Using a waste audit and a knowledge assessment survey to investigate plateauing MSW recycling rates in Australia

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Abstract It has been widely acknowledged that MSW recycling rates are beginning to plateau below their full potential [1] [2] [3]. This study investigated a local government area in Australia experiencing plateauing MSW recycling rates, to understand how waste system recovery capabilities and separation behaviour determine recycling plateau level. Data was collected from a waste audit and a household survey. Materials and products assessed in the waste audit and household survey were divided into a variety of categories; ease of identification (easy, moderate, hard), material type (glass, plastic), and waste type (recyclable, general waste). The recycling full potential was determined by the capability of the waste system to recover materials, and the gap below full potential was governed by the separating ability of the populace. It was found that approximately 75 percent of dry recyclables were being captured by the MSW system. The 25 percent of recyclables lost was due to misidentification of recyclables as general waste. This was more likely to occur for materials classed as moderate or hard to identify. It was apparent that some materials caused greater confusion than others.

Keywords: recycling, plateau, waste audit, survey

1. Introduction

Municipal Solid Waste (MSW) recycling rates have been showing signs of plateau below full potential in developed countries. National data for the US indicates MSW recycling rates are stagnating around 26% recovery of dry recyclables in 2012 (Figure 1) [2]. Dry recyclables refer to manufactured products such as plastics, paper, metals, paperboard and glass. MSW recycling rates in the UK were showing similar trends in 2014, plateauing at around 27% (Figure 1) [1]. Waste audits in the US, UK and Australia indicate that dry recyclables are usually 32 to 36% of the waste stream, meaning that approximately 25% of recyclables are unrecovered [4] [5] [6] [7] [8].

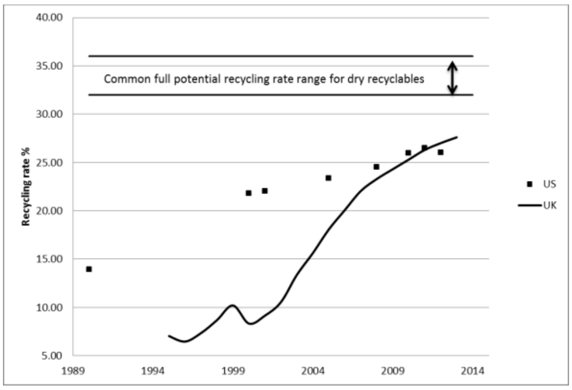

Figure 1. US and UK recycling rates of dry recyclables [1] [2]

Although national MSW recycling data is not available for Australia, there is evidence that similar plateauing trends are occurring. Australian local government areas have reported plateauing recycling rates in multiple states [9] [10]. Inside Waste, Australia's national waste periodical, has stated that MSW recycling rates showed improvement in the 20th century but are now plateauing [11]. As Australia, the US and UK use similar MSW disposal systems it is to be expected they are experiencing similar recycling dynamics.

MSW is governed at the Local Government level in Australia. As part of the waste disposal service it is standard for each household to receive a general waste and a comingled recycling bin [12]. In recent years, a garden waste bin has also been provided. Kerbside bins are collected on a weekly or fortnightly cycle [12]. Comingled recycling bins commonly accept paper, paperboard, aluminium, steel cans, some plastics, and some glass [13]. Australian home owners are charged an annual waste service fee by their local council [14]. The onus is upon Australian households to separate their waste correctly.

To optimize the sorting process, education campaigns are organized by local governments. Education materials, providing broad disposal rules, are found on kerbside bin stickers and collection calendars. The collection calendars are mailed to households annually [12]. There are infrequent campaigns on television, internet or radio that provide additional disposal information [15].

The goal of this paper is to use a waste audit and household survey assessing disposal knowledge to investigate causes for recycling plateaus below full potential. Certainty scales are used alongside knowledge assessment to gain additional insights into disposal behaviour. A material or category in need of further clarification will be identified by possessing low levels of knowledge and certainty, and being a significant proportion of the waste flow.

2. Methods

a. Local Government Region Case study

An Australian local government region experiencing recycling plateaus below full potential was used as a case study. Case study households were provided three kerbside bins for waste disposal; a 240L recycling bin, a 120L general waste bin and a 240L garden waste bin. The general waste bin was collected weekly, while the recycling and garden waste bins were collected fortnightly. Garden waste was excluded from the scope of this study and was omitted when calculating recycling rates.

Kerbside recycling was introduced to the case study region in July 2003. The case study region was sub-divided into 10 collection zones. The household disposal rules for the case study region can be seen in Table 1.

Table 1. Disposal guide for case study region

Recycling	*General waste*
Rigid plastics containers	*Plastic bags*
Steel cans	*Crockery*
Aluminium cans, trays and foil	*Disposable nappies*
Paper and paperboard	*Windows/drinking glasses*
Glass bottles and jars	*Food items*
	Light globes
	Bubble wrap
	Clothing
	Polystyrene

b. Waste audit

A MSW audit was carried out over a two-week period in October 2015. The waste audit goal was to assess the composition of each collection zone in the region. Collection zones were named using day of collection and letters A or B (e.g. Monday A, Friday B). Waste samples were collected each week day over the two-week period, with 50 households randomly selected each day. Bin collection took place approximately 1 hour before the usual pick up time. Households were unaware of auditing, although an information pack was available if collection drivers were questioned. Random selection of households considered the proportion of separate and multi-unit dwellings in the collection zone region. The collection vehicle performed two collections each morning; a collection of 50 recycling bins and a collection of 50 general waste bins from the same households. Each day approximately 1 tonne of waste was collected and audited. State government guidelines were used to direct the audit procedures and sample size [16] [17].

The auditing process was performed by a team of 6 over a 6 to 7-hour period each week day. General waste auditing was prioritized to remove decomposing organics. General waste was sorted into 19 separate categories and measured by weight using electronic scales. Recycling was sorted into 7 categories and measured by weight using electronic scales. Recycling and general waste contamination was isolated, and sorted into the previously mentioned categories. Contamination was also counted and product description data collected.

c. Survey

A household survey was distributed in September 2016 to evaluate disposal behaviour. The survey asked the responders to assess 36 items as recyclable or general waste (landfill). A certainty scale was marked after each disposal decision. An example of this structure can be seen in Figure 2. 18 of the survey items were plastic and 18 survey items were glass. Only two material types were chosen to provide opportunity to probe characteristics of material streams to sufficient depth. Plastic was chosen as there are significant proportions of both recyclable plastic and general waste plastic. Glass was selected as it is predominantly recyclable. 18 of the items were recyclable and 18 of the items were general waste. 12 items were considered easy to identify, 12 moderately difficult to identify and 12 items difficult to identify.

Figure 2. Survey structure

The combination of knowledge assessment and certainty scales has precedent. This structure has been used to analyse decisions made under uncertainty and has also been used to optimize the learning process [18] [19].

3 of the 10 collection zones in the Local Government case study region were chosen to participate in the household survey. They were representative of different recycling behaviour; high achievers, moderate achievers and low achievers. The 'recycling high achievers' had high recycling rates and low bin contamination. The 'recycling moderate achievers' had moderate recycling rates and moderate bin contamination. The 'recycling low achievers' had low recycling rates and high bin contamination. These categories were based upon the waste audit data and historical weighbridge data from the local Recycling Facility and Landfill.

The 3 collection zones consisted of 4395 dwellings. 3000 postal surveys were distributed amongst randomly selected households. 612 surveys were returned via online and paper surveys.

3. Results

a. Case study region recycling rates

Recycling rates for the Local Government region were calculated using monthly weighbridge data from the local Recycling Facility and Landfill. The recycling rate was calculated using equation 1. A 6-interval moving average was used to smooth data oscillation and can be seen in Figure 3.

$$\textbf{Recycling rate} = \frac{\textbf{Recycling}\ (\textbf{Tons})}{\textbf{Recycling}\ (\textbf{Tons})+\textbf{Landfill}(\textbf{Tons})} \quad \textbf{[1]}$$

The recycling rate history seen in Figure 3 demonstrates a plateau dynamic. At the time of the waste audit the monthly recycling rate was 27.02%, measured from recycling facility and landfill weighbridges. According to waste audit data there was a theoretical maximum recycling rate of 31.66%.

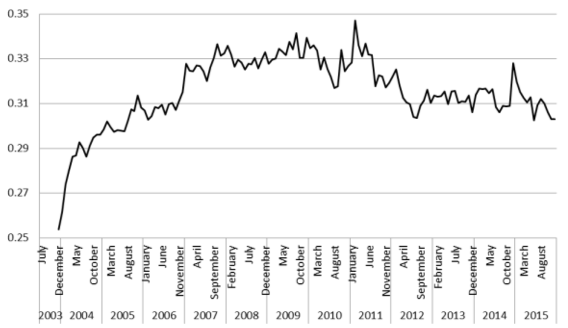

Figure 3. Case study region recycling rate history (smoothing applied: moving average 6-point interval)

b. Glass

The categories of glass considered in this study included recyclable glass (glass drink containers & food and sauce jars), mixed glass fines and other glass (plate glass, Pyrex, light globes, medical glass, opaque glass). Recyclable glass and mixed glass fines were considered recyclable while other glass was considered general waste.

The household survey indicated that the percent correct was higher for recyclable glass (M = 0.8379, SD = 0.1666) compared to general waste glass (M = 0.5495, SD = 0.3486). Survey results also indicated that responders were more certain about recyclable glass decisions (M = 3.39) than general waste glass choices (M= 3.06). Waste audit data demonstrated that recyclable glass dominated glass waste flow (0.9819) compared to general waste glass (0.0181).

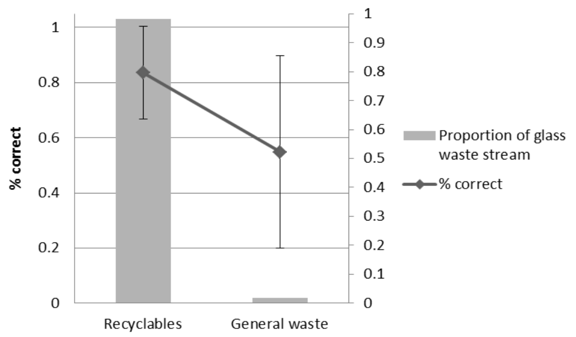

Figure 4. Glass proportions and percentage correct

Statistical analysis was performed to determine significant difference between recyclable glass and general waste glass knowledge levels. The Shapiro-Wilk test and QQ plots indicated that data was not normally distributed. As a non-parametric alternative to the independent sample t-test, the 2-sample Wilcoxon Test was applied. Results indicated that the null hypothesis of equal mean knowledge between recyclable and general waste glass could be rejected. It can be concluded that ability to classify general waste glass correctly is significantly lower than recyclable glass. However, due to the low proportion of general waste glass this likely does not have a large impact on recycling rates.

Table 2. 2-sample Wilcoxon Test of glass knowledge and certainty levels

	Recycling knowledge/ GW knowledge	Recycling certainty/ GW certainty
Wilcoxon test	265890***	226030***

Wilcoxon test. *, **, *** indicate statistical significance at the 10%, 5% and 1% level respectively.

c. Plastic

The categories of plastic included in this study encompassed recyclable plastics (codes 1-6), expanded polystyrene, other plastic (Tupperware, toys, multi-blend plastic, synthetic textiles, pots), and plastic bags and film. All categories, except recyclable plastics, were considered general waste.

The mean percent correct for recyclable plastic (M = 0.7880, SD = 0.2017) was found to be less than general waste plastic (M = 0.8105, SD = 0.2203). Disposal decisions for recyclable plastic had greater levels of certainty (M= 3.29) than plastic general waste (M = 2.99). Proportions of recyclable plastic (0.5965) were a similar magnitude to the proportion of general waste plastic (0.4035).

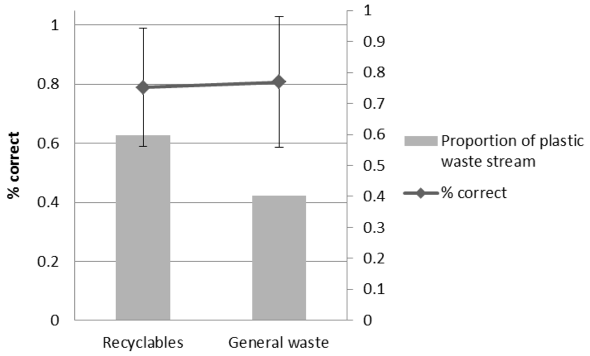

Figure 5. Plastic proportions and percentage correct

The 2-sample Wilcoxon Test indicated a significant difference between recycling plastic and general waste plastic knowledge levels. However, this knowledge difference appears to be marginal. For both glass and plastic, the general pattern is greater proportions of waste stream result in higher levels of classification knowledge.

Table 3. 2-sample Wilcoxon Test of plastic knowledge and certainty levels

	Recycling knowledge/ GW knowledge	Recycling certainty/ GW certainty
Wilcoxon test	167320***	221000***

Wilcoxon test. *, **, *** indicate statistical significance at the 10%, 5% and 1% level respectively.

d. Ease of identification

Household waste was also divided into 3 categories (easy, moderate, hard) to investigate effect of 'ease of identification'. Easy, moderate and hard categories were defined using local government education material. Items that directly matched education material were considered easy to identify. Items that bore a resemblance to education material were considered moderately difficult to identify. Examples include broken or deformed containers. Items that had little similarity to education material were considered hard to identify. Data relating to category proportions was gathered by taking a 10kg to 20kg daily sample from the waste stream during the waste audit.

The household survey found that the percent correct was greatest for easy glass (M = 0.8339, SD = 0.2785), followed by hard glass (M= 0.6269, SD = 0.3636), and moderate glass (M= 0.6203, SD = 0.4054). Responders were most certain about easy glass disposal choices (M = 3.34), followed by moderate glass (M= 3.12) and hard glass (2.90). Most glass was considered easy to classify (0.9645), with a small proportion in the moderate (0.002) and hard (0.0335) categories.

A perusal of recyclable glass incorrectly disposed indicated most were glass bottles and jars.

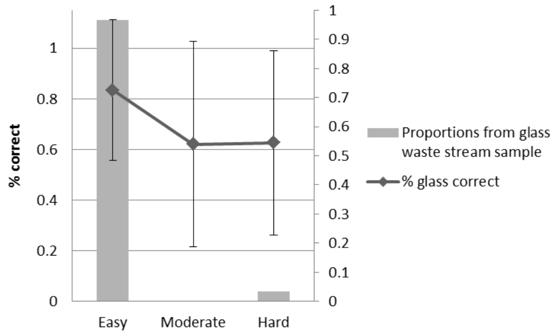

Figure 6. Glass 'ease of identification' categories knowledge levels & contamination proportions

The 2-sample Wilcoxon Test was also applied to 'ease of identification' categories. A significant difference was found between knowledge levels of easy and moderate glass items, and easy and hard glass items. No significant difference in knowledge levels was found between moderate and hard glass items.

Table 4. 2-sample Wilcoxon Test of glass 'ease of identification' categories

	Wilcoxon Test
easy-mod	955070***
easy-hard	984050***
mod-hard	748050

Wilcoxon test. *, **, *** indicate statistical significance at the 10%, 5% and 1% level respectively.

When the same process was applied to plastic, easy plastic mean knowledge levels (M= 0.8917, SD = 0.2348) were greater than moderate plastic (M = 0.7845, SD = 0.2619), and hard plastic (M = 0.7215, SD = 0.3415). Mean certainty levels were highest for easy plastic (M= 3.26), followed by moderate plastic (M = 3.01) and hard plastic (M = 2.79). Most the plastic was easy to classify (0.5179), followed by moderate (0.3840) and hard (0.098) categories. The 2-sample Wilcoxon Test showed significant difference between all levels of plastic difficulty groups.

An inspection of recyclable plastics incorrectly disposed indicated most were plastic containers, in either good condition or deformed. It was also common to see non-container rigid plastic and plastic chemical containers.

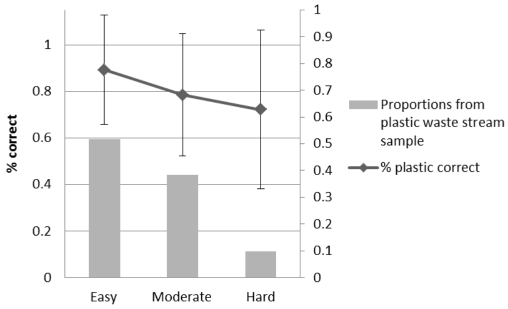

Figure 7. Plastic 'ease of identification' categories knowledge levels & contamination proportions

Table 5. 2-sample Wilcoxon Test of plastic 'ease of identification' categories

	Wilcoxon Test
Easy-mod	926520***
Easy-hard	947800***
Mod-hard	786060***

Wilcoxon test. *, **, *** indicate statistical significance at the 10%, 5% and 1% level respectively.

3.5 Major findings

When material types (plastic and glass) were sub-divided by waste type (recyclables and GW), knowledge levels tended to correlate with proportion of waste flow. That is, households possessed classification knowledge on what they saw in abundance.

When plastic and glass were observed by 'ease of identification' categories an inefficiency was apparent. Plastics moderately difficult to classify possessed knowledge levels significantly lower than plastics easy to classify, and were a significant proportion of the plastic waste stream. Results from this study indicate that this portion of the waste stream requires further clarification for householders.

4. Conclusion

Inefficiencies in waste sorting lead to recycling rate plateauing below full potential. This study is using a combination of a waste audit and a household survey to identify segments of the waste stream that could be targeted to improve recycling rates experiencing plateaus. Plastics moderately difficult to classify were identified as possessing lower levels of knowledge (M = 0.7845, SD = 0.2619) and certainty (M = 3.01), and being a significant proportion of the waste flow (0.3840). This represents just over 8% of recyclable plastic.

Plastics in this category were described as items that bore some resemblance to education material but were not identical. This consisted of plastic container parts, and broken or deformed rigid plastic containers. Information from Table 1 indicates that local government education describes recyclable plastic as 'rigid plastic containers'. If a rigid plastic item does not resemble a plastic container, this introduces confusion. Plastic items commonly incorrectly disposed included non-container rigid plastics, deformed or broken plastics, and plastic chemical containers. There is potential for clarification for these product types in new education campaigns.

Further research is needed to carry out this process for untested material streams (paper, paperboard, steel, aluminium). There is also potential for further comparison between correctly and incorrectly disposed wastes.

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