National and regional waste stream in the United States: conformance and disparity

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Abstract

Accurate estimation of municipal solid waste (MSW) composition is critical for efficient waste management. In the United States, site-specific and material flow approaches determine the MSW composition at regional and national levels. The material flow-based national estimates are determined by the US EPA; the US EPA’s estimates are known to differ substantially from the aggregated tonnage of MSW managed by waste handling facilities in the United States. However, the material class-specific discrepancies of the US EPA’s material flow approach resulting in these differences are unknown. To find the basis of these discrepancies, we analyze the discarded MSW stream of 27 US states, which roughly accounts for 73 percent of the US population. Our analysis indicates that the material flow-based national estimates are accurate for the food, plastic, and glass material classes. In contrast, we find that the US EPA’s material flow-based predictions underestimate paper waste disposal by at least 15 million tons annually. These differences likely stem from incorrect assumptions of residence time. These results highlight the material class-specific strengths and drawbacks of the US EPA’s material flow-based MSW estimates.

1. Introduction

Recent estimates predict that the amount of municipal solid waste (MSW) generated globally will continue to increase in the near future, albeit at a slower rate [1]. Accompanying this increase will be a simultaneous rise in environmental impacts associated with waste disposal. To limit these environmental impacts, it is essential to classify the MSW stream with accuracy for better regulation, management, and planning [2–4]. Waste management involves multi-faceted approaches—source reduction and reuse, recycling, composting, incineration for energy recovery, and landfilling [5]. Source reduction, reuse, and recycling are preferred before the end-of-life phase of a product [6]. The remaining waste management schemes, i.e., incineration for energy recovery and landfilling, are the predominant means of waste disposal in the United States (figure 1). However, they can have a negative impact on the environment. For instance, wastes disposed of in landfills are sources of methane emissions [7–11], and life-cycle assessments indicate that incineration for energy recovery can have variable impacts on the climate depending on the waste composition [12]. Additionally, the suitability of alternative recovery methods, i.e., pyrolysis, liquefaction, gasification, and biomethanation, is dependent on the composition of MSW [13]. Therefore, from a management perspective, a comprehensive understanding of MSW composition is essential to plan recovery facilities that are suited for materials present in the waste stream; accurate estimation and subsequent planning can help eliminate mismanaged trash that can adversely affect the natural habitat [14], such as the accumulation of plastic waste in our oceans [15–17].

MSW composition can be estimated via two different approaches, namely, the material flow analysis and site-specific studies. In the United States, the United States Environmental Protection Agency (US EPA) estimates the amount of MSW generated annually via a material flow approach [2, 18, 19]. The material flow
approach offers a framework for assessing the flow of materials through a system defined in space and time [20, 21]. Similarly, the US EPA’s material flow approach comprises collecting production data for the materials and products in the municipal waste stream from industry associations and businesses [24]; subsequent adjustments to the collected data for imports, exports, and recycled products along with certain assumptions, i.e., the residence time of products, yields the estimates of MSW composition. The US EPA annual material flow based MSW estimates provide an aggregated composition of MSW for the entire United States without delineating the underlying seasonal, geographic, and socioeconomic differences in MSW composition at the regional level [25]. Therefore, at the regional level, states and counties conduct site-specific waste characterization studies (waste sorts) for assessing and improving existing waste management programs [18]. Site-specific studies comprise collecting representative waste samples from waste handling facilities—landfills, waste-to-energy plants, and material recovery facilities—in different seasons. The site-specific studies entail sampling protocols that ensure the waste samples collected represent the MSW generated, i.e., the waste samples collected are representative of the entire waste stream. The site-specific characterization studies comply with ASTM D5231-92, which enumerates guidelines for determining the composition of MSW [26]. However, complete adherence to ASTM D5231-92 is impractical. For instance, some materials in the MSW stream cannot be strictly classified into a single material class, i.e., a plastic container filled with food can belong to two material classes—food and plastic. In addition, the site-specific characterization approach is resource-intensive, i.e., manual characterization of waste is labor and time-intensive and thus cannot be adopted for determining the MSW composition at the national level. Hence, the material flow approach is suited for determining MSW estimates at the national level. However, selected studies have reported that material flow-based annual MSW generation estimates predicted by the US EPA do not agree with the aggregated tonnage of MSW managed in all the US states [7, 19, 27]. For instance, the State of Garbage in America survey estimated that approximately 389.5 million tons of MSW were generated in 2008. For the same year, the US EPA’s material flow-based annual MSW generation estimates were 249.6 million tons [27]. Moreover, a study by Powell et al. reported that 262 million tons of MSW were landfilled in 2012. In contrast, the US EPA’s material flow-based generation estimates predicted that MSW landfilled in 2012 was approximately 122 million tons [7]. Thus, these reports suggest that the US EPA’s material flow-based estimates have been consistently inaccurate. The US EPA’s estimates of MSW generation are arrived at by combining the material flow-based generation estimates of several different material classes present in the waste stream [24]. Therefore, errors in the generation estimates of any of these material classes can be responsible for the resulting nonconformity between the US EPA’s material flow-based generation estimates and the aggregated tonnage of MSW managed in all the US states. These material class-specific drawbacks that undermine the accuracy of the EPA’s material flow-based MSW generation estimates are unknown. It may be that EPA’s MSW estimates are accurate for certain material classes while unreliable for others. Thus, identifying material class-specific inaccuracies and subsequent rectification of the EPA’s material flow approach is essential for predicting MSW generation estimates with sufficient accuracy.

In this study, we identify the material class-specific inaccuracies of the US EPA’s MSW generation estimates by analyzing the national (material flow-based) and regional (site-specific) estimates of the discarded waste stream (landfilled and incinerated waste). To do so, we compare the national and regional disposal estimates of six material classes—paper, food, plastic, metals, glass, and yard waste—by collecting MSW disposal estimates from 27 site-specific studies. These site-specific studies account for 73% of the US population (2010 census). The findings uncover the material class-specific drawbacks and strengths of the US EPA’s material flow approach. Depending on the results of the analysis presented herein, the existing EPA’s material flow approach can be modified to enhance the robustness and the accuracy of the future EPA’s MSW estimates.
2. Data source

In this study, we rely on two different datasets. The first dataset from the US EPA provides national-level material flow-based estimates of MSW generation [5]. The second dataset corresponds to regional level site-specific estimates of MSW generation. These regional level estimates have been adopted from several site-specific studies of different US states. A detailed description summarizing the data collection methodology from different site-specific studies is provided in the supplementary information (https://stacks.iop.org/ERIS/1/031002/mmedia). Our analysis is based on site-specific estimates of MSW composition from 27 regional studies that roughly account for 73% of the US population. However, not all 27 regional studies provide tonnage disposal estimates. Thus, the tonnage disposal data is limited to 19 regional studies that account for 55% of the US population.

3. Material and methods

In this study, the US EPA’s definition of MSW is adopted. The US EPA considers garbage generated from residential, commercial, institutional, and industrial sources as MSW. The EPA’s MSW definition does not include construction and demolition waste, biosolids, and industrial process wastes. Further, in this study, the terms discarded and disposed MSW refers to the MSW that is landfilled and incinerated for energy recovery. The national level estimates of MSW generation were collected from data published by the US EPA. The US EPA disaggregates the MSW generation estimates into several material classes, namely, paper and paperboard, glass, metals, plastics, rubber and leather, textiles, wood, food, and yard trimmings [5]. The regional level estimates of MSW generation were collected from 27 site-specific studies. The site-specific studies also disaggregate the MSW into several material classes. However, the disaggregated material classes of the site-specific studies are not necessarily identical to the EPA’s partitioned material classes. Thus, the site-specific MSW composition estimates for different material classes cannot be directly compared with material class-specific EPA estimates. We mitigate this limitation by merging and splitting material classes in the site-specific studies; this step is intended to ensure correspondence between disaggregated material classes in the site-specific studies and the EPA MSW estimates. Specifically, the material classes in the site-specific estimates are merged and split into six classes: paper, food, plastic, yard, metal, and glass. The analysis in this paper is restricted to six material classes because data corresponding to these material classes could be collected from all the site-specific studies without any ambiguity. Steps detailing the merging and splitting of material classes for site-specific studies are provided in the supplementary resources.

The US EPA’s annual MSW generation estimates are for the entire United States. In this paper, we aim to establish material class-specific strengths and drawbacks of the EPA’s material flow approach. To do so, we compare the data from national (material flow-based) and site-specific MSW generation estimates. The MSW data is compared in two ways: first, we perform a qualitative comparison of percentage compositions of material classes in the disposed waste stream consisting of paper, food, plastic, yard, metal, and glass. Second, we perform a quantitative comparison between the national and regional estimates of MSW. For quantitative comparison, we select the per capita disposal as a metric. For comparing the average national estimates with site-specific estimates, we calculate site-specific average national disposal estimates for all the six material classes from site-specific studies. The site-specific average national disposal estimates \( W_i \) are established by computing the population-weighted mean of yearly per capita disposal of different material classes from site-specific studies (equation (1)).

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W_i = \frac{\sum_j p_j w_j}{\sum_j p_j}, \quad (i = \text{paper, food, plastic, yard, metal, and glass}) . \quad (1)
\]

In equation (1), the subscript \( j \) symbolizes site-specific studies; \( W_i \) represents per capita site-specific average national disposal estimate of the \( i \)th material class, \( p_j \) is the population covered by the \( j \)th site-specific study, and \( w_j \) is the yearly per capita disposal estimates of the \( i \)th material class in the \( j \)th site-specific study. The variables \((p_j \text{ and } w_j)\) for all the site-specific studies are mentioned in supplementary table ST1. The site-specific studies sample MSW in different seasons and establish an average MSW composition. For every site-specific study, we calculate per capita yearly disposal estimates for all the material classes based on the average MSW composition. To compute per capita yearly disposal estimates for material classes, first, we multiply the percentage composition of a material class with the tonnage of MSW generated in the area covered by the site-specific study. Then, we divide the product with the population of the area covered by the site-specific study. These steps yield yearly per capita disposal estimates for all the material classes relevant to this study. The tonnage
of MSW was collected from the site-specific studies. These MSW generation estimates from site-specific studies account for imports and exports, and the generation data collected is limited to the regional area under consideration. This is done by limiting the waste sorts to the MSW generated in the area under consideration. Further, in this study, the yearly per capita disposal estimates are expressed in lbs person$^{-1} \text{ year}^{-1}$ (abbreviated as ypcd). Finally, for studying the relationship between socio-economic parameters and MSW generation, we collected GDP and population estimates from the website of different organizations. GDP figures were accessed from the website of the US Bureau of Economic Analysis [28]. Population estimates of different states in different years were accessed from the website of the US Census Bureau [29, 30]. Specifically, we use the power law relationship to access relationships between socio-economic parameters and MSW generation estimates. County-level population estimates were accessed from the website of the Economic Research Service, United States Department of Agriculture [31]. The land area of different US counties was collected from the website of the US Census Bureau [32].

4. Results and discussion

4.1. Material classes in the national and regional waste stream

The material flow-based national estimates of MSW composition, its means of disposal, and composition of the recycled, landfilled, and incinerated waste fractions for the year 2017 are depicted in figure 2. Paper, food, yard, plastic, metal, and glass (hereafter mentioned as PFYPMG) account for 80% of the MSW generated (generated waste, figure 2(a)). 35% of the generated MSW is recycled and composted, 52% is landfilled, and the remaining 12% is incinerated (disposal pathways, figure 2(a)). Together, paper and yard material classes account for more than 70% of the recycled waste stream (recycled, figure 2(a)). The presence of PFYPMG material classes in the

Figure 2. Waste disposal pathways and material classes in the MSW stream of the United States. (a) Overall and disposal pathway specific composition of the MSW for the United States in 2017. (b) Percentage composition of material classes—paper, food, plastic, yard, metal, and glass waste in the discarded waste stream. (c) Trends in percentage composition with time. (d) Yearly per capita disposal of material classes in the discarded waste stream. (e) Trends in disposal with time. The MSW stream is assumed to be solely composed of paper, food, plastic, yard, metal, and glass material classes. Percentage composition and disposal figures are based on data published by the US EPA (material flow-based estimates) [5]. Note that 1 lbs = 0.453 kg. Discarded waste stream includes MSW that is landfilled and incinerated.
landfilled and incineration waste streams are 75 and 71%, respectively (landfilled, incinerated, figure 2(a)). Hence, there is an opportunity to advance the materials recovery of the PFYPMG material classes from the discarded waste stream. Recovery beyond the existing levels will only be possible if the MSW composition is accurately estimated and recovery pathways in sync with the composition are pursued.

PFYPMG material classes form \(\sim 80\%\) of the discarded waste stream, and for these material classes, disposal data from site-specific studies could be gathered by merging and splitting material classes. Hence, this study is restricted to the PFYPMG material classes, and the aggregate percentage composition of the PFYPMG material classes is normalized to 100. Percentage composition and yearly per capita disposal of PFYPMG material classes in the discarded waste stream are shown in figures 2(b)–(e). The discarded MSW composition at the national level has remained consistent since 2010 (figures 2(b)–(e)). The percentage contribution of paper waste has declined from 35% in 2000 to 17% in 2017 (figure 2(c)), which is likely due to increased adoption of digital technologies and increased recycling of the disposed paper waste \([33, 34]\).

The decline in percentage composition of paper waste is accompanied by an increase in percentage compositions of food and plastic waste (figure 2(c)). Between 2000 and 2017, the yearly per capita disposal for food and plastic material classes are relatively constant, varying between 213 and 236 ypcd (lbs person\(^{-1}\) year\(^{-1}\)) for food waste and 171 and 199 ypcd for plastic waste (figure 2(e)). The percentage composition of yard waste varied between 10 and 8% between 2000 and 2017; during the same period, its disposal indicates a steady decline, i.e., 105 to 66 ypcd (figures 2(c) and (e)). The percentage composition of the metal material class increased from 8 to 12%. In the same period, the metal waste disposal increased from 87 to 103 ypcd (figures 2(c) and (e)). Between 2010 and 2017, the percentage composition of the glass waste in the disposed waste stream varied between 6 and 7% (figure 2(c)); its disposal decreased from 70 to 51 ypcd (figure 2(e)). MSW composition of

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**Figure 3.** Percentage composition of material classes in the disposed MSW stream of US states. For states where results from multiple sampling studies are available, percentage composition from the latest available site-specific study is reported. The year of characterization study is mentioned within parenthesis. States where paper waste is dominant appears first, followed by states where food waste is dominant and are arranged in decreasing sequence (top to bottom and left to right). Star denotes states with prohibitions on landfilling of yard waste. The percentage compositions for Hawaii, New York, and North Carolina are based on site-sampling studies conducted in Honolulu, New York City, and Orange County, respectively.
the recycled fraction is depicted in figure S1. Next, we perform a qualitative comparison between the national estimates of MSW composition from material flow approach with state specific MSW composition estimates. These qualitative comparisons are based on data collected from 27 site-specific studies.

The percentage contribution of PFYPMG material classes to the disposed waste stream of 27 US states are illustrated in figure 3. Paper, food, and plastic material classes comprise 70 to 90% of the PFYPMG material classes (figure 3). Paper is the dominant material class in most states, followed by food and plastic (figure 3). The percentage contribution of yard waste is less than 10% for all the states with restrictions on yard waste landfilling (figure 3). For comparison, the percentage composition of material classes from the site-specific (regional) and material flow-based (national) estimates versus time are illustrated in figure 4. The percentage composition of paper has decreased in both the national and regional waste streams (figure 4(a)). Similarly, a trend of increase in percentage composition of food is present in both the regional and national waste streams (figure 4(b)). However, the regional and national waste streams do not display similar trends for the remaining material classes—plastic, yard, metal, and glass (figures 4(c)–(f)). For the paper material class, the percentage composition from the materials flow approach (national) in all years lies well below the percentage composition of paper from site-specific studies (regional, figure 4(a)). Similarly, except for a few outliers, the national estimates of percentage composition of food, plastic, yard, metal, and glass from the material flow approach lie above the percentage compositions from site-specific studies (regional, figures 4(b)–(f)). These observations suggest significant differences between the material flow-based and site-specific estimates of MSW composition. Hence, we further investigate these differences by comparing the yearly per capita disposal estimates of material classes from site-specific studies with material flow-based national estimates.

4.2. Comparison between the national and regional waste stream

The yearly per capita disposal estimates of material classes from the site-specific studies are tabulated in supplementary table ST1 and depicted in figure ST2. Previously, the material flow-based national estimates indicated that the MSW stream has become steady after 2010 (figures 2(c) and (e)). For these material flow-based estimates, the slope of the best fit lines between yearly per capita disposal and time for each material class is indicated in figure S3. The slope of the best fit lines for the PFYPMG material classes are $-4.28, 2$, $-3.60, 1.76$, $1.46$, and $-0.34 \text{ lbs year}^{-1}$, respectively. Moreover, the average yearly per capita disposal (material flow-based national estimates) for the PFYPMG material classes between 2010 and 2017 are 151.5, 228.75, 83.87, 191.5, 97.37, and 52.62 lbs year$^{-1}$, respectively. Hence, for the material flow-based national estimates, average annual change in per capita disposal estimates of PFYPMG material classes are 2.82, 0.87, 4.29, 0.91, 1.49, and 0.64 percent, respectively. The average annual change in per capita disposal estimates for all the material classes is
less than 5 percent. Hence, we assume that the national disposed waste stream has become steady after 2010. Based on this assumption, we compute the average of yearly per capita disposal estimates for the PPYPMG material classes from the material flow-based national estimates between 2010 and 2017, i.e., period in which the waste stream is steady.

The material flow-based national estimates represent an average picture for the entire United States. Studies in the past have indicated significant differences between the material flow-based estimates and aggregated tonnage of MSW handled in the United States [7, 27]. For instance, material flow-based estimates underestimated the tonnage of MSW landfilled by 134.7 million tons in 2008 and 140 million tons in 2012 [7, 27]. Thus, the methodological shortcomings of the material flow-based estimates are relatively consistent across years. Together, we assume that the material flow-based predictions and the accompanying inaccuracies are steady after 2010. Since the material flow-based estimates are average predictions for the entire United States, we further presume that the waste stream of US states has also become steady after 2010. This assumption enables us to identify the material class-specific strengths and shortcomings inherent in the US EPA’s MSW estimates. Precisely, we compute site-specific yearly per capita average national estimates for all the material classes. The site-specific yearly per capita average national estimate for each material class is the population-weighted mean of per capita disposal estimates from site-specific studies conducted after 2010. To identifying material class-specific shortcomings in the US EPA’s MSW estimates, we compare the site-specific average national estimates with the average of yearly per capita disposal estimates from the material flow-based national estimates. Hereafter, the average from the material flow-based national estimates is referred to as the national average, whereas the average from the site-specific studies is the regional average. The regional and national averages are compared in figure 5(a). For the paper waste, the national and regional averages are 148 and 389 pounds, respectively (figure 5(a)). At the same time, it is interesting to note that the percentage composition of paper from site-specific studies (regional) in different years exceeds the EPA determined percentage composition of paper (national) (figure 4(a)) in corresponding years, which suggests that the US EPA’s material-flow approach significantly underestimates paper waste disposal. The regional average for the paper material class is 262% of the national average (figure 5(a)). In our study, we could not find MSW estimates from site-specific studies for all the US states. However, as a conservative estimate, if we assign the national average of 148 pounds to the remaining populace not covered by the site-specific studies included in this paper, the resulting yearly per capita disposal of paper for the entire US comes out as 239 pounds, which is 91 pounds excess of the national estimates of paper predicted from the material-flow estimates. A difference of 91 pounds means an annual underestimation of 15 million tons for the paper material class alone (figure 5(b)). Alternatively, we consider the regional average of 389 pounds as an accurate estimate of yearly per capita disposal of the paper material class for the entire United States. In that case, the difference between the national estimates and the regional estimates can be as high as 241 pounds. So, on a per capita basis, the annual difference between national and regional averages for the paper material class can range between 91 and 241 pounds. This suggests that the US EPA’s material flow estimates underestimate the paper waste disposal between 15 and 40 million tons annually (figure 5(b)). The US EPA’s material flow estimates report MSW tonnage figures on a dry basis; however, food and yard waste are reported on a wet basis and these material classes contain most of the moisture in MSW [25]. Therefore, an underestimation of 15–40 million tons cannot be completely attributed to the moisture that the paper discards may have gained during the commingling of different waste fractions. Most importantly, the material flow-based estimates rely on different assumptions, i.e., the residence time of products, which may not accurately reflect the consumer behavior, and may form the basis for incorrect estimates. Hence, these observations suggest shortcomings in the US EPA’s material flow approach in estimating paper waste.

For food and plastic material classes, the regional averages are 111 and 114% of the national averages (figure 5(a)). This suggests that the US EPA’s material flow approach accurately estimates the yearly per capita disposal for food and plastic material categories. Meanwhile, for the yard waste, the regional average is 160% of the national average (figure 5(a)); the regional average is the population-weighted mean of yearly per capita disposal estimates of yard waste from site-specific studies. The site-specific studies are conducted in different seasons to account for seasonal variations in MSW generation; however, sampling duration is limited. Specifically, the yard waste generation shows time sensitivity [35]. Hence, a difference of 60% between regional and national averages can also manifest if the yard waste sampling by the site-specific studies is unrepresentative of the yard waste generation. This limitation restricts us from commenting on the appropriateness of the US EPA’s material flow approach for estimating yard waste generation. For the glass material class, the regional average is 90 percent of the national average (figure 5(a)). Based on this observation, we conclude that the US EPA’s material flow approach precisely estimates glass waste disposal. Finally, for the metal material category, the regional average is 73 percent of the national average. The US EPA’s material flow estimates include discarded white goods as sources of metal waste. However, state-specific studies classify white goods as a separate material class; thus, they do not come under the metal material class. This difference may explain the observed difference between the national and regional averages for the metal material class. Alternatively, it may be that
Figure 5. Inferences from site-specific studies and national estimates. (a) Averages of yearly per capita disposal of material classes from site-specific studies (regional) and material-flow based estimates (national) for the period after 2010. Cumulative refers to the sum of average yearly per capita disposal estimates from site-specific studies and material-flow based estimates of paper, food, plastic, yard, metal, and glass material categories. Percentage values indicate the value of regional estimates with respect to national estimates. (b) Paper waste disposal underestimated by the materials flow approach for different possible scenarios of differences between the national and regional estimates. Note that 1 lbs = 0.453 kg.

Figure 6. Power law relationship between population, GDP, and MSW generation. (a) The power law relationship between population and MSW generation estimates of 215 countries. The MSWI generation estimates correspond to the year 2016. Relationship is modelled by the function \( Y(p) = Y(o) \times P^\beta \), where \( Y(p) \) is the amount of waste generated at population \( p \), \( Y(o) \), and \( \beta \) are constants. (b) The power-law relationship between GDP and MSW generation estimates of 213 countries. Relationship is modelled by the function \( Y(g) = Y(o) \times G^\beta \), where \( Y(g) \) is the amount of waste generated at a GDP of \( g \), \( Y(o) \), and \( \beta \) are constants. The corresponding data has been adopted from the report ‘What a Waste 2.0’ published by the World Bank [46]. LIC: low-income countries, LMC: lower middle-income countries, UMC: upper middle-income countries, HIC: high income countries. (c) Weak power law relationship between yearly per capita disposal of paper and per capita GDP for US states. (d) Weak power law relationship between yearly per capita disposal of plastic and per capita GDP for US states.

more metal products are recycled than estimated by the EPA’s material flow approach, which may also explain the difference between the national and regional averages.

In this study, the analysis presented is based on MSW disposal estimates from site-specific waste characterization studies commissioned by 27 US states, which roughly represents 73 percent of the US population. For the remaining US states, we could not find site-specific studies. Hence, we further evaluate the association between site-specific MSW disposal estimates and socioeconomic parameters. This step is intended to examine if we can predict MSW disposal estimates for states for which site-specific studies are unavailable.
4.3. Correlation amongst socioeconomic parameters

Waste generation depends on many factors, namely population, household income, the material basis of the economy, climatic conditions, waste management regulations, and anthropological behavior [36–40]. Mathematical models relate MSW generation estimates with socioeconomic parameters, such as gross domestic product (GDP) and population [41–45]. Specifically, the power-law distribution is used to model the relationship between population, GDP, and MSW generation [41]. At the international level, the power-law relationship yields strong correlations between MSWI generation and socioeconomic indicators. For instance, the power-law relationship between population, GDP, and MSW generation of 215 countries based on the data published by the world bank are depicted in figures 6(a) and (b). However, the same power-law model yielded a weak correlation between site-specific estimates of yearly per capita disposal of PFYPMG material classes and per capita GDP. \( R^2 \) for paper, food, plastic, yard, metal, and glass material classes are 0.08, 0.29, 0.12, 0.03, 0.09, and 0.03. Best fit lines for the paper and plastic material categories are shown in figures 6(c) and (d). The power-law relationships work well when data spans many orders of magnitude. However, such is not the case with per capita MSW generation estimates of different US states. Thus, estimates based on socioeconomic parameters are inappropriate for US states and may result in inaccurate predictions. Inaccurate estimates narrow our understanding of waste composition, limiting our ability to plan waste management facilities in sync with waste composition. Thus, this analysis underscores the importance of site-specific studies in waste management and regulation.

5. Conclusion

In the United States, the national-level estimates of MSW generation are calculated by the US EPA. The estimates are based on a material flow approach. In the past, several studies suggested discrepancies between the US EPA’s MSW estimates and the aggregated tonnage of MSW managed by waste handling facilities in the United States. This study uncovered the basis of these discrepancies by comparing the material flow-based estimates with site-specific estimates. Our analysis suggested that the US EPA’s material flow-based estimates are accurate for food, plastic, and glass material classes. In contrast, our findings indicate that the US EPA’s estimates are unreliable for the paper material category. We estimated that the EPA’s material flow-based framework annually underestimates paper waste disposal between 15 and 40 million tons. The material flow-based estimates are based on certain assumptions, i.e., the residence time of products. The highlighted discrepancies primarily stem from the inaccurate assumptions of residence time. These results are based on the best available estimates of MSW generation in US states and have been arrived at under the assumption that the MSW stream of US states is steady after 2010. Thus, we emphasize that the extent of conformity and disparity is dependent on the validity of the steady-state assumption.

The inaccuracies in the EPA’s material flow approach can be eliminated by addressing the drawbacks highlighted in this study. Moreover, our analysis highlighted that the material flow-based estimates are robust for specific material categories and provide a good framework for estimating MSW generation. Thus, the material flow approach can be extended to predict MSW generation estimates at the regional, national, and international levels. Such a material flow-based framework can be made precise and robust by comparing its estimates with the results from site-specific waste characterization studies. Accurate MSW generation estimates will help better understand MSW composition and thus improve waste management practices, thereby minimizing environmental costs associated with MSW management.

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Data availability

All data that support the findings of this study are included within the article (and any supplementary information files).
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