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Investigation of waste diversion rates in the construction and demolition sector in Australia

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Received 15 February 2020
Revised 30 June 2020
Accepted 31 July 2020

Abstract

Purpose – Waste diversion rate (WDR) is a key indicator of effective waste management and circular economy. However, it has not yet been widely used in the construction and demolition waste (C&DW) sector. This study aims to promote the application of WDR as an effective measure for waste management through the investigation of the current status of C&DW diversion in the Australian construction industry.

Design/methodology/approach – A mixed-method approach, which combines a desk study and a case study of 12 residential projects was used in this study. Data retrieved from the National Waste Database (NWD) were used for the descriptive analysis.

Findings – The analysis of the national waste data revealed that the national average WDR in Australia is 64%. WDR varies based on material types and across the states. The analysis facilitated the forecasting of the possible future trend of waste diversion in Australia. The studied projects from two states in Australia presented slightly different results. Most of the waste stream, except mixed waste, presented above 95% of WDR in each project.

Research limitations/implications – Although the studied projects showed a higher recycling rate, this study claims that achieving a higher rate of recovery by diverting the waste could not be assured unless accurate estimation is carried out with reliable and verifiable data. Lack of reliable data is considered as the limitation of this study. While the scope of descriptive analysis of waste generation and diversion covers the whole country, the case study analysis is limited to the states of New South Wales and Victoria.

Originality/value – The study highlights the significance of WDR in assessing the performance of effective waste management in the C&DW sector. WDR is a comprehensive measure that takes the output of the waste life cycle into account for benchmarking waste management. The results provide a critique of the current practices of waste management and the essence of the consistent, transparent and verifiable waste data to enable accurate WDR estimation in Australia. The outcome is useful for waste managers and policymakers in developing potential waste management strategies and C&DW specific legislation for building a more ecologically sustainable industry.

Keywords Australia, Waste diversion rate, Residential projects, Waste generation, Effective waste management

Paper type Research paper

1. Introduction

The construction industry is a major source of solid waste which has substantially affected the efficiency of the industry, health and social life, environment and economy (Arshad *et al.*, 2017; de Magalhães *et al.*, 2017; Ding *et al.*, 2018; Formoso *et al.*, 2002; Manowong, 2012). In Australia, the construction and demolition (C&D) sector is the second-largest producer of waste amongst other core waste sectors, namely municipal solid waste (MSW) and commercial and industrial waste (C&IW). Making wastes as common will miscarry the actual name of the core waste sectors. The C&D sector has generated around 20.4 megatonnes of waste during the years 2017–2018 only, contributing to 30.5% of the total solid waste generated annually across different states of Australia and out of which around 27% of the generated waste is landfilled (Pickin *et al.*, 2018). Globally, construction activities contribute between 30% and 40% of the total solid waste generation (Ajayi and Oyedele, 2017) and out of which an average of 35% of the total waste is directed to landfill (Ajayi *et al.*, 2016). It is estimated that between 80% and

Built Environment Project and Asset Management

2044-124X
DOI 10.1108/BEPAM-01-2020-0012

90% of landfilled waste could be recovered through effective waste management practices (Chiveralls *et al.*, 2012). Effective waste management, therefore, is of significance in order to recover the potential resources from waste and create a more ecologically sustainable environment through which the community, industry and the environment can benefit through the reduction in carbon emissions, greater availability of recycled products, reduced cost and reduced pressure on natural resources and landfill capacities. Many countries across the world have developed several environment-related waste management strategies which aim to minimise waste through effective waste diversion strategies such as setting up recycling target rates and limits for disposal, imposing fees for landfills and incentives for better waste management performance (Freitas and Magrini, 2017). However, the outcome of the implementation of these strategies has not been optimised yet (Kabirifar *et al.*, 2020).

Waste diversion rate (WDR) is the percentage of waste diverted from landfill through different interventions such as reuse, recycling, repair, treatment and energy recovery. WDR is a key dimension of sustainability and performance indicator (KPI) used by many municipalities in implementing the successful waste recycling programmes and evaluating the performance of their waste management systems (Zaman and Lehmann, 2013). A more common approach used in previous studies is the waste generation rate (WGR), which has been widely used as a KPI in benchmarking waste management performance and recognising and implementing the best practices for performance improvement (Bakshan *et al.*, 2015; Lu *et al.*, 2015). More effective waste management plans (WMPs) can be formulated and informed decisions can be made on developing sustainable strategies and mandatory legislation by comparing the WGRs and WDRs at different levels such as project, organisation, industry and the nation. In a circular economy concept, waste management is measured in terms of the percentage of waste reused/recycled and diverted from landfill. Therefore, more detailed evaluation and understanding of these rates are critical for the assessment of the efficiency of construction and demolition waste (C&DW) management and extent of the achievement of circular economy and sustainability. Although WDR is an essential tool that helps project managers and policymakers to develop sustainable waste management strategies, recycling programmes and policies, not many studies have been dedicated to this area. Therefore, this study attempts to promote the significance of the WDR by investigating the current status of C&DW management and its trend over the last 12 years in the Australian construction industry. This study focusses on the waste diverted during the construction stage by using WDR as the prevailing measurement instrument in assessing waste management performance. This paper is organised into five major sections. The first section covers a review of the literature to provide an insight into various waste diversion strategies and their implications. The second section includes an evaluation of the trend of WDRs in the context of the Australian C&DW sector. The third section provides an analysis of the WGRs and WDRs from actual residential projects. The last two sections cover the discussion, implications and conclusion of the study, respectively.

2. Literature review

The waste diversion is strongly linked with the economy and the environment. The implementation of sustainable waste management and diversion strategies is therefore essential to minimise the detrimental impact of C&DW on the environment and achieve the desired circular economy goals and benefits (Ratnasabapathy *et al.*, 2019). At the same time, sustainable efforts have been increasingly adopted to divert the waste from landfill mainly through reuse/recycling options which, in turns, leads to conservation of non-renewable resources, with economic benefits and mitigation of environmental impacts associated with landfilling (Crawford *et al.*, 2017; Jin *et al.*, 2017; Li *et al.*, 2018; Lockrey *et al.*, 2016).

Previous studies focussed on performance indicators such as WGR, recycling rate, zero waste index (ZWI) and life cycle assessment (LCA), which are used to assess the effectiveness of waste management performance and help to make informed decisions on developing strategies to improve waste management practices (Greene and Tonjes, 2014; Zaman and Lehmann, 2013). However, the effectiveness of C&DW management has yet not been well developed using a more comprehensive mechanism (Kabirifar *et al.*, 2020). According to Ajayi and Oyedele (2017), waste minimisation through diversion requires not only the improvement in existing waste management policies/legislative frameworks but also adequate inputs from construction professionals.

2.1 Waste generation rate

The evaluation of waste generation comprising the volume, type and composition of C&DW helps waste management practitioners to make informed decisions concerning sustainable development through waste minimisation (Moyano and Agudo, 2013). However, the accuracy of waste generation estimation is considered as a prerequisite to the success of waste management strategic planning and implementation (Li *et al.*, 2016; Ojha, 2011). WGR has been used to measure the amount of waste generated and to identify the origins of such waste (Bossink and Brouwersz, 1996). Waste generation can be measured either by sorting the waste into categories based on their properties (e.g. hazardous and non-hazardous) or as the total generated waste (Lu *et al.*, 2011). Different practices have been adopted in assessing WGRs such as percentage of total waste by volume (m^3) or weight (kg or ton) (Poon *et al.*, 2001), the volume of waste generated per m^2 of gross floor area (Lin, 2006; Lu *et al.*, 2015; Mcdonald and Smithers, 1998; Poon *et al.*, 2004), the difference between the amount of material purchased and used (Tam *et al.*, 2007) and the difference between the material purchased and final inventory of materials and design quantity (Formoso *et al.*, 2002). Alternatively, Lu *et al.* (2011) measured the WGR based on the quantity of waste material per the area selected for on-site sorting and weighing.

2.2 Waste diversion rate

Waste diversion, which also can be referred to as landfill diversion, is the process of redirecting the waste from lawful landfill facilities through several possible options such as reuse, recycling, repair, waste to energy, treatments and/or by source reduction activities.

Evidence from previous studies shows that 3Rs (reduce, reuse and recycle) strategies offer benefits through preserving natural resources, minimising the burden of C&DW reaching landfill (Suthar *et al.*, 2016) and creating economic paybacks (Crawford *et al.*, 2017; Jin *et al.*, 2017; Li *et al.*, 2018; Lockrey *et al.*, 2016). In particular, the recycling process uses end-of-life materials to create new products, avoids waste going to landfill, replaces natural resources and reduces energy usage and manufacturing costs (State of NSW and the NSW Environment Protection Authority, 2018). As such, these processes are advocated as an environmentally sound, economically feasible and socially acceptable practice for achieving sustainable goals in urban development (Suthar *et al.*, 2016). Waste trading is another sustainable approach, enabling the transformation of waste into resources through 3Rs strategies. Besides, waste trading greatly contributes to waste reduction by diverting the most of the waste from landfill and hence, it is an effective strategy that substitutes the disposal process of waste (GDRC, 2016; Pun *et al.*, 2007). Waste trading enables efficient use of waste materials through selling and/or exchanging options, thus prompting the circularity of waste from where it is generated/stored/recycled to where it is to be consumed, by creating more value to the waste. Source reduction of waste can be achieved by improving the efficiency of the design such as design for deconstruction and off-site construction and use of modular and prefabricated building components.

WDR can be calculated as the ratio of the total amount of waste that is diverted from lawful landfill to the total amount of waste generated (Greene and Tonjes, 2014; NSW EPA, 2019).

Thus, WDR would generally comprise the amount of waste recovered through reuse, recycling, waste to energy and/or other recovery options such as treatments, composting corresponding to the total amount of waste that is diverted from landfill, thus covering the whole life cycle of the waste. The WDR generally varies by the types and efficiency of the waste diversion methods used.

According to Zaman (2013), WDR can be calculated based on either waste disposal or waste generation. In both methods, the concept of waste generation remains the same. However, in both methods, accuracy of the output depends on the completeness and reliability of the waste data used. For instance, the estimation of waste generation data may exclude some of the unrecorded waste that was reused on-site and dumped at an unlicensed site. This study adopted the disposal method to estimate WDR. The unit of analysis for estimating WDR could be a project, region or nation. The units of analysis used in this study are both project and nation.

Although studies on WGRs have been conducted in Australia (Zaman, 2013), similar research on WDR is limited in the C&D sector where it bounds the understanding of its potential implications in improving the waste management performance. One reason for the limitation of such studies might be due to the lack of reliable data. Studies in other countries are also limited and only a few studies have assessed the impact of surged WDR in terms of jobs and sales of recycled materials (Kabirifar *et al.*, 2020). The aim of this study is, therefore, to explore WDRs in the Australian C&D sector. This study is significant for both academic and Industry practitioners. Through the evaluation of the trend of C&DW management, a clear picture of the current state of the art of the waste management practices is highlighted, which helps researchers to focus on the current issues highlighted on WDR and limited practices. Furthermore, it helps the government, waste management practitioners and/or regulatory bodies in making resourceful decisions and developing future policies/legislation.

3. The research methodology

The research study adopted a mixed-method approach to collect data using a desk analysis and case study of residential projects in New South Wales and Victoria states. Initially, in order to establish an insight of the common waste management methods and the diversion rates of waste materials in the C&D sector in Australia, a descriptive analysis was undertaken. For this purpose, the data were retrieved from the National Waste Database (NWD) of Australia. The NWD is a reporting tool, comprising the outputs of different types of waste records including C&DW data. This database provides the amount of the waste measured in tonnes and categorised based on year, jurisdiction, category of materials, strategies used to manage waste and the fate of waste since 2007. However, the data are not available for all years. It is also important to mention that not all the records in the database have been verified for accuracy and completeness. It was noted that some of the data from previous years have been used in subsequent years to which the actual data are not available. This is probably attributed by the inconsistency in waste reporting each year. However, the data provide a good overview of WGRs and WDRs in Australia. In this research, over 31,000 waste records have been analysed. First, the data were sorted based on waste stream (i.e. C&DW sector). Then, additional filtration was conducted to eliminate duplicated data (such as the sum of different categories of material stream). Subsequently, a descriptive analysis was conducted to determine the overall status of waste management in Australia.

To calculate the WDR of each material stream, the output of recycling, landfill, energy recovery and treatment for each waste material stream were taken into account. Based on the definition of WDR highlighted in the previous section, the following formulas were used to calculate the WDR in this study:

$$\text{WDR} = \frac{\text{Total Waste Diverted}}{\text{Total Waste Generated}} \times 100\% \tag{1}$$

$$\text{WDR} = \frac{\text{Recyling} + \text{Energy Recovery}}{\text{Recyling} + \text{Treatment} + \text{Energy Recovery} + \text{Landfill} + \text{Other Disposal}} \times 100\% \tag{2}$$

In order to assess the WGRs and WDRs in the case study projects, waste data were collected from recently completed projects developed by one of the leading property group companies in Australia. Altogether, waste data from 20 projects were collected and out of which only 12 projects were considered for this study due to the incompleteness of waste data to determine the WGRs and WDRs. The projects selected for this study are multi-storied residential projects with value ranging from 200 to 600 million Australian dollars in total. The composition of waste from each project was obtained through site-specific monthly waste bin inspection and recycling reports. Data from the monthly reports were compiled to obtain the total amount of each material wasted and recycled during the construction stage. Finally, the monthly progress reports were reviewed to check the status of waste that was cleared from the project site each month. The WGR was computed using Formula (3).

$$\text{WGR}\left(\frac{\text{Kg}}{\text{m\$}}\right) = \frac{\text{Waste net weight (Kilogram)}}{\text{Project contract sum (Million Dollar)}} \tag{3}$$

4. The data analysis and results

4.1 Construction and demolition waste generation and diversion trend in Australia

The results of the desk study based on the NWD provide an in-depth assessment of the total amount of waste generated and WDRs based on material category and waste management strategies used in Australia. A total of 150,046,226.5 tonnes of C&DW has been generated during the years 2007, 2009, 2010, 2011, 2014, 2015, 2016 and 2018. This gives an average of 18,755,778.3 tonnes of waste generated every year. Figure 1 shows that New South Wales (NSW) generated the highest amount of C&DW followed by Victoria (Vic), Queensland (Qld), Western Australia (WA), South Australia (SA), Australian Capital Territory (ACT), Northern Territory (NT) and finally Tasmania (Tas). NWS is the fastest growing economy in Australia

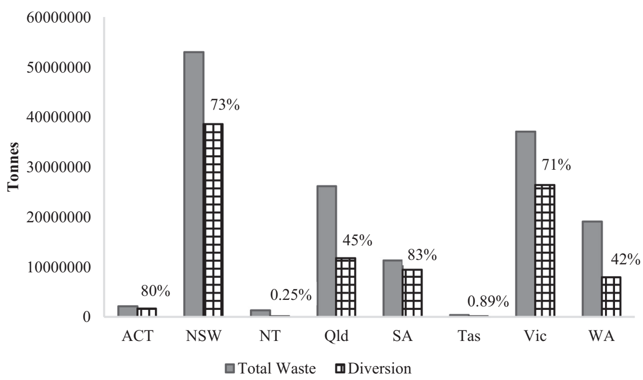

Figure 1.
Total waste generated and diversion rate in different states and territories in Australia

and the higher amount of waste generated is the result of many residential and infrastructure projects that have been developed in this state. In terms of the diversion rate, which was calculated based on the formulas highlighted in the Research Methodology section, SA achieved the highest diversion rate of 83% amongst others. This is followed by ACT with 80%, NSW with 73% and Vic with 71%. The least state is NT with only 0.25% diversion rate. These diversion rates reflect the effectiveness of strategies and recycling programmes developed and implemented in each state. For instance, implementation of SA's Waste Strategy 2015–2020, under the environmental protection and zero waste legislation, placing the highest landfill levies in metropolitan Adelaide which is one of the high commissioning cities in SA, has been a motivating factor to achieve a higher diversion rate in SA. The major goal of a zero-waste strategy is to achieve optimum resource recovery from waste by diverting 100% of waste that goes to landfill (Zaman, 2013).

Australian state and territory governments continue to encourage best waste management and resource recovery practices in the C&DW sector, aiming to maximise each state's potential to utilise the waste at its maximum level. Those waste management practices are based on the strategies of waste hierarchy that are enshrined in relevant legislation and regulations in Australia (Waste Authority, 2013). The management of C&DW is controlled by regulatory rules, which have been sanctioned by the legislature of the jurisdiction in which the waste is generated, administered and enforced by the relevant state or territory regulatory agency (SKM, 2012). The Waste Account Australia of the Australian Bureau of Statistics 2014, categorises broadly three "destinations" for Australia's waste as disposal to landfill, recovery for the domestic economy (includes energy recovery) and exports. Most jurisdictions use strategies that guide organisations and industries in improving waste management systems and these strategies mostly set targets for resource recovery; however, some strategies have focussed on improving the quality of waste data and data reporting.

Figure 2 shows the amount of waste generated and the diversion rate based on the material category. The masonry materials are the highest stream of waste materials which include asphalt, bricks, concrete, rubble and plasterboard and cement sheeting. Organic materials include food and garden organics, timber, biosolids (non-contaminated) and other organics. Hazardous waste includes asbestos and contaminated soil. The metal category includes steel, aluminium and non-ferrous metal (excluding aluminium). Other waste includes

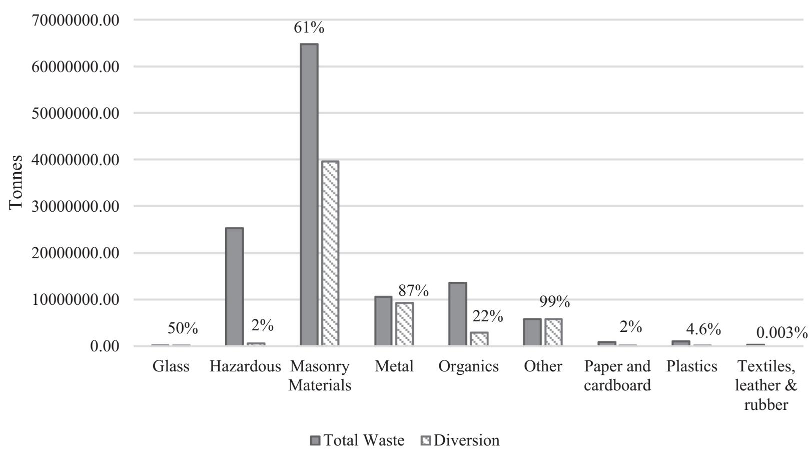

Figure 2.
Diversion rate based on material category (diversion rate shown as percentage)

unclassified waste materials. No ash material was reported in the database. Metal is the highest material in terms of diversion rate with 87% of waste diverted from landfill. This is followed by masonry (61% diversion rate) and glass (about 50%). Other unclassified materials have a high diversion rate of 98.9%. On the other hand, hazardous materials have only 2.3% diversion rate because most of the hazardous waste is directed to landfill. Less amount of hazardous waste such as contaminated soil and asbestos is treated before disposal which is categorised as other disposals.

Figure 3 shows the accumulated waste amount compared to recycling, disposal or landfill, energy recovery and other disposals. The functions shown in the figure are useful to predict the amount of waste in the future and provide an overall status of each of the waste management strategies. For example, disposal through landfill has been reduced slightly during the past years. This is indicated by the negative sign of the regression line of the disposal waste. This result indicates that the efforts to reduce landfill waste have been paid off. However, since the reduction is minor, more efforts are still needed to reduce landfill waste. Energy recovery from C&DW has been reduced slightly as indicated by the negative sign of the regression line function. However, this result should be interpreted with some caution because the correlation between the variables (i.e. years and waste amount) is not strong as shown in the result of the coefficient of determination ($R^2 = 0.0126$).

Figure 4 shows the WDR in each of the studied years in Australia. The total average diversion rate is 64%. This result well resonates with a previous study which positioned Australia in the rank 15th in recycling compared with other developed countries (Pickin and Randell, 2017). However, the diversion rate has been increased as shown in the linear regression function. It is anticipated that the diversion rate in 2025 will reach 78% considering the current trend, which is less than the rate of 80% which is the target rate to be achieved by 2021–2022 (NSW EPA, 2018).

4.2 Assessment of waste diversion rates based on case studies

The monthly waste reports used to analyse WDR in this study comprised the total amount of waste generated, recycled and disposed of in each month during the construction stage of the

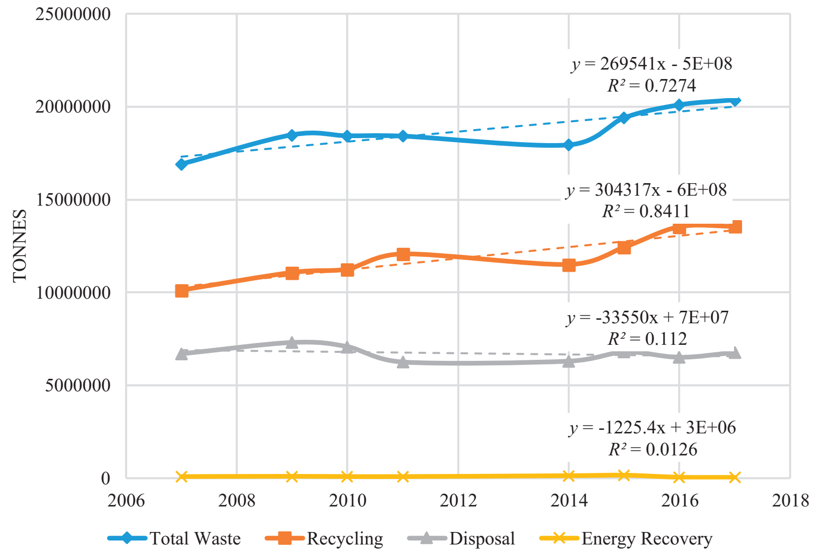

Figure 3.
Total waste generation compared to recycling, disposal and energy recovery in Australia

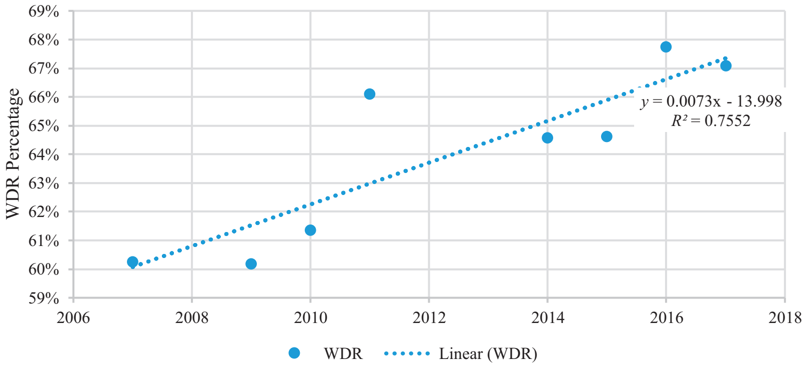

Figure 4.
Overall waste diversion trend in Australia

projects. There were no records found on energy recovered from the waste generated from these projects. Typically, monthly waste reports are issued by the waste processing facility where the waste transported by a waste contractor is sorted into recyclable and non-recyclable materials and processed off-site. The waste contractor is responsible for managing the containerisation, collection and transportation of waste from the construction site to the waste processing facility. Altogether, 12 projects were considered for this study and the monthly waste reports from inception to completion of each project were compiled for the analysis. Further, the developer's project-specific WMPs and monthly progress reports were reviewed and the monthly progress reports revealed that all the waste generated at sites have been collected by the waste contractor and transported to the waste processing facility. Instances, such as waste that is managed on-site (e.g. disposal of fly ash on-site) and reused were not recorded in these projects.

The distribution of the waste generated from material streams at the studied projects includes concrete (41%), wood (25%), metals (11%), masonry (9%), gypsum (4%), paper and cardboard (4%), plastics (3%), excavated material (2%) and mixed waste (1%). Figure 5 shows the WGR of each project, which indicates the level of waste generation per every million Australian dollar's cost of construction work. All the projects have generated WGRs below point 1.0, which is ranked as "good" performance in terms of managing waste in building projects (Lu *et al.*, 2015).

Figure 6 compares the WDR of each waste stream. Since all the materials fall under the category of recyclable materials, more than 95% of materials have been recycled and hence, all projects have achieved a quite high diversion rate, which is 97% on average. Excavated material (virgin excavated natural materials that are not mixed with any other waste)

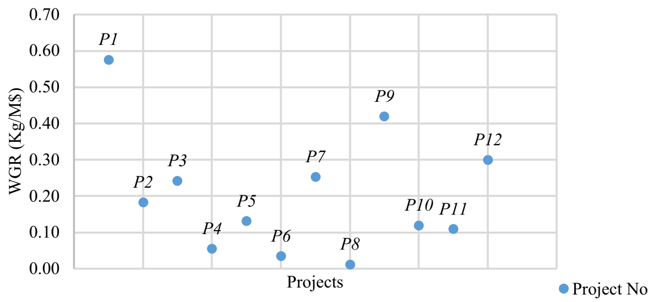

Figure 5.
Waste generation rate from each project

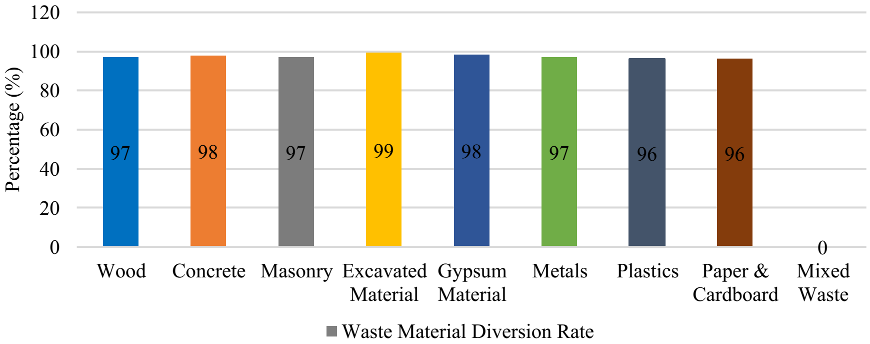

Figure 6. Waste diversion rate of each waste stream from residential projects

obtained the highest diversion rate of 99% amongst others. The landfill rates for all materials fall between 0% and 4%, which means that the diversion rate has been highly achieved by recycling, indicating that these projects have had a high tendency in achieving zero waste. However, mixed waste which consists of non-hazardous materials that cannot be reused or recycled recorded a zero diversion rate. Most of the non-hazardous materials not sorted at the site and mixed up in the waste bin were directed to the landfill.

These results are based on data collected from monthly waste bin inspection and recycling reports issued by the waste contractors. However, the reliability of this data is questionable. This is because the waste disposal dockets that indicate the amount of waste discarded from the construction sites and the amount of waste disposed at lawful landfills are not available to verify the actual amount of waste composition and waste diversion. In the studied projects, the developer has maintained no records of on-site reuse of waste materials. Furthermore, there is a lack of records regarding the types and destination of waste materials recycled off-site. As such, the accuracy of waste diversion could not be fully guaranteed. It can be a limitation of this study in terms of data reliability and accuracy.

5. Discussion and implication of the study

The research findings highlight some latent facts that are to be considered in improving the current waste management practices and developing new policies/legislations in Australia. For example, the accumulated WDR curves can help to predict the WDR in future. The diversion rates were determined based on material categories in each state. With the current efforts applied to reduce landfill and increase recycling, it is anticipated that the diversion rate will escalate to 78% by 2025. The prediction would help to establish WMPs and viable recycling programmes and waste diversion targets for future developments. Despite the influence of WDR on assessing the effectiveness C&DW management practices, immensely contributing to preserving natural resources and reducing the detrimental impact on the environment, it is crucial to understand and evaluate both WGR and WDR in benchmarking the waste management performance and developing sustainable strategies and setting future recycling target for efficient waste management.

There are considerable inconsistencies in waste data and reporting systems across the different states and waste data reporting is not mandatory in all jurisdictions in Australia. Considering the need and essence of maintaining consistent waste data, there is a pressing need to implement a mandatory policy to collect and report waste data that are readily available and traceable for assessing waste management performance at different levels such as project, local authority, state and nation. Mandating waste reporting should start from the project level, which will in turn make national waste data more consistent and reliable. The utilisation of smart data management technologies such as blockchain would provide a resourceful solution by enhancing the consistency, transparency and traceability in capturing and reporting waste data which are fragmented in nature. Such smart technologies would also enable the circularity of waste information efficiently and help to drive a shift towards moving to a circular economy in the C&DW sector (Ratnasabapathy *et al.*, 2019).

The major challenge faced by the construction industry and the government is constantly changing the way the waste is treated and managed. Stakeholders' attitude and their involvement in the whole waste management play a major role in achieving higher WDRs. Therefore, the stakeholders need to be motivated to engage and collaborate throughout the life cycle of waste and recognise possible means of waste diversion. This is not possible unless the government and other relevant authorities take necessary initiatives to make changes in the attitudes and behaviours of the stakeholders who involve in waste management from inception to destination. With regards to the results from case studies results, the waste generator (i.e. the developer) is not incentivised to engage and collaborate with other stakeholders involved in the waste management processes. Developers have fewer concerns regarding the waste beyond the project site. Nevertheless, the project-specific WMP is developed as an operational plan to maximise waste reduction and resource recovery in all stages of the construction. The plan is mainly prepared for complying with regulatory and certification requirements. Contractors and developers should be continuously encouraged to develop waste diversion strategies in the WMP itself that enable the transformation of waste into resources and cooperate with other stakeholders to effectively implement the developed plans. However, consistent and precise data are essential to determine the rates on C&DW generation, reuse/recycling, disposal and energy recovery that need to be considered in developing the WMPs.

Moreover, the lack of economic benefits of waste management for the stakeholders is one of the major barriers for waste diversion and circular economy application in the construction industry. Therefore, illustrating the economic benefits by adopting different business models like the circular business model through the concept of waste trading would also be a sustainable approach. Stimulating the market for reusable/recycled materials would ultimately help to divert more waste from landfill and make recycling more viable, creating more job opportunities and economies of scale. The government should initiate and implement relevant strategies through legislation to motivate the stakeholders. The increase of landfill levies has been successful in achieving higher WDRs as shown in the case of SA. Different strategies such as incentives (e.g. tax reductions) to waste generators and waste management businesses, penalties for illegal waste disposal and relevant education and awareness programmes would be beneficial in achieving higher WDRs. Further, the revenue from increased levies can be the source for governments to fund sustainable waste management programmes and related training.

6. Conclusion and recommendations

This study attempted to evaluate and understand the trend of waste diversion in Australia. The diversion rates were determined based on material categories across all states. However, the case study showed a different picture with quite high diversion rates. The results of the case study were compiled based on residential projects of one developer and hence cannot be generalised to the whole residential construction sector in Australia. This paper showed that the evaluation of WDR could help in assessing the effectiveness of waste management in the C&DW sector and preparing more effective WMP for construction projects. In addition, WDR can support the government and regulatory bodies to develop effective waste management programmes and strategies and implement specific C&DW management policies and legislations.

Since the effectiveness of C&DW management has not been benchmarked yet, this study suggests that WDR can be considered as a simple and yet comprehensive tool to assess the C&DW management performance, given the fact that WDR takes the output of reuse, recycling, energy recovery, treatment and disposal into account which are the major stages of the waste life cycle. This study also suggests further research studies to determine the cost involved in the overall waste management and the economic benefit that can be achieved by diverting the waste from landfill through different waste diversion strategies. This would attract new investments in secondary product markets and create circular business models, thus driving a shift towards the circular economy while achieving more economic benefits.

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