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MEASURING WASTE DIVERSION PROGRAMS USING THE MISSED OPPORTUNITY RATE

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ABSTRACT

Waste management programs rely on diversion rates to understand the success of waste diversion programs. There are several problems with relying on diversion rates alone: (1) they can be misleading, such as when a waste reduction program is implemented; (2) the definition of diversion may vary in what may be considered diverted, such as diversion to waste-to-energy plants; and most importantly (3) diversion rates do not take into account whether materials they describe are actually diverted from landfill. Given these drawbacks to the diversion rate, it is a problem in the zero waste industry that there has been little to no innovation since the diversion rate became the de facto descriptor for a waste program's success. We propose a novel additional waste metric, the Missed Opportunity Rate, to evaluate total recycling and diversion program efficiency. The metric can be applied to programs that have access to the following additional data points: the amount of recyclables in the trash stream, amount of trash in the recycling stream, and amount of contaminated recyclables in the recycling stream. We compare missed opportunity rates to diversion rate measurements in four scenarios, including scenarios with high and low amounts of divertible waste. This new metric better accounts for the reality of recycling in programs and materials, including contaminated materials and missed opportunities, and thus provides better insight and guidance to program managers for programs performance, than the diversion rate alone.

Keywords: waste metric, diversion, missed opportunity, recycling, zero waste, contamination.

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1. Introduction:

The problem with Recycling Metrics

The standard metric to measure the effectiveness of a recycling program is the Diversion Rate. Diversion Rate for a particular enterprise estimates how much of their waste is sent out to recycling or other preferred disposal, as a percentage of total waste generated. It is intended to provide an estimate of the enterprise's sustainability performance in waste. However, Diversion Rate alone does not take into account the effectiveness of the recycling effort (Cavalletti, 2018; Pan, 2019; Zaman, 2014). Diversion Rate does not indicate how much of the materials separated for recycling are actually recycled (some is landfilled at the recycling facility) or how much materials sent to landfill ought to have been recycled (recyclables that are in the landfill waste stream).

Source separation recycling programs are far from perfect. Materials that ought to have been recycled are often found in the trash stream (EPA, 2022) and vice versa. One study found that at sites with source-separated recycling programs, twenty percent or more of the waste placed in the trash stream consisted of recyclable materials. An additional 25% or more could be diverted through an organics program (Dengler, 2022). Moreover, trash is often found contaminating recycling waste streams, causing efficiency, cost, and safety problems at sorting facilities (Andrews, 2013; Marshall, 2017). Contamination includes materials that do not belong in the recycling or composting category, i.e., hoses, propane tanks, and materials that belong in the recycling or composting category but are not prepared the right way, like food left in a recyclable container (Marshall, 2017). Twenty-five percent or more of recyclables need to be dumped as trash when reviewed at transfer stations or recycling sorting centers due to this contamination (Albeck-Ripka, 2018). These are all losses to the recycling effort and reductions in performance toward sustainability that are not captured in the standard diversion rate metrics.

Most waste streams will include materials that cannot be easily diverted via available recycling and composting programs (Andrews 2013; Dengler 2022). Composite materials, for instance, that could, in theory, be broken down into recyclable parts are not accepted in most recycling markets (Albeck-Ripka, 2018; Yang, 2012). In addition, many types of plastics are not accepted in commercial recycling programs (Evode, 2021). Diversion Rate does not differentiate between these and recyclable materials that could be diverted and captured.

This set of problems leads us to consider a novel additional metric to be measured and reported alongside the Diversion Rate – the Missed Opportunity Rate. This new metric describes the percent of the material in the waste that could have been diverted, along with the amount of contaminated recyclables that are not diverted. Identifying how much material is not recycled or composted but has the potential to be diverted is key to understanding the efficiency of the recycling program or any waste diversion program. Understanding this metric, alongside the diversion ratio, enables programs managers to determine how well recycling programs are functioning with respect to contamination levels within waste streams.

In this paper we define Missed Opportunity Rate, describe how it is used in waste stream analysis and compare it to diversion ratio alone, and with other waste metrics. We then analyze how Missed Opportunity Rate would fit into a sample waste management program, test it in four fictional scenarios that embody different types of waste materials and varied levels of program success, and discuss the results. We provide further discussion on how Missed Opportunity Rate fits into the broad discussion of waste stream analysis alone and in complement to other metrics. Waste diversion or recycling programs refer to various methods of managing waste in a city, a company, a campus, or a single facility. To simplify the concepts named herein, we have opted to reference single facilities in our examples, as needed.

3.0 The Missed Opportunity Rate

Depending on the program implemented, the Missed Opportunity Rate could refer to recyclable materials alone or both recyclable and organic materials, as the following formulas show, developed by the authors:

Recycling alone:

$$Missed\ Opportunity\ Ratio\ \%\ (MOR) = \frac{T_r + R_{sr}}{T_r + R_r + R_{sr}}$$

Or with organics included

$$Missed\ Opportunity\ Ratio\ \%\ (MOR) = \frac{T_r + T_o + R_{sr} + R_o}{T_r + T_o + R_r + R_{sr} + R_o}$$

T= Trash Stream
R= Recycling stream
r= Recyclable material
t= Trash material
o= organic material
s= Soiled
T_r = Recyclables in Trash Stream
T_o = Organics in Trash Stream
R_{sr} = Soiled Recyclables in Recycling Stream
R_o = Organics in Recycling Stream
R_r = Clean Recyclable material in Recycling Stream
O_o = Organics in the Organics Stream

Eq. 1 – Missed Opportunity Rate equations, without organics and with organics diversion available.

In a waste management program, where organic waste is diverted for composting or aerobic digestion, the materials Recyclables in Trash Stream and Organics in Recycling Stream have the potential to be diverted. We made Organics in Recycling Stream a contaminant in the Recycling Stream separate from Soiled Recyclables since organic matter often soils an otherwise recyclable container. If organic material is left in a plastic container, for example, the organic material is a missed opportunity separate from the plastic container. The plastic without excess organic waste is then categorized as soiled plastic in the recycling stream. Both are considered contamination and included in the numerator of the Missed Opportunity Rate as missed opportunities.

All materials considered relevant to Missed Opportunity Rate are those that either have been diverted or could have been with existing programs.

Waste in the Trash Stream is excluded, except for divertible materials, as shown in Figure 1, where we have provided an example waste stream that has a little more than half being considered non-recyclable waste by weight and the rest considered divertible waste.

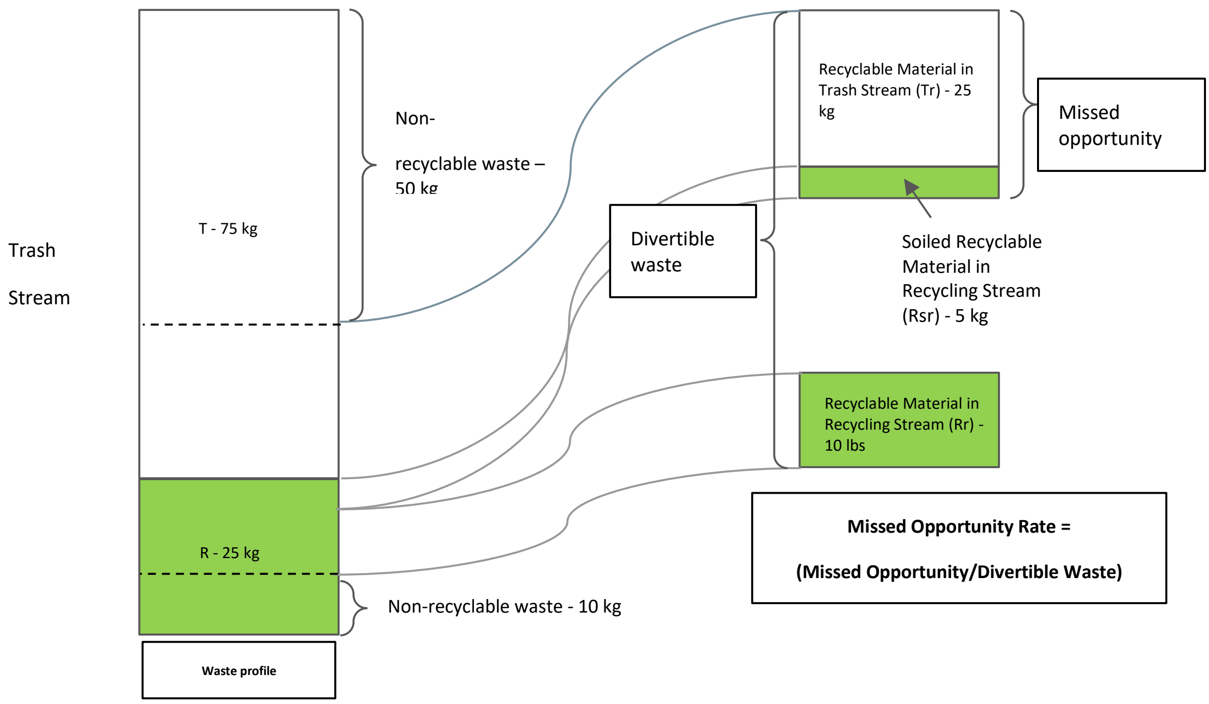


Figure 1 - A fictional example Waste Profile broken down into the components for the Missed Opportunity Rate. This example profile does not have an organics diversion program. Organic materials are included in the non-recyclable waste portion.

Based on the sample weights presented, Figure 1 shows Missed Opportunity Rate to be (5 kg+25 kg)/(10 kg+5 kg+25 kg) = 75%. Missed Opportunity Rate provides a true reflection of the program's efficiency by focusing on the materials that have a potential for diversion under available programs, such as recycling and organics recycling. The remaining waste materials excluded from Missed Opportunity Rate must be addressed through other programs aimed at waste reduction. If a waste diversion method is identified for the remaining materials, that material can be included in Missed Opportunity Rate.

The rest of this paper first discusses Missed Opportunity Rate compared to other waste metrics in Section 3 and then describes our implementation in Section 4. Section 3 describes how we evaluated our system and presents the results. Section 6 presents our conclusions and describes future work.

4.0 Comparison to Other Waste Metrics

The most important core data for quantifying waste programs are total amounts of waste and total amounts per waste stream (i.e., recycling stream, compost stream, etc.) Tracking needs to be done regularly to provide insight into waste diversion and reduction over time.

It is worth noting natural limitations in data collection. Amounts may vary naturally without meaningful changes to the waste program. Changes in building occupancy, such as a tenant move-out, or a new restaurant, can substantially change waste profiles in a commercial multi-tenant property, for example. In addition, total amounts make it difficult to compare facilities that vary in size or operations or to gauge the efficiency of a waste program. Metrics like Diversion Rate and Missed Opportunity Rate can help fill in the gaps.

A standard formula for Diversion Rate divides the total amount of diverted material (by recycling, composting, and other methods of repurposing waste) by the total amount of waste. Using this formula, Diversion Rate for Figure 2 is 25%. Incidentally, the inverse of Diversion Rate in this scenario, 75%, matches Missed

Opportunity Rate. However, in further examples, they will diverge.

$$Diversion\ Generation\ =\ (Reduce\ +\ Reuse\ +\ Compost\ +\ Recycle)\ \times material\ weights$$

$$Total\ Materials\ Generation = (Landfill + WTE + Incineration + Reduce + Reuse + Compost + Recycle) \times material\ weights$$

$$Diversion\ Rate\ = \frac{Diversion\ Generation}{Total\ Materials\ Generation}$$

Eq. 2 - TRUE's Diversion Rate equation (GBCI 2022)

Although the U.S. Green Building Council (USGBC) TRUE (Total Resource Use and Efficiency) zero waste rating system provides a way to include upstream programs (reduce + reuse), most waste programs only account for downstream waste diversion activities. This review just considers downstream waste information. Downstream waste programs include only waste programs that take effect once the decision to dispose of a material is made and will include activities such as waste hauler procedures, source separation, educational materials on disposal programs, and at the building level, janitorial procedures, and rightsizing bins. Upstream waste diversion activities target the source of waste. The zero waste hierarchy categorizes those under the headings rethink/redesign and reduce (ZWIA, 2022) and would include such activities as duplex printing and working with vendors to reduce packaging on frequent purchases. In the TRUE certification process, both upstream and downstream waste diversion activities are included in Diversion Rate's numerator (GBCI, 2017). Encapsulating upstream and downstream activities in a single number is ambitious but not without merit since it creates an incentive toward upstream activities that would otherwise not be reflected in Diversion Rate or could have a negative impact on the diversion rate. The problem is that it is difficult to accurately quantify and consistently implement.

TRUE Zero Waste's diversion rate definition specifies that neither landfill nor WTE are part of the numerator (GBCI, 2017). However, in zero waste-to-landfill initiatives, waste-to-incineration is included in the Diversion Rate numerator. In this scenario, diversion is anything outside of sending waste to the landfill, so that waste-to-energy/incineration (WTE) is considered an environmental benefit (Lausselet, 2016), and thus part of the numerator in the diversion rate. USGBC's green building certification, LEED (Leadership in Energy and Environmental Design), allows construction projects to claim diversion through waste-to-energy systems if reuse and recycling methods are not readily available in the project's location, and a team can demonstrate they exhausted these strategies before sending waste material to energy facilities (USGBC, 2013). WTE is controversial; although incineration replaces fossil fuel-generated energy, there are still environmental problems (Kalogirou, 2010; Tang, 2018) that result from incineration plants, as well as health impacts on surrounding communities, disproportionately impacting communities of people of color (New School, 2019). Negative impacts on social justice and equity alone would preclude incineration from Environmental, Social and Governance (ESG) reporting. Excluding both landfill and incineration from the diverted materials categories reflects a more robust environmental stewardship initiative and social impact.

Additionally, Diversion Rate can sometimes be confused with the Recycling Rate, which refers to the amount "actually recycled by a processor versus the amount of materials that consumers made available for collection" (GBCI, 2022). In Figure 2, that would be R_r (10 kg) divided by the total waste (100 kg), or 10%. There is an added limitation in both the Recycling Rate and Diversion Rate that they provide limited, if any, insight about the material that is not diverted or recycled. The remaining material may not be able to be diverted with diversion options available in the region. In this case, a facility would be reasonably efficient at waste diversion, regardless of the diversion rate. Likewise, facilities in separate regions may have a similar diversion rate, where one is diverting all possible materials and another with more diversion options not diverting enough.

Great Forest's waste audit reports also provide an additional metric, the "potential diversion rate (Potential Diversion Rate)." Potential Diversion Rate acknowledges how much the facility could divert if all practically divertible materials were diverted through available recycling and organics programs. Potential Diversion Rate is the level considered practical and achievable (based on other enterprise results in the market) and thus has some room for manipulation.

$$PDR = \frac{Total\ waste\ potentially\ diverted\ from\ landfill\ and/or\ incineration}{Total\ waste\ produced}$$

Eq. 3 – Potential Diversion Rate equation

Potential Diversion Rate is useful to compare against the calculated Diversion Rate and speaks to the kinds of material not diverted. The Potential Diversion Rate is the amount of material that could be diverted divided by the total material. This answers the question: if the facility utilized existing programs better, how high could their Diversion Rate be? It does not speak directly to how much of the facility's recyclable material is not being captured but could be. This can be resolved by comparing the Potential Diversion Rate to the current Diversion Rate. While not contained in a single metric, Potential Diversion Rate can be better defined by more substantive measurements to enable an accurate description of Missed Opportunity Rate. As Missed Opportunity Rate decreases, Diversion Rate increases and the more aligned the Potential Diversion Rate and Diversion Rate become.

5.0 Implementation: How Missed Opportunity Rate Fits into Waste Stream Analysis

As noted, Diversion Rate does not reflect what is diverted out of divertible material. Similarly the Recycling Rate, which excludes Recycling Stream contamination from the numerator in the Diversion Rate formula, does not address the material not being diverted. If Diversion Rate or Recycling Rate shows 25% was diverted, that does not mean that the remaining 75% is divertible through available programs. Pie charts in Figures 2 and 3 show how much information from a waste stream analysis is ignored using Diversion Rate and Recycling Rate.

In a traditional waste stream breakdown, calculating the Diversion Rate requires the following stream designations: Trash, Recycling and Organics. Not much is known about the Trash stream or the quality of the recyclables in the Recycling stream collected. The Recycling Rate is helpful in accounting for contamination in the Recycling stream: soiled recyclables (Rsr) and organic materials (Ro) (Fig. 2).

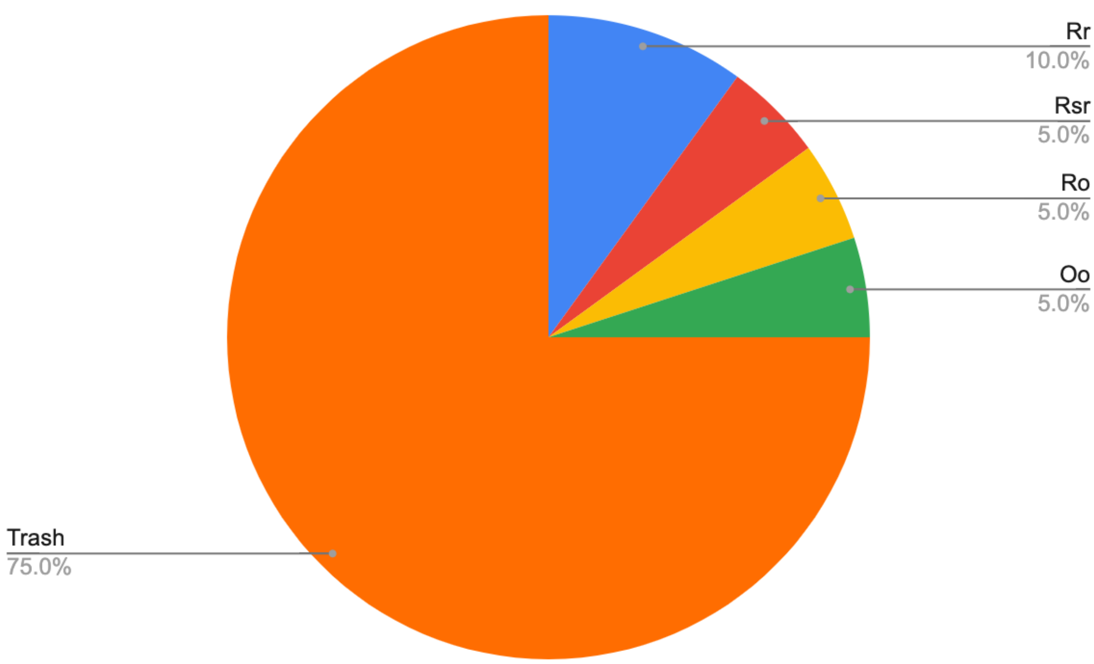


Figure 2 - Contamination in the Recycling stream (soiled recyclables (Rsr) and organics (Ro)), which is needed to calculate the Recycling Rate.

However, the Trash Stream is a mystery in both metrics, Diversion Rate and Recycling Rate. In Fig. 2, we calculate that Diversion Rate is 25%, while the Recycling Rate is 15% with contamination removed (5% Soiled Recyclables (Rsr) and 5% Organics in Recycling Stream (Ro)).

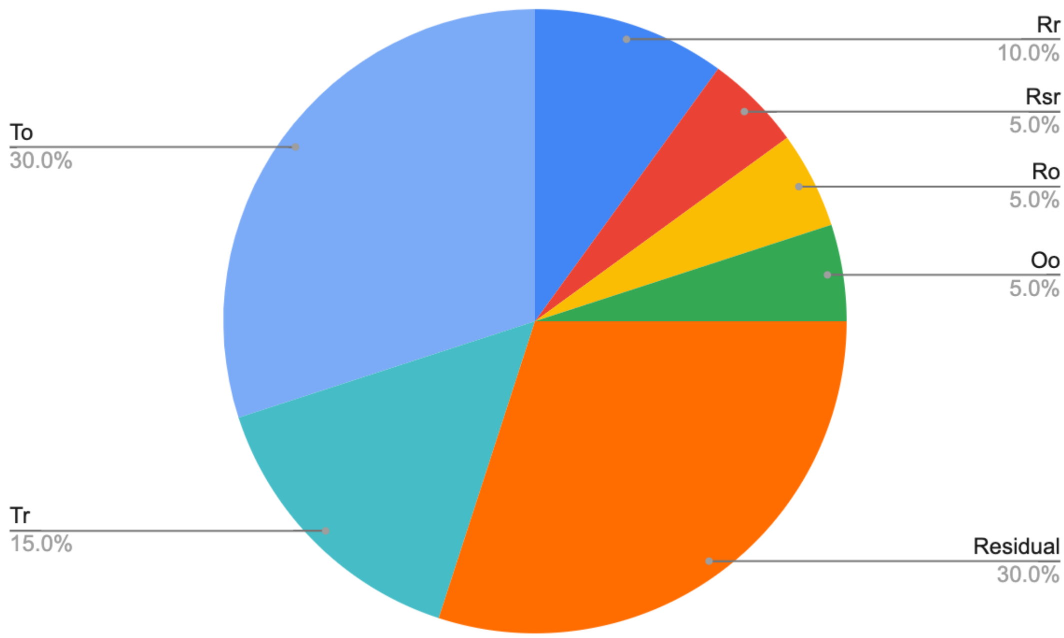


Figure 3 - Clean Recyclable material in Recycling Stream (Rr), Soiled Recyclables in Recycling Stream (Rsr), Organics in Recycling Stream (Ro), Organics in the Organics Stream (Oo), Recyclables in Trash Stream (Tr), and Organics in Trash Stream (trash in Recycling Stream). "Residual" has been provided as the identifier for the remaining material in the Trash Stream.

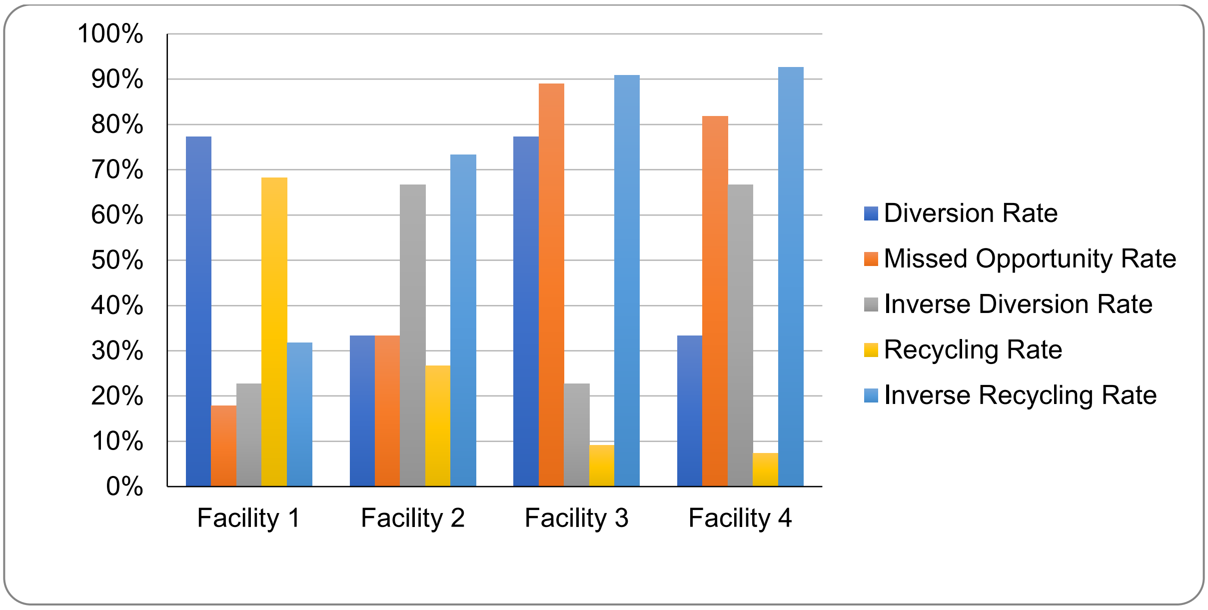
Figure 3 provides details for material in the trash stream (Organics and Recyclables in Trash Stream and Residual). This pie chart accurately represents the breakdown of the trash portion of a typical enterprise's waste stream (Dengler, 2022). If the materials under Residual could be diverted, the Missed Opportunity Rate in this example would be 85%, matching the percent not diverted (the inverse of the Recycling Rate). However, to calculate the Missed Opportunity Rate, the non-divertible materials are removed from the total in order to perform the Missed Opportunity Rate calculation; in this case it is 78% (Rr+Oo)/(Rsr+Ro+To+Tr).

The following case study reviews four fictional facilities that each exemplify a different level of effectiveness in waste programs. All facilities in this comparison are shown to have the same amount of overall waste and similar amounts of recycling in the Trash (Tr). The differences are (1) Facilities 3 and 4 have a high amount of contamination in the recycling stream, while Facilities 1 and 2 have low contamination, (2) Facilities 2 and 4 have a greater amount of waste in the Trash stream, while Facilities 1 and 3 have an overall lower amount of waste in the Trash stream. The effectiveness of each program is described in a variety of ways. Figure 4 and Table 1 show how these metrics compare in each scenario.

In our review, Facility 1 has low contamination in the recycling stream and more divertible material overall than the trash stream. This type of facility could represent something like a manufacturing facility that has consistent control over the materials purchased and materials discarded. Facility 2 also has a low amount of contamination in the recycling stream, but the weight of the trash stream is over 100 units higher than the recycling stream. This could represent a facility managed and occupied by a single entity that has consistent control of purchased materials but the majority of materials discarded are not divertible with available recycling outlets. Facility 3 provides a very different scenario where the recycling stream is much higher than the trash stream, which could represent a facility with multiple tenants using a mixed recycling compactor. The recycling compactor gets a high amount of use, hence the high weights, but most of the material going into the compactor is not recyclable. The last facility, 4, has a similar Trash Stream profile as Facility 2, but the Recycling Stream profile mirrors that of Facility 3, although it has a less dramatic amount of contamination. This could represent a similar set up as Facility 3, with a similar waste stream profile overall but where more trash is being directed to the Trash Stream than the Recycling Stream.

Table 1 Material weight in each site by waste stream: trash, recycling.

		Facility 1	Facility 2	Facility 3	Facility 4
Trash	Tt	75	264	75	261
Stream	Tr	25	29	25	33
Recycling Stream	Rr	300	117	40	33
	Rsr	40	29	300	114
Total		**440**	**440**	**440**	**440**



	Facility 1	Facility 2	Facility 3	Facility 4
Diversion Rate	77.27%	33.33%	77.27%	33.33%
Missed Opportunity Rate	17.81%	33.33%	89.04%	81.82%
Inverse Diversion Rate	22.73%	66.67%	22.73%	66.67%
Recycling Rate	68.18%	26.67%	9.09%	7.41%
Inverse Recycling Rate	31.82%	73.33%	90.91%	92.59%

Figure 4 Waste metrics by site compared.

Each site in Fig. 4 is an example of a different scenario where a high Diversion Rate, Facilities 1 and 3, do not equate to an efficient recycling program. Similarly, a low Diversion Rate does not equate to an inefficient recycling program. Instead, Missed Opportunity Rate provides the greatest insight into efficiency.

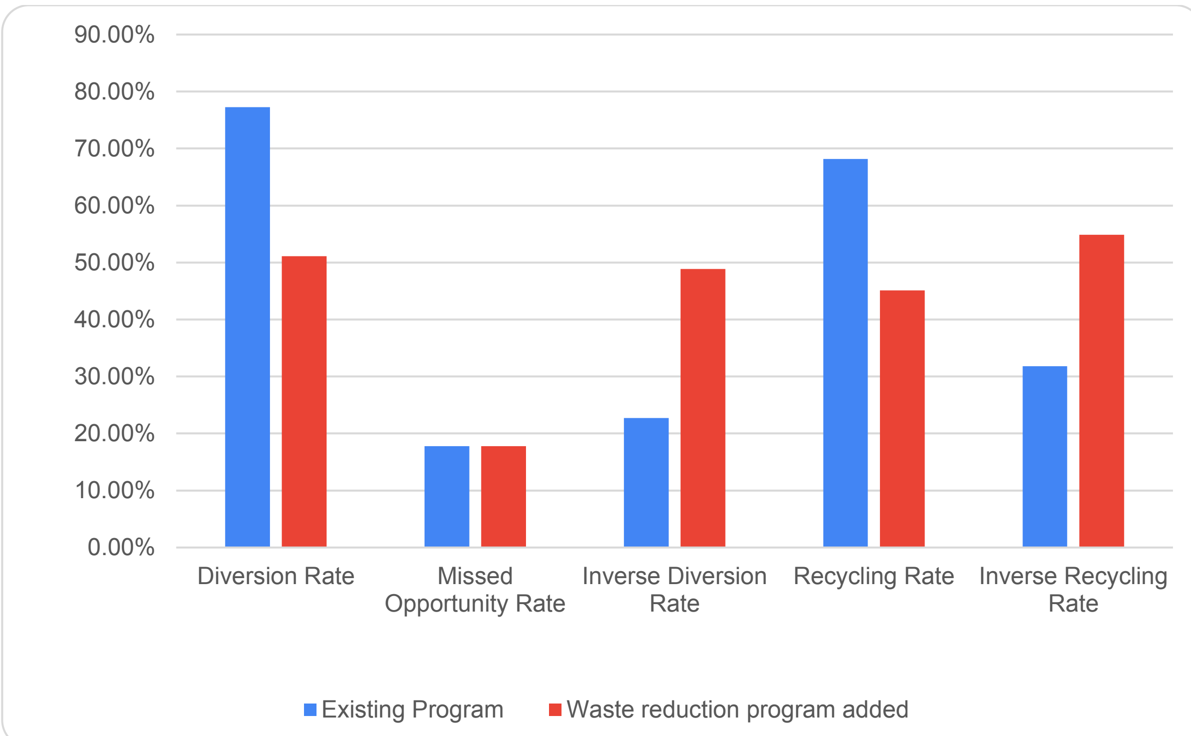
For comparison, the waste metrics include Diversion Rate, Missed Opportunity Rate, Inverse Diversion Rate, Recycling Rate, and Inverse Recycling Rate. The Inverse of the Recycling Rate is the percentage of all waste not recycled, which includes contamination and trash in the recycling stream. These metrics are included to show that they do not show the same information provided in Missed Opportunity Rate and cannot be substituted, although at times, Missed Opportunity Rate will be similar to Inverse Diversion Rate, and in other scenarios, Missed Opportunity Rate may be similar to Inverse Recycling Rate.

Facility 1 (high Diversion Rate, low Missed Opportunity Rate) is a scenario where most of their waste is recyclable (Rr=300, Rsr=40, Tr=25), and they are diverting more material in total than the other facilities and likewise has a high Diversion Rate of 77.3%. As a high Diversion Rate usually signifies success in a waste program, this example facility would be considered a success, looking at the Diversion Rate alone. When the Missed Opportunity Rate is considered, 17.8%, and a low Missed Opportunity Rate indicates a successful program, the Missed Opportunity Rate and Diversion Rate in this instance are in agreement. In the Facility 4 example, the low Diversion Rate and high Missed Opportunity Rate are also in agreement, showing a poor performance of the diversion program.

Facility 2 is an example of an entity with upstream programs in place that have reduced the amount of waste across all material types, resulting in a low amount of recyclables (Rr=117, Rsr=29, Tr=29). Under this scenario, the Diversion Rate and Recycling Rate (26.67-33%) penalized the facility for having a majority non-recoverable waste. However, the low Missed Opportunity Rate (33%) reflects the program's efficiency, where a high amount of divertible materials were diverted.

Facility 3 (high Diversion Rate, high Missed Opportunity Rate) has a majority recyclables (Rr=40, Rsr=300, Tr=29), but they are mostly soiled and nonrecoverable. Compared to Facility 1, they have the same Diversion Rate, but the Missed Opportunity Rate is high, reflecting poor downstream programs like source separation.

Taking this a step further, we reviewed what would happen to Facility 1's metrics after a waste reduction initiative of recyclable materials is implemented. Figure 5 shows a 75% reduction in recycling uniformly distributed across Recyclables in Trash Stream, Recyclables in Recycling Stream, and Soiled Recyclables.



		Existing Program	Waste reduction program added
Trash Stream	Tt	75	75
	Tr	25	6
Recycling Stream	Rr	300	75
	Rsr	40	10
Total		440	166

Figure 5 Facility 1's existing program versus the same program with waste reduction.

	Existing Program	Waste reduction program added
Diversion Rate	77.27%	51.13%
Missed Opportunity Rate	17.81%	17.81%
Inverse Diversion Rate	22.73%	48.87%
Recycling Rate	68.18%	45.11%
Inverse Recycling Rate	31.82%	54.89%

Table 2 Comparison of rates resulting from Facility 1's existing program versus the same program with waste reduction.

The reduction program does not negatively impact Missed Opportunity Rate, as it does Diversion Rate and Recycling Rate. Missed Opportunity Rate cannot alone indicate the impact of a waste reduction program. However, when a facility's waste totals show a reduction in combination with a low Missed Opportunity Rate, this shows a waste reduction due to improved material management efficiencies.

Missed Opportunity Rate provides a more accurate understanding of how much further a facility needs to go to both divert waste and either reduce waste or redesign waste processes. Missed Opportunity Rate highlights the materials for which there is a diversion program (recycling or compost) but which were not properly disposed of; this is a gauge of how much further a program must go to capture those recyclables. Everything excluded from Missed Opportunity Rate, or "Residual," equals how much material has no applicable diversion program. Waste reduction and redesign of materials or processes are needed for those materials.

6.0 Discussion

Reduction and reuse programs are valuable but quantifying the impact on a waste program is still in the early stages of standardization within ESG statistics. The Missed Opportunity Rate methodology is valuable in better quantifying how well diversion programs are actually functioning. When reduction and reuse programs are implemented, Missed Opportunity Rate provides a better model for evaluation for the waste professional.

Availability of reuse and reduction data is inconsistent; including reduction and reuse measures into Missed Opportunity Rate, while possible, may be unnecessary when considering the additional information it provides. The assumption is that the details needed to calculate Missed Opportunity Rate require an in-depth waste stream analysis. Although many companies undertake this initiative, a comprehensive waste audit capturing the materials within each waste stream can burden facilities. More accessible are hauler data and a right-sizing exercise, but these do not provide sufficient information to generate Missed Opportunity Rate. Data may simply not be available for this level of analysis.

In general, Missed Opportunity Rate focuses on the problematic areas of waste rather than a feel-good measure of the waste being diverted, to which reduction and reuse measures apply. It is a measure that will help the waste professional determine how well their educational programs are performing, as it tracks contamination levels in waste streams. This provides insight and guidance necessary for decision makers of organizations and could also be applied on a larger scale to municipalities. The strength in the Missed Opportunity Rate is that it captures a picture of the waste stream that is not often communicated, and highlights the work needed to be done. But its nuances are such that it may not be a useful public-facing indicator as it is currently designed. The formula that makes Missed Opportunity Rate different and more detailed from Diversion Rate may complicate general understanding by those outside the waste community. We must also assume that waste professionals can make use of this technique appropriately, without adding confusion to their public communications. Nevertheless, as Missed Opportunity Rate becomes more widely adopted, researchers can utilize this metric in better understanding and comparing the success of a variety of recycling and diversion programs. Missed Opportunity Rate improves our ability to make those comparisons across a variety of scenarios, where Diversion Rate falls short.

7.0 Conclusion

Specifications of the Missed Opportunity Rate and all waste metrics that attempt to quantify the success of waste management programs can be addressed through further testing and research. By focusing on the missed opportunities, we can separate the discussion of improving waste management from the discussion of expanding upstream policies. Upstream policies, such as going paperless, are often the focus of efforts to reduce waste but do not favorably impact the Diversion Ratio. Missed Opportunity Rate accurately describes performance using solely downstream information without penalizing upstream improvements. A more complete picture of a waste program is presented by adopting the Missed Opportunity Rate, in addition to the Diversion Rate. Moreover, the inclusion of a new metric in the waste management field can improve waste data accuracy by having variables specific to local diversion capabilities. Accurate, consistent, and meaningful data will be necessary to ensure waste metrics are utilized effectively in all waste management scenarios.

References

Albeck-Ripka, L. (2018) Your Recycling Gets Recycled, Right? Maybe, or Maybe Not. *New York Times*. 29 May 2018. Available online: https://www.nytimes.com/2018/05/29/climate/recycling-landfills-plastic-papers.html (accessed 28 January 2022).

Andrews, A.; Gregoire, M.; Rasmussen, H.; Witowich, G. (2013) Comparison of recycling outcomes in three types of recycling collection units. *Waste Management*, 33 (3): 530-535.

Cavalletti, B.; Corsi,M. (2018) By diversion rate alone: The inconsistency and inequity of waste management in a single-indicator system. *Regional Science, RSAI Regional Science Association International* 98(1): 307-329.

Dengler, A.; Arrigo, L.; Fuller, R. (2022) Waste Characterization Study Of Pre-Covid-19 Commercial Buildings. *Journal of Solid Waste Technology and Management* 49(2): 274-288.

EPA. (2022) National Overview: Facts and Figures on Materials, Wastes and Recycling. Available online: https://www.epa.gov/facts-and-figures-about-materials-waste-and-recycling/national-overview-facts-and-figures-materials#NationalPicture (accessed 28 January 2022).

Evode, N.; Qamar, S.A.; Bilal, M.; Barceló, D.; Iqbal, H.M.N. (2021) Plastic waste and its management strategies for environmental sustainability. *Case Studies in Chemical and Environmental Engineering*, 4:100142.

GBCI (2012) The U.S. Zero Waste Business Council. TRUE Zero Waste Rating System.

GBCI (2022) TRUE Diversion Data Additional Guidance Version 1.1.

Kalogirou, E.N.; Themelis, N.; Samaras, P.L.; Karagiannidis, A. (2010) Fly Ash Characteristics From Waste-to-Energy Facilities and Processes For Ash Stabilization. *Environmental Science*.

Lausselet, C.; Cherubini, F.; del Alamo Serrano, G.; Beciden, M.; Strømman, A.H. (2016) Life-cycle assessment of a Waste-to-Energy plant in central Norway: Current situation and effects of changes in waste fraction composition. *Waste Management* 58:191-201.

Marshall, C.; Bandhauer, K. (2017) The heavy toll of contamination. *Recycling Today*. Available online: https://www.recyclingtoday.com/article/the-heavy-toll-of-contamination/ (accessed 28 January 2022).

Pan, C.; Bolingbroke, D.; Ng, K.T.W.; Richter, A.; Vu, H.L. (2019) The use of waste diversion indices on the analysis of Canadian waste management models. *Journal of Material Cycles and Waste Management* 21: 478-487.

Tang, Y., You, F. (2018) Multicriteria Environmental and Economic Analysis of Municipal Solid Waste Incineration Power Plant with Carbon Capture and Separation from the Life-Cycle Perspective. *ACS Sustainable Chemistry & Engineering* 6(1): 937–956. (https://doi.org/10.1021/acssuschemeng.7b03283).

The New School Tishman Environment and Design Center (2019). *U.S. Municipal Solid Waste Incinerators: An Industry in Decline*. Available online: https://static1.squarespace.com/static/5d14dab43967cc000179f3d2/t/5d5c4bea0d59ad00012d220e/1566329840732/CR_GaiaReportFinal_05.21.pdf (accessed 28 January 2022).

U.S. Green Building Council (2013) LEED Reference Guide for Building Design and Construction, 2013 Edition. pp 590.

Yang, Y.; Boom, R.; Irion, B.; van Heerden, D.J.; Kuiper, P.; de Wit, H. (2012) Recycling of composite materials. *Chemical Engineering and Processing: Process Intensification*, 51: 53-68.

Zaman, A.U. (2014) Measuring waste management performance using the 'Zero Waste Index': the case of Adelaide Australia. *Journal of Cleaner Production* 66: 407-419.

Zero Waste International Alliance (2022) Zero Waste Hierarchy of Highest and Best Use 8.0. Available online: https://zwia.org/zwh/ (accessed 9 November 2022)