



Investigating the drivers of solid waste generation and disposal: evidence from South Africa

Abiodun Olusola Omotayo¹

Received: 28 May 2023 / Accepted: 28 April 2024
© The Author(s) 2024

Abstract

With rapid population growth and urbanization, the global annual waste generation is expected to increase to 3.40 billion tonnes by the year 2050, while improper waste disposal poses a potential threat of growing concern. Using a South African nationally representative survey dataset, the General Household Survey, this study unraveled the determinants of solid waste generation and factors influencing payment for its disposal. The estimation approach employed was essentially based on descriptive (percentage, standard deviation, mean) statistics. Additionally, Tobit regression of the composite solid waste were generated from the Principal Component Analysis, while Probit Regression model assessed the factors influencing the household's payment for solid waste. The empirical results revealed that household's socio-economic characteristics contributes to solid waste generation and payment for its disposal. The results of the two models indicated that, although household's asset portfolio (financial, physical, natural, and human assets) appear intangible, they contributed significantly to solid waste generation and payment for its disposal. Therefore, policy incentives targeted at investment in human capital, environmental awareness programmes and clearer solid waste management strategies should be encouraged in South Africa, given that environmental sustainability is key to the households' health and economic prosperity.

Keywords Environmental health · Pollution · Sanitation services · Sustainable development goals · Waste management

1 Introduction

The amount of waste generated globally is increasing, which can be attributed to the global population explosion, rapid urbanization and industrialization (Khan et al., 2022; Yukalang et al., 2017), particularly in developing nations (Aleluia & Ferrão, 2016; Keho, 2016). These patterns, together with the lockdowns and restrictions due to COVID-19 pandemic, increased the solid waste generation globally. It therefore becomes essential for governments at local and national levels to ensure that more

✉ Abiodun Olusola Omotayo
Olusola.Omotayo@nwu.ac.za

¹ North-West University, Mafikeng, South Africa

sustainable solid waste disposal practices are in place (Moh & Abd Manaf, 2014; Omotayo et al., 2020; Raj & Samuel, 2023). As in other developing nations, solid waste generation in South Africa is rapidly increasing, putting pressure on the already constrained municipal service delivery resources and infrastructure (Dlamini et al., 2017; Haywood et al., 2021; Omotayo et al., 2020; Swilling, 2010).

Solid waste streams, including from businesses, garden refuse, building and demolition wastes, as well as households and community waste, have been established to have harmful health and welfare impacts, particularly on those living in adjacent marginalised communities (Moh & Abd Manaf, 2014; Raj & Samuel, 2023; Tsheleza et al., 2019). Besides the negative health impact caused by water contamination, rodents and insect invasions, improper solid waste management can also have a damaging effect by causing environmental problems such as flooding due to blocked drainages and sewage systems (Ferronato et al., 2017; Ikpe et al., 2020; Omotoso & Omotayo, 2024; Suleman et al., 2015; Ziraba et al., 2016). In addition, the impact of inadequate waste management on health could be physical problems, infection transmission, and emotional and psychological stresses (Raj & Samuel, 2023; Raj et al., 2023).

The need to improve waste generation and management has become increasingly essential with the growing population and urbanization in South Africa, where the local authorities are required to carry out a proper waste disposal (Omotayo et al., 2020; Rodseth et al., 2020). The South Africa national standards for waste collection sets out the various service delivery requirements for instance, a reported solid waste container must be removed within 24 h and a minimum of time in a week to avoid insect breeding, pollution and other environmental hazards (Haywood et al., 2021; Oelofse, 2011).

Improperly disposed households solid wastes, such as paper, plastic wraps, aluminium and glass, contributes to environmental challenges, such as drains blocked, which can cause flooding (ElSaid & Aghezzaf, 2018; Solberg, 2012). In addition, high temperatures and relative humidity increase the leaching of organic waste material, which affects natural ecosystems by contaminating ground water, thereby potentially leading to health issues (Ferronato & Torretta, 2019; Omotoso et al., 2023). Likewise, the water held in waste items (condemned pots, plates, empty tins and cans) could attract mosquitoes or other undesirable insects, while food wastes attract rodents, insects, and play a role in spreading infectious diseases (Solberg, 2012). Furthermore, solid waste generation in South Africa is faster than any other environmental pollutants, while their burning releases greenhouse gases (Challcharoenwattana & Pharino, 2015; Rada et al., 2014).

Environmental sustainability is key in South Africa, however there is scarcity of literature on the determinants of households' waste generation and disposal. Given the possible relationship between a household's livelihoods assets, the environmental and solid waste management, and the efforts to achieve their Sustainable Development Goals (SDGs 3, 6 and 11), this study seeks to investigate the common solid waste disposal practices and their links to household's socioeconomics. An important feature that distinguishes this study from previous research is that it relies on a detailed dataset from the South Africa General Households Survey to explore factors that influence solid waste generation. Having an understanding of these interactions is pertinent for timely policies to address the present and potential future environmental issues. Such information can help to inform the development of awareness that serves the public health interest.

2 Theoretical framework, context and related literature

The Theory of Planned Behaviour (TPB) focuses on changes in individual behaviour, underpinned by attitudes, subjective norms, and perceived behavioral control. It emphasizes control beliefs, which focus on the behavioral changes (Ajzen, 1985, 1991). The concept of self-efficacy was initially emphasized by (Armitage & Conner, 2001). However, TPB has been criticized for placing more emphasis on intention rather than belief (Gonçalves et al., 2021; Sheeran & Orbell, 1999). Some empirical studies, reported that the socio-economics, health, and environmental factors can also explain human behaviours (Duncan et al., 2012; Hagger & Hamilton, 2021; McEachan et al., 2011; Schüz et al., 2017; Sniehotta et al., 2014).

Literature, adopted the TPB in waste recycling behaviours (Ioannou et al., 2013; Kumar, 2019; Kumar et al., 2017; Omotayo et al., 2020, 2021). In the same vein, solid waste generation is a function of people's income levels (Kamran et al., 2015; Khan et al., 2016, 2022; Suthar & Singh, 2015). Other studies have analysed the linkages between recycling behaviour and incomes and education (Omotayo et al., 2020; Saphores & Nixon, 2014; Yokoo et al., 2018). Additionally, Callan and Thomas (2017), found that the quantities of recycled wastes increased with income and education, while Ferrara and Missios (2005), found that the decline in household income led to a fall in their participation in recycling, whereas an increase in educational attainment led to an increase in their participation in recycling.

Moreso Grover and Singh (2014), explained that income was insignificantly leading to generating wastes among some households in Dehradun City. In the same vein, studies, identified that conservation knowledge predicted recycling behavior. Furthermore, people with better information participates in waste recycling, which is in line with several findings (Babaei et al., 2015; Hopper & Nielsen, 1991; Saphores & Nixon, 2014; Saphores et al., 2012). However, some studies have reported better conservation attitudes in urban areas and some occupational status, with no conclusive result in relation to age of individuals (Frederiks et al., 2015; Frick et al., 2004).

South Africa is a major contributor of solid waste (Serge Kubanza & Simatele, 2020), being an upper-middle income nation that generates millions of tonnes per annum (see Fig. 1). In 2012, the nation generated an estimated 108 million tonnes of waste, out of which 59 million tonnes were general waste, with a total of 44 million tonnes household solid waste (Serge Kubanza & Simatele, 2020). The 2019 South African Department of Environmental Affairs and Tourism (DEAT), states that over 42 million cubic metres of general waste is annually generated, with the largest (42%) contributor being the Gauteng Province, having the highest number of people and being the economic hub of the country (Aboginije et al., 2020; Duncan et al., 2012; Nyika & Onyari, 2021; Omotayo et al., 2020).

South Africa's biggest contributors to the solid waste production are mining with 72.3%, pulverized fuel ash of 6.7%, waste from agricultural activities of 6.1%, waste from urban activities of 4.5% and sewage sludge of 3.6% (Muzenda, 2014; Nkosi et al., 2013) with (90.1%) of the country's waste being landfilled, while the waste recycling level has remained at 9.9%, being very low compared to the international standards, with the western nations, such as Germany, Austria recycling up to 63% of theirs (Premalatha et al., 2014). In addition, the Goal 2 of the South Africa's National Waste Management Strategy align with this study that being to ensure adequate delivery of waste services, as solid waste generation increases exponentially while the basic sanitation services have not increased as needed (Fig. 1). The Waste Act 59 of 2008 highlights various instruments tools, waste classification (Serge Kubanza & Simatele, 2020).

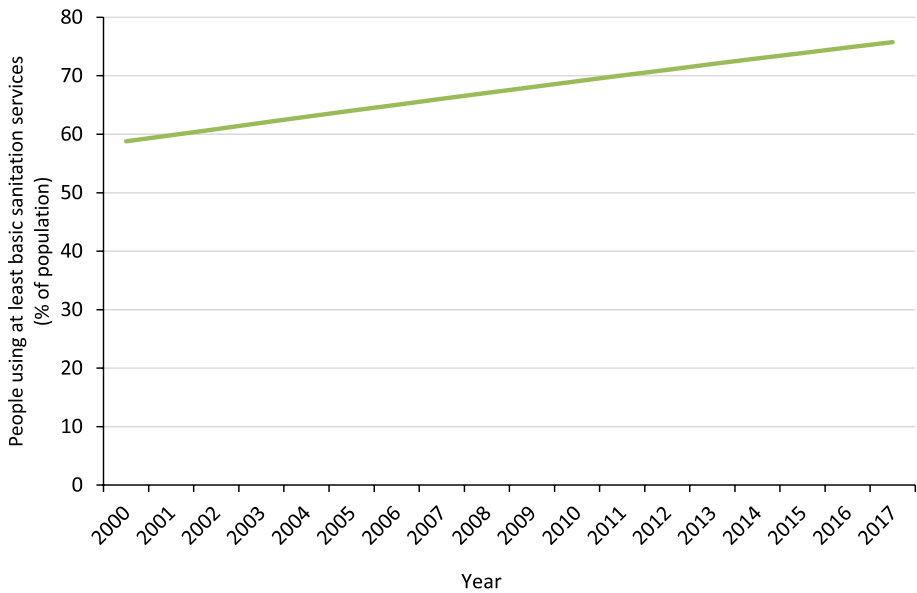


Fig. 1 Trends of people using at least basic sanitation services (% of total population) in South Africa: Source: own plot based from the (World Bank, 2017)

In spite of these, ineffective municipal solid services continue in the country, with 66% of the nation receiving proper waste collection services from local authorities or private companies, which indicates an obvious solid waste disposal problems and the need for solutions to transform solid waste into an economic contributor (Samson & Creation, 2004). The potential of recycling sector in South Africa needs to be conceived, prioritized as economic advantage (Godfrey et al., 2013). Hlahla et al. (2014) noted that this is an avenue to promote sustainable waste management in the nation. Therefore, enhancing household's livelihood assets in South Africa could contribute to the poor and marginalized household's poverty thereby, making it possible to pay for solid wastes and other financial obligations (<https://www.fao.org/3/a0273e/a0273e04.htm>). Similarly, Hangulu and Akin-tola (2017), expressed that the contribution of non-governmental organizations (NGOs) towards solid waste disposal in South Africa needs to be recognized as a commonality that must be encouraged by the green economy principles.

2.1 Emerging approaches to solid waste management

The circular economy concept is more than reducing the waste that needs disposal (Appendix 2). It is an active approach that design products in order to reduce solid waste, this is achieved through a durable output and back into the economy (Gaustad et al., 2018; Mestre & Cooper, 2017; Reike et al., 2018). In the transition of a nations environmental sustainability move where every manufacturer is economically responsible for their consumed/ utilised products (Appendix 2). The application of this principles to solid waste disposal common in the high-income countries, and is at its early stages in the upper-middle income nations like South Africa.

3 Material and methods

3.1 Study area

South Africa has an estimated population of 60 million, and a land mass of 1,220,813 km² (Omotayo et al., 2020, 2021) with nine provinces which are endowed with different natural resources (Fig. 2). It has different forms of residential areas with different level of refuse delivery through the municipalities (Omotayo et al., 2020, 2021). The nation generates

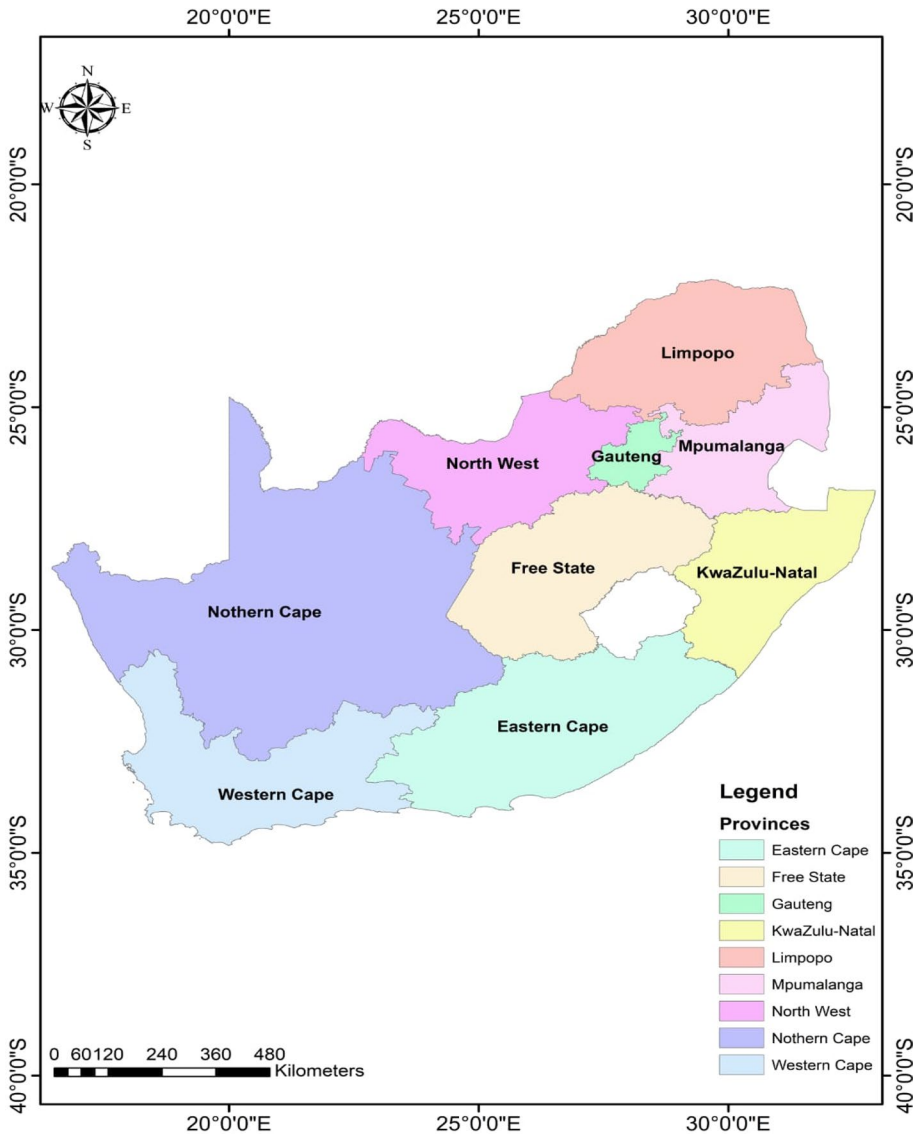


Fig. 2 Geographical location of the South Africa, indicating the nine provinces of the nation

roughly millions tons of waste per year, the extent of waste generation depends on the household's income (van der Merwe, 2020; Verster & Bouwman, 2020).

3.2 Data sources

The data used was obtained from the 2019 GHS, a yearly cross-sectional national study by Statistics South Africa that is administered to households in all nine provinces. In total, data from 19,649 households was captured in the 2019 GHS and used in this research. The sampling procedure involves a two-stage, stratified design with a probability-proportional-to-size (PPS) sampling of primary sampling units (PSUs) from within strata and a systematic sampling of dwelling units (DUs) from the sampled PSUs (Mthethwa & Wale, 2021).

3.3 Analytical techniques

The Principal Components Analytical (PCA) was employed to generate a composite index for household's waste generation. Thereafter, a Tobit regression model was applied on the 2019 GHS dataset to examine the factors influencing solid waste generation.

3.3.1 Principal composite analysis (PCA) for generating solid waste composite index

Principal Components Analysis (PCA) was used to form a composite index of the waste based on five main sources of solid waste generation (Kaza et al., 2018). This helps capture the different dimensions of households' solid wastes in a composite manner. The choice of the indicators was drawn from the literature and data available (Kaza et al., 2018; Omotayo et al., 2020; Rada et al., 2014). Solid waste generation are represented by at least one indicator (Vyas & Kumaranayake, 2006). The variable's dummy form of papers, glass, plastic, metals/aluminum cans, food wastes were computed thus:

$$\text{Solid waste generation index} = \theta_i + \beta_i \sum_{n=1}^C N_{ir} + z_v, \quad (1)$$

where the solid waste generation is the composite waste index, θ_i and β_i are parameters to be estimated, N_{ir} represents the vector of variables and z_v is the error term. Using the index generated as the dependent variable in the Tobit regression analysis.

3.3.2 Tobit regression

To analyse the drivers of solid waste generation, Tobit regression model was regarded as suitable due to its strength in measuring the elasticity of the probability on the household's waste generation. Following earlier studies (Adelekan & Omotayo, 2017; Awotide et al., 2019; Ndhlovu et al., 2020), the composite solid waste index generated previously through the PCA was used as the dependent variable. The latent unobserved variable g_i^* which depends linearly on z_i through a parameter vector α . Where τ_i is a distributed error term. The observed variable g_i is defined as being equal to the latent variable when it is above zero and equal to zero if otherwise (2).

$$g_i = \begin{cases} \sigma_i^{*} & \text{if } o \\ \sigma_i^{*} \leq o \end{cases} \tag{2}$$

where g_i^* is a latent variable:

$$g_i^* = az_i + \tau_i, \\ \tau_i \sim \mathcal{N}(0, \sigma^2)$$

Freeman (1998), proved that the likelihood estimator (Omotayo, 2016; Tobin, 1958a, 1958b), was consistent. The likelihood function of the model (1) is given by L (Eq. 3).

$$L = \prod_o Fi(goi) \prod_i fi(g_i) \\ L = \prod_o [1 - F(z_i a / \sigma)] \prod_i e^{-f[(g_i - z_i a) / \sigma]} \tag{3}$$

where f and F are the standard normal density and cumulative distribution functions, respectively.

Then we can write the log-likelihood function (Eq. 4).

$$\log L = \sum_0 \log(1 - F(Z_i a / \sigma)) + \sum_1 \log \left(\frac{1}{(2 \prod \sigma^2)^{1/2}} \right) - \sum_1 \frac{1}{2 \sigma^2} (g_i - az_i)^2 \tag{4}$$

Which is there estimated by maximizing the log-likelihood function (Eq. 5)

$$\begin{cases} \frac{\partial \log L}{\partial \sigma} = - \sum_0 \frac{z_i f \left(\frac{z_i a}{\sigma} \right)}{1 - F \left(\frac{z_i a}{\sigma} \right)} + \frac{1}{\sigma^2} \sum_1 (g_i - az_i) z_i = 0 \\ \frac{\partial \log L}{\partial \sigma^2} = \frac{1}{2 \sigma^2} \sum_0 \frac{\alpha z_i f \left(z_i \alpha / \sigma \right)}{1 - F \left(Z_i \alpha / \sigma \right)} - \frac{n_i}{2 \sigma^2} + \frac{1}{2 \sigma^4} \sum_1 (g_i - \alpha z_i)^2 = 0 \end{cases} \tag{5}$$

The variables used in the analysis are presented in Table 1, with their descriptions, mean and standard deviation. It was therefore hypothesized in a null form that, there is no significant relationship between the household’s socio-economic profile and solid waste generation in South Africa.

3.3.3 Probit regression of factors influencing payment for household’s solid waste disposal

The study applied probit model for the binary responses to the payment preferences question (Olagunju et al., 2021; Omotayo, 2018a; Omotayo et al., 2022). Probit regression analysis relied on the cumulative normal probability distribution and the binary dependent variable, y , takes on the values of zero and one (Aldrich & Nelson, 1984). In this case, the payment for solid waste disposal preference was taken as 1, while nonpayment preference was coded as 0. It is assumed that the household obtains maximum utility, having payment for solid waste disposal in preference to nonpayment (Liao & Liao, 1994; Karaca-Mandic

Table 1 Determinants of composite waste generation indices in South Africa

Variable	Description	Mean	Std. Dev	Min	Max
<i>Dependent</i>					
Solid waste generation index	Solid wastes' composite indices of waste generation	-6.51e-09	1.916	-10.703	0.547
<i>Independent variables</i>					
Western Cape	Dummy, 1 if yes, 0 if otherwise	0.089	0.286	0	1
Eastern Cape	1 if yes, 0 if otherwise	0.130	0.337	0	1
Northern Cape	1 if yes, 0 if otherwise	0.044	0.205	0	1
Free State	1 if yes, 0 if otherwise	0.064	0.245	0	1
KwaZulu Natal	1 if yes, 0 if otherwise	0.162	0.369	0	1
North West	1 if yes, 0 if otherwise	0.068	0.252	0	1
Gauteng	1 if yes, 0 if otherwise	0.249	0.432	0	1
Mpumalanga	1 if yes, 0 if otherwise	0.081	0.273	0	1
Limpopo	1 if yes, 0 if otherwise	0.112	0.315	0	1
Household size	Number of members (Continuous)	3.511	2.354	1	7
Gender	1 male, 0 otherwise	0.897	0.395	0	1
Population group	1 if African/Black, 0 = Otherwise	0.339	0.839	0	1
Age	Number of years (Continuous)	49.342	15.658	19	71
Type of material used for the roof	1 if Corrugated iron, 0 = otherwise	0.967	0.178	0	1
Type of material used for the walls	1 if Bricks, 0 = otherwise	0.254	0.435	0	1
Type of material used for the floor	1 if Ceramic tiles, 0 = otherwise	0.981	0.137	0	1
Market value of the property	Total value in South African Rands (Continuous)	0.767	0.423	0	1
House subsidy received	1 if yes, 0 if otherwise	0.199	0.399	0	1
Water supply interruption	1 if yes, 0 if otherwise	0.612	0.487	0	1
Toilet facility shared	1 if yes, 0 if otherwise	0.808	0.394	0	1
Uses buses for transport	1 if yes, 0 if otherwise	0.942	0.233	0	1
Uses train for transportation	1 if yes, 0 if otherwise	0.985	0.123	0	1

Table 1 (continued)

Variable	Description	Mean	Std. Dev	Min	Max
Farming practice	1 if crop rotation, 0 if otherwise	0.979	0.144	0	1
Household expenditure	Total value in South African Rands (Continuous)	7511.111	9775.506	1027.53	18,201.98
Total households' income	Total value in South African Rands (Continuous)	7516.181	9884.607	2750.04	33,872.83
Social grant	1 if yes, 0 if otherwise	0.330	0.470	0	1
Grant for farming	1 if yes, 0 if otherwise	0.997	0.056	0	1
Poverty status	1 if poor, 0 if otherwise	0.000	0.007	0	1
Livestock production	1 if yes, 0 if otherwise	0.897	0.304	0	1
Poultry production	1 if yes, 0 if otherwise	0.922	0.268	0	1
Fruit and vegetable production	1 if yes, 0 if otherwise	0.902	0.298	0	1
Has DVD player/Blu-Ray player	1 if yes, 0 if otherwise	0.571	0.495	0	1
Has pay TV (M-Net/DSTV/Top TV)	1 if yes, 0 if otherwise	0.495	0.499	0	1
Has sir conditioner (excluding fans)	1 if yes, 0 if otherwise	0.946	0.226	0	1
Has computer/desktop/laptop	1 if yes, 0 if otherwise	0.804	0.397	0	1
Has vacuum cleaner/floor polisher	1 if yes, 0 if otherwise	0.906	0.291	0	1
Has dishwashing machine	1 if yes, 0 if otherwise	0.959	0.199	0	1
Has washing machine	1 if yes, 0 if otherwise	0.613	0.487	0	1
Has deep freezer—free standing	1 if yes, 0 if otherwise	0.775	0.418	0	1
Has electric stove	1 if yes, 0 if otherwise	0.102	0.302	0	1
Has microwave oven	1 if yes, 0 if otherwise	0.420	0.494	0	1
Has radio	1 if yes, 0 if otherwise	0.622	0.485	0	1
Number of observations	19,649				

The average exchange rate in 2019 (the time of survey) was 1 USD= 14.4496 ZAR (South African Rands)

et al. 2012). The probability p_i of choosing any alternative over not choosing it can be expressed as in (6), (Aldrich & Nelson, 1984):

$$P_i = \text{prob}[Y_i = 1] = \int_{-\infty}^{x_i\beta} (2\pi)^{-1/2} \exp\left(-\frac{t^2}{2}\right) dt = \phi(X_i\beta) \quad (6)$$

The marginal effect associated with the continuous explanatory variables (Table 2) X_k on the probability $P(Y_i=1 | X)$, holding the other variables constant, can be thus derived (Eq. 7) (Aldrich & Nelson, 1984):

$$\frac{\partial p_i}{\partial x_{ik}} = \phi(x'_i\beta)\beta_k, \quad (7)$$

where ϕ represents the probability density function of a standard normal variable. Discrete changes in the predicted probabilities constitute an alternative to the marginal effect when evaluating the influence of a dummy variable. Such an effect can be derived from the following (Eq. 8) (Aldrich & Nelson, 1984):

$$\Delta = \phi(\bar{X}\beta, d = 1) - \phi(\bar{X}\beta, d = 0) \quad (8)$$

The marginal effects give deeper knowledge on how the explanatory variables shift the probability of payment for waste disposal (Hosmer & Lemeshow, 1980), the data are ranked according to the predicted probability of the outcome from the model that is being evaluated (Kramer & Zimmerman, 2007). See Eq. 9:

$$HL = \sum_{i=1}^K \frac{(o_i - n_i\bar{p}_i)^2}{n_i\bar{p}_i(1 - \bar{p}_i)} \sim \chi^2_{K-2} \quad (9)$$

where o_i is the number of outcomes, events, in group i , n_i is the number of observations in group i , \bar{p}_i is the average predicted probability in group i , and K is the number of groups. Equation 9 is referred to as the Hosmer–Lemeshow test statistic HL , which is approximately distributed as a chi-square with a $K-2$ degrees of freedom (Guffey, 2012).

Herewith, it was assumed that the socio-economic status of the households affected the preferences for the payment of solid waste disposal in South Africa. These characteristics were gender, age, household size and income. Table 2 shows the variable definitions, standard deviation, and mean values. The study formulated the second hypothesis relating to socio-economic and demographic factors affecting solid waste disposal among the households. The null hypotheses were therefore that the socio-economics of the households does not significantly affect their payment for solid waste disposal.

4 Socio-economic profile of the South African households

The results across the provinces of South Africa (Table 3) revealed that the average household heads' age was 49 years, which varied slightly between provinces. The result was in line with (Burger et al., 2014; O'Brien & Thondhlana, 2019), whose reports established that the majority of the family heads were in their economically active age groups. In addition, the compiled dataset result reveal that a large percentage (86.69%) of households' heads had educational attainments, the lowest being Mpumalanga Province (79.91%) and the highest the Western Cape Province (95.42%). Education

Table 2 Description of variables influencing solid waste disposal in South Africa (n = 19,649)

Variable	Description	Mean	Std. Dev	Min	Max
<i>Dependent</i>					
Payment for solid waste disposal preference	Dummy, 1 if yes, 0 if otherwise	0.561	0.304	0	1
<i>Independent variables</i>					
Western Cape	Dummy, 1 if yes, 0 if otherwise	0.089	0.286	0	1
Eastern Cape	1 if yes, 0 if otherwise	0.130	0.336	0	1
Northern Cape	1 if yes, 0 if otherwise	0.044	0.205	0	1
Free State	1 if yes, 0 if otherwise	0.064	0.245	0	1
KwaZulu Natal	1 if yes, 0 if otherwise	0.162	0.369	0	1
North West	1 if yes, 0 if otherwise	0.068	0.252	0	1
Gauteng	if yes, 0 if otherwise	0.249	0.432	0	1
Mpumalanga	1 if yes, 0 if otherwise	0.081	0.273	0	1
Limpopo	1 if yes, 0 if otherwise	0.112	0.315	0	1
Gender	1 male, 0 otherwise	0.897	0.395	0	1
Age	Number of years (Continuous)	49.342	15.658	19	71
Household size	Number of household member (Continuous)	3.511	2.355	1	7
Frequency of waste recycle	1 if always, 0 if otherwise	0.966	0.182	0	1
Environmental littering	1 if yes, 0 if otherwise	0.644	0.479	0	1
Uses buses for transportation	1 if yes, 0 if otherwise	0.942	0.233	0	1
Uses train for transportation	1 if yes, 0 if otherwise	0.984	0.123	0	1
Buyers of the agricultural products sold	1 if local buyers, 0 if otherwise	0.982	0.134	0	1
The number cattle the household owns	Number of cattle (Continuous)	85,911.78	18,011.98	47,096.11	105,709.22
The number sheep the household owns	Number of sheep (Continuous)	88,156.44	12,575.13	53,603.67	99,702.06
The number goats the household owns	Number of goats (Continuous)	86,288.44	17,240.32	29,852.12	115,983.44
The number pigs the household owns	Number of pigs (Continuous)	88,272.87	12,218.69	17,402	101,843.11
The number chickens the household owns	Number of chickens (Continuous)	81,990.39	23,779.44	20,216.68	89,083.75

Table 2 (continued)

Variable	Description	Mean	Std. Dev	Min	Max
Remittances	1 if yes, 0 if otherwise	0.843	0.363	0	1
Consistent income	1 if yes, 0 if otherwise	0.509	0.499	0	1
Other income sources	1 if yes, 0 if otherwise	0.975	0.156	0	1
Total households' income	Total value in South African Rand (Continuous)	7516.181	9884.607	0	1
Access to social grant	1 if yes, 0 if otherwise	0.330	0.470	0	1
Has pay TV	1 if yes, 0 if otherwise	0.179	0.383	0	1
Has swimming pool	1 if yes, 0 if otherwise	0.966	0.181	0	1
Has DVD player/Blu-Ray player	1 if yes, 0 if otherwise	0.571	0.495	0	1
Has air conditioner (excluding fans)	1 if yes, 0 if otherwise	0.946	0.226	0	1
Has computer/desktop/laptop	1 if yes, 0 if otherwise	0.804	0.397	0	1
Has tumble dryer	1 if yes, 0 if otherwise	0.999	0.017	0	1
Has deep freezer—free standing	1 if yes, 0 if otherwise	0.775	0.418	0	1
Has home theatre system	1 if yes, 0 if otherwise	0.876	0.329	0	1
Has solar electrical panel	1 if yes, 0 if otherwise	0.989	0.100	0	1
Has rain water tank/harvesting system	1 if yes, 0 if otherwise	0.939	0.239	0	1
Has borehole	1 if yes, 0 if otherwise	0.968	0.175	0	1
Has grey water tank	1 if yes, 0 if otherwise	0.952	0.214	0	1
Has radio	1 if yes, 0 if otherwise	0.622	0.485	0	1

The average exchange rate in 2019 (the time of survey) was 1 USD=14,4496 ZAR (South African Rands)

Table 3 Socio-economic profile of the households

Socio-economic variables	Percentage distribution of the provinces										
	WC	EC	NC	FS	KZN	NW	G	M	L	Pooled	
Age (Years)	46.23	48.19	49.12	48.49	47.35	51.34	55.3	50.09	47.98	49.34	
Income (Rand)	13,644.4	1922.23	12,300.49	16,067.71	6719.2	2297.77	4496.22	7298.12	2899.22	7516.16	
Social Grants	14.88	13.89	12.76	9.31	10.46	10.07	15.71	11.09	13.68	12.43	
Formal Education	95.42	91.62	82.78	86.12	87.96	90.19	83.89	79.91	82.31	86.69	
Gender											
Male	70.29	75.45	48.25	54.56	78.23	42.67	31.32	45.9	69.36	57.34	
Female	29.71	24.55	51.75	45.44	21.77	57.33	68.68	54.1	30.64	42.66	
Household Size	3.21	3.37	4.12	2.62	2.07	2.57	3.52	4.77	5.31	3.51	
Population group of the household head											
African/Black	90.11	81.43	78.25	90.17	80.42	81.43	83.39	79.73	80.17	82.76	
Colored	6.31	5.91	8.67	5.07	8.26	9.06	10.13	10.54	6.21	7.90	
Indian/Asian	1.21	1.26	2.11	2.01	2.91	1.84	2.09	1.78	2.49	1.99	
White	2.37	11.4	10.97	2.75	8.41	7.67	4.39	7.95	11.13	7.35	

Provinces: WC = Western Cape; EC = Eastern Cape; NC = Northern Cape; FS = Free State; KZN = KwaZulu-Natal; NW = North West; G = Gauteng; M = Mpumalanga; L = Limpopo

contributes to the family status and sustainability (Olagunju et al., 2021; Omotayo, 2018b; Omotayo et al., 2020; Omotoso et al., 2022). Furthermore, a report by (Bonal, 2007; Challcharoenwattana & Pharino, 2016; Omotayo et al., 2018), revealed that educational attainments plays a crucial contribution in the mitigation of the negative impact of environmental shocks on people's wellbeing.

In addition, the finding further shows an average monthly income of R7 516.16, with the Western Cape and Free State Provinces earning the highest average monthly incomes of R13 644.44 and R16 067.70 respectively, and the lowest being the Eastern Cape (R1 922.23) and North West Provinces (R2297.77). Households income level affects solid waste disposal globally (Kaza et al., 2018; Thomas et al., 2021). This study's findings indicated that 12.44% of the of the participants have access to social grants, with the highest at 14.88% and 15.71% at the Western Cape and Gauteng Provinces respectively. Social grants (pensions, disability and child grants) are a form of benefit that is intended to reduce poverty for people regarded as being marginalized to improve households' ideal on environmental conservation (Kabeer, 2014; Omotayo et al., 2018). The average rate of 12.44% household's beneficiary across South Africa can be improved in order to reduce the poverty intensity across the nation.

Social grants are needed by many South African households, particularly those who have been negatively affected by the lockdown measures implemented to address the COVID-19 pandemic that results in substantial job losses, as this may have affected their ability to pay for solid waste removal. Male-headed households constituted approximately 57.34% of the study participants, with 48.25% in the Northern Cape, 42.67% in the North West and 31.32% Guateng Provinces. Studies by (Burgess, 1982; Horrell & Krishnan, 2007; Katapa, 2006; Oginni et al., 2013), explained that households' headed by female are poor and usually food starved. They added that they are also usually unmarried, older than their male counterparts, and are typically poorer.

Furthermore, the average households' size of four recorded in the pooled data indicates a fairly moderate family membership compared to the average income (R7 516.16) of the participants. However, large household sizes could aggravate poverty and more use of material that needs to be disposed of as solid waste, which they are unable to pay for. The extent of households' waste generation depends on their income, with Appendix 1 further presenting some of the socio-economic characteristics and asset portfolio items related to their dwelling places. This background indicates how the household's income and access to some basic facilities can influence their waste and its disposal. Over one quarter (25.15%) of households in the pooled data set indicated ownership of their residence, the various associated factors suggesting that a proper structure indicates good income sources, which translates into their having access to and using municipal wastes services.

The monthly rent or mortgage and market value of the South African property shows the presence of economically active households, which translates into greater use of various municipal waste services. Despite having ownership, a national average of 62.23% had not benefited from the governments housing subsidy for first time buyers, this is not good for the poor who are predominantly blacks in the nation. However, many home owners in the Free State (67.23%), KwaZulu-Natal (55.78%) and Limpopo (78.23%) provinces had benefited from this provision, indicating considerable economic activity to enable people to qualify for home loans. Finally, 66.95% of the pooled data indicated water supply interruption across all nine provinces (Appendix 1), which is a major concern, as the prolonged absence of potable water can contribute to health problems (Omotayo et al., 2021). Such incidence of water interruption can make households resolve to use materials such as

paper, tissue paper to improvise for water shortage during domestic and activities hence leading to increase in refuse wastes and disposals in the environments.

4.1 Household's waste disposal and perceptions about the environment

Table 4 revealed that refuse dump/container (77.56%) is the principal method in the study, this being similar to that reported by (Kaza et al., 2018; Omotayo et al., 2020), with each province having their own preferred method. Waste disposal through local authorities (once a week) accounted for 76.23% and 66.67% of the participants from the Free State and Eastern Cape provinces respectively. Limpopo (15.11%) and North West (18.76%) provinces constituted the least. Households in Gauteng (71.09%) and Limpopo (84.49%) provinces ranked highest in term of communal container waste disposal methods. This corroborates the findings of Kaza et al. (2018) on upper middle-income countries and patterns on waste disposal, as illustrated in Fig. 3. More so, Godfrey et al. (2013), revealed that the potential of the recycling needs to be explored and advanced, owing to its numerous associated livelihood and environmental benefits.

In the same vein, Table 5 indicates the households' perceived environmental problems in South Africa, with littering being a major concern (28.81%) and land degradation (3.01%) being of limited concern. The distributions of respondents across the nine provinces revealed that Gauteng (55.34%) and Free State (76.23%) indicated that littering as a major problem. Lack of proper waste removal was the majorly (23.90%) in Gauteng Province. This corroborates the existing body of literature from South Africa that illegally dumped refuses contributes to several environmental challenges, as drains are blocked by the wastes and could cause flooding during rainy seasons (ElSaid & Aghezzaf, 2018; Solberg, 2012).

However, Table 5 further shows that 4.24% of the households had water pollution challenge, specifically in the Gauteng and Free State provinces, with the highest levels of 7.56% and 4.59% respectively. The statistic may be due to contaminations of water body, such as streams and river, due to improper and inappropriate facilities. Inadequate solid waste disposal is capable of leading to negative effects on people's health and the environment (Ferronato et al., 2017; Ikpe et al., 2020; Suleman et al., 2015; Ziraba et al., 2016).

4.2 Solid waste generation, disposal and recycling behaviour

The increasing volumes and changing waste compositions have resulted in municipal solid waste becoming a global challenge, with serious environmental, health and economic cost implications (Alfaia et al., 2017; Kulkarni & Anantharama, 2020; Kumar et al., 2017). Paper, glass, plastic and metal/aluminum are the major sources of waste generation (Bartelings & Sterner, 1999). South Africa has not been excluded, as the type of solid waste recycled (Fig. 3) revealed that paper and cardboard boxes (6.31%) are the most recycled material, while metal (0.87%) is the least. The Western Cape (11.88%) has the highest percentage of recycled paper while the North West (2.91) occupied the least in term of paper recycling. Owing to this, circular economy (Appendix 2) addresses a long possible waste rework, and back into the economy, which is needed in South Africa (Gaustad et al., 2018; Mestre & Cooper, 2017; Reike et al., 2018).

Furthermore, 52.45% of the households pay for waste disposal (Table 6), while the highest was Free State (89.12%) and KZN provinces (75.18%) however, Limpopo (12.34%) and the Eastern Cape (23.89%) households had the lowest. This finding attests to the economic

Table 4 Provincial waste disposal

Waste disposal methods	Percentage distribution of the South African provinces										
	WC	EC	NC	FS	KZN	NW	G	M	L	Pooled	
Local authority/private company at least once a week	55.25	66.67	32.24	76.23	23.13	18.76	55.34	22.19	15.11	34.78	
Local authority/private less than once a week	5.21	4.56	21.19	0.00	8.21	0.00	3.51	7.56	8.90	7.18	
Community members contracted	8.12	3.51	2.45	4.56	4.56	1.02	0.00	0.00	1.36	2.24	
Communal container/central collection	66.67	55.34	76.23	34.78	68.90	55.90	71.09	63.71	84.49	70.45	
Communal refuse dump	74.99	91.34	70.80	82.89	70.80	73.27	63.90	61.40	76.23	77.56	
Own refuse dump	0.00	1.15	3.51	0.00	0.00	1.15	0.00	3.51	4.16	1.89	
Dump or leave rubbish anywhere	0.00	0.00	4.21	15.11	1.15	4.56	3.51	0.00	1.15	2.12	
Other places	0.00	0.00	0.00	1.15	0.14	0.00	0.14	1.02	2.45	0.98	

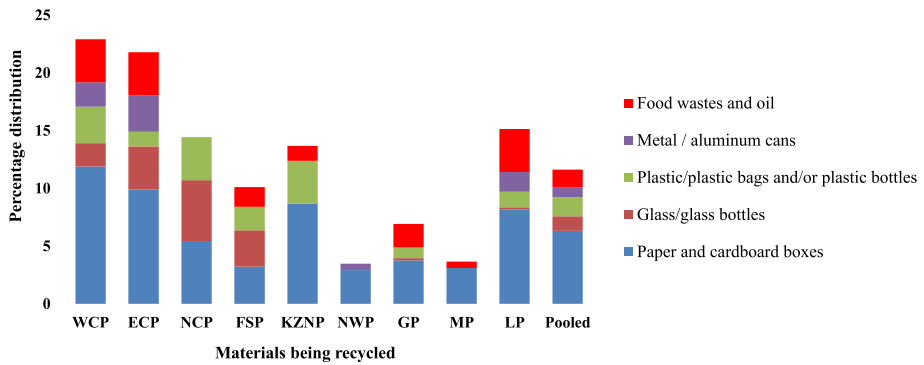


Fig. 3 Provincial households recycling waste generated

Table 5 Provincial indication of environmental challenges

Environmental issues	Percentage distribution of the South African provinces									
	WC	EC	NC	FS	KZN	NW	G	M	L	Pooled
Irregular or no waste removal	5.21	7.56	15.11	8.21	7.56	15.11	4.21	5.21	2.14	7.90
Littering	31.22	15.11	39.24	76.23	23.13	18.76	55.34	22.19	32.24	28.81
Water pollution	4.21	4.24	2.14	4.59	3.51	4.21	7.56	1.15	2.56	4.24
Outdoor/indoor air pollution	2.33	4.21	7.56	15.11	21.56	12.27	18.09	10.43	15.24	13.87
Land degradation	2.14	3.39	4.21	7.56	2.21	4.13	3.39	4.21	3.21	3.01
Excessive noise pollution	8.21	7.56	5.21	3.51	7.56	2.14	7.56	3.39	4.56	5.89

Table 6 Provincial payment for solid waste disposal

Willingness to pay	Percentage distribution of the South African provinces									
	WC	EC	NC	FS	KZN	NW	G	M	LP	Pooled
Currently paying for refuse service										
Yes	65.67	23.89	56.23	89.12	75.18	82.17	42.12	52.78	12.34	52.45
No	28.9	64.23	34.78	5.61	21.67	16.9	54.12	44.12	62.11	42.12
No response	5.43	11.88	8.99	5.27	3.15	0.93	3.73	3.09	25.55	5.43

level of the households in the mentioned provinces, it is an indication of the poverty level of the Limpopo and the Eastern Cape provinces who were the poorest provinces since ability to pay is supposed to move in the direction of the participant’s financial capability.

In addition, Table 6 further indicates those that were doing otherwise, with Limpopo and Eastern Cape Provinces with 62.11% and 64.23% respectively, while Free State (5.61%) and North West Provinces (16.9%) reported the lowest percentages. The literature corroborate these finding, with solid wastes generated from these provinces having potentials that can be explored for economic and livelihood benefits (Kaza et al., 2018; Omotayo et al., 2020; Ozturk et al., 2017). Therefore, exploring these underlining factors that

influence the payment of solid waste disposal could inform the development of awareness campaigns that serve the public health interest in South Africa.

5 The determinants of solid waste generation and disposal in South Africa

PCA was used to formulate the household's solid waste generation index, which was the dependent variable in the Tobit model. In order to avoid inconsistency and bias in the result, the variables were subjected to a multicollinearity test, through the variance inflation factor (VIF), with 1.48 mean. In addition, a high degree of tolerance computed indicates the absence of serious multicollinearity in the result. Therefore, the socio-economic and livelihood assets indicated a different level of statistical significance (Table 7), the null hypothesis should be rejected. The coefficients of the dummy variables representing the South Africa's nine provinces were significant ($p < 0.01$) and positive, which implies a direct relationship between them and their composite solid waste generation level. Households generate solid wastes of different degree based on income and other socio-economic attributes. However, many solid waste types are hazardous to the environment and human life, and need to be carefully treated according to proper waste regulations. The findings corroborates existing studies across the provinces of South Africa (Haywood et al., 2021; Moleko, 2019; Niyobuhungiro & Schenck, 2020; Nyika & Onyari, 2021; Schoeman, 2021; Sowman & Brown, 2006; Tsheleza et al., 2019).

Similarly, the household size was significant ($p < 0.05$) and positive (0.0129) which implies that, as the number of household increases, the composite solid waste generation indices increased. This is to be expected, as an increase in the household number raise the family income, which would influence consumption and therefore solid waste generation. This agrees with the concept of income effect, that shows that change in demand for goods is triggered by an adjustment in consumer's purchasing power resulting from a change in the real income (Balassa, 1964; Boulding, 1945; Rogoff, 1996). Alternatively, the coefficients of the participant's population group, age, house roofing materials and market value of the property were negative and significant ($p < 0.01$, $p < 0.01$, $p < 0.1$ and $p < 0.05$) respectively. This indicates that these variables contribute negatively to the households' composite solid waste index. Furthermore, the population group (1 if African/black, 0 = otherwise) indicates that Black households head respondents have a lower possibility of increasing the household's solid waste generation level. More so, increasing age of the head reduces the solid waste generation level of the household, which may be due to a reduction in the consumption pattern as households' age.

Likewise, the parameter of the household's housing material (1 if corrugated iron, 0 = otherwise) shows that households with corrugated iron roof material have less possibility of increasing their composite solid wastes compared to those with other forms of roofing materials. This could be due to the households being poor with limited income, as solid waste generation levels travel in the same direction of their income. Similarly, the parameters of the property market value (total value in South African Rand) indicates that an increasing amount translates into lower household's waste generation, which is unexpected, as increase in the market value would be assumed to lead to increase in waste generation.

The parameters of a household's access to housing subsidy, water supply interruption and total household's income were positive ($p < 0.01$), which indicates that these variables have a strong positive relationship with solid waste generation. Expectedly, households are

Table 7 Tobit Regression estimates of the correlates of composite solid waste generation

Variables	Coefficients	Robust Std. Error	t	P> t	Tolerance
Western Cape Province	–	–	–	–	–
Eastern Cape Province	1.2804	0.0889	14.39	0.000***	0.3667
Northern Cape Province	1.3405	0.0947	14.15	0.000***	0.6526
Free State Province	1.3228	0.0894	14.80	0.000***	0.5640
KwaZulu-Natal Province	1.3113	0.0875	14.98	0.000***	0.3272
North West Province	1.1146	0.0909	12.26	0.000***	0.5568
Gauteng Province	0.9123	0.0892	10.23	0.000***	0.3192
Mpumalanga Province	1.2722	0.0893	14.25	0.000***	0.4894
Limpopo Province	1.2852	0.0849	15.14	0.000***	0.4062
Household size	0.0129	0.0059	2.18	0.029**	0.5749
Gender	–0.0047	0.0247	–0.19	0.848	0.9015
Population group	–0.2909	0.0311	–9.35	0.000***	0.5134
Age	–0.0028	0.0008	3.55	0.000***	0.7557
Type of material used for roof	–0.1076	0.0641	–1.68	0.093*	0.9866
Type of material used for walls	0.0024	0.0311	0.08	0.938	0.5494
Type of material used for floor	0.0405	0.0748	0.54	0.588	0.9468
Market value of property	–0.0481	0.0192	–2.50	0.012**	0.7181
House subsidy received	0.0748	0.0215	3.47	0.001***	0.6487
Water supply interruption	0.1348	0.0249	5.41	0.000***	0.9325
Toilet facility shared	–0.0513	0.0317	–1.62	0.106	0.7305
Uses buses for transport	–0.0751	0.0448	–1.68	0.094*	0.9530
Uses train for transportation	–0.1059	0.1116	–0.95	0.343	0.9709
Farming practice	0.0051	0.1007	0.05	0.959	0.8645
Household expenditure	–0.0977	0.0663	–1.47	0.141	0.9842
Total households income	0.1059	0.0271	3.91	0.000***	0.7912
Social grant	–0.0436	0.0313	–1.39	0.163	0.5387
Grant for farming	–0.4343	0.0989	–4.39	0.000***	0.9924
Poverty status of the household	–0.1188	0.0479	–2.48	0.013**	0.9986
Livestock production	–0.1117	0.0407	–2.75	0.006***	0.2555
Poultry production	0.1395	0.0461	3.03	0.002***	0.2637
Fruit and vegetable production	0.2069	0.0459	4.51	0.000***	0.7729
Has DVD player/Blu-Ray player	0.0097	0.0265	0.36	0.715	0.8108
Has pay TV (M-Net/DSTV/Top TV)	–0.0433	0.0306	–1.42	0.156	0.6256
Has air conditioner (excluding fans)	–0.0587	0.1109	–0.53	0.596	0.7152
Has computer/desktop/laptop	0.0851	0.0462	1.84	0.066*	0.6207
Has vacuum cleaner/floor polisher	0.5680	0.0931	6.10	0.000***	0.5461
Has dishwashing machine	0.5225	0.1557	3.35	0.001***	0.6749
Has washing machine	0.0254	0.0317	0.80	0.424	0.5185
Has deep freezer, free standing	0.0859	0.0422	2.04	0.042**	0.7318
Has electric stove	0.5244	0.0259	2.02	0.043**	0.8292
Has microwave oven	0.0421	0.0252	1.67	0.095*	0.5605
Has radio	0.1567	0.0261	6.00	0.000***	0.9084
Constant	–1.0212	0.2873	–3.55	0.000	
Number of observations	19,649				

Table 7 (continued)

Variables	Coefficients	Robust Std. Error	t	$P > t $	Tolerance
Prob > F (41)	0.0000				
Pseudo R^2	0.0348				
Log pseudo likelihood	-37,992.347				
Mean Variance Inflation Factor	1.48				

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$; Dependent variable = Solid waste generation index (Composite indices)—Mean (-6.51e-09), Std. Dev. (1.916)

likely to spend more money and generate more solid waste when they have access to a housing subsidy, leading to increased solid waste generation. Similarly, the coefficient of the household's experience of water supply interruption was captured as dummy, which implies that water interruption increases the chances of households' solid waste generation. This supports the apriori knowledge of this study that, the frequency of households' water supply interruption could lead to the use of alternative materials (paper, tissue, wipes) for domestic activities, which invariably increases their solid waste generation level. The parameter of the household total income indicates that access to multiple sources of income increases the households' waste generation propensity, which is to be expected and supported by the concept of "income effect" (Balassa, 1964; Rogoff, 1996).

Alternatively, the coefficients of household head's use of public buses for transport ($p < 0.1$), access to a grant for farming activities ($p < 0.01$), poverty status ($p < 0.05$) and livestock's production ($p < 0.01$) were negative and significant. This indicates that an increase in these variables leads to a reduction in solid waste generation. Other variables were contrary to the expected outcomes, as the use of public buses, grants for farming and engagement in livestock production were expected to lead to an increase in solid waste generation. However, an increase in the poverty status of a households could lead to a reduction in solid waste generation, based on the fact that an increase in income and prosperity could increase solid waste generation.

Finally, nine of the household's asset portfolios (poultry, and fruit and vegetable production, having a computer, vacuum cleaner, dishwashing machine, deep freezer, electric stove, microwave oven and radio were positively significant ($p < 0.01$, $p < 0.01$, $p < 0.1$, $p < 0.01$, $p < 0.01$, $p < 0.05$, $p < 0.05$, $p < 0.1$ and $p < 0.01$ respectively) to solid waste generation. This is, as expected, as these assets are also indicators of income, which increases solid waste generation (Balassa, 1964; Rogoff, 1996). The asset portfolio of the households was major determinant of their solid waste generation, with the model showing that although factors such as financial, natural, physical, and human assets appear intangible, they contributed significantly to solid waste generation. Therefore, it must be seen as both with consumption benefits and potential environmental threat that is capable of generating waste in South African communities.

5.1 Estimates of the factors influencing payment for solid waste disposal

The results being reported in Table 8 Sows the estimate of the determinants of payment for solid wasted disposal in South Africa, a multicollinearity test among the variables was 1.22 with a high tolerance computed which translates into the absence of serious multicollinearity therefore, second null hypothesis is hereby rejected. Furthermore, the marginal effects

Table 8 Probit regression analysis result of the factors influencing payment for solid waste disposal

Variable	Coefficients	Robust std. error	t	P> t	Tolerance	Marginal effects	Robust std. error
Western Cape	—	—	—	—	—	—	—
Eastern Cape	0.7714	0.0502	15.36	0.000***	0.4004	0.1909	0.0095
Northern Cape	0.4561	0.0606	7.52	0.000***	0.6728	0.1213	0.0133
Free State	0.7150	0.0554	12.90	0.000***	0.5839	0.1727	0.0097
KwaZulu Natal	0.9357	0.0465	20.12	0.000***	0.3864	0.2249	0.0084
North West	1.0489	0.0569	18.44	0.000***	0.5772	0.2204	0.0073
Gauteng	0.4133	0.0409	10.09	0.000***	0.3341	0.1199	0.0109
Mpumalanga	0.5510	0.0536	10.28	0.000***	0.5256	0.1436	0.0112
Limpopo	1.3574	0.0556	24.41	0.000***	0.4529	0.2661	0.0064
Gender	0.0185	0.0238	0.78	0.436	0.8758	0.0058	0.0075
Age	-0.0153	0.0008	-18.37	0.000***	0.7601	-0.0048	0.0003
Household size	-0.0100	0.0061	-1.63	0.103	0.5794	-0.0031	0.0019
Frequency of waste recycle	0.2168	0.0636	3.41	0.001***	0.9237	0.0726	0.0226
Environmental littering	-0.4495	0.0243	-18.46	0.000***	0.9339	-0.1344	0.0069
Uses buses for transport	-0.2709	0.0491	-5.52	0.000***	0.9555	-0.0778	0.0127
Uses train for transportation	-0.1608	0.0847	-1.90	0.057*	0.9737	-0.0477	0.0236
Buyers of the agricultural products sold	-0.4126	0.1619	-2.55	0.011**	0.8676	-0.1107	0.0357
Number of cattle the household owns	-9.15e-06	1.35e-06	-6.77	0.000***	0.7332	-2.88e-06	0.0000
Number of sheep the household owns	-1.49e-07	1.67e-06	-0.09	0.929	0.8605	-4.70e-08	0.0000
Number of goats the household owns	-3.71e-06	1.21e-06	-3.07	0.002***	0.7891	-1.17e-06	0.0000
Number of pigs the household owns	-5.41e-06	1.89e-06	-2.87	0.004***	0.9188	-1.70e-06	0.0000
Number of chickens the household owns	-0.0000	9.71e-07	-13.44	0.000***	0.7502	-4.10e-06	0.0000
Remittances	0.0381	0.0354	1.08	0.282	0.8111	0.0119	0.0111
Consistent income	0.1243	0.0271	4.59	0.000***	0.6712	0.0391	0.0085
Other income sources	0.2026	0.0699	2.90	0.004***	0.9631	0.0637	0.0222

Table 8 (continued)

Variable	Coefficients	Robust std. error	t	P > t	Tolerance	Marginal effects	Robust std. error
Total households income	-0.0000	1.29e-06	-9.52	0.000***	0.7302	-3.86e-06	0.000
Access to social grant	0.2686	0.0320	8.38	0.000***	0.5380	0.0816	0.0094
Has pay TV	0.6519	0.0382	17.04	0.000***	0.8082	0.1729	0.0081
Has swimming pool	0.6769	0.0859	7.87	0.000***	0.8120	0.2476	0.0341
Has DVD player/Blu-Ray player	0.1709	0.0236	7.26	0.000***	0.8110	0.0542	0.0075
Has air conditioner	0.5731	0.0631	9.08	0.000***	0.7377	0.2058	0.0247
Has computer	0.5414	0.0309	17.48	0.000***	0.6687	0.1865	0.0115
Has tumble dryer	-0.0643	0.5108	-0.13	0.900	0.9889	-0.0198	0.1533
Has deep freezer—free standing	0.2738	0.0287	9.54	0.000***	0.7598	0.0902	0.0099
Has home theatre system	0.2947	0.0347	8.50	0.000***	0.8320	0.0992	0.0124
Has solar electrical panel	0.1998	0.1129	1.77	0.077*	0.9736	0.0668	0.0398
Has rain water tank/harvesting system	-0.3858	0.0572	-6.75	0.000***	0.8512	-0.1062	0.0135
Has a borehole	-0.5147	0.0786	-6.54	0.000***	0.8747	-0.1328	0.0159
Has grey water tank	-0.7241	0.0696	-10.41	0.000***	0.9042	-0.1723	0.0113
Has radio	0.0643	0.0233	2.76	0.006***	0.9091	0.0203	0.0074
Constant	2.8628	0.6695	4.28	0.000			
Number of observations	19,649						
Wald χ^2 (39)	4139.71						
Prob > χ^2	0.0000						
Pseudo R^2	0.3105						
Log pseudolikelihood	-191.915						
Goodness of fit measure, Hosmer-Lemeshow χ^2	30.61						
Prob > χ^2	0.0002						
Mean Variance Inflation Factor (VIF)	1.22						

*** $p < 0.1$, ** $p < 0.05$, * $p < 0.01$; Dependent variable = Payment for solid waste disposal preference (Dummy)—Mean (0.561), Std. Dev. (0.304)

were estimated and reported for better interpretation of result (Greene, 2012). Furthermore, the goodness of fit for the model were through Wald χ^2 , Pseudo R^2 and Hosmer–Lemeshow χ^2 Archer and Lemeshow (2006), which were equally reported in the Table, with the employed diagnostics measures indicating that the Probit model was a good fit. The results show that the households' provinces captured in their dummy form increased the probability of paying for solid waste disposal significantly ($p < 0.01$). In other words, households from the Western Cape Province have a higher probability of paying for their solid waste disposals than with their counterparts from other provinces. This could be due to the Western Cape Province's single largest contributor to the region's economy with agricultural produce and wine dominating exports (Midgley et al., 2005).

Additionally, the coefficients of age (-0.0153) and household's frequency of waste recycling (0.2168) were significant ($p < 0.01$). This implies that increasing age of the household head has a lower probability of influencing the household's payment for solid waste disposal. It indicates that an increase in the respondents' age has a 0.0048 probability of reducing payment for solid waste disposal. Meanwhile, the parameter of the household's frequency of waste recycling was significant and positive, which indicates that households with higher frequency of recycling their solid waste have higher probability of paying for their solid waste disposals. This means that a unit increase in the household's frequency of waste recycling has a 7.26% increase in the willingness to pay for waste disposal.

Alternatively, the parameters of variables such as environmental littering ($p < 0.01$), use of buses ($p < 0.01$) and trains for transport ($p < 0.1$), and buyers of the agricultural products sold ($p < 0.05$) were negatively significant. This indicates that an increase in this variable can reduce the probability of the household's payment for solid waste disposal. The marginal effect of the variables was also negative and significant, implying that a unit increase will result in reductions in environmental littering (13.44%), use of buses (7.78%) and trains for transport (4.77%) and buyers of agricultural products sold (11.07%) in the likelihood of the households to pay for waste disposal. Likewise, the parameters of some natural capitals, such as the number cattle, sheep, goat, pig, and chickens the household own, were negative and significant ($p < 0.01$). This implies that increasing the number of these natural capitals has the potential to reduce the households' payment for solid waste disposal. This does not corroborate the apriori expectation that an increase in the households' natural capital is likely to lead to a propensity to pay for solid waste disposal.

Furthermore, additional dimensions of financial and natural capital (total household's income, has a rain water tank/harvesting system, borehole, and grey water tank) were negatively significant ($p < 0.05$) variables. This indicates that the households that have these financial and natural capital items, all things being equal, have a lower likelihood of payment for solid waste disposal. The parameter of these variables were further explained as an increasing accumulation of the assets leads to varying degrees of reductions in the probability of paying for solid waste disposal by the households. This is unexpected, as a larger asset portfolio should lead to the capability to pay for solid waste disposal, although this could be a peculiar issue with South Africa or perhaps solid waste disposal is just not available, so they cannot pay for it.

Some important financial capital items stood out to influence households' payment for solid waste disposal in the study. The coefficient of access to a consistent household income, other income sources and social grants were significant ($p < 0.01$). This shows that access to these variables increases the households' probability of paying for solid waste disposal. This supports the assertions in the literature that a household's financial asset possession affords them the ability to generate more wastes and the economic power to pay for wasted disposal (Anand, 1999; Bartelings & Sterner, 1999; Ferronato & Torretta, 2019;

Owusu et al., 2013; Tsheleza et al., 2019). Similarly, the parameters of selected households' possession of physical capital items, such as television set ($p < 0.01$), swimming pool ($p < 0.01$), DVD player ($p < 0.01$), air conditioner ($p < 0.01$), computers ($p < 0.01$), deep freezer ($p < 0.01$), home theatre system ($p < 0.01$), solar electrical panel ($p < 0.1$) and radio set ($p < 0.01$) were positive and significant for their probability of paying for solid waste disposal (Table 8). This was expected, as it implies that respondents who possess these physical capital items have higher likelihood of paying for their solid waste disposal *ceteris paribus*.

On the other hand, participants that answered 'yes' to the possession of these physical capitals have higher probability of paying for their solid waste disposal because they live where waste is available. This is possibly due to their having more disposable income with which to buy non-essential items and therefore generating more wastes. The importance of livelihood assets cannot be overemphasized in the request for household's payment for solid waste disposal, enabling the accumulation of assets by the poor to reduce poverty and vulnerability will help in the pursuit of this goal, as well as ability to pay for their waste disposal (Gorman et al., 2001; Peprah et al., 2017). This emphasizes the role of livelihood assets as key determinants of solid waste disposal in South Africa. According to Peprah et al. (2017), social protection programmes have the capacity to empower the poor with economically productive livelihood assets that transform and move them out of the extremely poor class, their increasing purchasing power being key to their prosperity and payment for solid wastes disposal.

5.2 Practical implications, limitations and directions for future research

While this study does have limitations, it is important to emphasize that the limitations do not impact the validity of the present findings. This finding emphasized that the practice of waste generation and factors influencing the payment for solid waste disposal among the South African is still inadequate, since food waste is being combined with other household garbage. This work serves as a foundational dataset in a location where scarce research has been prioritized in this area. Although certain components of this study are significant, additional on children and teenagers as participants, as well as a more comprehensive questionnaire that addresses specific health consequences. More so, the study is constrained to the South Africa, which necessitates a broader Southern African Development Communities (SADC) nations to extrapolate the bigger picture of the findings. Likewise, the survey questions relied on self-reporting, which might be susceptible to bias, also the dataset requires additional variables to analyze cultural elements, in addition to economic, sociological, and environmental issues. Furthermore, using questionnaires in conjunction with secondary data in future research will improve the assessment and verification of a statistically robust framework and hypotheses for a more robust and representative report. It is therefore advisable to do further research by observing households or waste collection stations in order to supplement the survey. Furthermore, the connection between socio-economic characteristics within households and their impact on health outcomes was restricted herewith. Subsequent research should investigate this issue in order to develop more targeted and long-lasting public awareness initiatives. Finally, employing instrumental variable models and sensitivity analysis for evaluation of future study would be a superior choice to address any potential selective bias that may arise throughout the research analysis as well as the impact and practical implications of the study.

6 Conclusion, recommendation, and policy implications

In South Africa, households are at environmental and health risk as a result of poor waste collection service delivery. Using a nationally representative South African survey dataset, the complexities of the factors influencing household's solid waste generation and disposals were unravelled. The study found that 52.45% of households pay for solid waste disposal, and access to new technologies, including political will, the allocation of adequate resources and therefore appropriate services, water interruptions and poor environmental sanitation. Where they are available, ineffective and irregular waste collection services results in improper and illegal waste disposals and littering (leaving rubbish anywhere). These inappropriate waste practices led to associated refuse dump environmental problems. The main sources of households waste generation were paper and cardboard boxes, glass/glass bottles, plastic/plastic bags and/or plastic bottles and metal/aluminum cans. The study applied Principal Component Regression of factors influencing the households waste generation, with many of their socio-economic and livelihood assets variable being statistically significant. Likewise, the Probit regression model found that solid waste generation and disposal was greatly determined by their socio-economic and asset portfolio, such as financial, physical and human assets, which are intangible but regarded as significant indicators by the two models. Household's solid waste generation and disposal must therefore be seen in the light of both consumption—utilization and investments assets as their livelihood assets have a tangible effect on their waste generation and payment for disposal. The findings further stressed the need for the government to enhance the wellbeing of the citizenry through capacity development and skill building programs, such as social protection programmes. Clearer guidelines and strategies could also help to inform decision-making and public health campaigns to reduce exposure to uncollected waste. Ensuring political will and enhancing the capacity of government institutions through policy-making, regulatory, technical and managerial capacity of the local authorities who are responsible for their implementation is a major dimension to explore if South Africa is to achieve the SDG 3-good health and wellbeing; 6- clean water and sanitation and 11- sustainable cities and communities.

Appendix 1

See Table 9.

Table 9 Selected livelihood indicators related to household's dwelling place

Households residents profile	Percentage distribution of the South African provinces									
	WC	EC	NC	FS	KZN	NW	G	M	L	Pooled
Ownership of dwelling	15.77	63.18	1.40	3.51	9.01	5.77	1.07	10.21	8.21	13.13
Rented	1.31	0.61	1.80	2.11	76.12	2.18	1.40	1.40	5.77	10.30
Owned, but not yet paid off to bank/fin	5.25	0.18	3.83	12.33	1.31	1.40	2.18	1.40	1.40	3.25
Rented from other (including municipality)	0.69	5.67	1.23	10.21	5.07	1.80	5.77	1.40	15.77	5.29
Owned, but not yet paid off to private	1.12	7.89	3.56	5.15	3.83	3.83	24.90	1.80	21.89	8.22
Owned and fully paid off	15.90	24.67	41.21	7.09	5.77	1.40	20.29	3.83	16.01	15.13
Occupied rent-free	23.12	18.90	1.21	14.67	3.12	55.78	29.51	1.40	20.19	18.66
Unspecified	35.21	51.12	59.10	62.31	15.25	23.83	32.33	51.31	31.40	40.21
Monthly rent/mortgage										
Less than R500	4.65	0.9	21.74	3.83	12.33	1.31	1.4	3.83	12.33	6.92
R500—R3000	5.07	0.53	3.51	9.01	5.77	1.07	10.21	3.51	9.01	5.30
R3001—R7000	3.83	0.72	5.77	1.07	10.21	8.21	5.15	5.77	1.07	4.64
R7001—R10,000	3.12	9.72	0.18	3.83	12.33	1.31	1.4	0.18	3.83	3.99
Above R10,000	1.64	0.02	0.69	5.67	1.23	10.21	5.07	1.8	0.69	3.00
Unspecified	76.99	20.85	45.67	41.4	53.51	49.01	65.77	71.07	10.21	48.28
Market value of property										
Less than R50,000	23.32	2.18	1.40	1.40	5.06	1.07	10.21	5.77	1.07	5.72
R50,000—R250,000	27.22	1.40	1.80	1.80	3.83	0.72	5.77	1.07	3.83	5.27
R250,000—R1000,000	12.67	1.80	3.83	3.83	0.02	0.69	5.67	1.23	10.21	4.44
Above R1000,000	7.77	3.83	1.40	1.23	7.89	3.56	5.15	3.83	3.83	4.28
Unspecified	22.91	75.71	91.80	93.56	89.72	92.18	63.83	78.33	81.31	76.59
House subsidy received										
Yes	16.01	21.89	9.12	67.23	55.78	12.56	10.67	29.51	78.23	33.44
No	56.23	72.19	67.09	24.89	37.11	71.09	70.23	38.12	20.19	50.79

Table 9 (continued)

Households residents profile	Percentage distribution of the South African provinces										
	WC	EC	NC	FS	KZN	NW	G	M	L	Pooled	
Unspecified	27.76	5.92	23.79	7.88	7.11	16.35	19.1	32.37	1.58	15.76	
Water supply interruption											
Yes	78.21	82.51	89.25	56.72	60.05	89.22	40.04	92.01	14.56	66.95	
No	21.08	9.12	5.11	36.66	23.14	8.9	56.11	4.15	12.54	19.65	
Not applicable	0.71	8.37	5.64	6.62	16.81	1.88	3.85	3.84	72.9	13.40	

Appendix 2

See Fig. 4.

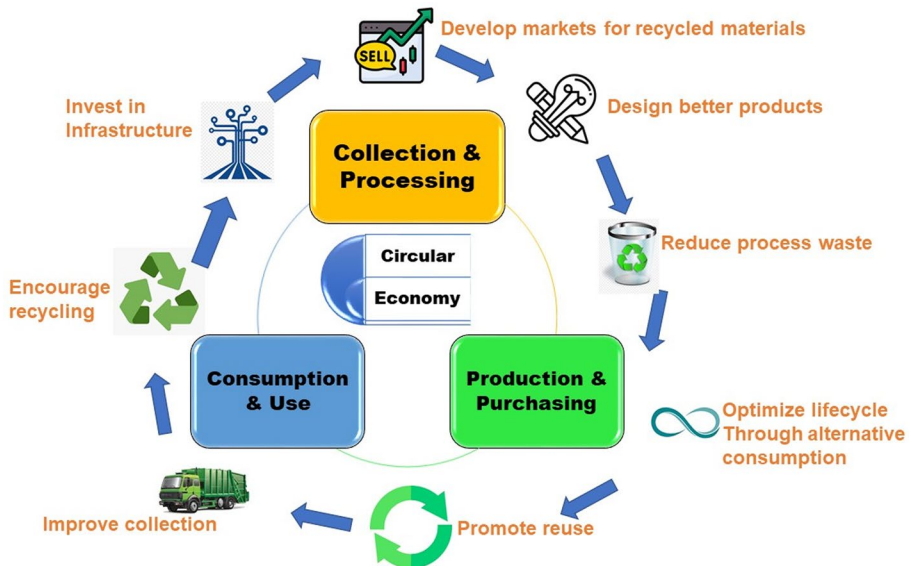


Fig. 4 Circular economy concept

Author contribution The author did the study design, conceptualization and other part of this work before approving the final manuscript.

Funding Open access funding provided by North-West University. No funding.

Data availability Accessible upon request.

Declarations

Competing interest No competing interests.

Ethical approval and consent to participate The data utilized does not require ethic approval.

Consent for publication This is not applicable.

Open Access This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit <http://creativecommons.org/licenses/by/4.0/>.

References

- Aboginije, A., Aigbavboa, C., Thwala, W., Samuel, S. (2020). Determining the impact of construction and demolition waste reduction practices on green building projects in Gauteng province, South Africa. In Proceedings of the international conference of industrial engineering and operation management, Dubai, UAE (pp. 10–12).
- Adelekan, Y. A., & Omotayo, A. O. (2017). Linkage between rural non-farm income and agricultural productivity in Nigeria: A Tobit-two-stage least square regression approach. *The Journal of Developing Areas*, *51*, 317–333.
- Ajzen, I. (1985). From intentions to actions: A theory of planned behavior. *Action control: From cognition to behavior* (pp. 11–39). Springer.
- Ajzen, I. (1991). The theory of planned behavior. *Organizational Behavior and Human Decision Processes*, *50*, 179211.
- Aldrich, J. H., & Nelson, F. D. (1984). *Linear probability, logit, and probit models*. Sage.
- Aleluia, J., & Ferrão, P. (2016). Characterization of urban waste management practices in developing Asian countries: A new analytical framework based on waste characteristics and urban dimension. *Waste Management*, *58*, 415–429.
- Alfaia, R. G. S. M., Costa, A. M., & Campos, J. C. (2017). Municipal solid waste in Brazil: A review. *Waste Management & Research*, *35*, 1195–1209. <https://doi.org/10.1177/0734242X17735375>
- Anand, P. (1999). Waste management in Madras revisited. *Environment and Urbanization*, *11*, 161–176. <https://doi.org/10.1177/095624789901100214>
- Archer, K. J., & Lemeshow, S. (2006). Goodness-of-fit test for a logistic regression model fitted using survey sample data. *The Stata Journal*, *6*, 97–105.
- Armitage, C. J., & Conner, M. (2001). Efficacy of the theory of planned behaviour: A meta-analytic review. *British Journal of Social Psychology*, *40*, 471–499.
- Awotide, B., Abdoulaye, T., Alene, A., Manyong, V. M. (2019). Socio-economic factors and smallholder cassava farmers' access to credit in South-Western Nigeria. <https://bibliol1.iita.org/handle/20.500.12478/6111>
- Babaei, A. A., Alavi, N., Goudarzi, G., Teymouri, P., Ahmadi, K., & Rafiee, M. (2015). Household recycling knowledge, attitudes and practices towards solid waste management. *Resources, Conservation and Recycling*, *102*, 94–100.
- Balassa, B. (1964). The purchasing-power parity doctrine: A reappraisal. *Journal of political Economy*, *72*, 584.
- Bartelings, H., & Sterner, T. (1999). Household waste management in a Swedish municipality: Determinants of waste disposal, recycling and composting. *Environmental and Resource Economics*, *13*, 473–491.
- Bonal, X. (2007). On global absences: Reflections on the failings in the education and poverty relationship in Latin America. *International Journal of Educational Development*, *27*, 86–100.
- Boulding, K. E. (1945). The consumption concept in economic theory. *The American Economic Review*, *35*, 1–14.
- Burger, R., Steenekamp, C. L., Zoch, A., & van der Berg, S. (2014). The middle class in contemporary South Africa: Comparing rival approaches. *Development Southern Africa*, *32*(1), 25–40. <https://doi.org/10.1080/0376835X.2014.975336>
- Burgess, S. L. (1982). Determinants of homeownership: A comparison of single female and single male headed households. *Housing and Society*, *9*, 87–94. <https://doi.org/10.1080/08882746.1982.11429892>
- Callan, S. J., & Thomas, J. M. (2017). The impact of state and local policies on the recycling effort. *The economics of residential solid waste management* (pp. 301–313). Routledge.
- Challcharoenwattana, A., & Pharino, C. (2015). Co-benefits of household waste recycling for local community's sustainable waste management in Thailand. *Sustainability*, *7*, 7417–7437.
- Challcharoenwattana, A., & Pharino, C. (2016). Multiple-criteria decision analysis to promote recycling activities at different stages of urbanization. *Journal of Cleaner Production*, *137*, 1118–1128.
- Dlamini, B. R., Rampedi, I. T., & Ifegbesan, A. P. (2017). Community resident's opinions and perceptions on the effectiveness of waste management and recycling potential in the Umkhanyakude and Zululand District Municipalities in the KwaZulu-Natal Province of South Africa. *Sustainability*, *9*, 1835.
- Duncan, M. J., Ravis, A., & Jordan, C. (2012). Brief report: Understanding intention to be physically active and physical activity behaviour in adolescents from a low socio-economic status background: An application of the theory of planned behaviour. *Journal of Adolescence*, *35*, 761–764.
- ElSaid, S., & Aghezzaf, E.-H. (2018). A progress indicator-based assessment guide for integrated municipal solid-waste management systems. *Journal of Material Cycles and Waste Management*, *20*, 850–863.

- Ferrara, I., & Missios, P. (2005). Recycling and waste diversion effectiveness: evidence from Canada. *Environmental and Resource Economics*, 30, 221–238. <https://doi.org/10.1007/s10640-004-1518-z>
- Ferronato, N., & Torretta, V. (2019). Waste mismanagement in developing countries: A review of global issues. *International Journal of Environmental Research and Public Health*, 16, 1060.
- Ferronato, N., Torretta, V., Ragazzi, M., & Rada, E. C. (2017). Waste mismanagement in developing countries: A case study of environmental contamination. *UPB Scientific Bulletin*, 79, 185–196.
- Frederiks, E. R., Stenner, K., & Hobman, E. V. (2015). The socio-demographic and psychological predictors of residential energy consumption: A comprehensive review. *Energies*, 8, 573–609.
- Freeman, R. B. (1998). War of the models: which labour market institutions for the 21st century? *Labour Economics*, 5, 124. [https://doi.org/10.1016/S0927-5371\(98\)00002-5](https://doi.org/10.1016/S0927-5371(98)00002-5)
- Frick, J., Kaiser, F. G., & Wilson, M. (2004). Environmental knowledge and conservation behavior: Exploring prevalence and structure in a representative sample. *Personality and Individual Differences*, 37, 1597–1613.
- Gaustad, G., Krystofik, M., Bustamante, M., & Badami, K. (2018). Circular economy strategies for mitigating critical material supply issues. *Resources, Conservation and Recycling*, 135, 24–33.
- Godfrey, L., Scott, D., & Trois, C. (2013). Caught between the global economy and local bureaucracy: The barriers to good waste management practice in South Africa. *Waste Management & Research*, 31, 295–305.
- Gonçalves, J., Mateus, R., Silvestre, J. D., Roders, A. P., & Bragança, L. (2021). Attitudes matter: Measuring the intention-behaviour gap in built heritage conservation. *Sustainable Cities and Society*, 70, 102913.
- Gorman, M., Mannion, J., Kinsella, J., & Bogue, P. (2001). Connecting environmental management and farm household livelihoods: The rural environment protection scheme in Ireland. *Journal of Environmental Policy and Planning*, 3, 137–147.
- Greene, W. H. (2012). *Econometric analysis*. Prentice Hall.
- Grover, P., & Singh, P. (2014). An analytical study Oif effect of family Income and size on per capita household solid waste generation in developing countries. *American Research Institute for Policy Development*, 3, 127–143.
- Guffey, D. (2012). *Hosmer-lemeshow goodness-of-fit test: translations to the cox proportional hazards model*. University of Washington.
- Hagger, M. S., & Hamilton, K. (2021). Effects of socio-structural variables in the theory of planned behavior: A mediation model in multiple samples and behaviors. *Psychology & Health*, 36, 307–333.
- Hangulu, L., & Akintola, O. (2017). Health care waste management in community-based care: Experiences of community health workers in low resource communities in South Africa. *BMC Public Health*, 17, 1–10.
- Haywood, L. K., Kapwata, T., Oelofse, S., Breetzke, G., & Wright, C. Y. (2021). Waste disposal practices in low-income settlements of South Africa. *International Journal of Environmental Research and Public Health*, 18, 8176.
- Hlahla, S., Hill, T., & Goebel, A. (2014). “No longer going to sleep hungry”: Income generation through ‘green-preneurship’, KwaZulu-Natal, South Africa. *Skills at Work: Theory and Practice Journal*, 7, 67–77.
- Hopper, J. R., & Nielsen, J. M. (1991). Recycling as altruistic behavior: Normative and behavioral strategies to expand participation in a community recycling program. *Environment and Behavior*, 23, 195–220.
- Horrell, S., & Krishnan, P. (2007). Poverty and productivity in female-headed households in Zimbabwe. *The Journal of Development Studies*, 43, 1351–1380.
- Hosmer, D. W., & Lemeshow, S. (1980). Goodness of fit tests for the multiple logistic regression model. *Communications in Statistics-Theory and Methods*, 9, 1043–1069.
- Ikpe, A., Ndon, A.-I.E., & Etim, P. J. (2020). Assessment of the waste management system and its implication in Benin City metropolis, Nigeria. *Journal of Applied Research on Industrial Engineering*, 7, 79–91.
- Ioannou, T., Zampetakis, L. A., & Lasaridi, K. (2013). Psychological determinants of household recycling intention in the context of the theory of planned behaviour. *Fresenius Environmental Bulletin*, 22, 2035–2041.
- Kabeer, N. (2014). The politics and practicalities of universalism: Towards a citizen-centred perspective on social protection. *The European Journal of Development Research*, 26, 338–354.
- Kamran, A., Chaudhry, M. N., & Batool, S. A. (2015). Effects of socio-economic status and seasonal variation on municipal solid waste composition: A baseline study for future planning and development. *Environmental Sciences Europe*, 27, 1–8.
- Karaca-Mandic, P., Norton, E. C., & Dowd, B. (2012). Interaction terms in nonlinear models. *Health Services Research*, 47, 255–274. <https://doi.org/10.1111/j.1475-6773.2011.01314.x>

- Katapa, R. (2006). A comparison of female-and male-headed households in Tanzania and poverty implications. *Journal of Biosocial Science*, 38, 327–339.
- 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*. World Bank Publications.
- Keho, Y. (2016). What drives energy consumption in developing countries? The experience of selected African countries. *Energy Policy*, 91, 233–246.
- Khan, D., Kumar, A., & Samadder, S. (2016). Impact of socioeconomic status on municipal solid waste generation rate. *Waste Management*, 49, 15–25.
- Khan, S., Anjum, R., Raza, S. T., Bazai, N. A., & Ihtisham, M. (2022). Technologies for municipal solid waste management: Current status, challenges, and future perspectives. *Chemosphere*, 288, 132403.
- Kramer, A. A., & Zimmerman, J. E. (2007). Assessing the calibration of mortality benchmarks in critical care: The Hosmer-Lemeshow test revisited. *Critical Care Medicine*, 35, 2052–2056.
- Kulkarni, B. N., & Anantharama, V. (2020). Repercussions of COVID-19 pandemic on municipal solid waste management: Challenges and opportunities. *Science of the Total Environment*, 743, 140693.
- Kumar, A. (2019). Exploring young adults' e-waste recycling behaviour using an extended theory of planned behaviour model: A cross-cultural study. *Resources, Conservation and Recycling*, 141, 378–389.
- Kumar, S., Smith, S. R., Fowler, G., Velis, C., Kumar, S. J., Arya, S., Rena, Kumar, R., & Cheeseman, C. (2017). Challenges and opportunities associated with waste management in India. *Royal Society Open Science*, 4, 160764.
- Liao, T. F. F., & Liao, T. F. (1994). *Interpreting probability models: Logit, probit, and other generalized linear models*. Sage.
- McEachan, R. R. C., Conner, M., Taylor, N. J., & Lawton, R. J. (2011). Prospective prediction of health-related behaviours with the theory of planned behaviour: A meta-analysis. *Health Psychology Review*, 5, 97–144.
- Mestre, A., & Cooper, T. (2017). Circular product design. A multiple loops life cycle design approach for the circular economy. *The Design Journal*, 20, S1620–S1635.
- Midgley, G., Chapman, R., Hewitson, B., Johnston, P., De Wit, M., Ziervogel, G., Mukheibir, P., Van Niekerk, L., Tadross, M., & Van Wilgen, B. (2005). *A status quo, vulnerability and adaptation assessment of the physical and socio-economic effects of climate change in the Western Cape*. CSIR Environmentek.
- Moh, Y. C., & Abd Manaf, L. (2014). Overview of household solid waste recycling policy status and challenges in Malaysia. *Resources, Conservation and Recycling*, 82, 50–61.
- Moleko, K. (2019). Evaluation of municipal waste services in matjhabeng local municipality, free State Province. <http://ir.cut.ac.za/handle/11462/2234>
- Mthethwa, S., & Wale, E. (2021). Household vulnerability to food insecurity in rural South Africa: Evidence from a nationally representative survey data. *International Journal of Environmental Research and Public Health*, 18, 1917.
- Muzenda, E. (2014). A discussion on waste generation and management trends in South Africa. *International Journal of Chemical, Environmental & Biological Sciences*, 2, 105–112.
- Ndhlovu, P. T., Omotayo, A. O., Aremu, A. O., & Otang-Mbeng, W. (2020). Herbal-based cosmeceuticals and economic sustainability among women in South African rural communities. *Economies*, 8, 51.
- Niyobuhungiro, R., & Schenck, C. (2020). A global literature review of the drivers of indiscriminate dumping of waste: Guiding future research in South Africa. *Development Southern Africa*, 39(3), 1–17. <https://doi.org/10.1080/0376835X.2020.1854086>
- Nkosi, N., Muzenda, E., Zvimba, J., Pilusa, J. (2013). The current waste generation and management trends in South Africa: A review. <https://researchspace.csir.co.za/dspace/handle/10204/6792>
- Nyika, J. M., & Onyari, E. K. (2021). A review on solid waste management using the DPSIR framework in a Southern Africa case study. *Handbook of research on waste diversion and minimization technologies for the industrial sector* (pp. 13–34). IGI Global.
- O'Brien, J., & Thondhlana, G. (2019). Plastic bag use in South Africa: Perceptions, practices and potential intervention strategies. *Waste Management*, 84, 320–328.
- Oelofse, S. (2011). Understanding the national domestic waste collection standards: solid waste. *Résource*, 13, 8–9.
- Oginni, A., Ahonsi, B., & Ukwuije, F. (2013). Are female-headed households typically poorer than male-headed households in Nigeria? *The Journal of Socio-Economics*, 45, 132–137.
- Olagunju, K. O., Ogunniji, A. I., Oyetunde-Usman, Z., Omotayo, A. O., & Awotide, B. A. (2021). Does agricultural cooperative membership impact technical efficiency of maize production in Nigeria: An analysis correcting for biases from observed and unobserved attributes. *PLoS ONE*, 16, e0245426.

- Omotayo, A. O. (2016). Economic synergy between rural off-farm income and households' poverty in Ekiti State, Nigeria. *Journal of Human Ecology*, *56*, 99–106.
- Omotayo, A. O. (2018a). Climate change and food insecurity dynamics in the rural Limpopo Province of South Africa. *Journal of Economics and Behavioral Studies*, *10*, 22–32.
- Omotayo, A. O. (2018). *Economics of food intake, nutrition and farm households' health in Southwest Nigeria*. North-West University (South Africa).
- Omotayo, A. O., Nkonki-Mandleni, B., & Khumalo, M. L. (2018). *Social protection: A panacea to alleviating poverty in the Republic of South Africa* (p. 14). Acta Universitatis Danubius.
- Omotayo, A. O., Olagunju, K. O., Omotoso, A. B., Ogunniyi, A. I., Otekunrin, O. A., & Daud, A. S. (2021). Clean water, sanitation and under-five children diarrhea incidence: Empirical evidence from the South Africa's general household survey. *Environmental Science and Pollution Research*, *25*(44), 1–13. <https://doi.org/10.1007/s11356-021-15182-w>
- Omotayo, A. O., Omotoso, A. B., Daud, A. S., Ogunniyi, A. I., & Olagunju, K. O. (2020). What drives households' payment for waste disposal and recycling behaviours? Empirical evidence from South Africa's general household survey. *International Journal of Environmental Research and Public Health*, *17*, 7188.
- Omotayo, A. O., Omotoso, A. B., Daud, S. A., Omotayo, O. P., & Adeniyi, B. A. (2022). Rising food prices and farming households food insecurity during the COVID-19 Pandemic: Policy implications from SouthWest Nigeria. *Agriculture*, *12*, 363.
- Omotoso, A. B., Daud, S. A., Okojie, L., & Omotayo, A. O. (2022). Rural infrastructure and production efficiency of food crop farmers: Implication for rural development in Nigeria. *African Journal of Science, Technology, Innovation and Development*, *14*, 197–203.
- Omotoso, A. B., Letsoalo, S., Olagunju, K. O., Tshwene, C. S., & Omotayo, A. O. (2023). Climate change and variability in sub-Saharan Africa: A systematic review of trends and impacts on agriculture. *Journal of Cleaner Production*, *414*, 137487.
- Omotoso, A. B., & Omotayo, A. O. (2024). The interplay between agriculture, greenhouse gases, and climate change in Sub-Saharan Africa. *Regional Environmental Change*, *24*, 1.
- Owusu, V., Adjei-Addo, E., & Sundberg, C. (2013). Do economic incentives affect attitudes to solid waste source separation? Evidence from Ghana. *Resources, Conservation and Recycling*, *78*, 115–123.
- Ozturk, M., Saba, N., Altay, V., Iqbal, R., Hakeem, K. R., Jawaid, M., & Ibrahim, F. H. (2017). Biomass and bioenergy: An overview of the development potential in Turkey and Malaysia. *Renewable and Sustainable Energy Reviews*, *79*, 1285–1302.
- Peprah, P., Kyiyaga, E. M., Afful, H., Abalo, E. M., & Agyemang-Duah, W. (2017). Does the Ghanaian livelihood empowerment against poverty programme lead to an increase in household productive livelihood assets? Analysing the Ashanti scenario. *Cogent Social Sciences*, *3*, 1298174.
- Premalatha, M., Tabassum-Abbasi, Abbasi, T., & Abbasi, S. (2014). The generation, impact, and management of e-waste: State of the art. *Critical Reviews in Environmental Science and Technology*, *44*, 1577–1678.
- Rada, E. C., Ragazzi, M., Ionescu, G., Merler, G., Moedinger, F., Raboni, M., & Torretta, V. (2014). Municipal solid waste treatment by integrated solutions: Energy and environmental balances. *Energy Procedia*, *50*, 1037–1044.
- Raj, A., & Samuel, C. (2023). Application of total interpretive structural modeling (TISM) for analysis of barriers influencing healthcare waste management sector: A case study. *International Journal of Healthcare Management*, *16*, 445–459.
- Raj, A., Samuel, C., & Singh, A. K. (2023). Addressing the healthcare waste management barriers: A structural equation modeling approach. *Health Services Management Research*. <https://doi.org/10.1177/09514848231186775>
- Reike, D., Vermeulen, W. J., & Witjes, S. (2018). The circular economy: New or refurbished as CE 3.0?—exploring controversies in the conceptualization of the circular economy through a focus on history and resource value retention options. *Resources, Conservation and Recycling*, *135*, 246–264.
- Rodseth, C., Notten, P., & Von Blottnitz, H. (2020). A revised approach for estimating informally disposed domestic waste in rural versus urban South Africa and implications for waste management. *South African Journal of Science*, *116*, 1–6.
- Rogoff, K. (1996). The purchasing power parity puzzle. *Journal of Economic Literature*, *34*, 647–668.
- Samson, M., & Creation, J. (2004). *Organizing in the informal economy: A case study of the municipal waste management industry in South Africa*. Citeseer.
- Saphores, J.-D.M., & Nixon, H. (2014). How effective are current household recycling policies? Results from a national survey of US households. *Resources, Conservation and Recycling*, *92*, 1–10.

- Saphores, J.-D.M., Ogunseitán, O. A., & Shapiro, A. A. (2012). Willingness to engage in a pro-environmental behavior: An analysis of e-waste recycling based on a national survey of US households. *Resources, Conservation and Recycling*, *60*, 49–63.
- Schoeman, D. C. (2021). *Recycling in the city of Johannesburg: Role of households*. University of Johannesburg (South Africa).
- Schüz, B., Li, A.S.-W., Hardinge, A., McEachan, R. R., & Conner, M. (2017). Socioeconomic status as a moderator between social cognitions and physical activity: Systematic review and meta-analysis based on the theory of planned behavior. *Psychology of Sport and Exercise*, *30*, 186–195.
- Serge Kubanza, N., & Simatele, M. D. (2020). Sustainable solid waste management in developing countries: A study of institutional strengthening for solid waste management in Johannesburg, South Africa. *Journal of Environmental Planning and Management*, *63*, 175–188.
- Sheeran, P., & Orbell, S. (1999). Augmenting the theory of planned behavior: Roles for anticipated regret and descriptive norms 1. *Journal of Applied Social Psychology*, *29*, 2107–2142.
- Sniehotta, F. F., Presseau, J., & Araújo-Soares, V. (2014). Time to retire the theory of planned behaviour. *Health Psychology Review*, *8*(1), 1–7. <https://doi.org/10.1080/17437199.2013.869710>
- Solberg, E. (2012). *Waste is a resource: A study on the opportunities in a new solid waste management in Iringa municipality*. Høgskolen i Oslo og Akershus.
- Sowman, M., & Brown, A. (2006). Mainstreaming environmental sustainability into South Africa's integrated development planning process. *Journal of Environmental Planning and Management*, *49*, 695–712.
- Suleman, Y., Darko, E., & Agyemang-Duah, W. (2015). Solid waste disposal and community health implications in Ghana: Evidence from sawaba, asokore mampong municipal assembly. *Journal of Civil & Environmental Engineering*, *5*(6), 202.
- Suthar, S., & Singh, P. (2015). Household solid waste generation and composition in different family size and socio-economic groups: A case study. *Sustainable Cities and Society*, *14*, 56–63.
- Swilling, M. (2010). Sustainability, poverty and municipal services: The case of Cape Town, South Africa. *Sustainable Development*, *18*, 194–201. <https://doi.org/10.1002/sd.489>
- Thomas, J. M., Bhattacharya, A., Mehra, A., Menon, M., & Bhargava, A. (2021). Environmentally sustainable solid waste management case study of gurgaon. *Journal of Agricultural Research Pesticides and Biofertilizers*, *2*(1), 8.
- Tobin, J. (1958). Estimation of relationships for limited dependent variables. *Econometrica: Journal of the Econometric Society*, *26*, 24–36.
- Tobin, J. (1958). Liquidity preference as behavior towards risk. *The Review of Economic Studies*, *25*, 65–86.
- Tsheleza, V., Nakin, M. D., Ndhleve, S., Kabití, H. M., & Musampa, C. M. (2019). Vulnerability of growing cities to solid waste-related environmental hazards: The case of Mthatha, South Africa. *Jàmbá: Journal of Disaster Risk Studies*, *11*, 1–10.
- van der Merwe, C. (2020). *An in-depth investigation into the relationship between municipal solid waste generation and economic growth in the City of Cape Town*. Stellenbosch University.
- Verster, C., & Bouwman, H. (2020). Land-based sources and pathways of marine plastics in a South African context. *South African Journal of Science*, *116*, 1–9.
- Vyas, S., & Kumaranayake, L. (2006). Constructing socio-economic status indices: How to use principal components analysis. *Health Policy and Planning*, *21*, 459–468. <https://doi.org/10.1093/heapol/czl029>
- World Bank Group (2017) DataBank world development indicators: World Bank. <https://databank.worldbank.org/source/world-development-indicators>
- Yokoo, H.-F., Kawai, K., & Higuchi, Y. (2018). Informal recycling and social preferences: Evidence from household survey data in Vietnam. *Resource and Energy Economics*, *54*, 109–124. <https://doi.org/10.1016/j.reseneeco.2018.08.001>
- Yukalang, N., Clarke, B., & Ross, K. (2017). Barriers to effective municipal solid waste management in a rapidly urbanizing area in Thailand. *International Journal of Environmental Research and Public Health*, *14*, 1013. <https://doi.org/10.3390/ijerph14091013>
- Ziraba, A. K., Haregu, T. N., & Mberu, B. (2016). A review and framework for understanding the potential impact of poor solid waste management on health in developing countries. *Archives of Public Health*, *74*, 1–11. <https://doi.org/10.1186/s13690-016-0166-4>