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# Quantitative Assessments of Municipal Waste Management Systems: Using different indicators to compare and rank programs in New York State

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## Abstract

The primary objective of waste management technologies and policies in the United States is to reduce the harmful environmental impacts of waste, particularly those relating to energy consumption and climate change. Performance indicators are frequently used to evaluate the environmental quality of municipal waste systems, as well as to compare and rank programs relative to each other in terms of environmental performance. However, there currently is no consensus on the best indicator for performing these environmental evaluations. The purpose of this study is to examine the common performance indicators used to assess the environmental benefits of municipal waste systems to determine if there is agreement between them regarding which system performs best environmentally. Focus is placed on how indicator selection influences comparisons between municipal waste management programs and subsequent system rankings. The waste systems of ten municipalities in the state of New York, USA, were evaluated using each common performance indicator and Spearman correlations were calculated to see if there was a significant association between system rank orderings. Analyses showed that rank orders of waste systems differ substantially when different indicators are used, suggesting that the current suite of indicators may not be suitable for evaluating environmental quality of municipal systems. Therefore, comparative system assessments based on indicators should be considered carefully, especially those intended to gauge environmental quality. Insight was also gained into specific factors which may lead to one system achieving higher rankings than another. However, despite the insufficiencies of indicators for comparative quality assessments, they do provide important information for waste managers and they can assist in evaluating internal programmatic performance and progress. To enhance these types of assessments, a framework for scoring indicators based on criteria that evaluate their utility and value for system evaluations was developed.  This framework was used to construct an improved model for waste system performance assessments.

**Keywords**

Indicator; Environmental performance; Ranking; System evaluation; Municipal waste management; Indicator criteria

# 1. Introduction

Beginning in the 1970s in the United States, concern about the environmental effects associated with increased waste generation and perceived decreasing landfill capacity led to increased public interest in recycling. In response to this concern, local municipalities implemented numerous recycling and waste reduction programs to reduce negative environmental effects associated with waste generation (Sidique et al., 2010; Loughlin and Barlaz, 2006). Awareness of the environmental impacts of waste has continued to grow and effective waste management is currently a key target in environmental policies worldwide (Jenkins et al., 2009; Hazel, 2009). It is now understood that growth in waste production unrestrained by proper reduction and management techniques can damage natural systems (Mendes et al., 2012). Therefore, how waste is managed directly affects local and global environmental quality (Vergara et al., 2011; Bahor et al., 2009; Fischer, 2011).

## 1.1 Objectives of Waste Management Systems

The main purpose of waste management technologies and policies are to protect human and environmental health by reducing the negative impacts of waste and finding beneficial reuses for it (Melosi, 2000; USEPA, 2012a). Specific foci of waste systems will differ depending on the level of system sophistication. Many developing countries still have unsophisticated, non-modernized waste systems (Asase et al., 2009; Henry et al., 2006), and this has led to a growing concern over the insufficiency of solid waste management in these countries (Al-Khatib et al., 2007; Taboada-Gonzalez et al., 2011). Public health tends to be the motivating factor for waste policies in countries with unsophisticated waste management infrastructure (Wilson, 2007; Vergara and Tchobanoglous, 2012). In the United States, however, public health was a key driver of waste practices from the 19th century through the 1960s, but now drivers have shifted to environmental concerns (Wilson, 2007). Improved environmental protection through the optimization of waste management practices is the typical focus of waste management policies and technologies in countries where strong legislation has been well established and immediate health concerns have been controlled (Vergara and Tchobanoglous, 2012; Wilson, 2007).

## 1.2 Performance Indicators

Environmental performance indicators are an indispensable management tool for making performance-based decisions about program strategies, and when used correctly, they can drive innovative policy development and technological design. Indicators have become an integral component of international and national environmental policies since the 1990s (King et al., 2000), and are now considered an essential tool for tracking environmental progress, informing the public, and supporting policy evaluation (OECD, 2003). Waste indicators, in particular, are important for programmatic comparisons, communication regarding systems, and for guiding progress towards improved waste system policy and design (Wen et al., 2009). In a general sense, waste indicators identify needed measurements to determine whether system objectives are being met (Vergara and Tchobanoglous, 2012). Since the objective of most waste systems in the developed world is to provide environmental benefit, indicators are used to indicate progress towards this objective.

The most common indicator for measuring the environmental effectiveness of waste systems is the recycling rate (Kaufman et al., 2010). This is because waste regulations commonly introduce quantitative targets for recycling of selected waste materials (Snell and Hurst, 2009; Tojo and Fischer, 2011) because recycling ranks highest on the waste hierarchy after reduction. Waste reduction is difficult to measure so the recycling rate has become the prevalent measure for assessing waste management system quality. However, the use of recycling rates has been questioned recently and a shift to different system evaluation methods has been suggested (Kaufman et al., 2010; NYSDEC, 2010). Kaufman et al. (2010) point out that while recycling many materials is preferable, the recycling rate is not a suitable measure of waste system sustainability and environmental benefit. Lehman (2012) also suggests that although recycling is an important part of sustainable policies, recycling on its own is not enough to achieve sustainable systems because the recycling rate doesn't reflect the differences in environmental impacts when managing non-recyclable wastes using various technologies, such as landfilling or waste-to-energy (WTE) incineration. Finally, Kollikkathara et al. (2009) advocate for a move away from recycling rates because recycling alone is insufficient to offset environmental impacts of current consumption rates in a growing population. Some governments locally and globally have acknowledged issues with recycling rates. For instance, in the New York State Department of Environmental Conservation's (NYSDEC) Beyond Waste Plan (2010) for New York State, a shift to per capita disposal rates is proposed.

The acknowledgement that recycling rates may not be suitable on their own for environmental benefit evaluations leads to the examination of other possible indicators which may be used to represent how environmentally beneficial a system is. Although they explicitly examine different aspects of waste systems, they are all designed to be a measure of environmental quality. Analysis of these other indicators can help answer the following questions: is the recycling rate the proper performance indicator to measure environmental benefits of waste systems? Are there other indicators that provide a more accurate reflection of overall environmental quality?

### 1.2.1 Indicators Used to Assess Waste Systems

A four tier system for waste indicators was developed with each tier representing an increase in complexity from the one prior. This tier system is similar to those used for other types of scientific indicators. For instance, ecological indicators for ecosystem health assessments are commonly classified into eight levels which range from very reductionist qualities in level one to holistic indicators in level eight (Jorgensen et al., 2010). Each tier of waste indicators represents one of the different classifications of indicators as outlined in the ISO14031 Guidance on Environmental Performance Evaluation Standard (Table 1). ISO14031 gives guidance on the design and use of environmental performance evaluation, and on the identification and selection of environmental performance indicators (Jasch, 2000; Scipioni et al., 2008).

Table 1. Indicator Classification

| Indicator Classification | Tier | Definition |
|---|---|---|
| Absolute Indicator | 1 | Direct figure taken from input-output analysis (e.g. tons of raw materials) |
| Indexed Indicator | 2 | Figures expressed as percentage with respect to the total |
| Relative Indicator | 3 | Figures expressed as references to other variables |
| Aggregate Depictions | 4 | Figures of the same units summed over lifecycles |

Waste indicators were selected based on their prevalence in the scientific, as well as the public, literature. Tier one represents the tonnages collected in certain waste categories. It provides no information on how these tonnages relate to the total amount of materials collected within the system and is simply a measure of materials managed. Tier two utilizes tonnages managed by the facility, but measured by percent to provide a better understanding of the relative effect of each waste management strategy. Tier three indicators are ratios indicating the amount managed in specific categories relative to the full time population in the Planning Unit (according to the US Census). Tier four represents the outputs from a waste life cycle analysis (LCA). Waste LCAs are aimed at assessing environmental performance of interconnected waste management technologies based on the specific waste composition from the point of waste generation to final disposal/management. Typically, indicators from tier two and three are used to evaluate and compare systems (e.g. Suttibak and Nitivattananon, 2008; Mendes et al., 2012), but tier four evaluations have become more common in recent years (e.g. Wittmaier et al., 2009; Vergara et al., 2011) (Table 2).

Table 2. Description of Performance Indicators

| **Tier** | **Indicator** | **Definition** | **Optimization for Environmental Performance** |
|---|---|---|---|
| **Tier One: Tonnages** | Tons Recycled | Tons of MSW recycled[a] | Maximize |
| | Tons Disposed in Landfill | Tons of MSW landfilled | Minimize |
| | Tons Diverted | Tons of MSW diverted[b] from incineration or landfilling | Maximize |
| **Tier Two: Percentages** | Recycling Rate | Ratio of MSW recycled[a] per total amount of MSW collected (excluding composting) (expressed as a percent) | Maximize |
| | Landfill Disposal Rate | Ratio of MSW landfilled per total amount of MSW collected (expressed as a percent) | Minimize |
| | Diversion Rate | Ratio of MSW diverted[b] from incineration or landfilling per total amount of MSW collected (expressed as a percent) | Maximize |
| **Tier Three: Per Capita Rates** | Recycling Per Capita | Tons recycled[a] per capita | Maximize |
| | Landfill Disposal Per Capita | Tons disposed in landfill per capita | Minimize |
| | Diversion Per Capita | Diversion[a] per capita | Maximize |

| | | | |
|---|---|---|---|
| **Tier Four: LCA Analysis Outputs** | Energy Savings | Energy saved from MSW generation and management (in million BTU) | Maximize |
| | GHG Emission Reductions | GHG emission reductions from MSW generation and management (in $MTCO_2E$) | Maximize |

[a] does not include composting
[b] does include composting

In higher tiers, the indicators are more computationally complex although they still rely on inputs from tier one. Therefore, the validity of each indicator is only as accurate as the information from tier one. Additionally, because an increase in tiers indicates an increase in computational complexity, more data are needed for the higher tiers which lead to more sources of error and potential inaccuracy in calculations. When indicators have two or more input components, the uncertainties of each input are propagated through to the output (Mendes et al., 2011). As a result, the uncertainty of the indicator is based on the addition of the uncertainties from each input (Mendes et al., 2011), and therefore, there is a greater chance of having an uncertain indicator if it has more (potentially uncertain) inputs. The inputs into LCA models which are used for tier four calculations lead to even greater challenges, especially with regards to the decisions made by the modelers. Differences in system boundaries and the strong dependence on model assumptions have led to considerable variation in model outputs (Chester and Martin, 2009; Beigl et al., 2008; Winkler and Bilitewski, 2007). Additionally, most LCAs of waste systems are extremely complex, time and resource intensive, oftentimes subjective, and difficult to handle by non-experts (Blengini et al., 2012). Therefore, it is not immediately clear whether more complex indicators are always better than simpler measures of environmental performance. Appendix A provides a detailed description of issues associated with each indicator.

## 1.3 Study Objectives

There is limited examination of the performance indicators used for waste system assessments and there is no consensus as to which indicators provide meaningful information for environmental quality evaluations.  No prior work has analyzed how performance rankings of municipal systems differ based on the indicator that is used.  Furthermore, indicators for waste system assessments are often selected for use without formal criteria for assessing utility. This study seeks to fill these gaps by providing essential information about how programs are compared and ranked, and ultimately give insight into the best way to do these assessments. Focus is placed on how indicator selection influences comparisons between municipal waste management programs and subsequent system rankings. Three main research questions are explored: 1. Is there agreement between the waste indicators regarding which waste system performs best environmentally relative to the others?; 2.   Do these indicators reflect the objective (environmental quality) of waste systems?; and 3. What indicators should be used when assessing systems?

## 2. Methodology

### 2.1 Selection of Cases

Data were collected from Planning Units in New York State (NY), USA. Planning Units are given the responsibility and authority by the state to manage local wastes.  Only cases from NY were included to allow for comparability between cases.  All of the recycling programs in NY are mature, municipalities are held under the same state-wide legal constraints, and they are all managed under the NYSDEC Beyond Waste Solid Waste Management Plan (2010).  The Beyond Waste Plan attempts to move towards more sustainable waste management in NY by progressively reducing the amount of wastes disposed and it suggests state-wide disposal goals which all municipalities are encouraged to achieve. Furthermore, in addition to similar waste goals and regulations, all municipalities in NY have other common situations which facilitate comparisons between municipalities. For instance, all municipalities in the state fall under the New York Bottle Bill which issues a deposit return when applicable containers are recycled. Seventy-three percent of targeted cans and bottles that are sold annually are recovered through this deposit law (NYSDEC, 2010), but these materials are not included in municipal data. Finally, NY is the third largest economy and third highest populated state in the US (US Govt. Revenue, 2010), and is a major generator of MSW, generating more than 30 million tons of waste in 2008 (NYSDEC, 2010). These factors suggest NY is a place where there is a need for innovative waste management solutions to minimize negative environmental impacts of waste, and to accomplish this, a better understanding of NY waste system assessments is needed.

Cases were selected using five criteria.

(i) Cases provide a thorough representation of the various disposal technologies in NY: As recycling and waste management programs in NY have matured and evolved over the past three decades, a variety of system designs for collection and processing have been developed (Chester et al., 2008; Ferrara and Missios, 2005). Cases with each main type of disposal structure were included (i.e. waste-to-energy, landfilling, and a combination of both).

(ii) Single family homes are the majority: Studies show that compared to single family waste programs, multi-family programs have different program organization, such as the predominance of private contracted waste collectors, reduced recycling enforcement, differing costs (Clarke and Maantay, 2006; USEPA, 2001), and lower waste diversion (Ando and Gosselin, 2005; Stevens, 1999; USEPA, 2001). Differences in recycling convenience, particularly with regards to difficulties with recyclable storage and collection, and occupant demographics are likely the main causes for these differences (Alexander et al., 2009; Ando and Gosselin, 2005). Therefore, to ensure the most accurate comparisons between cases, Planning Units with multi-family housing as the majority were excluded.

(iii) Populations are between 100,190 and 500,000: This ensures that cases had moderately high populations. The median of the populations for all NY Planning Units was 101,190, so only cases above the median were selected. However, the four Planning Units with populations greater than 500,000 were excluded because their high populations could affect waste management systems considerably.

(iv) Sufficient and reliable data is available: This ensures that performance indicators may be calculated for each case. It is typical in the waste field to use data availability as a criterion for case selection because oftentimes sufficient data may not be available for every case. For instance, Troschinetz and Mihelcic (2009) and Suttibak and Nivattananon (2008) only examined waste systems with sufficient and reliable data.

(v) Population densities are greater than 139.21 people per square mile: This ensures that cases had relatively high densities. The median density for all NY Planning Units was 139.21 people per square mile (NYS Department of Health, 2009), so only cases above the median were selected. Population density can considerably affect waste management practices (Gellynck et al. 2011; NYSDEC, 2010).

Of the 64 Planning Units in New York State, there were 27 Planning Units with populations between 100,190 and 500,000. Of these 27, there were ten which had majority single family homes, population densities greater than 139.21 people per square mile, and sufficient data available. These ten cases were from all areas of NY and have varying municipal characteristics (Table 3). All of the municipalities have recycling and composting programs in place, but they differ in the way that they manage refuse. Map 1 shows the location of all cases.

Table 3: Municipal Characteristics of Cases

| Municipality | Population[a] | Population Density (people/sq.mi.) | Land Area (square miles)[a] | Percentage Single Family Homes[a] | Refuse Disposal Method |
|---|---|---|---|---|---|
| **Brookhaven Town** | 486,040 | 1,877 | 259 | 84% | WTE |
| **Dutchess County** | 297,488 | 371 | 802 | 67% | Landfill |
| **Huntington Town** | 203,264 | 2,162 | 94 | 91% | WTE |
| **Islip Town** | 335,543 | 3,196 | 105 | 81% | WTE |
| **Onondaga County** | 467,026 | 599 | 780 | 66% | WTE |
| **Orange County** | 372,813 | 810 | 460 | 69% | Landfill |
| **Rockland County** | 311,387 | 1,790 | 174 | 67% | Landfill |
| **Schenectady County** | 154,727 | 751 | 206 | 62% | WTE and Landfill |
| **Smithtown Town** | 117,801 | 2,182 | 54 | 91% | WTE |
| **Tomkins County** | 101,564 | 221 | 460 | 53% | Landfill |

[a] Source: 2010 US Census

## 2.2 Data Collection

Raw data for this study were collected directly from municipal sources and from New York State records. The data are for the year 2011. In most cases, personal communication was carried out with waste managers from the municipalities to ensure accurate and complete data.

Comparisons are often difficult to make between municipalities because they use different definitions for waste streams and they do not calculate the same performance indicators (Greene, 2010). Here the variation in data sets was minimized by excluding certain items so inter-municipality comparisons could be made. This was done by using primary sources of data, concentrating on comparing similar kinds of efforts, and calculating the performance indicators using the same formulas. Only MSW was examined and the analysis did not include any Construction and Demolition (C&D) materials, industrial wastes, hazardous wastes, or biosolids. As defined by the USEPA, MSW includes durable goods, non-durable goods, containers and packaging, food wastes, yard wastes, and miscellaneous inorganic wastes from residential, commercial, and institutional sources (USEPA, 2012a). Recycled items which were excluded from the analysis to allow for better comparisons are those that are typically called ‘other recycling’ (textiles, concrete, waste oil, batteries, and wood pallets) (see Appendix B for a detailed list of included and excluded materials). This approach yields conservative recycling tonnages which are generally lower than those calculated directly by municipalities.

Although best efforts were made to minimize data issues which could adversely affect the outcomes of indicator calculations and complicate comparisons, there are some unavoidable data issues. Some data may be missing from datasets due to systematic or intentional errors in waste reports, often from regions relying heavily on private waste collection and facilities (Tonjes and Greene, 2012; NYSDEC, 2010). Waste reporting by private organizations is recognized to be less reliable than that directly measured from municipal sources (NYSDEC, 2010). Additionally, there is no consistency regarding the sectors included in waste data, as some municipalities will only report residential wastes, while others report residential, commercial and institutional. Waste reports may also miss data when unlicensed scavengers collect materials or contract carters divert recyclables themselves to enhance revenues (Scheinberg and Anschutz, 2006). Even so, the data provided by the municipal sources and state records is believed to be the best available (NYSDEC, 2010) and sufficient for this analysis.

### 2.3 Data Analysis

All of the cases were analyzed by calculating each performance indicator using the formulas listed in Table 1. Rankings were established to show which cases achieved the highest environmental performance relative to the others based on each indicator. Spearman's Rho was calculated for the relationships between the rankings of each variable to see if there is agreement between the indicators in terms of system rankings. Spearman's Rho can be interpreted as the Pearson Correlation Coefficient between ranked variables (Blalock, 1979). The null hypothesis tested was that the ranks of one variable do not covary with the other, and the alternative hypothesis is that the ranks of one variable will covary with the other. The rankings were based on a rank of one indicating the best environmental performance. If two municipalities had identical ranks, ranks were assigned based on the average score of the ranks that they would have otherwise occupied (Blalock, 1979). If all indicators are effective indicators of environmental performance, the rank order of cases using different indicators should be highly correlated, signifying the indicators are in agreement with each other. Spearman's Rho and significance levels were calculated using STATA11.

The tier four indicators were calculated using the United States Environmental Protection Agency's (USEPA) Waste Reduction Model (WARM) (version 12, updated February 2012). WARM is a simplified, stream-lined LCA developed specifically for waste managers (USEPA, 2012b). Rather than being used to make complex decisions about systems, WARM has been used to give approximations of greenhouse gas (GHG) emissions and energy savings for waste systems (NYSDEC, 2010; Vergara et al., 2011; Bahor et al., 2009; DSM, 2008). These are applicable environmental impact categories because environmental challenges related to long term waste management are climate change and energy use (Pires et al., 2011). WARM has been used in previous waste-focused studies (e.g. Vergara, 2011; Chester and Martin, 2009). A detailed description of the model, including assumptions, is given by the USEPA (2012b).

WARM incorporates region specific electricity grid factors to allow for accurate calculations of avoided electricity-related emissions in the landfilling and combustion pathways. For this analysis, the electricity grid mix emission factor was based on the fact that all cases were located in New York which falls into WARM's northeast category. WARM varies outputs based on landfill gas recovery (no landfill gas recovery, landfill gas recovery, or a "national average"). "National average" was used for the analysis because, although the tonnages landfilled for each case were known, it was not always clear which landfill wastes went to. WARM also uses the transport distances for wastes from facility to facility (i.e. from transfer station to landfill); default distances were used. For municipalities that use WTE, no landfilling tonnages were used despite that WTE combustion leaves ash residues (15% by volume, 30% by mass) (Papageorgiou et al., 2009). The landfilling tonnages of the ash were not included in the analyses because landfill ash is generally considered to have no significant climate change impact (Papageorgiou et al. 2009). As organic carbon in waste is destroyed by the incineration, no greenhouse gas emissions arise from the disposal of the ash in the landfill (Papageorgiou et al. 2009; USEPA, 2012b).

## 3. Results

Results show that the cases vary considerably in ranking with regards to environmental performance depending on the indicator used, suggesting there is little agreement between indicators (Appendix C). This shows that the indicators used can notably affect performance assessments. This is further emphasized by examining the Spearman's Rho and significance levels for each case's ranking. Out of the 66 bivariate associations which were examined, 17 showed statistically significant correlations at the .05 significance level. Upon closer inspection, it can be seen that most of the relationships that were statistically significant were between rankings of variables that were already assumed to be directly related to each other. This includes the bivariate relationships between rankings with recycling rate, tons recycled, and recycling per capita. Statistically significant relationships were also found between pairs of the landfilling indicators (landfilling per capita, tons disposed in landfills, and the disposal rate). As a result of the relatively few statistically significant correlations, the null hypothesis for most associations fails to be rejected.

Statistically significant associations were seen between each tier four indicator and one other variable. There was a statistically significant association between energy savings and recycling rate, as well as between GHG reductions and diversion rate. This suggests that the recycling rate may indicate energy savings and the diversion rate may indicate greenhouse gas reductions (at least with regards to the WARM model). The major difference between recycling rate and diversion rate is that the diversion rate includes composting, suggesting that composting may affect GHG emissions. Although GHG reductions was not significantly associated with the landfilling indicators, three (of the four) municipalities that landfill wastes scored poorly on GHG reductions, indicating that landfilling may not be best for GHG reductions (even with gas recovery). In fact, two of the cases which landfill wastes showed that waste management programs did not increase GHG reductions and, instead, resulted in GHG emissions (only one other municipality-Dutchess-also showed GHG gains). It should be noted that there was no strong correlation between the tier four indicators with each other which suggests that a system that may be better at reducing greenhouse gas emissions may not always score highly with regards to energy savings when using the WARM model. For instance, both Orange and Dutchess ranked poor for GHG reductions (ranked 7 and 8, respectively), but they ranked better for energy savings (ranked 4 and 1, respectively).

It also is important to discuss notable non-significant correlations. Although significant associations were present for recycling rate and tons diverted; recycling per capita and tons diverted; diversion per capita and tons recycled, recycling rate, and recycling per capita; there was not a strong association between diversion rate and recycling rate, which are often used interchangeably. This suggests that although a municipality may rank first with regards to recycling rate, they may not also have the highest diversion rate. Furthermore, there was no significant association between recycling tonnage and tonnage disposed in landfill, or between recycling rate and landfilling per capita or landfill disposal rate, or between recycling per capita and landfill disposal per capita. Oftentimes, municipalities with the highest recycling rates are cited as the greenest and most environmentally sound, but in actuality, they still may be landfilling considerable amounts of waste. Ultimately, these findings indicate that a municipality may have a relatively high recycling rate, but they still may not be diverting much from disposal relative to the other municipalities. Therefore, a high score with regards to one indicator does not ensure a high score in another, and the lack of correlation between these variables indicates that the choice of indicator will affect environmental performance rankings.

The lack of strong relationship between diversion rate and recycling rate was examined more closely. The diversion rate includes composting, while the recycling rate does not, so when composting is excluded from the rate (for recycling rate calculations), the rankings of the cases change, sometimes considerably. Both Islip and Smithtown move from higher rankings when using diversion rates (5 and 3, respectively) to lower rankings when using recycling rates (9 and 8, respectively).  This suggests that their high diversion rates are due to yard waste composting. Conversely, Dutchess County moves higher in the rankings when composting is excluded, indicating its diversion success is not dependent on composting. This is something that is important to be aware of when looking at program rankings.  It also suggests that it is important to examine site specific characteristics when looking at relative ranks among indicators. For instance, municipalities in rural areas may have very low composting rates (based on what goes to the municipal site) because much composting is done at home (and this is not counted in the municipal data).  Therefore comparing diversion rates for municipalities that have high levels of municipal composting with those that do not (possibly due to the presence of home composting or an urban setting with little yard waste) may be misleading.

It also is beneficial to examine the recycling rate in terms of curbside recyclables. Curbside recycling has expanded considerably in the US since the 1990s, and today there are more than 9,000 programs nationwide (USEPA, 2011).  Although programs differ, most include collection of mixed paper and corrugated cardboard in addition to metal, plastic and glass containers, which together are generally referred to as curbside recyclables. As with the recycling rate, composting was excluded from the numerator and denominator when calculating curbside recycling rate.  Although the curbside recycling rate and the recycling rate are significantly associated when looking at ranks, the differences between the highest ranking program and the lowest ranking program are much smaller when examining curbside recycling rates instead of the diversion or recycling rate. The difference between the highest curbside rate (Onondaga) and the lowest curbside rate (Islip) is 23 percentage points, compared to a difference of 41 points for diversion rate and 46 points for recycling rate. This indicates that the wide disparities in diversion rates are due to materials other than curbside recyclables. The high quantities of bulk and scrap metal recycling in Onondaga and Tompkins increase their recycling rates considerably; however, when these materials are excluded for the curbside analysis, Tompkins and Onondaga perform much closer to the other cases.

## 4. Discussion

### 4.1 Case Rankings

The findings provide insight into the nature of environmental evaluations for waste systems. A system can rank high with regards to environmental quality in certain categories, and poorly in others, which is not intuitively obvious. Expectations are that highly ranked systems should rank highly in terms of recycling, diversion, GHG reductions, energy savings, and low landfilling rates, which all theoretically should represent high environmental quality. Correlation analysis indicated, however, that this was not the case. This is important in the waste field because waste programs are frequently ranked relative to each other based on indicators (e.g. WRN, 2012; Montgomery, 2013; San Francisco, 2010; Recycle Mania, 2013; Aneki.com, 2013). It is not uncommon for a municipality to be cited as the most ‘environmentally friendly’ or ‘greenest’ municipality due to a top ranking based on a single indicator (e.g. Cereplast, 2012; Huff Post, 2012). Furthermore, the differences in how a program ranks based on the indicator used may explain the inconsistency in the indicators that municipalities choose to use when reporting their performance.  It is likely that if municipalities are self-reporting performance, they will use the indicator that sets their program in the best light.  Ultimately, when comparing programs, the indicator that is chosen will affect rank ordering of systems.

These findings substantiate recent claims that the recycling rate, which frequently is used to evaluate systems, may not be sufficient on its own to determine relative environmental quality of waste systems. This is emphasized by the fact that there was no strong correlation between rankings for recycling rate and diversion rate, recycling rate and landfill disposal rate, recycling tonnage and tonnage landfilled, or diversion rate and landfilling rate. This collaborates the observation that some US municipalities with the highest recycling rates are still landfilling large amounts of wastes per person. Therefore, despite a municipality performing relatively high with regards to one performance indicator, there is no assurance that they will also perform highly when analyzed in terms of another performance indicator.  As a result, a municipality with a high recycling rate may not be performing well environmentally overall and, therefore, conclusions about the ‘greenest’ municipalities are not reliable when they are based solely on recycling rate rankings.

When looking at the correlations between the tier four indicator rankings and the others, it can be seen that rankings for recycling rate correlate well with energy savings, and GHG reductions correlate well with diversion rate. There were no indicators that significantly correlated with both tier four indicators, suggesting that no indicator, on its own, is indicative of both relatively high GHG reductions and energy savings. Furthermore, the tier four indicator rankings did not significantly correlate with each other which show that a case may rank high with regards to one LCA output, but not the other.  Ultimately, the current suite of common indicators may not be suitable to evaluate environmental quality of waste systems and system rankings using these indicators should be viewed with caution.

It can be concluded that performance indicators are insufficient for rank ordering systems in terms of environmental quality. Instead of using a single indicator, environmental quality should be evaluated holistically to ensure that all system components are accounted for so that decision makers can better understand system dynamics and overall complexity (Eriksson and Baky, 2010; Pires et al, 2011). Furthermore, it is essential that specific site characteristics, including environmental stressors and susceptibilities, be taken into account during environmental quality assessments because site conditions may affect reporting and environmental impacts. Currently, few waste system assessments take local ecosystem sensitivity into account when characterizing environmental impacts (Cleary, 2009). None of the current waste indicators can account for all of these factors, suggesting they are not suitable for evaluating the overall objectives (high environmental quality) of waste systems.

Despite the inadequacies of indicators for comparing and rank ordering the environmental quality of systems, they do provide important information for waste managers, and they can assist in evaluating internal programmatic performance. They must be taken at face-value for what they represent, instead of as a gauge for something else (environmental quality, for instance). Indicators can be utilized for goal-setting and progress assessment, particularly for determining how a system is changing over time. The conclusion that indicators are most valuable for goal-setting and progress assessment leads to the question: which of the common indicators is best for these purposes?

## 4.2 Performance Indicator Scoring

Much work has focused on the proper criteria for selecting general indicators (e.g. Scipioni et al., 2008; Jorgensen, et al., 2010), although little has been done in the waste field. To improve the use of indicators for internal program evaluations, it is necessary to systematically assess each one to see which are best suited to evaluate performance of a waste system.

### 4.2.1 Methodology for Scoring

A formal, utility based framework of criteria for selecting waste indicators was developed; methods to generate criteria and score the waste indicators were as follows. First, a hierarchy of candidate indicators was listed based on a literature review, similar to Jennings (2005) and Piet et al. (2008). In step two, criteria were developed for assessing waste indicators that focus on assessing if the indicator provides correct, concise information concerning the most relevant and meaningful aspects of waste systems (Table 4).

Table 4. Evaluation Criteria

| Criteria | Definition | Source |
|---|---|---|
| Direct (C1) | Indicator measures closely to the possible result it is intended to measure (indicator reports on environmental performance) | Indicators should fulfill the purpose they are designed for (Scipioni et al. 2003), match the purpose of assessment (Corvaln et al., 2000) and be adequate for intended use (ISO, 1999). |
| Objective and Specific (C2) | No ambiguity in measurements; indicator is clearly defined and uses common definitions | Indicators should be specific (Schomaker, 1997; Rice and Rochet 2005). |
| Clear (C3) | Indicator should be simple and easy to interpret | Indicators should be simple, easy to understand (Jorgensen et al. 2010; Corvaln et al., 2000) and clear (Scipioni et al., 2003). |
| Comparable (C4) | Indicator allows for program comparisons | Indicators should allow for comparability (ISO, 1999). |
| Practical (C5) | Data can be obtained timely at reasonable costs | Data must be readily available (Corvaln et al., 2000) or |

| | | |
|---|---|---|
| | | obtainable (Gallopin, 1997). Indicators should require low resource demand (Niemeijer and Groot, 2008) and be cost effective (Gallopin, 1997). |
| Reliable (C6) | Data for indicator is of sufficient, dependable and consistent quality for decision making | Author |
| Useful for Waste Managers (C7) | Indicator provides meaningful measurement of system change; indicator is useful for daily decision making regarding system; indicator indicates progress towards improved system design | Indicators should be usable (Corvaln et al., 2000) and appropriate to management efforts (ISO, 1999). |
| Relevant (C8) | Indicator provides information that is of priority interest; indicator is important for communicating information about systems | Indicators should be relevant and understandable to interested parties (ISO, 1999). |
| Minimal Error (C9) | Errors do not propagate through calculations | Indicators should be operationally simple (Riley, 2001). |
| Policy Relevance (C10) | Indicator is relevant to state/federal waste and environmental policies | Indicators should have policy relevance (Niemeijer and Groot, 2008). |

In step three, the indicators were scored against the criteria using a matrix system with the criteria arrayed across the top and the candidate indicators listed down the left side. The quality of indicators were evaluated relative to each criterion using an ordinal scoring of three scores (1=’poor’, 2=’fair’, 3=’good’), similar to how Chavez et al. (2011) used a three-value scale of for evaluating waste management indicators environmentally, economically, and socially. Those scores were: ‘poor’ (P) (indicator does not adequately reflect the criterion; ‘fair’ (F) (indicator is appropriate for the criterion); and ‘good’ (G) (indicator is clearly useful and reflective of criterion). The total points were summed for each indicator, with a higher value indicating better performance (Table 5). This scoring methodology has similarities to that used by Suttibak and Nitivattananon (2008) and Piet et al. (2008).

Table 5. Indicator Ranking Totals

| Candidate Indicators: | | Number of ‘POOR’ Ranks (1) | Number of ‘FAIR’ Ranks (2) | Number of ‘GOOD’ Ranks (3) | TOTAL POINTS |
|---|---|---|---|---|---|
| **Tier One: Tonnages** | Tons Recycled | 5 | 1 | 4 | 19 |
| | Tons Disposed in Landfill | 4 | 2 | 4 | 20 |
| | Tons Diverted | 5 | 1 | 4 | 19 |
| **Tier Two: Percentages** | Recycling Rate | 3 | 2 | 5 | 22 |
| | Landfill Disposal Rate | 2 | 2 | 6 | 24 |
| | Diversion Rate | 3 | 1 | 6 | 23 |
| **Tier Three: Per Capita Rates** | Recycling Per Capita | 3 | 3 | 4 | 21 |
| | Landfill Disposal Per Capita | 2 | 2 | 6 | 24 |
| | Diversion Per Capita | 3 | 1 | 6 | 23 |
| **Tier Four: LCA Analysis Outputs** | Energy Use | 3 | 6 | 1 | 18 |
| | GHG Emissions | 3 | 6 | 1 | 18 |

### 4.2.2 Scoring Results

The tier two and three indicators scored highest, with landfill disposal rate, diversion rate, landfill disposal per capita, and diversion per capita receiving the highest scores. Tons recycled, tons diverted, energy use, and GHG emissions scored the lowest. All indicators scored ‘poor’ or ‘fair’ in the ‘objective and specific’ (C2) criterion. Most waste indicators are not yet objective because there still is no standard metric definitions or inclusion criteria for formulas in the US or abroad (Themelis and Kaufman, 2010; Lave et al., 1999; Rabasca, 1994). Oftentimes even if the same performance indicator formula is used, the numerator and denominator entries vary between programs. This occurs because those entering the metrics define recycling and MSW differently; materials are often included in waste statistics that do not fit general definitions, such as Construction and Demolition (C&D) materials and automobiles (Tonjes and Greene, 2012; Arsova et al., 2008; Themelis and Kaufman, 2010; NYBWRR, 2001; Greene, 2010; Pillsbury, 1998). Furthermore, in terms of recycling, some municipalities will count collected materials, while others count only those materials sent to market (Tonjes and Swanson, 2000). This difficultly in counting recycling makes indicators involving recycling (tons recycled, tons diverted, recycling rate, diversion rate, recycling per capita, diversion per capita) score lower in terms of objectivity than other indicators (although no indicator received a 'good' score).

Every indicator ranked 'poor' in terms of the 'reliable' criterion because it is hard to consider waste indicators reliable. Data which are used to calculate performance indicators are often inconsistent (Wen et al., 2009; Simmons et al., 2006), which has led to general confusion with regards to waste assessments. Dahlen et al. (2009) pointed out that on top of inconsistent waste stream definitions, there are over ten additional sources of error in official waste statistics. These include incorrect measurements at scales and gaps due to waste not collected in the normal waste management systems (e.g. home composting, illegal dumping). Studies show that waste stream redefinitions and reconsiderations will greatly change MSW data and calculated performance indicators, particularly when different materials are included in the rate calculations (Rhyner, 1998; NYBWRR, 2001).

It is important to realize that quantitative comparisons are of little use for cross-program comparisons if details of calculations are not provided (Einstein, 1996) and the indicator being reported is not clearly identified (Greene, 2010). Once this is done, indicators will rank higher in terms of objectivity and reliability. It should be noted that the United States Environmental Protection Agency (USEPA) (Pillsbury, 1998) and others have attempted to standardize waste data collection and performance metric calculation using standard definitions and recycling rate formulas (Kaufman and Themelis, 2009; Dahlen, 2005; Pillsbury, 1998; USEPA, 1997; Dahlen et al., 2009). Conceptually, if waste data is quantified consistently between programs and the same definitions exist for waste streams, waste management systems can be accurately compared (Dahlen, 2005; Goldstein, 2007). However, there is no mandate for local governments to comply, and although the USEPA has been working on this issue for nearly 20 years, not much progress has been made. It is likely that standardization has not yet been adopted due to the inherent difficulties with the collection of waste data in a standard manner. Standardizing waste accountings either means idiosyncratic waste streams will not comply with specific waste categories, they will be excluded, or will be force-fitted to comply (Tonjes and Greene, 2012). Additionally, there are data collection issues at the facility level, such as inaccurate measurements and improper waste diversions (for example by scavengers), that setting standards does not address (Lange, 2012; Einstein, 1996; Tonjes and Greene, 2012).

The ‘minimal error’ (C9) criterion deserves noting. The uncertainty of an indicator is based on the addition of the uncertainties from each input (Mendes et al., 2011), and as a result, there is a greater chance of having an uncertain indicator if it has more (potentially uncertain) inputs. The tier one and tier two indicators scored ‘good’ for this criterion because they represent raw data or very simple modifications of the raw data collected from facilities. However, for tiers three and four, the indicators become more computationally complex, and consequently, there is additional room for error. Tier three includes the error associated with population estimates, such as inaccurate costs or effects from seasonal influxes of people that are not included in the year-round populations. Tier four has even more errors because of many model assumptions, the sometimes subjective nature, and lack of consistency with regards to model parameters and inputs.

The tier one, two and three indicators all scored ‘good’ for the ‘clear’ (C3) criterion because they are straight forward and easy to interpret. All three also received a ‘good’ score for the ‘practical’ criterion (C5) because the data needed for these calculations are collected on a regular basis by most municipalities using relatively few resources. Moreover, the tiers one, two, and three indicators also all scored ‘good’ on the ‘useful for waste managers’ (C7) criterion. These indicators must be regularly viewed by waste managers to accurately assess changes in systems, to make proper decisions, and ultimately improve system function. The tiers two and three scored ‘good’ for the ‘comparable’ (C4) criterion, unlike the tier one indicators. Since tier one is a directly measured tonnage, it has little relative value, which makes comparisons between programs difficult. For the ‘relevant’ criterion (C8), the tier one indicators also scored ‘poor’ because the public and policy makers tend to be more interested in percentages and per capita values (based on their prevalence non-academic literature, such as news articles, and waste policy) (e.g. Sullivan, 2011; NYSDEC, 2010). The recycling rate and recycling per capita scored ‘fair’ for C8 because recycling values do not indicate disposal methods for non-recycled materials or provide information on what is being composted, both of which are important. All of the tiers one, two, and three indicators scored ‘poor’ in the ‘direct’ (C1) criterion. These indicators clearly do not directly measure environmental impacts; this conclusion is supported by the findings in the first section of the paper. Lastly, the tier one and two indicators scored ‘fair’ with regards to ‘policy relevance’ (C10) because although they are important to monitor progress towards regulatory compliance, they are not the current indicators preferred by New York. The NYSDEC has advocated for a switch to per capita disposal and diversion rates because per capita indicators reduce data anomalies inherent in a state, such as NY, with variations in demographics and geography (NYSDEC, 2010).

The tier four indicators ranked ‘poor’ with regards to criteria for ‘practical’ (C5), ‘minimal error’ (C9), and ‘useful for waste managers’ (C7), because lifecycle analyses (LCAs) are extremely complex, time and resource intensive, and difficult to understand by non-experts (Blengini et al., 2012). This has restricted their diffusion to end-user populations, particularly local waste managers and operators (Blengini et al., 2012). The complexity of LCAs also make them somewhat unclear (C3) and difficult to compare between systems (C4). Differences in system boundaries and the strong dependence on model assumptions have led to considerable variation in model outputs (Chester and Martin, 2009; Beigl et al., 2008; Winkler and Bilitewski, 2007). These limitations of LCAs have been previously described (e.g. Ekvall et al., 2007; Morrissey and Browne, 2004). Nonetheless, LCA has been identified as a powerful tool for assessing environmental impacts, but their limitations must be recognized. LCA outputs may not be appropriate as indicators used for regular system evaluations; rather, they are best used by LCA experts to make long-term, detailed system analyses. The tier four indicators did score high in the ‘relevant’ (C8) criterion because GHG reductions and energy savings are important environment impact categories, ones managers and the general public have expressed interest in. However, they scored ‘fair’ in the ‘direct’ criterion (C1), because each indicator only measures one aspect of environmental impact (GHG reductions or energy savings), as opposed to total environmental impacts. Lastly, the tier four indicators scored ‘fair’ with regards to ‘policy relevance’ (C10) because most policies still set requirements and goals using tier two or tier three indicators.

### 4.2.3 Discussion of Indicator Evaluations

In conclusion, landfill disposal rate, diversion rate, landfill disposal per capita, and diversion per capita were the indicators with the highest overall rankings. Because each of these indicators has well characterized weaknesses (Appendix A), waste managers and policy makers should consider them in a combinatory form to effectively assess programmatic performance and to guide policy making. An improved model for waste system performance assessments uses these core indicators in combination so that wastes diverted from disposal and the percentage material landfilled are easily apprehended. This illuminates how waste materials are managed relative to the entire waste stream and also in relation to population size, which will support system improvements when they are tracked over time. However, these indicators do not (on their own or in this group of four) indicate overall environmental quality of a system. Many other factors, particularly site-specific ones, must be accounted for to achieve this.

## 4.3 Study Limitations and Directions for Future Research

Although efforts were made to make data consistent between municipalities, there are still some inherent, unavoidable problems with MSW data, primarily involving the lack of complete data (Chowdury, 2009; Kaufman, 2008; Vergara, 2011). It is well known that poor data quality is a major difficulty encountered when proposing to use indicators (Tsoulfas and Pappis, 2008) because an indicator can only yield a reliable representation of environmental performance if it is based on good quality data (Perotto et al., 2007). Improvements in data collection could address these problems which may make future indicator studies more accurate.

In particular, better reporting of private waste practices would be useful, as it tends to be incomplete and inaccurate. Additionally, if waste management practices are structured to allow for it, municipalities should keep separate accounts of different waste stream sectors (i.e. residential, commercial, and institutional). This would yield better sector-specific analyses which could increase comparability between cases and support increased sophistication of analyses. However, it is clear that there are numerous difficulties with improving waste data in these ways, particularly because many private companies release data begrudgingly, and companies and/or municipalities operationally mix sectors, making separation of data tricky.

The evaluation of data quality for calculating environmental indicators is important for the correct interpretation of indicators (Mendes et al., 2011). Perotto et al. (2007) showed that understanding measurement uncertainty, in particular, is essential for correct performance evaluation using indicators. However, there still are very few studies that formally assess the quality of data used for indicator construction, and uncertainty in indicators has not been explored much (Mendes et al., 2011). Some mathematical analysis methods (such as fuzzy mathematical programming and interval mathematical programming) have been developed to support waste planning and policy decisions (Li et al., 2012), although they tend to focus on internal planning, rather than comparative analyses between systems. Furthermore, they have not explicitly shown how uncertainties affect indicators calculations and system rankings. It would be beneficial to formally assess the degree of uncertainty associated with each data input for waste indicators, and see how these uncertainties propagate through to the indicator output and affect municipal rankings.

Another limitation was the innate differences between municipalities being compared. Both Lavee and Khatib (2010) and Gellynck et al. (2011) demonstrated that factors such as income, presence of private contractors, housing density, and waste disposal costs can affect recycling performance of a municipality. Criteria for case selection minimized these issues to some degree, although factors such as local legislative mandates, tipping fees, and budget issues could not be normalized. It is clear that comparisons of waste systems cannot be done without first standardizing the data to some degree, ensuring that only the same efforts are being compared. Ultimately, perfect waste standardizations are impossible due to inherent program differences, but some controls on variations can be imposed.

There is inherent subjectivity in indicator scoring. By eliciting participation and feedback from diverse areas of expertise (such as waste managers, stakeholders, and partners in the waste field), the experts could substantiate the criteria and scoring, thus refining the performance indicator rankings. Behn (2003) notes that performance measure applicability may be dependent on the needs of a user, suggesting that some people may be more interested in particular performance indicators than others. Secondly, it is likely that some criteria are more important than others when ranking indicators. Indicators could be evaluated using prioritized criteria, such as Multi-Criteria Decision Analysis (MCDA).

Lastly, there is room to expand this research to system wide sustainability assessments which incorporate environmental, social, and economic factors. These sustainability assessments have recently become more common in the waste management field due to their ability to serve as more complete system evaluations (Vinyes et al., 2013; Vermeulen et al., 2012). Just as indicators for environmental performance were scored, similar methods may be used to assess economic and social indicators for waste systems. It has been noted that a comprehensive set of sustainability indicators needs to be developed for waste management programs and policies to track progress towards sustainability initiatives (Desmond, 2006).

## 5. Conclusion

Indicators are commonly used to evaluate the environmental performance of municipal waste management systems and to provide as a basis for system comparisons and ranking. Analyses showed that environmental performance rankings of waste systems using different indicators are inconsistent, suggesting that the common indicators are not suitable for rank ordering systems when the purpose of ordering is to determine the most environmentally sound system. This can lead to inaccurate comparisons or wrong conclusions to be made about programs, and therefore, comparative system assessments based on indicators should be considered carefully, particularly those intended to gauge environmental quality. However, indicators do provide important information for waste managers and policy makers and they can help in evaluating internal programmatic performance and progress (rather than gauge overall environmental quality). An assessment of waste indicators shows that several indicators (landfill disposal per capita, diversion per capita, diversion rate, and landfill disposal rate) may be the most effective at this. By calculating these indicators for municipalities, and doing so in a consistent way, system performance and progress can be determined. This can have important implications for discussions about environmentally sound waste systems, for waste planning, policy making, and ultimately, the transition to sustainable waste management.

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## Appendix A. Issues with Indicators

There are issues with all waste indicators that need to be recognized. Despite the problems with them, they are useful for evaluating programmatic aspects of waste systems. Additionally, many of the problems with waste system analyses are due to the inaccuracy of waste data rather than problems with the indicators themselves. Indicators in higher tiers are more complex, although they still rely on inputs from tier one. As a result, the validity of each indicator is only as accurate as the information from tier one because the issues associated with lower tiers carry though to those above them. In addition to data issues, each tier generates other unique concerns, which are described in this Appendix. Ultimately, the higher tiers (which are more computationally complex) have more sources of error, inaccuracy, and uncertainty.

By being aware of waste indicator imperfections, waste analysts can make use of the indicators to assess waste systems, but they can do so in a sophisticated and informed manner.

Highlighting the issues associated with each indicator also may encourage waste managers and academics to improve waste data and indicators so that future assessments may be more accurate.

**Tier One:** Tons Recycled, Tons Disposed, Tons Diverted

The data used to calculate tier one indicators are often imperfect, inconsistent, and may not reflect all wastes which are generated within a municipality. Although efforts were made to make data consistent between municipalities in this study, there were still some inherent, unavoidable problems with MSW data (Chowdury, 2009; Kaufman, 2008; Vergara, 2011), primarily involving the lack of complete data. Dahlen et al. (2009) has identified over ten sources of error in official waste statistics, including incorrect measurements at weighbridges and gaps due to waste not collected in the normal waste management systems (e.g. home composting, illegal dumping). Despite these issues, the data provided by municipal sources and state records is believed to be the best available and sufficient for the analysis.

Another important issue with waste data is that there is no consistency regarding the sectors included in waste data (residential, commercial, and institutional). As a result, the tier one indicators may reflect various waste sectors. For example, the Town of Smithtown's waste indicators include only residential wastes, while Tompkins County includes residential, commercial and institutional.

Lastly, the data used to calculate the tons recycled indicator may be uncertain because municipalities may count recycling in different ways. Some municipalities will count collected materials, while others count only those materials sent to market (Tonjes and Swanson, 2000).

**Tier Two:** Recycling Rate, Curbside Recycling Rate, Diversion Rate, Landfilling Rate

The tier two indicators generally have the same issues as the tier one indicators. However, by introducing an arithmetic calculation, there is a greater chance that computational errors may be made. The uncertainty of the indicator is based on the addition of the uncertainties from each input (Mendes et al., 2011), and therefore, there is a greater chance of having an uncertain indicator if it has more (potentially uncertain) inputs.

**Tier Three:** Recycling Per Capita, Landfilling Per Capita, Diversion Per Capita

Tier three indicators include data based on population, and by including population statistics, more error is introduced into the indicator. Firstly, as was noted for tier one, some municipalities will include various sectors (residential, industrial, commercial) in their waste data, while others do not. If rates are calculated based on population in a given municipality, indicators will be inflated or deflated based on if the waste data include materials from other sectors. Secondly, population data may not actually reflect the amount of people living in a municipality at certain times. For example, some communities have large summer increases in population that are not reflected in census reports. These summer visitors generate waste which is counted in the municipal data, but they are not included in the population statistics.

**Tier Four:** Energy Savings, GHG Emission Reductions

In addition to all the sources of inaccuracy in tiers one through three, tier four indicators lead to even more challenges, especially with regards to modeling assumptions. Differences in system boundaries and the strong dependence on model assumptions have led to considerable variation in model outputs. Therefore, alternative outcomes will be reached when different life cycle analysis (LCA) models are used, and different outcomes may also be achieved even if the same LCA model is used due to varying decisions made by modelers. Finally, most LCAs of waste systems are extremely complex, time and resource intensive, oftentimes subjective, and difficult to handle by non-experts (Blengini et al., 2012).

## Appendix B. Data Input Descriptions

Included in Analyses:

MSW, corrugated cardboard, mixed paper, newspaper, paperboard/boxboard,  office paper, books, junk mail, PET, HDPE, plastic film/bags, mixed plastics, glass containers, tin/aluminum containers, aluminum foil/trays, gable tops, commingled containers, commingled recyclables, bulk metal, scrap metal, incinerator metals, metals reported by automobile dismantlers/junkyards/scrap metal processing, enameled appliances/white goods, leaves and grass, brush/branches/trees/stumps, food scraps, cars, tires, computers/e-waste

Excluded from Analyses:

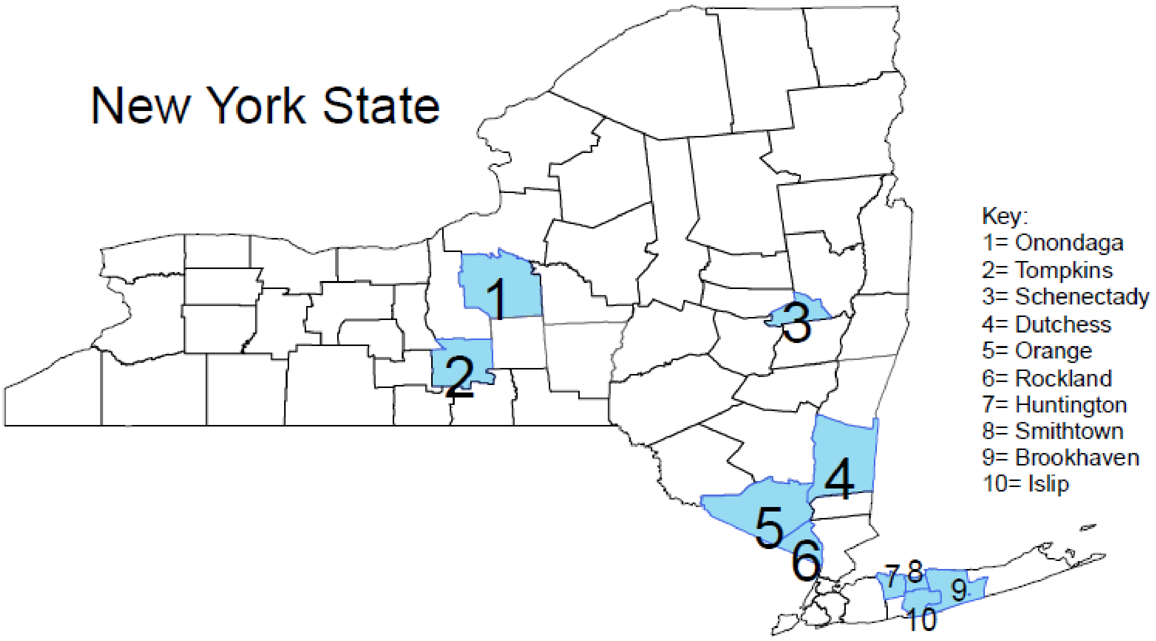
Biosolids, C&D Debris, industrial wastes , food processing waste, renderings, cooking oil, masonry materials, batteries, used oil, antifreeze, oil filters, concrete, asphalt/pavement, drywall, textiles, light bulbs, wood pallets, wood, street sweepings, contaminated soil, industrial scrap metal, industrial hazardous wastes, industrial scrap glass, industrial scrap plastic, rock, land clearing debris, manure

## Appendix C. Municipal Rankings Using Each Indicator

Table C.1 Municipal Rankings

| **Municipality** | **Tons Recycled** | **Tons Landfilled** | **Tons Diverted** | **Diversion Rate** | **Recycling Rate** | **Curbside Recycling Rate** | **Landfilling Rate** | **Recycling Per Capita** | **Landfilling Per Capita** | **Diversion Per Capita** | **GHG Reductions** | **Energy Savings** | **Range** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Brookhaven | 6 | 3.5 | 4 | 4 | 5 | 6 | 3.5 | 7 | 3.5 | 6 | 6 | 7 | 3.5-7 |
| Dutchess | 5 | 3.5 | 7 | 6 | 4 | 2 | 3.5 | 5 | 3.5 | 7 | 8 | 1 | 1-8 |
| Huntington | 8 | 3.5 | 8 | 8 | 6 | 5 | 3.5 | 6 | 3.5 | 9 | 3 | 5 | 3-9 |
| Islip | 7 | 3.5 | 6 | 5 | 9 | 10 | 3.5 | 10 | 3.5 | 8 | 4 | 6 | 3.5-10 |
| Onondaga | 1 | 3.5 | 1 | 2 | 2 | 1 | 3.5 | 1 | 3.5 | 1 | 1 | 3 | 1-3.5 |
| Orange | 2 | 9 | 2 | 7 | 3 | 8 | 9 | 3 | 9 | 4 | 7 | 4 | 2-9 |
| Rockland | 4 | 10 | 3 | 9 | 7 | 4 | 10 | 4 | 10 | 3 | 10 | 9 | 3-10 |
| Schenectady | 9 | 8 | 10 | 10 | 10 | 9 | 8 | 8 | 8 | 10 | 9 | 10 | 8-10 |
| Smithtown | 10 | 3.5 | 9 | 3 | 8 | 7 | 3.5 | 9 | 3.5 | 5 | 5 | 8 | 3-10 |
| Tompkins | 3 | 7 | 5 | 1 | 1 | 3 | 7 | 2 | 7 | 2 | 2 | 2 | 1-7 |

**Map 1. Map of Cases**



Map 1 shows the locations of the municipalities in New York that were analyzed.