approaches for food waste. Both the meta-analysis and USEPA estimates indicated that the proportion of food waste disposed increased with time, but the correlations with time were significantly different (z=-2.59, p<0.05), with the USEPA’s being stronger (r=0.96, r=0.72, respectively) (Figure 2). The aggregate food waste disposal rate as determined from the meta-analysis of waste characterization studies was 0.615 ppd (0.279 kg) while the average for the same period as reported by USEPA was 0.548 ppd (0.249 kg). In five out of 13 years, USEPA estimates for food waste disposal proportion was within the 95 percent confidence bounds for the meta-analysis estimates. USEPA estimates for the per capita food waste disposal rate was within the 95 percent confidence bounds for eight out of 13 years. However, the overall USEPA average for 1995 to 2013 for both proportion and rate was not within the bounds for the aggregate mean as determined from the meta-analysis (Table 2).

Per capita food waste disposal rates increased with time and total MSW disposal rate decreased with time (albeit neither trend was statistically significant). The increase in food waste proportion is partially related to waste reduction in other components of MSW, which is supported by the downward trend of overall MSW disposal rates. The proportion of food waste is consequently higher relative to these other waste components, even if the amount of food waste disposed remains constant or only slightly increases. Waste reduction of other materials may be due to consumer purchasing choices, material light weighting, increased product durability, and waste avoidance.
Over the past 25 years there has been an increase in policies aimed at diverting materials away from disposal, including yard waste disposal bans, bottle bills, more aggressive curbside recycling program, and volume based waste pricing systems.\textsuperscript{37} Increases in food waste proportions with time may also be partially related to more food being disposed, possibly resulting from more food being allowed to spoil, increases in over stocking and over preparation of food,\textsuperscript{39} confusion over food labels such as “sell by” dates,\textsuperscript{40} misconceptions regarding food safety and desirability\textsuperscript{41}, or changes in household shopping practices, particularly the size of the grocery store and the frequency of shopping.\textsuperscript{42} An extension of the meta-analysis to analyze other materials would provide insight into specific system dynamics, including significant increases or decreases in other materials which may be influencing the food waste proportion.

Higher proportions of disposed food waste in the western compared to the eastern and central U.S. was observed for all sample groups; the effect was significant for the sector group (separate samples from residential and institution/commercial sectors). The higher proportion of disposed food waste in the western U.S. may be partially due to superior separation of other materials out of the waste stream in this region, such as removal of traditional recyclables. Robust recycling programs would lead to a large proportion of food waste being left behind in the disposed waste stream relative to the other materials in MSW. However, the per capita disposal rate of food waste was also significantly higher in the west than in east and central regions. It is unclear why the western U.S. had higher food waste proportions and rates; future work should focus on examining differentiating factors between the west and the other regions to determine which factors contribute to increased food waste disposal.

The proportion of food waste disposed from residential sectors did not differ significantly from that disposed by commercial/institutional sectors (residential: 0.182; commercial/institutional:
These proportions were higher than the overall aggregate (0.147) possibly because some of these sector samples excluded wastes dropped off at management sites directly by generators (self-haul waste). Self-haul waste has been found to contain lower food waste proportions than wastes collected from generation points by waste collectors. Since MSW disposal tonnages from residential versus commercial/institutional sectors are thought to be between a 60:40 and a 50:50 proportion, considerable food waste tonnages are disposed by both sectors. This suggests that it may be equally beneficial to target both sectors with food waste recovery or prevention policies. However, there are specific industries (e.g., restaurants, supermarkets) that dispose of food waste at much higher proportions than the overall aggregate for all commercial and institutional establishments. Targeting large scale generators, such as the approach taken in 2014 by the state of Massachusetts, may be the easiest way to initiate a food waste management policy.

There were no significant differences between the proportion of food waste disposed in urban versus rural areas (urban: 0.155; rural: 0.152). This finding was somewhat surprising, as urbanization is generally thought to lead to increased food waste generation. It may be possible that it is not urbanization on its own which affects food waste generation; rather urbanization commingled with other linked factors, such as economic development, globalization, and industrialization may together lead to increased wastage. Iacovidou et al. point out that economic condition is a critical factor when assessing food waste generation rates; it acts as an indicator of a country’s wellbeing and food waste disposal weight has been shown to increase from low to high income countries. Therefore, it is possible that the strong differences between food waste generation in urban and rural populations may be reduced if overall standards of living are high within a country, as in the U.S.
In summary, this was the first study to formally collate and statistically analyze waste characterization studies in a transparent, repeatable, and systematic way using the powerful statistical and conceptual tools of systematic review and meta-analysis. The approach serves as a strong alternative to the ambiguous methods used to date to estimate food waste and it may be extended to quantify other materials. The methods used here are systematic, allow for repeatability, help eliminate biases regarding study inclusion, and enable clarity with regard to how estimates are determined. The approach is unique in that it focused on food waste disposed in the MSW stream which makes the findings important for waste management, particularly for planning and policy making. Furthermore, this approach represented a bottom-up approach which integrated smaller scale, real-world sampling studies, as opposed to top-down, large scale, modeling approaches that tend to over-simplify and are rarely validated. It is both essential and urgent that USEPA adopt a similar scientifically transparent and defensible approach to organic waste estimations.

Study limitations

Waste characterization studies rely on sampling because it is neither practically feasible nor desirable to perform waste sorts on all disposed waste. Sampling may lead to random sampling error and the waste sorting procedure itself may introduce further error. During waste sorting, food waste components are generally separated out of their packaging but there are some items which make separation difficult (e.g., mustard packets, sealed cans). The classification of items which cannot be easily separated from their packaging to the category which proportion by mass prevails is recommended by the ASTM standard, but discrepancies may occur when packaging which could have been easily separated is included in the food category or packaging whose proportion is higher than the food inside is counted in the food category. No estimates are
available regarding the dimension of included food packaging within food waste categories from waste characterization studies. Error also may occur through screening. ASTM recommends that sorting be continued until the maximum size of remaining waste particles is approximately 12.7 mm.\textsuperscript{24} At this point, apportioning of the remaining particles into corresponding waste components represented in the remaining waste mixture should be done based on a visual estimate of the mass of the fraction of waste components remaining. This may lead to underestimations of food in the sample, but the exact scale of this error is difficult to quantify.\textsuperscript{46}

Agreement does not always exist regarding the definition of MSW and specific waste categories.\textsuperscript{47,10} Most of the waste sorts included in the meta-analysis used fairly consistent MSW and food waste definitions, but there may have been some differences across studies. There are some inherent, unavoidable problems with MSW tonnage data, primarily involving the lack of complete data; quantifying this uncertainty is challenging. Data may be missing due to systematic or intentional errors in waste reports, unlicensed scavengers collecting materials, or wastes which are disposed outside of the waste shed.\textsuperscript{19} Per capita disposal rates are subject to error due to the introduction of population statistics. Population data may not accurately reflect the amount of people living or staying in a municipality at certain times, such as summer residents or tourists.

Although inclusion criteria began with studies performed as early as 1989, only waste characterization studies from 1995 forward (that fit other inclusion criteria) were located for the total MSW group. Therefore, only USEPA data from 1995 forward were included in the comparison to ensure comparability. However, data for years 1996, 1997, 2001, and 2003 were missing from the waste sort dataset and data for 2013 was missing from the USEPA dataset; these data gaps may have affected the meta-analytic results.
Future work

Analyses showed that a considerable amount of food waste is disposed on a regular basis throughout the U.S. These data are important because they indicate how much food waste can potentially be reduced or diverted from disposal. More research is necessary to evaluate the impacts and feasibility of food waste prevention and diversion policies. The meta-analyses indicated that despite the explanatory power of some of the variables (year, region), considerable heterogeneity remained, suggesting that food waste disposal may be influenced by other factors, such as education, socio-economic status, or age of residents. Future work should aim to quantify the effects of other variables.

The technique for quantifying and statistically analyzing the results of waste characterization studies may be expanded to other waste stream components. It is possible to aggregate findings from waste characterization studies to determine the overall disposal proportions and rates for other waste types, as well as to determine if specific moderators are affecting their disposal. It also would be valuable to perform trend analyses on the proportions of other materials in the disposed waste stream and per capita disposal rates to determine how other materials are fluctuating with time. It is necessary to continue performing similar meta-analyses in the future to assess how moderator effects are changing with time and to determine if food waste proportion continues increasing. Furthermore, as more food waste prevention and recovery policies are initiated in the U.S., it will be possible to use the meta-analysis methodology to assess the effectiveness of these programs and to determine the differences between regions with food waste collections in place versus those without.

The study findings indicate that it is necessary to critically evaluate the impacts of food waste prevention and alternative treatments for food waste to determine if they can offer environmental,
economic, and social benefits. The considerable proportion of food waste in the disposed waste stream and the substantial tonnages that are annually disposed suggest that food waste prevention and diversion away from disposal should be a key priority of sustainable waste systems. If the objective of waste systems is to minimize the amount of materials being disposed in order to ultimately reduce environmental harm and achieve maximal benefit, then a focus on food waste should be a key component of this strategy. Quantifying wasted food will help bring national attention to the issue, which can greatly advance campaigns to minimize and divert it.

Figure 1. Sectors contributing to food loss and food waste. Sectors noted as ‘Included’ were captured in the meta-analysis.
Figure 2. Proportion food waste in disposed stream from USEPA and meta-analysis of waste characterization studies.

There were several years where data were missing (1996, 1997, 2001, and 2003 were missing from the waste sort data and 2013 was missing the USEPA data). Data were linearly interpolated in Fig. 2.
<table>
<thead>
<tr>
<th>Region</th>
<th>Sample Size (n)</th>
<th>Aggregate Mean Estimate</th>
<th>95% Confidence Interval</th>
<th>Proportion Food Waste</th>
<th>Per Capita Food Waste Disposal Rate (^{\text{A}})</th>
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<tr>
<td>Central Region</td>
<td>(n=13)</td>
<td>0.137</td>
<td>0.120, 0.155</td>
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<td>0.577</td>
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<td>0.722</td>
<td>0.663, 0.781</td>
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<td>East Region</td>
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<td>0.503</td>
<td>0.436, 0.570</td>
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<td><strong>Overall Aggregate</strong></td>
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<td>0.137, 0.157</td>
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<td>0.615</td>
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</tbody>
</table>

**Table 1.** Aggregate mean effect sizes (proportions and per capita disposal rates) for samples including all MSW.

\(^{\text{A}}\) in pounds of food waste disposed per person per day.
<table>
<thead>
<tr>
<th>Year A</th>
<th>Waste Sort Aggregate</th>
<th>USEPA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Proportion B</td>
<td>Per-capita Rate B, C</td>
</tr>
<tr>
<td>1995</td>
<td>0.105</td>
<td>0.647 (+/− 0.023)</td>
</tr>
<tr>
<td>1996</td>
<td></td>
<td>0.140</td>
</tr>
<tr>
<td>1997</td>
<td></td>
<td>0.150</td>
</tr>
<tr>
<td>1998</td>
<td>0.144 (+/− 0.105)</td>
<td>0.592 (+/− 0.283)</td>
</tr>
<tr>
<td>1999</td>
<td>0.147 (+/− 0.031)</td>
<td>0.649 (+/− 0.283)</td>
</tr>
<tr>
<td>2000</td>
<td>0.119 (+/− 0.022)</td>
<td>0.701 (+/− 0.043)</td>
</tr>
<tr>
<td>2001</td>
<td></td>
<td>0.162</td>
</tr>
<tr>
<td>2002</td>
<td>0.137 (+/− 0.051)</td>
<td>0.583 (+/− 0.165)</td>
</tr>
<tr>
<td>2003</td>
<td></td>
<td>0.166</td>
</tr>
<tr>
<td>2004</td>
<td>0.132 (+/− 0.027)</td>
<td>0.493 (+/− 0.105)</td>
</tr>
<tr>
<td>2005</td>
<td>0.136</td>
<td>0.558</td>
</tr>
<tr>
<td>Year</td>
<td>Mean Food Waste Disposed (lbs/day)</td>
<td>Mean Food Waste Disposed (lbs/person/day)</td>
</tr>
<tr>
<td>------</td>
<td>----------------------------------</td>
<td>-----------------------------------------</td>
</tr>
<tr>
<td>2006</td>
<td>0.139 (+/− 0.080)</td>
<td>0.176 (+/− 0.203)</td>
</tr>
<tr>
<td>2007</td>
<td></td>
<td>0.191</td>
</tr>
<tr>
<td>2008</td>
<td>0.167 (+/− 0.028)</td>
<td>0.213 (+/− 0.089)</td>
</tr>
<tr>
<td>2009</td>
<td>0.158 (+/− 0.032)</td>
<td>0.213 (+/− 0.093)</td>
</tr>
<tr>
<td>2010</td>
<td>0.172 (+/− 0.025)</td>
<td>0.210 (+/− 0.084)</td>
</tr>
<tr>
<td>2011</td>
<td>0.133 (+/− 0.046)</td>
<td>0.214 (+/− 0.091)</td>
</tr>
<tr>
<td>2012</td>
<td></td>
<td>0.211</td>
</tr>
<tr>
<td>2013</td>
<td>0.206 (+/− 0.061)</td>
<td>0.216 (+/− 0.147)</td>
</tr>
<tr>
<td>Mean</td>
<td>0.147 (+/− 0.010)</td>
<td>0.176 (+/− 0.049)</td>
</tr>
</tbody>
</table>

434 | Table 2. Annual Waste Sort and USEPA Food Waste Estimates.  

435 | A There were several years where data were missing (1996, 1997, 2001, and 2003 were missing  
436 | from the waste sort data and 2013 was missing the USEPA data).  
438 | B Aggregate mean as determined by meta-analysis; 95% confidence interval indicated.  
439 | C in pounds of food waste disposed per person per day.  
440
Supporting Information.

Detailed description of methods, study limitations, and additional tables. This material is available free of charge via the Internet at http://pubs.acs.org.

Corresponding Author

* Corresponding author: Krista L. Thyberg

Department of Technology and Society
Stony Brook University
Stony Brook, NY 11794-3760

KLTthyberg@gmail.com
P: 631-632-8770

Author Contributions

The manuscript was written through contributions of all authors. All authors have given approval to the final version of the manuscript. All contributed equally.

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ABBREVIATIONS

CI confidence interval; LCA life cycle assessment; MSW municipal solid waste; PPD pounds of
waste disposed per person per day; USEPA United States Environmental Protection Agency.

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