



Ranking Canadian waste management system efficiencies using three waste performance indicators

Derek Mensah¹ · Nima Karimi¹ · Kelvin Tsun Wai Ng¹ · Tanvir S. Mahmud¹ · Yili Tang¹ · Sotonye Igoniko¹

Received: 30 May 2022 / Accepted: 7 February 2023 / Published online: 18 February 2023
© The Author(s), under exclusive licence to Springer-Verlag GmbH Germany, part of Springer Nature 2023

Abstract

Three waste management system (WMS) efficiency indicators are adopted to systematically assess WMS efficiency in Canada from 1998 to 2016. The study objectives are to examine the temporal changes in waste diversion activities and rank the performance of the jurisdictions using a qualitative analytical framework. Increasing Waste Management Output Index (WMOI) trends were identified in all jurisdictions, and more government subsidiaries and incentive packages are recommended. With the exception of Nova Scotia, statistically significant decreasing diversion gross domestic product (DGDP) ratio trends are observed. It appears that the increases in GDP from Sector 562 were not contributing to waste diversion. On average, Canada spent about \$225/tonne of waste handled during the study period. Current spending per tonne handled (CuPT) trends are decreasing, with *S* ranging from +5.15 to +7.67. It appears that WMSs in Saskatchewan and Alberta are more efficient. The results suggest that the use of diversion rate alone to evaluate WMS may be misleading. The findings help the waste community to better understand the trade-offs between various waste management alternatives. The proposed qualitative framework utilizing comparative rankings is applicable elsewhere and can be a useful decision support tool for policy-makers.

Keywords Sustainable waste management system · Municipal solid waste · Diversion efficiency · Cost-effectiveness · Materials handled efficiency indicators · Provincial-wide comparisons

Abbreviations

Location abbreviations

CA	Canada
NS	Nova Scotia
ON	Ontario
SK	Saskatchewan
AB	Alberta

Other abbreviations

CuPT	Current spending per tonne handled
DGDP	Diversion gross domestic product ratio
GDP	Gross domestic product
MK	Mann–Kendall
MSW	Municipal solid waste

NAICS	North American Industrial Classification System
WMOI	Waste Management Output Index
WMS	Waste management system
DR	Diversion rate
PC	Percentage change
SAW	Simple additive weighting

Introduction

Municipal solid waste management

Global municipal solid waste (MSW) generation has increased significantly over the past decades (Karak et al. 2012). It is estimated that around 11.2 billion tonnes per year of solid waste is collected globally, and the organic portion of this waste contributes roughly 5% of global greenhouse gas emissions (United Nations 2018; Mora et al. 2021). MSW generation characteristics and recycling behaviors can be location specific but is generally attributed to population growth (Chhay et al. 2018), industrialization (Hamid and Asghar 2018), and urbanization (Vij 2012). A 2018 World

Responsible Editor: Ta Yeong Wu

✉ Kelvin Tsun Wai Ng
kelvin.ng@uregina.ca

¹ Faculty of Engineering and Applied Science, University of Regina, 3737 Wascana Parkway, Regina, SK S4S 0A2, Canada

Bank report estimated that global waste will increase around 70% by 2050 if proper MSW plans and waste minimization programs are not fully developed and implemented (Kaza et al. 2018). Temporal changes in MSW composition have also been reported in different countries (Abdel-Shafy and Mansour 2018; Vu et al. 2021b). The ever-changing waste quantity and quality makes proper waste management planning and performance evaluation challenging. The adverse environment effects associated with improper MSW management such as biodiversity loss, surface and groundwater contamination, and human health degradation have been well documented (Bernache 2003; Khadka 2021; Maryev and Smirnova 2021). In addition, the environmental and social costs associated with municipal waste management and recycling are increasingly expensive (Mohsenizadeh et al. 2020; Harijani and Mansour 2022).

Many waste studies have focused on the examination of various plans, specific management strategies, and the regulation of particular waste management schemes (Park and Berry 2013; Kosoe et al. 2021; Parizeau et al. 2021). For example, Lakhani (2015) studied MSW recycling in Ontario, Canada, and concluded that the elimination of recycling programs in high-cost regions such as northern rural areas may improve waste management efficiency without negatively impacting the overall waste diversion rate. Wang et al. (2016b) used a province wide comparison approach to investigate the MSW generation trends and recycling characteristics in Western Canadian provinces. Their results showed that curbside recycling programs and pay as you throw collection systems are important factors for improving waste diversion in Saskatchewan, Canada (Wang et al. 2016b). Richter et al. (2017) evaluated the associations between waste diversion and disposal trends using different socio-economic factors such as gross domestic product (GDP), employment, expenditure, and business size in various Canadian provinces and reported that Nova Scotia's waste diversion increased by 35% compared to the national increase of 1.5% over the 14-year study period (Richter et al. 2017). Waste management system efficiencies in low-density population regions of Nova Scotia, Canada, are further assessed by Richter et al. (2021), considering their expenditure in waste collection. According to Richter et al. (2021), the spatial distribution of waste facilities, as well as the presence of an intensified road network, is important to an efficient and cost-effective waste management system. Assuah and Sinclair (2021) studied twelve First Nations communities in Canada's western provinces and concluded that sufficient funding is vital to the continued success of various waste management programs. Most of the waste studies however do not explicitly address waste management system (WMS) efficiency and effectiveness. The present study applies efficiency indicators with a qualitative ranking framework to assess WMS efficiency in Canada.

Waste management system efficiency in Canada

Canada generates more MSW per capita than most industrialized nations (Bruce et al. 2016; Wang et al. 2016b), and it is selected as the study area. In 2018, over 25.7 million tonnes of waste were generated and only about 30% is recycled (Statistics Canada 2021a, c). Canadian waste studies are however limited (Ghosh and Ng 2021; Islam et al. 2022). Given the large land area of Canada, the efficiency and effectiveness of WMSs is especially important (Kabir et al. 2022).

Most of the Canadian MSW have been disposed of at landfills, and landfilling is the most commonly used MSW treatment method (Richter et al. 2019b; Karimi et al. 2020; Nazari et al. 2021). For example, data showed that the number of landfills per capita in prairie provinces of Canada was over 15 times greater than those in the United States in 2015 (University of Michigan 2017; Government of Saskatchewan 2020). Despite of the popularity of landfilling in Canada, permanent land disposal is often considered as the least preferred option in many waste management hierarchies (Pires and Martinho 2019; Statistics Canada 2021b; Tsai et al. 2021). Landfill gas emission (Bruce et al. 2018; Karimi et al. 2021) and groundwater contamination by leachate (Fallah et al. 2019; Pan et al. 2019b) are common concerns. Waste recycling is therefore universally preferred. However, recycling is an expensive and energy intensive practice. Therefore, efficiency and effectiveness of waste systems are crucial if recycling systems are to be adopted. Waste diversion rate (DR), a jurisdictionally comparable index, is often used to quantify the extent of recycling activities (Statistics Canada 2018).

Waste diversion performance indicators

Reliable and assessable data is required for compressive evaluation of any WMS efficiency (Reutter et al. 2017; Sarra et al. 2020; Xu et al. 2020). DR is widely used to measure the sustainability of waste management plans and recycling programs across the globe (Ratnasabapathy et al. 2020; Akinwonmi 2021). A higher DR usually signals a more comprehensive recycling program and/or a higher willingness for the residents to participate in the recycling programs and waste minimization initiatives. Pan et al. (2019a) examined the performance of MSW diversion models in four Western Canadian provinces between 1998 and 2014 and reported that the use of DR alone has failed to adequately describe the performance of Canadian WMSs. Bolingbroke et al. (2021) stated that DR is not a WMS efficiency indicator and that the sole use of DR in the evaluation of WMS can be misleading. Many

researchers have suggested alternative performance indicators accounting for the total costs of such a system to better address waste system efficiency (Zaman and Lehmann 2013; Cavalletti and Corsi 2019; Bolingbroke et al. 2021).

Pan et al. (2019a) proposed an original set of indices including the Waste Management Output Index, the diversion-GDP ratio, and the diversion-expenditure ratio to examine the efficiency characteristics of waste management programs. Recently, Bolingbroke et al. (2021) developed a jurisdictionally comparable index known as diversion size indicator and successfully applied it to assess the efficiency of Canadian WMSs. Bolingbroke et al. (2021) further concluded that input–output indicators are crucial in evaluating the financial and managerial efficiencies of MSW management programs, particularly with respect to waste diversion. Comparing to most industrialized nations, Canadians generate more MSW per capita (Conference Board of Canada 2021) and recycle less (Richter et al. 2017). Canada is selected in this study as the location to examine WMS efficiency from 1998 to 2016, the years of which data is available.

Study objectives, novelty, and potential impact

The study objectives are to [i] examine the temporal changes in waste diversion activities in four Canadian provinces and the national average using descriptive statistics and Mann–Kendall tests, [ii] evaluate the performance of the provinces using a set of efficiency indicators, and [iii] rank the provinces using a qualitative analytical framework. Unlike other waste studies that investigated waste management performance in a given city, this study comprehensively evaluates the overall effectiveness of WMSs using the Waste Management Output Index (WMOI), the diversion-GDP ratio (DGDP), and the current expenditure per tonne of waste handled (CuPT). These indicators were originally proposed by Pan et al. (2019a) and Bolingbroke et al. (2021). The mathematical formulations are provided in the “Methodology” section. The indicators were adopted in this study to systematically assess Canadian WMSs efficiency in temporally. In addition, a qualitative assessment framework utilizing comparative rankings is proposed. The framework is believed to be applicable in Canada and other jurisdictions. Studies on WMS effectiveness and efficiency are very limited (Pan et al. 2019a; Bolingbroke et al. 2021; Kabir et al. 2022), and the proposed ranking system is easy to use and of interest and beneficial to any decision-maker in MSW management sector. The use of efficiency indicators with a qualitative ranking framework is original and fills the literature gap in the assessment of WMSs. The proposed analytical approaches are easy to implement and can be applied in other countries.

Methodology

Waste statistics and study area

Canadian waste statistics from 1998 to 2016 were collected using the national biennial waste data sets from Statistics Canada (Statistics Canada 2018). The most recent available set is 2018; however, the 2018 set is excluded due to the fact that Statistics Canada customarily revises the most recent data set in the subsequent biennial report. Canadian data on hazardous waste and other directly diverted waste such as backyard composting were not considered in the waste diversion calculations. All monetary inputs such as GDP and current expenditures are expressed in Canadian dollars (\$). Data availability and uncertainties associated with the Canadian waste statistics have been reported and discussed by others (Bruce et al. 2016; Wang et al. 2016b). Hence, Statistics Canada data was adopted for waste statistics and monetary inputs to allow rapid comparison with literature.

Given their waste management characteristics and recycling behaviors, a total of four representative provinces were selected in this study, including Nova Scotia (NS), Ontario (ON), Saskatchewan (SK), and Alberta (AB). Nova Scotia was selected since it has implemented many pioneering waste management programs, particularly its organic recycling program, and has some of the country’s highest waste diversion rates (Richter et al. 2019a; Diggle and Walker 2020). Ontario is the most populous province in Canada and its waste management and recycling plans are generally used as a benchmark for other provinces (Lakhan 2015; Chowdhury et al. 2017). Saskatchewan and Alberta were selected to identify the waste management characteristics in the Canadian prairies since many communities are currently considering waste management regionalization to improve operation efficiency (Karimi et al. 2020, 2022; Ghosh and Ng 2021). The national average for Canada (CA) is also considered for comparison purposes. In this study, efficiency is defined as the ability to get higher outputs from the same inputs to a WMS.

Waste management system performance indicators

The North American Industry Classification System (NAICS) is a widely adopted standard for classifications of business activities in Canada, the USA, and Mexico. NAICS Sector 562 generally addresses the Waste Management and Remediation Services (Statistics Canada 2016). Specifically, the three primary sub-disciplines of Sector 562 are Sectors 5621 — Waste Collection; 5622 — Waste Treatment and Disposal; and 5629 — Remediation and other Waste

Management Services. Sectors 5621 and 5622 are directly related to the MSW management industry. Sector 5629 also includes site remediation works such as cleanup of polluted buildings, mining areas, polluted water resources, land soils (Statistics Canada 2016), and other waste management services. To better understand the effectiveness of a WMS, total economic output from Sector 562 was compared to the total economic output of the provinces. This dimensionless indicator was first proposed by Pan et al. (2019a) and is known as the Waste Management Output Index (WMOI), shown in Eq. 1. This indicator is useful in North America and other countries who have adopted the NAICS for trading purposes.

$$WMOI = \frac{\text{GDP from Sector 562}}{\text{GDP from all Sectors}} \times 100\% \quad (1)$$

For a given jurisdiction, a smaller WMOI means that the waste sector does not drain a lot of the jurisdiction's overall gross domestic product, whereas a WMOI of one indicates that the jurisdiction's GDP is solely dependent on the economic output of Sector 562.

A diversion ratio indicator, diversion-GDP ratio or DGDP, is used to analyze the effectiveness of MSW recycling in a jurisdiction for a given economic output. The DGDP ratio, proposed by Pan et al. (2019a) with a unit of $\$^{-1}$, is shown in Eq. 2. The current expenditure per tonne of waste handled (CuPT), first proposed by Bolingbroke et al. (2021), is an indicator that signifies how much financial resource a jurisdiction spends on managing a given quantity of MSW. The amount of waste handled comprises the total of diverted and disposed waste by weight. CuPT is expressed in $\$/\text{tonne}$, as shown in Eq. 3. Both DGDP and CuPT are used to examine the temporal changes of the jurisdiction's WMS. The rationales of the WMOI, DGDP, and CuPT are discussed previously (Pan et al. 2019a; Bolingbroke et al. 2021) and are not repeated here. Recently, Kabir et al. (2022) adopted these indicators and compared the economic efficiency of Canadian WMSs integrating the fuzzy analytic hierarchy process with the efficacy method.

Unlike the dimensionless WMOI, both DGDP and CuPT specifically assess the efficiency of WMS in terms of its economic performance. The three indicators are integrated to develop a qualitative provincial comparative ranking system in this study, as further discussed in the “A qualitative analytical framework and province-wide comparison” section.

$$DGDP = \frac{\text{Diversion rate}}{\text{GDP from Sector 562}} \quad (2)$$

$$CuPT = \frac{\text{Current expenditure}}{\text{Tonnes of waste handled}} \quad (3)$$

Trend analysis

Most simple regression analysis requires a normal distributed data set. Given the limited sample size ($n = 10$) in this study, Mann–Kendall (MK) tests are used to examine the temporal changes of the waste diversion rates from 1998 to 2016. MK test is a non-parametric statistical tool that is used to identify monotonic trends in time-series data (Chowdhury et al. 2017; Tiwari and Pandey 2019) and is adopted in the current study to analyze the recycling behavior of different WMSs. Unlike linear regression, the MK test can handle irregular data intervals regardless of data normality distribution (Fu and Weng 2015; Wang et al. 2016a), and a normal distribution of the data is not necessary. Sen's slope (S) describes the linear trend in a time series. A positive Sen's slope ($S > 0$) indicates a rising monotonic trend, whereas a negative value ($S < 0$) indicates a falling trend (Mann 1945; Pranuthi et al. 2014). Similar to Leveugle et al. (2009) and Andrade et al. (2019), a confidence level of 95% was adopted in the MK trend analysis ($p < 0.05$).

Short-term changes of the diversion rates can be presented by the percentage change (PC). It is calculated for each of the 2-year Statistics Canada reporting period using the previous reporting year as the denominator and can be positive or negative (Eq. 4). Mean PC is the average of all the PCs during the entire 18-year study period and is used in this study as a supplementary parameter to assess the short-term variability of waste diversion activities within a jurisdiction.

$$PC = \frac{\text{Current DR} - \text{Previous DR}}{\text{Previous DR}} \times 100\% \quad (4)$$

A qualitative analytical framework and province-wide comparison

The performance of the selected four provinces was investigated using the three mean indicators during the 18-year study period. The national average (CA) was also used as a benchmark in the province-wide comparison. The relative provincial performances were then translated into a final score using a simple additive weighting (SAW)–based technique. Since the selected three indicators (Eqs. 1–3) examine different aspects of a WMS and have different units, the final score should be interpreted qualitatively and not quantitatively. We believe a relative comparison approach is more appropriate in this study because factors affecting WMS efficiency such as population densities and intensity of road network (Richter et al. 2021) are inconsistent among the jurisdictions.

Integration of multiple performance indicators to form an overall assessment is commonly used for comparative

rankings in multi-criteria-decision-analysis studies (Kaliszewski and Podkopaev 2016; Fernandes et al. 2018; Rutten-van Mólken et al. 2018). For example, Jovanovic et al. (2016) applied a basic SAW technique to integrate all features of the proposed waste management treatment solutions. Similarly, Karimi et al. (2020) adopted a SAW method to incorporate constraints and rank suitable regions for future waste facilities. The proposed assessment framework is shown in Fig. 1. The jurisdictions with the lowest values of all three efficiency indicators (i.e., WMOI, DGDP, and CuPT) are ranked as 3, whereas provinces with the highest efficiency indicators are ranked as 15. A higher rank represents a province with a more efficient and effective WMS and vice versa. Uncertainties in Canadian waste data is not uncommon (Bruce et al. 2016; Wang et al. 2016b); the use of a province-wide comparison framework allows meaningful analysis of WMS efficiency.

Results and discussion

Diversions rates among Canadian provinces

Table 1 shows the descriptive statistics and data variations of provincial and national waste diversion rates (DR). During the study period, the Canadian national (CA) average DR was 23.95% with a mean PC of +1.33%. NS, one of the Maritime provinces, has a national leading waste diversion program, with the highest mean DR of 37.60%.

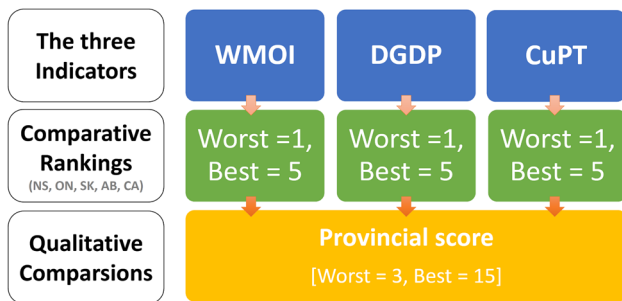


Fig. 1 The development of a qualitative ranking system using the three WMS indicators

Richter et al. (2017) reported that NS has considerably more waste management businesses per capita and more waste sector employees compared to other Canadian provinces. Specifically, there were nearly twice as many waste management businesses per capita in NS (6.35 business/cap) than in ON (3.65 business/cap) in 2010 (Richter et al. 2017). Diggle and Walker (2020) also reported that NS has been considered a pioneer in attaining waste minimization goals through diversion and recycling. The mean PC of NS was +9.55%, over 7 times higher than the national average (the national averages are bolded in Table 1). PC measures the short-term variability of diversion rates within a 2-year period. A high positive mean PC in NS suggested that the WMS is dynamic and improving steadily in the 18-year study period.

The most populous province, ON, have similar, but slightly lower, mean DR (22.33%) and mean PC (+1.09%) compared to the national average. According to Lkhan (2016), the financial allocation of Ontario's municipal recycling funding failed to meet its maximum waste diversion goals. Furthermore, the prairie provinces AB and SK have much lower mean DR from 1998 to 2016. For example, mean DR of AB was only 15.38%, about 36% less than the national average. Similar finding is reported by Bruce et al. (2016), which showed the average diversion rate in AB from 1996 to 2010 was 15.01%. On the other hand, waste diversion activities in AB appear responsive and improving, with the second highest mean PC of +6.79%. The improvement in diversion rates may be attributed to AB's progressive solid waste management plan in 2007 where targeted disposal bans and various paper and packaging programs were promoted (Alberta environmental network 2021). SK had the lowest mean diversion of 14.34%, slightly lower than that of AB. Waste diversion rates were historically lower in Canadian prairie provinces (Wang et al. 2016b; PPPEC 2019), probably due to lower population densities, larger rural populations, and poorer accessibility to waste diversion programs and initiatives (Assuah and Sinclair 2021; Ghosh and Ng 2021; Richter et al. 2021). Unlike other provinces, the mean PC was negative (−2.04%) due to the reduction in waste diversion rates from 1998 to 2006 (Wang et al. 2016b).

Table 1 Average waste DRs in Canada from 1998 to 2016 (ordered based on the mean DR)

Province	Min DR (%)	Mean DR (%)	Max DR (%)	Mean PC (%)
Nova Scotia (NS)	20.30	37.60	45.01	+9.55
Canada (CA)*	20.95	23.95	27.06	+1.33
Ontario (ON)	19.02	22.33	25.89	+1.09
Alberta (AB)	10.26	15.38	19.28	+6.79
Saskatchewan (SK)	11.36	14.34	20.56	−2.04

*CA is the national average

Temporal variations of the three waste indicators

Waste Management Output Index

WMOI quantifies the relative economic output of the waste management sector in a jurisdiction (Eq. 1), and the temporal variations of WMOI are shown in Fig. 2. Statistically significant increasing monotonic trends were detected by MK test in all jurisdictions from 1998 to 2016 ($+0.005 < S < +0.021$). The numerical results suggest that Canadian waste management sector was developing steadily and had become a larger leach on the economy during the 18-year period. For example, the national average (broken line, Fig. 2) increased over two-fold from 0.128% in 1998 to 0.309% in 2016. A closer look at the curves reveals that ON, the most populous province, contributed significantly to the national data. For example, a decreasing WMOI trend between 2014 and 2016 is observed in both ON and CA despite of the consistent increasing trends in AB, NS, and SK.

A substantial increase in AB's WMOI was observed after 2008, reaching the peak of 0.445% in 2016. The finding is consistent with Alberta's decision to better incorporate remediation strategies into the 2008 solid waste management plan (Government of Alberta 2017; Statistics Canada 2017). Pan et al. (2019a) also found that increased GDP from Sector 562 might be due to the ripple effect of clean-up activities in Alberta's oil and gas industry. Caution should be used when interpreting WMOI results. The use of WMOI alone to evaluate WMS efficiency is not recommended.

The variations are noticeably higher in the NS curve. For example, the NS's WMOI curve was similar to the national average (CA) from 1998 to 2002, above national average from 2004 to 2008, and below national average after 2010.

It is not clear why more variations are observed in NS, but the NS waste management sector appears more dynamic and responsive to the economy cycle (Richter et al. 2018). Unlike other curves, the WMOI of SK is significantly lower, with an average WMOI of about 0.102%. The SK curve also appears smoother, with less abrupt changes between the reporting years. More government subsidiaries and incentive packages are recommended to improve size of the waste management sector in Saskatchewan in a stagnant market.

Diversion–gross domestic product ratios

Temporal changes of the DGDP ratios are shown in Fig. 3. With the exception of NS, the MK test shows statistically significant decreasing trends in all jurisdictions ($-0.005 < S < -0.013$, $p < 0.05$). The MK test however failed to detect a statistically significant monotonic trend for NS ($p > 0.1$), probably due to the single peak of 0.641 $\text{\$}^{-1}$ in the year 2000.

The national average (broken line, Fig. 3) decreased from 0.471 $\text{\$}^{-1}$ in 1998 to 0.163 $\text{\$}^{-1}$ in 2014 and slightly increased to 0.174 $\text{\$}^{-1}$ in 2016. Consistent trend is again observed for ON, with a slight increase in DGDP between 2014 and 2016. The decreasing trend is most obvious in SK among the jurisdictions, with a MK test Sen's slope (S) of -0.013 ($p < 0.001$).

Overall decreasing DGDP trends in Fig. 3 suggest that the increases in GDP from Sector 562 depicted in Fig. 2 were not contributing directly to MSW diversion activities. Although more financial resources were allocated in the Canadian waste sector in the recent years, majority of them were not directed to MSW diversion and recovery, but to other services such as site remediation and industrial waste treatment. For example, AB has a more predominance waste sector economically between

Fig. 2 Economic outputs of waste management sector in four Canadian provinces over the study period

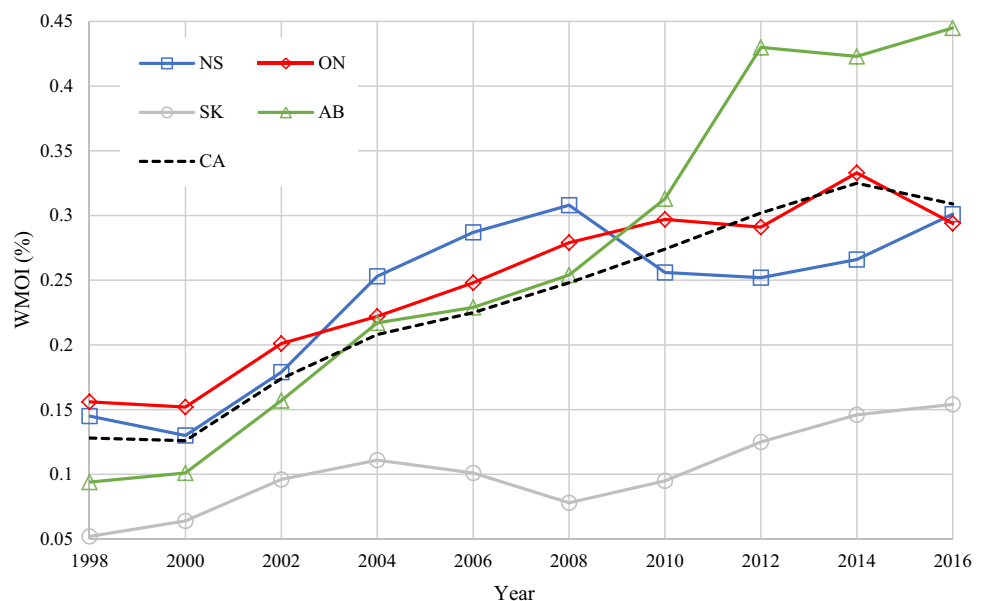
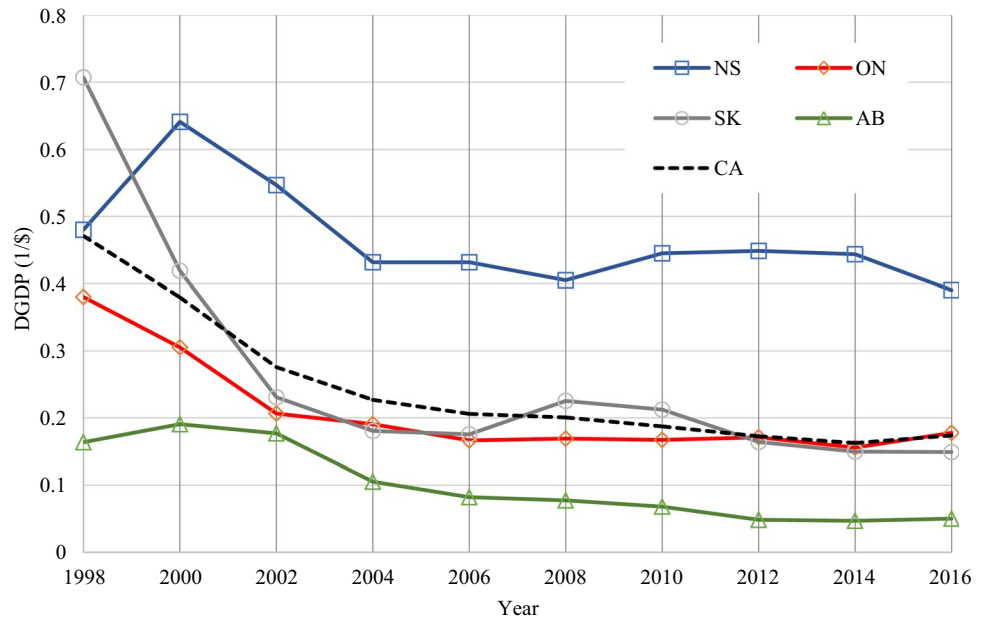


Fig. 3 Waste diversion per total monetary values of waste management services and products over the study period



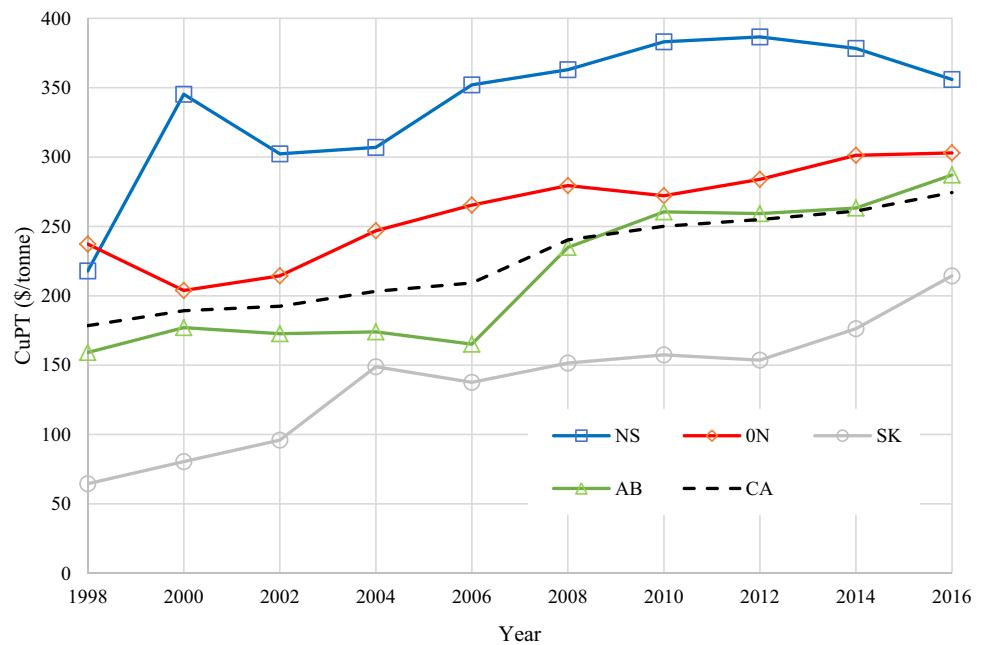
2012 and 2016 (green curve, Fig. 2), but the corresponding DGDP curve is flat and stagnant during the same period (Fig. 3). This observation is also consistent with Asha (2015), who concluded that AB’s waste management plan was narrowly defined and focused solely on a handful for residential waste diversion programs. On the other hand, NS has a considerably higher average DGDP of $0.466 \text{ \$}^{-1}$ than AB ($0.261 \text{ \$}^{-1}$), probably due to a considerably higher average DR (Table 1). Development of MSW diversion initiatives and educational outreach can be time-consuming and expensive (Ferrara and Missios 2005; Lakhan 2014; Chowdhury et al. 2017); it is thus recommended more

resources to be allocated specifically to MSW recycling and recovery.

Current expenditure per tonne of waste handled

On average, Canada spent about \$225/tonne of MSW handled during the study period (Fig. 4). Overall increasing CuPT trends are observed over the study period, with S ranged from + 5.15 to + 7.67 ($p < 0.01$). Unlike DGDP which focus solely on diversion, CuPT covers the entire life cycle of waste management services including on-site storage, collection

Fig. 4 Current spending per tonnes of waste handled over the study period



and transfer, processing and recovery, and treatment and disposal. An increasing trend suggests that Canadians spent more financial resources to handle MSW over the study period. For example, Canadians spent about \$179/tonne in 1998, and was increased to \$274/tonne in 2016, representing a 53.7% increase in 18 years (broken line, Fig. 4). The increasing CuPT trends may reflect the recent additions of programs and regulations to diversify waste management services, increased costs of the service, and overall higher customer expectations. Bolingbroke et al. (2021) however stressed that CuPT is sensitive to the wet weight of materials and can be affected by waste composition and origin. As such, the results among jurisdictions should be interpreted cautiously.

As shown in Fig. 4, CuPT in ON and AB is on par with the national average. On the other hand, the average CuPT for NS was \$339/tonne, about 150.5% of the national average, or 246.6% of SK. NS not only has a higher number of waste management enterprises and waste management personnel per capita (Richter et al. 2017), but also has the highest DR in the country (Table 1). SK spent the least monetary values on MSW management among the jurisdictions, with an average CuPT of \$138/tonne, or about \$87/tonne less than the national average. The lack of diversified waste management programs and financial resources in SK may be a factor on lower DR (Table 1).

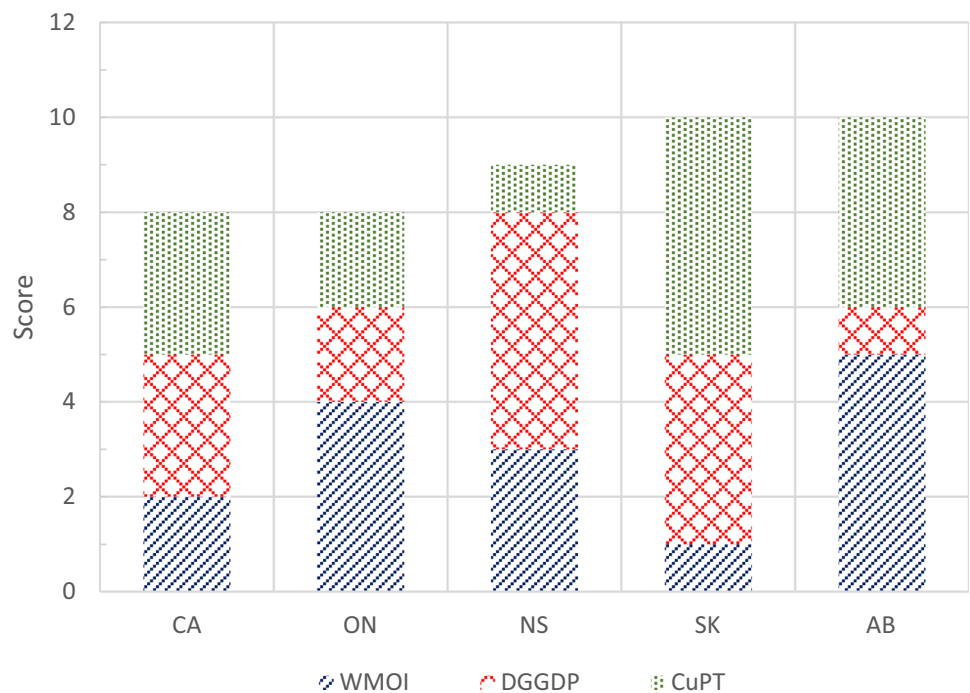
Provincial comparison based on the ranking of the provinces

Figure 5 shows the overall scores using a SAW-based provincial comparison. As discussed in the “Methodology”

section, a maximum score of 15 is awarded if a jurisdiction ranks first in all three indicators, representing better WMS performance. The lowest possible score is therefore 3. Among the provinces, ON has a score of 8, the lowest in the study. The national average, CA, also has a score of 8. On the contrary, the prairie provinces SK and AB have the highest score of 10. The finding is interesting that even though SK and AB lagged behind in DR (Table 1), the efficiency of their WMSs was relatively better. The results suggest that the use of DR alone to evaluate WMS may be misleading, as it fails to quantify the required inputs. For example, NS has been historically a national leader in MSW diversion, which obtained a mid-ranged score of 9 in this study. It appears that considerably higher monetary resources are required to achieve top diversion rates in Canada. This is probably due to the diminishing returns in waste diversion investment.

The relative contributions of the indicators to the final score can be quite different among jurisdictions. For example, the national average (CA), appears more well-rounded in the ranking. SK and AB, on the other hand, are heavily skewed. SK had a small WMOI and a small WMS sector, but was more efficient economically. AB, on the other hand, had a large presence of the waste management business sector, but lagged behind in waste diversion services (a least ranked DGGDP). Given the amount of MSW generated daily, the use of public money on WMS planning, design, and operation requires sound financial management. The findings help decision makers to better understand the trade-offs between various waste management options and to develop a sustainable WMS. Given rapid population growth and urbanization, an

Fig. 5 Provincial comparison of WMS efficiency using SAW method



efficient WMS is vital to many of our sustainable development goals. Currently, there is no universally accepted method on evaluation of WMS efficiency, and the proposed analytical framework fills the knowledge gap. Efficiency assessment tool is especially important during the pandemic period, as COVID-19-related administrative measures and lockdowns have impacted waste recycling and disposal practices in Canada (Vu et al. 2021a; 2021b).

Limitations

Due to the data availability, some of the recent data is not included. Privacy-related data suppression in some jurisdictions also creates impediments to a national comparison. Interprovincial or international transportation of waste materials is not uncommon in Canada, and recyclables may be transported in laboring jurisdictions for recycling and disposal. These MSW transportations crossing borders are not considered in the present study. Only three indicators are considered in the study. More input–output indicators can be incorporated in the proposed ranking framework. In the future, the proposed ranking framework can include waste from non-residential sector to provide a more comprehensive assessment of the WMS. Other operation research techniques such as data envelopment analysis (DEA) models can also be used to study waste management system efficiency (Wu et al. 2019; Molinos-Senante et al. 2022; Ye et al. 2022). WMS is complex, and multiple factors and metrics should be considered when evaluating WMS efficiency.

Conclusion

Many waste studies have focused on WMS of a single city, state, or province, but comprehensive examination of WMS at a national level is mostly ignored. In this study, the temporal changes in waste diversion are examined using various efficiency indicators, and overall, WMS performance is assessed using a SAW based ranking framework. NS is a national leader in waste diversion rate, with DR ranging from 20.3 to 45.0% over the 18-year study period. On the contrary, AB and SK have considerably lower average DR of 15.4% and 14.3%, respectively. A high positive mean PC of +9.55% in NS suggested that its WMS is more dynamic and responsive. Increasing WMOI trends were detected in all jurisdictions. SK had an average WMOI of about 0.102%, the lowest among the jurisdictions. More government subsidiaries and incentive packages are recommended. With the exception of NS, statistically significant decreasing DGPD trends are observed in all jurisdictions. It appears that

the increases in GDP from Sector 562 were not contributing to MSW diversion. The AB's DGPD curve is considerably lower than the national average, and more resources to MSW diversion is recommended. On average, Canada spent about \$225/tonne of MSW handled during the study period. CuPT trends are decreasing, with *S* ranging from +5.15 to +7.67, probably due to more diversified waste management services and improved level of services. The average CuPT for NS was \$339/tonne, about 150.5% of the national average, or 246.6% of SK. Diversion rate is commonly used as a WMS performance indicator. DR however is not an efficiency indicator and may fail to fully capture the true performance of a WMS. A qualitative ranking framework is adopted in this study to evaluate the WMS performance. The results suggest that the use of DR alone to evaluate WMS may be misleading. It appears that WMS in SK and AB are more efficient, at least using the three indicators considered in this study. The findings help the waste community to better understand the trade-offs between various waste management alternatives. We believe the use of input–output indicators is important to evaluate the true performance of WMS, and we recommend the use of these input–output indicators. The proposed qualitative framework utilizing comparative rankings is applicable elsewhere and can be a useful decision support tool for policy-makers.

Author contribution Derek Mensah, Nima Karim, and Kelvin Tsun Wai Ng wrote the original draft. Kelvin Tsun Wai Ng contributed to the study conception and project administration. Investigation and formal analysis were performed by Derek Mensah, Nima Karim, and Tanvir S. Mahmud. Yili Tang and Sotonye Igoniko reviewed the manuscript. All authors read and approved the final manuscript.

Funding The research reported in this paper was supported by a grant from the Natural Sciences and Engineering Research Council of Canada (RGPIN-2019-06154) to the corresponding author, using computing equipment funded by FEROF at the University of Regina. The views expressed herein are those of the writers and not necessarily those of our research and funding partners.

Data availability All data generated or analyzed during this study are included in this article.

Declarations

Ethics approval and consent to participate Not applicable.

Consent for publication Not applicable.

Conflict of interest The authors declare no competing interests.

References

- Abdel-Shafy HI, Mansour MSM (2018) Solid waste issue: sources, composition, disposal, recycling, and valorization. *Egypt J Pet* 27:1275–1290. <https://doi.org/10.1016/j.ejpe.2018.07.003>

- Akinwonmi O (2021) Exploring deconstruction initiatives in construction industry in Lagos State, Doctoral dissertation, Federal University Of Technology, Akure, accessed on <http://196.220.128.81:8080/xmlui/handle/123456789/4851>. by 2022/Jan/02
- Alberta Environmental Network (2021) Alberta announces long-term waste strategy accessed on <https://www.aenweb.ca/node/1827>. by Nov/06/21
- Alemi-Ardakani M, Milani AS, Yannacopoulos S, Shokouhi G (2016) On the effect of subjective, objective and combinative weighting in multiple criteria decision making: a case study on impact optimization of composites. *Expert Syst Appl* 46: 426–438 <https://doi.org/10.1016/j.eswa.2015.11.003>
- Andrade DF, Machado RC, Pereira-Filho ER (2019) Proposition of electronic waste as a reference material—part 2: homogeneity, stability, characterization, and uncertainties. *J Anal at Spectrom* 34(12):2402–2410. <https://doi.org/10.1039/C9JA00284G>
- Asha AZ (2015) Analysis and comparison of solid waste management systems and diversion practices in Alberta and British Columbia. MSc thesis, The University of Regina (Canada), accessed on https://ourspace.uregina.ca/bitstream/handle/10294/7646/Asha_Aklima_Zerin_200310681_MASC_EVSE_Spring2016.pdf?sequence=1&isAllowed=y. by 2022/Jan/02
- Assuah A, Sinclair AJ (2021) Solid waste management in western Canadian First Nations. *Waste Manage* 129:54–61. <https://doi.org/10.1016/j.wasman.2021.05.007>
- Bernache G (2003) The environmental impact of municipal waste management: the case of Guadalajara metro area. *Resour Conserv Recycl* 39(3):223–237. [https://doi.org/10.1016/S0921-3449\(03\)00029-6](https://doi.org/10.1016/S0921-3449(03)00029-6)
- Bolingbroke D, Ng KTW, Vu HL, Richter A (2021) Quantification of solid waste management system efficiency using input–output indices. *J Mater Cycles Waste Manag* 23:1015–1025. <https://doi.org/10.1007/s10163-021-01187-7>
- Bruce N, Asha AZ, Ng KTW (2016) Analysis of solid waste management systems in Alberta and British Columbia using provincial comparison. *Can J Civ Eng* 43(4):351–360. <https://doi.org/10.1139/cjce-2015-0414>
- Bruce N, Ng KTW, Vu HL (2018) Use of seasonal parameters and their effects on FOD landfill gas modeling. *Environ Monit Assess* 190:291. <https://doi.org/10.1007/s10661-018-6663-x>
- Cavalletti B, Corsi M (2019) By diversion rate alone: the inconsistency and inequity of waste management evaluation in a single-indicator system. *Pap Reg Sci* 98(1):307–329. <https://doi.org/10.1111/pirs.12356>
- Chhay L, Reyad MAH, Suy R, Islam MR, Mian MM (2018) Municipal solid waste generation in China: influencing factor analysis and multi-model forecasting. *J Mater Cycles Waste Manag* 20(3):1761–1770. <https://doi.org/10.1007/s10163-018-0743-4>
- Chowdhury A, Vu HL, Ng KTW, Richter A, Bruce N (2017) An investigation on Ontario’s non-hazardous municipal solid waste diversion using trend analysis. *Can J Civ Eng* 44(11):861–870. <https://doi.org/10.1139/cjce-2017-0168>
- Conference Board of Canada (2021) Municipal waste generation. Available at: <https://www.conferenceboard.ca/hcp/Details/Environment/municipal-waste-generation.aspx>. Accessed 2 Feb 2022
- Diggle A, Walker TR (2020) Implementation of harmonized extended producer responsibility strategies to incentivize recovery of single-use plastic packaging waste in Canada. *Waste Manag* 110:20–23. <https://doi.org/10.1016/j.wasman.2020.05.013>
- Fallah B, Richter A, Ng KTW, Salama A (2019) Effects of groundwater metal contaminant spatial distribution on overlaying kriged maps. *Environ Sci Pollut Res* 26(22):22945–22957. <https://doi.org/10.1007/s11356-019-05541-z>
- Fernandes ID, Ferreira FA, Bento P, Jalali MS, António NJ (2018) Assessing sustainable development in urban areas using cognitive mapping and MCDA. *Int J Sustain Dev World Ecol* 25(3):216–226. <https://doi.org/10.1080/13504509.2017.1358221>
- Ferrara I, Missios P (2005) Recycling and waste diversion effectiveness: evidence from Canada. *Environ Resour Econ* 30:221–238. <https://doi.org/10.1007/s10640-004-1518-z>
- Fu P, Weng Q (2015) Temporal dynamics of land surface temperature from Landsat TIR time series images. *IEEE Geosci Remote Sens Lett* 12(10):2175–2179. <https://doi.org/10.1109/LGRS.2015.2455019>
- Ghosh A, Ng KTW (2021) Temporal and spatial distributions of waste facilities and solid waste management strategies in rural and urban Saskatchewan, Canada. *Sustainability* 13(12):6887. <https://doi.org/10.3390/su13126887>
- Government of Alberta (2017) Highlights of Alberta economy accesses on http://www.albertacanada.com/files/albertacanada/SPEH_highlightsABEconomyPresentation.pdf. by 2021/Nov/16
- Government of Saskatchewan (2020) Saskatchewan’s solid waste management strategy accessed on <https://pubsaskdev.blob.core.windows.net/pubsask-prod/115530/Solid%252BWaste%252BManagement%252BStrategy%252B-%252B2020.pdf>. by 2021/Nov/16
- Hamid A, Asghar S (2018) Determination of present household solid waste generation rate, physical composition and existing SWM practices in selected areas of Lahore. *Nat Environ Pollut Technol* 17(1). [https://www.neptjournal.com/upload-images/NL-63-48-\(46\)-D-681.pdf](https://www.neptjournal.com/upload-images/NL-63-48-(46)-D-681.pdf). Accessed 5 May 2022
- Harijani AM, Mansour S (2022) Municipal solid waste recycling network with sustainability and supply uncertainty considerations. *Sustain Cities Soc* 81:103857. <https://doi.org/10.1016/j.scs.2022.103857>
- Islam MR, Kabir G, Ng KTW, Ali SM (2022) Yard waste prediction from estimated municipal solid waste using the grey theory to achieve a zero-waste strategy. *Environ Sci Pollut Res* 29:46859–46874. <https://doi.org/10.1007/s11356-022-19178-y>
- Jovanovic S, Savic S, Jovicic N, Boskovic G, Djordjevic Z (2016) Using multi-criteria decision making for selection of the optimal strategy for municipal solid waste management. *Waste Manag Res* 34(9):884–895. <https://doi.org/10.1177/2F0734242X16654753>
- Kabir G, Ahmed SK, Aalirezai A, Ng KTW (2022) Benchmarking Canadian solid waste management system integrating fuzzy analytic hierarchy process (FAHP) with efficacy methods. *Environ Sci Pollut Res* 29:51578–51588. <https://doi.org/10.1007/s11356-022-19492-5>
- Kaliszewski I, Podkopaev D (2016) Simple additive weighting—a metamodel for multiple criteria decision analysis methods. *Expert Syst Appl* 54:155–161. <https://doi.org/10.1016/j.eswa.2016.01.042>
- Karak T, Bhagat R, Bhattacharyya P (2012) Municipal solid waste generation, composition, and management: the world scenario. *Crit Rev Environ Sci Technol* 4215:1509–1630. <https://doi.org/10.1080/10643389.2011.569871>
- Karimi N, Richter A, Ng KTW (2020) Siting and ranking municipal landfill sites in regional scale using nighttime satellite imagery. *J Environ Manag* 256:109942. <https://doi.org/10.1016/j.jenvman.2019.109942>
- Karimi N, Ng KTW, Richter A (2021) Prediction of fugitive landfill gas hotspots using a random forest algorithm and Sentinel-2 data. *Sustain Cities Soc* 73:103097. <https://doi.org/10.1016/j.scs.2021.103097>
- Karimi N, Ng KTW, Richter A (2022) Development of a regional solid waste management framework and its application to a prairie province in central Canada. *Sustain Cities Soc* 82:103904. <https://doi.org/10.1016/j.scs.2022.103904>
- Kaza S, Yao L, Bhada-Tata P, Van Woerden F (2018) What a waste 2.0: a global snapshot of solid waste management to 2050 accessed on <https://openknowledge.worldbank.org/handle/10986/30317>. by 2022/Jan/02

- Khadka R (2021) Quantification of greenhouse gas emissions under different solid waste management scenarios: a case study of Kathmandu Metropolitan City, Nepal. Doctoral thesis Lincoln University accessed on <https://hdl.handle.net/10182/14287>. by 2022/Jan/02
- Kosoe EA, Osumanu IK, Darko FD (2021) 14 Connecting solid waste management to sustainable urban development in Africa. *Sustain Urban Futures Afr* 288. <https://doi.org/10.4324/9781003181484-14>
- Lakhan C (2014) Exploring the relationship between municipal promotion and education investments and recycling rate performance in Ontario, Canada. *Resour Conserv Recycl* 92:222–229. <https://doi.org/10.1016/j.resconrec.2014.07.006>
- Lakhan C (2015) North of the 46° parallel: Obstacles and challenges to recycling in Ontario's rural and northern communities. *Waste Manag* 44:216–226. <https://doi.org/10.1016/j.wasman.2015.06.044>
- Lakhan C (2016) The relationship between municipal waste diversion incentivization and recycling system performance. *Resour Conserv Recycl* 106:68–77. <https://doi.org/10.1016/j.resconrec.2015.11.010>
- Leveugle R, Calvez A, Maistri P, Vanhauwaert P (2009) Statistical fault injection: quantified error and confidence. *IEEE Proceedings of 2009 Design, Automation and Test in Europe, Conference & Exhibition* 502–506. <https://doi.org/10.1109/DATE.2009.5090716>
- Mann HB (1945) Nonparametric tests against trend. *Econometrica* 13:245–259. <https://doi.org/10.2307/1907187>
- Maryev VA, Smirnova TS (2021) Perspective of CE in Russia: from theory to practice. In: Ghosh SK, Ghosh SK (eds), *Circular Economy: Recent Trends in Global Perspective* 8:259–279 https://doi.org/10.1007/978-981-16-0913-8_8
- Mohsenizadeh M, Tural MK, Kentel E (2020) Municipal solid waste management with cost minimization and emission control objectives: a case study of Ankara. *Sustain Cities Soc* 52:101807. <https://doi.org/10.1016/j.scs.2019.101807>
- Molinos-Senante M, Maziotis A, Sala-Garrido R, Mocholí-Arce M (2022) Factors influencing eco-efficiency of municipal solid waste management in Chile: a double-bootstrap approach. *Waste Manag Res*. <https://doi.org/10.1177/0734242X221122514>
- Mora MDLL, Calabi-Floody M, Rumpel C (2021) Closing biogeochemical cycles and meeting plant requirements by smart fertilizers and innovative organic amendments. *Agronomy* 11(6):115. <https://doi.org/10.3390/agronomy11061158>
- Nazari L, Xu CC, Ray MB (2021) Conventional approaches for waste management—a Canadian perspective. in advanced and emerging technologies for resource recovery from wastes. Accessed on <https://www.springerprofessional.de/en/advanced-and-emerging-technologies-for-resource-recovery-from-wa/19031070>. by 2021/Dec/25
- Pan C, Bolingbroke D, Ng KTW, Richter A, Vu HL (2019a) The use of waste diversion indices on the analysis of Canadian waste management models. *J Mater Cycles Waste Manag* 21:478–487. <https://doi.org/10.1007/s10163-018-0809-3>
- Pan C, Ng KTW, Richter A (2019b) An integrated multivariate statistical approach for the evaluation of spatial variations in groundwater quality near an unlined landfill. *Environ Sci Pollut Res* 26(6):5724–5737. <https://doi.org/10.1007/s11356-018-3967-x>
- Parizeau K, Massow M, Martin RC (2021) Directly observing household food waste generation using composition audits in a Canadian municipality. *Waste Manag* 135:229–233. <https://doi.org/10.1016/j.wasman.2021.08.039>
- Park S, Berry FS (2013) Analyzing effective municipal solid waste recycling programs: the case of county-level MSW recycling performance in Florida, USA. *Waste Manag Res* 31(9):896–901. <https://doi.org/10.1177/0734242X13495725>
- Pires A, Martinho G (2019) Waste hierarchy index for circular economy in waste management. *Waste Manag* 95:298–305. <https://doi.org/10.1016/j.wasman.2019.06.014>
- PPPEC (2019) The 'worst performers' in waste management in Canada: Manitoba, Saskatchewan, and Alberta. Paper and Paperboard Packaging Environmental Council. Accessed on <https://ppep-paper.com/the-worst-performers-in-waste-management-in-canada-manitoba-saskatchewan-and-alberta/>. by 2021/Nov/06/
- Pranuthi G, Dubey SK, Tripathi SK, Chandniha SK (2014) Trend and change point detection of precipitation in urbanizing districts of Uttarakhand in India. *Indian J Sci Technol* 7(10):1573–1582. <https://doi.org/10.17485/ijst/2014/v7i10.20>
- Ratnasabapathy S, Alashwal A, Perera S (2020) Investigation of waste diversion rates in the construction and demolition sector in Australia. *Built Environ Proj Asset Manag* 11(3):427–439. <https://doi.org/10.1108/BEPAM-01-2020-0012>
- Reutter B, Lant PA, Lane JL (2017) The challenge of characterising food waste at a national level—an Australian example. *Environ Sci Policy* 78:157–166. <https://doi.org/10.1016/j.envsci.2017.09.014>
- Richter A, Bruce N, Ng KTW, Chowdhury A, Vu HL (2017) Comparison between Canadian and Nova Scotian waste management and diversion models—a Canadian case study. *Sustain Cities Soc* 30:139–149. <https://doi.org/10.1016/j.scs.2017.01.013>
- Richter A, Ng KTW, Pan C (2018) Effects of percent operating expenditure on Canadian non-hazardous waste diversion. *Sustain Cities Soc* 38:420–428. <https://doi.org/10.1016/j.scs.2018.01.026>
- Richter A, Ng KTW, Karimi N, Wu P, Kashani HA (2019a) Optimization of waste management regions using recursive Thiessen polygons. *J Cleaner Prod* 234:85–96. <https://doi.org/10.1016/j.jclepro.2019.06.178>
- Richter A, Ng KTW, Karimi N (2019b) A data driven technique applying GIS, and remote sensing to rank locations for waste disposal site expansion. *Resour Conserv Recycl* 149:352–362. <https://doi.org/10.1016/j.resconrec.2019.06.013>
- Richter A, Ng KTW, Karimi N (2021) Meshing Centroidal Voronoi Tessellation with spatial statistics to optimize waste management regions. *J Clean Prod* 295:126465. <https://doi.org/10.1016/j.jclepro.2021.126465>
- Rutten-van Mólken M, Leijten F, Hoedemakers M, Tsiachristas A, Verbeek N, Karimi M, Bal R, de Bont A, Islam K, Askildsen JE, Czypionka T (2018) Strengthening the evidence-base of integrated care for people with multi-morbidity in Europe using Multi-Criteria Decision Analysis (MCDA). *Health Serv Res* 18:576. <https://doi.org/10.1186/s12913-018-3367-4>
- Sarra A, Mazzocchitti M, Nissi E (2020) Optimal regulatory choices in the organization of solid waste management systems: Empirical evidence and policy implications. *Environ Sci Policy* 114:436–444. <https://doi.org/10.1016/j.envsci.2020.09.004>
- Statistics Canada (2016) North American Industry Classification System (NAICS) Canada Version 3.0 accessed on <https://www23.statcan.gc.ca/imdb/p3VD.pl?Function=getVD&TVD=1181553>. by 2021/Nov/06
- Statistics Canada (2017) Federal contaminated sites inventory accessed on <http://www.tbs-sct.gc.ca/fcsi-rscf/cen-eng.aspx?dataset=prov&sort=name>. by 2021/Nov/06
- Statistics Canada (2018) Solid waste diversion and disposal, Environmental indicators, Sustainability accessed on <https://www.canada.ca/en/environment-climate-change/services/environmental-indicators/solid-waste-diversion-disposal.html>. by 2021/Nov/06
- Statistics Canada (2021a) Disposal of waste by source in Canada accessed on <https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3810003201>. by 2021a/Nov/06

- Statistics Canada (2021b) Reducing municipal solid waste, “The waste hierarchy-rethinking to recovery” accessed on <https://www.canada.ca/en/environment-climate-change/services/managing-reducing-waste/municipal-solid/reducing.html>. by 2021b/Nov/06
- Statistics Canada (2021c) Waste Management Industry Survey: government sector accessed on <https://www150.statcan.gc.ca/n1/en/surveys/1736?sourcecode=1736&geoname=A0000%2CA0001>. Accessed 6 Nov 2021
- Tiwari H, Pandey BK (2019) Non-parametric characterization of long-term rainfall time series. *Meteorol Atmos Phys* 131(3):627–637. <https://doi.org/10.1007/s00703-018-0592-7>
- Tsai F, Bui TD, Tseng M, Lim MK, Wu K, Md Mashud AH (2021) Assessing a hierarchical sustainable solid waste management structure with qualitative information: policy and regulations drive social impacts and stakeholder participation. *Resour Conserv Recycl* 168:105285. <https://doi.org/10.1016/j.resconrec.2020.105285>
- United Nations (2018) Solid waste management accessed on <https://www.unep.org/explore-topics/resource-efficiency/what-we-do/cities/solid-waste-management>. by 2021/Nov/06
- University of Michigan (2017) Municipal solid waste factsheet accessed on <https://css.umich.edu/factsheets/municipal-solid-waste-factsheet>. by 2021/Nov/06
- Vij D (2012) Urbanization and solid waste management in India: present practices and future challenges. *Procedia Soc Behav Sci* 37:437–447. <https://doi.org/10.1016/j.sbspro.2012.03.309>
- Vu HL, Ng KTW, Richter A, Kabir G (2021) The use of a recurrent neural network model with separated time-series and lagged daily inputs for waste disposal rates modeling during COVID-19. *Sustain Cities Soc* 75:103339. <https://doi.org/10.1016/j.scs.2021.103339>
- Vu HL, Ng KTW, Richter A, Karimi N, Kabir G (2021) Modeling of municipal waste disposal rates during COVID-19 using separated waste fraction models. *Sci Total Environ* 789:148024. <https://doi.org/10.1016/j.scitotenv.2021.148024>
- Wang D, Singhasemanon N, Goh KS (2016a) A statistical assessment of pesticide pollution in surface waters using environmental monitoring data: Chlorpyrifos in Central Valley, California. *Sci Total Environ* 571:332–341. <https://doi.org/10.1016/j.scitotenv.2016.07.159>
- Wang Y, Ng KTW, Asha AZ (2016b) Non-hazardous waste generation characteristics and recycling practices in Saskatchewan and Manitoba, Canada. *J Mater Cycles Waste Manag* 18:715–724. <https://doi.org/10.1007/s10163-015-0373-z>
- Wu J, Zhang W, Zhou Z (2019) Construction resource allocation for industrial solid waste treatment centers in cities of Anhui Province, China. *Manag Environ Qual* 30(5):1190–1202. <https://doi.org/10.1108/MEQ-01-2019-0001>
- Xu J, Lu W, Ye M, Xue F, Zhang X, Lee BFP (2020) Is the private sector more efficient? Big data analytics of construction waste management sectoral efficiency. *Resour Conserv Recycl* 155:104674. <https://doi.org/10.1016/j.resconrec.2019.104674>
- Ye M, Liang X, Lin S, Kin H, Deng F (2022) Efficiency assessment of hazardous waste disposal in EU countries: a three-stage super-efficiency data envelopment analysis model. *Environ Manag* 70:650–665. <https://doi.org/10.1007/s00267-022-01675-y>
- Zaman AU, Lehmann S (2013) The zero waste index: a performance measurement tool for waste management systems in a ‘zero waste city.’ *J Clea Prod* 50:123–132. <https://doi.org/10.1016/j.jclepro.2012.11.041>

Publisher's note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Springer Nature or its licensor (e.g. a society or other partner) holds exclusive rights to this article under a publishing agreement with the author(s) or other rightsholder(s); author self-archiving of the accepted manuscript version of this article is solely governed by the terms of such publishing agreement and applicable law.