Decision Support Tool for Implementing Municipal Waste Separation at Source: Incorporating Socio-Economic and Environmental Impacts

Final Report

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EXECUTIVE SUMMARY

The SASCOST Model is a spreadsheet-based model developed by the CSIR for assessing the costs and benefits of alternative systems for implementing source separation of municipal household waste. It can be used by municipalities as a Decision Support Tool to identify an appropriate system for implementation, taking into account each municipality's unique circumstances. Version 1 of the SASCOST model focuses on financial costs and benefits; specifically, on vehicle/collection costs; communication costs; container costs; costs of sorting at the MRF; costs of transporting the residual fraction from the MRF to the landfill; income from sale of recyclables; and savings in terms of reduced collection, transport and disposal of waste to landfill.

The current project aimed to expand on Version 1 of the SASCOST model, by incorporating the broader socio-economic and environmental impacts (or 'externalities') of the different source separation systems (or options). Specifically, the following impacts were identified as critical for inclusion in the model:

1. Impact of informal collectors on the viability of a S@S programme
2. Impacts on employment and livelihoods (including formal job creation and informal sector livelihoods)
3. Additional/avoided emissions from collection and transport
4. Avoided social and environmental externalities from landfill disposal
5. Landfill airspace savings and increased lifespan

The approach to incorporating these impacts in the model was as follows: Firstly, having identified the key impacts to include (see above), the drivers of each of impact were identified, in order to be able to model the factors affecting the magnitude of each impact. Then, for each impact, a sub-model was developed, which quantifies the magnitude of the impact per tonne of waste, as a function of each of the drivers influencing that variable. Next, each of the socio-economic and environmental variables were valued in monetary terms, using an appropriate economic valuation technique. This is done so that the impacts can be incorporated within the monetary cost-benefit framework of the model (i.e., so that they can be included within the overall net cost-benefit calculation for each option), such that trade-offs can be compared using a common metric.

Finally, the socio-economic and environmental variables were incorporated into a revised version of the SASCOST model (Version 2), which quantifies in monetary terms the costs and benefits associated with each of these variables, for each of the separation at source (S@S) options (in Rand per year, Rand per household/month and Rand per tonne). A detailed description of how each of the socio-economic and environmental impacts were incorporated in the model is provided within the report. In the resulting model, the socio-economic and environmental impacts are quantified both in physical terms (e.g. number of jobs created, tonnes of CO_2 emissions saved, etc.); as well as in monetary terms. The monetized value of the impacts are incorporated within the aggregated net cost/benefit calculation (alongside financial costs and benefits); to provide an overall assessment of the net cost or benefit associated with each S@S option (from an integrated sustainability perspective, i.e. taking into account the financial, economic, social and environmental performance of each option).

The report also provides an indication of the extent to which the model results are affected by the incorporation of the socio-economic and environmental impacts. In Version 1 of the model (financial costs and benefits only); most of the options yielded net costs (although in some cases the truck and trailer option yielded net benefits). For example, based on hypothetical data for a set of 5 high income suburbs in the City of Cape Town, costs ranged from R736 per tonne for the post separation option, to R3 500 per tonne using a separate vehicle approach. In Version 2, however, with socio-economic and environmental impacts included, there is a big swing toward all options now yielding significant net *benefits*; ranging from R7 683 per tonne in the truck and trailer option, to R14 795 in the separate vehicle option (which now becomes the most attractive option), based on the same set of hypothetical input data. However, it should be noted that these results are disproportionately affected by the significant benefits associated with downstream, indirect and induced job creation; for which there is an argument for excluding from the model results. Even excluding these benefits, however, separation at source does appear more favourable when socio-economic and environmental impacts are considered as compared to when only financial considerations are taken into account; with a net benefit for some options (e.g. the truck and trailer option shows a net benefit of R625 per tonne, as compared to a net benefit of R297 when only financial costs and benefits are considered); and a net cost of R647 per tonne for the separate vehicle option (as compared to R3 500 per tonne when only financial costs and benefits are considered).

It should be noted that the above-mentioned results are based on hypothetical input data and should by no means be used to inform decision making. Instead, Version 2 of the model itself, which should be seen in parallel with this report, can be used to generate municipality-specific results. Specifically, the model can be used by any municipality (or its service provider) to make more informed decisions in identifying the most appropriate option for implementing source separation; from an integrated financial, socio-economic and environmental perspective; given its unique circumstances.

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1 Introduction

1.1 The need for Separation at Source and the SASCOST Model

The National Environmental Management: Waste Act, 2008 (No. 59 of 2008) (Republic of South Africa, 2008) calls for increased diversion of waste away from landfill towards re-use, recycling and recovery. Nevertheless, South Africa generates an estimated 108 million tonnes of waste per annum (as at 2011), of which 98 million tonnes (or 90%) is disposed of to landfill. This represents a significant loss of valuable resources that could otherwise be recovered and recycled (Department of Science and Technology (DST) 2014). Landfilling of waste also gives rise to significant financial, socio-economic and environmental costs (Nahman, 2011).

Countrywide, an estimated 20 million tonnes of municipal solid waste is generated per annum, of which about 25% consists of mainline recyclables (paper, plastics, glass, tins and tyres) (Department of Environmental Affairs (DEA) 2012). In 2014, an estimated 3.39 million tonnes of packaging was consumed in South Africa, of which only 52.6% was recycled (Packaging SA, 2015), with the remainder disposed of at landfills.

In response, government has set a target of 25% diversion of recyclables from landfill for re-use, recycling and recovery by 2016, as part of its National Waste Management Strategy (NWMS) (Department of Environmental Affairs, 2011). The NWMS also sets a 2016 target for all metropolitan municipalities, secondary cities and large towns to have initiated "Separation at Source" (S@S) programmes. More recently, the aspiration of the work stream on municipal waste at the Chemicals and Waste Phakisa is "*achieving a minimum of 50% of households in metros separating at source by 2023*" (Operation Phakisa, 2017).

In a S@S programme, waste generators (households, businesses etc.) must separate recyclables from non-recyclable waste, while the municipality must provide (or out-source) some form of separate collection system for the source-separated waste. The aim of S@S is to increase the diversion of waste from landfill, and to increase the supply of clean, good quality materials to the recycling industry. This could in turn contribute towards job creation and the development of a green economy in South Africa.

However, a separate collection system for source-separated recyclables is likely to significantly increase the costs of waste management for municipalities. A study conducted by the Council for Scientific and Industrial Research (CSIR, 2011) revealed that there is a lack of incentives for municipalities to invest in S@S programmes. Even among those municipalities who do see the benefits of source separation; there is currently a knowledge gap in terms of how to best implement it, specifically in terms of how the separated recyclables should be collected (e.g. separate vehicles, multi-compartment vehicles, truck and trailer, or incorporating the informal sector). The different collection options have different financial, socio-economic and environmental implications (costs and benefits); including capital and operating costs, job creation, impacts on the livelihoods of informal collectors, and environmental impacts associated with transport, such as CO_2 emissions.

In turn, the costs and benefits of alternative systems will be influenced by a range of factors (e.g. waste types and quantities generated, collection and transport distances, etc.). As such, these costs and benefits are likely to differ between municipalities, depending on the specific circumstances of the municipality (socio-economic profile, waste generation rates, waste composition, size, location, etc.). It is therefore unlikely that a 'one-size-fits all' system will be appropriate for all municipalities in South Africa. Instead, different municipalities will need to assess which system is most appropriate in their specific context.

As such, there is a need to provide municipalities with decision support in assessing the costs and benefits of alternative systems for implementing S@S. In response, the CSIR has developed a spreadsheet-based economic model (The SASCOST Model) which is able to assess the costs and benefits of alternative systems, and which can be used as a Decision Support Tool to assist in identifying an appropriate system for implementation, taking into account each municipality's unique circumstances. Version 1 of the SASCOST model (developed prior to this project) is described in Section 1.2.

1.2 Development of Version 1 of the SASCOST Model

The SASCOST Model is an economic model for assessing the costs and benefits of alternative systems for implementing source separation of municipal household waste. It can be used by municipalities as a Decision Support Tool for identifying an appropriate system for implementation, taking into account each municipality's unique circumstances. The model is currently spreadsheet-based, although an online web-based interface is being developed.

Currently, the following four systems (or options) are assessed by the SASCOST model:

1. "**POST SEPARATION**": No separation at source; post-separation of recyclables at 'dirty' MRF (Materials Recovery Facility); residual waste transported to landfill
2. "**TRUCK & TRAILER**": S@S; kerbside collection of recyclables in trailer hitched to back of normal waste collection vehicle; recyclables sorted and baled at 'clean' MRF; residual waste transported to landfill
3. "**SEPARATE VEHICLE**": S@S; kerbside collection in separate vehicles (by municipality, contractor/private sector or cooperative); recyclables sorted and baled at clean MRF; residual waste transported to landfill
4. "**RICH BAG**": Households place recyclables in separate bag at top of bin; collected by informal sector & sold to buy-back centres; or if not collected is post-separated at MRF; residual waste transported to landfill

Figure 1 provides a schematic representation of the S@S options included in the model[1]. Costs and benefits associated with each of these options are assessed up until the point where recyclables have been sorted and baled at the MRF. Costs and benefits associated with downstream

[1] The "split-compartment" option refers to a fifth possibility involving multi-compartment vehicles, which will be added to the model in future iterations.

recycling/processing activities are not currently included in the model (as these will not differ between the options); nor are costs or benefits incurred by households. The model boundaries are represented by the two red vertical lines in Figure 1.

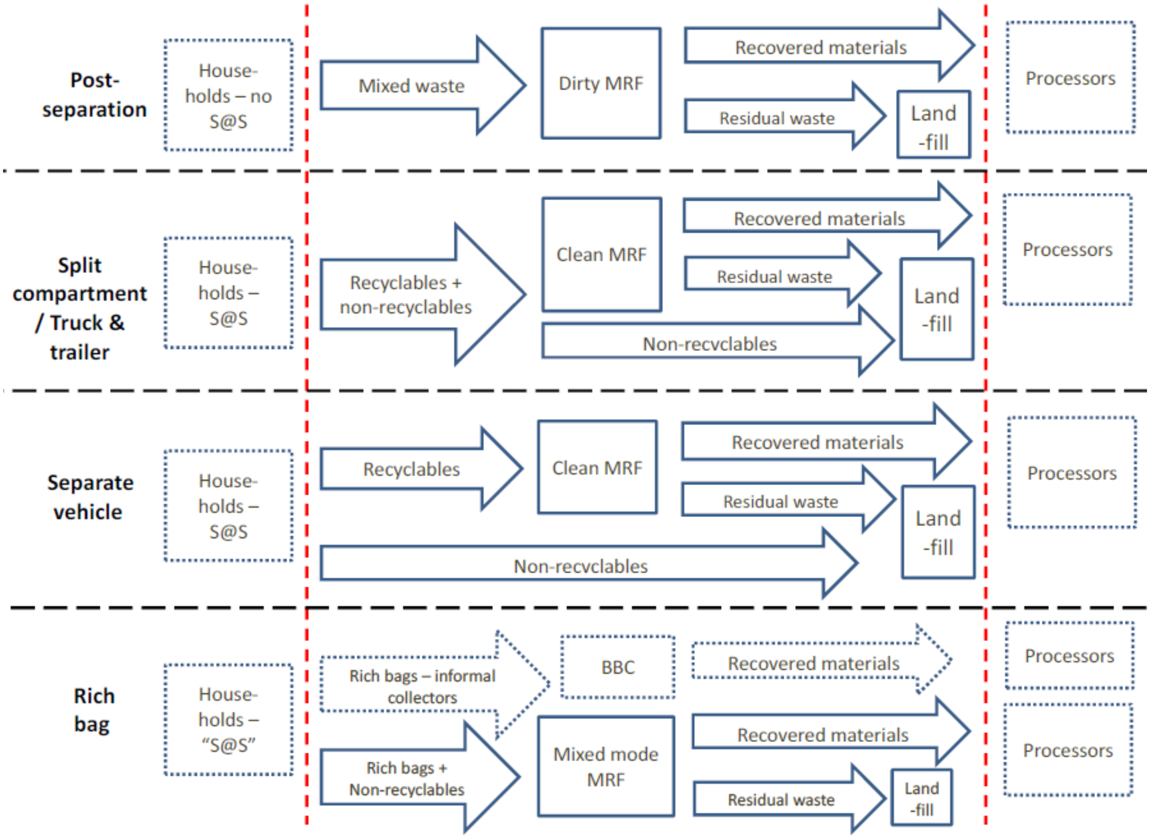

Figure 1: S@S Options and model boundaries

Version 1 of the model focuses on financial costs and benefits associated with source separation of post-consumer packaging waste (paper, plastic, glass and metals). Specifically, it assesses vehicle/collection costs; communication costs; container costs; costs of sorting at the MRF; costs of transporting the residual fraction from the MRF to the landfill; income from sale of recyclables; and savings in terms of reduced collection, transport and disposal of waste to landfill.

Based on user inputs, the model calculates the overall net cost or benefit of each of the S@S options (in Rand per year, Rand per household/month and Rand per tonne), for a defined set of 5 suburbs within a specific municipality. This allows the user to identify which option would be most cost-effective for implementation within that specific set of suburbs. The model can be run multiple times in order to obtain results for other suburbs, and to assess alternative scenarios based on varying input values. Figure 2 presents a screenshot of the results tab from Version 1 of the SASCOST model[2]. The results tab also provides an itemized account of all of the individual cost/benefit categories; so that users can identify particularly costly elements of the system, or exclude specific cost/benefit categories that may not be relevant to their decision making.

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[2] Due to size, only the first three options are shown (rich bag option omitted). Values are based on hypothetical input data

RESULTS*

***Note that results will be updated once input data is entered**

	POST SEPARATION				TRUCK & TRAILER				SEPARATE VEHICLE			
Costs/benefits	R/year	R/tonne (collected/ processed)	R/tonne (recovered / diverted)	R/ hhold/ month	R/year	R/tonne (collected/ processed)	R/tonne (recovered / diverted)	R/ hhold/ month	R/year	R/tonne (collected/ processed)	R/tonne (recovered / diverted)	R/ hhold/ month
NET COST (OR BENEFIT)	**649 196**	**110.43**	**736.22**	**2.85**	**(261 743)**	**(252.31)**	**(296.83)**	**(1.15)**	**3 086 598**	**2 975.32**	**3 500.38**	**13.54**
S@S costs (benefits)	**332 900**	**56.63**	**377.53**	**1.46**	**1 087 715**	**1 048.50**	**1 233.53**	**4.77**	**4 436 057**	**4 276.13**	**5 030.74**	**19.46**
Communication costs	0	0.00	0.00	0.00	342 000	329.67	387.85	1.50	342 000	329.67	387.85	1.50
Bag costs	0	0.00	0.00	0.00	691 600	666.67	784.31	3.03	691 600	666.67	784.31	3.03
Collection & transport to MRF	0	0.00	0.00	0.00	116 311	112.12	131.90	0.51	3 508 708	3 382.21	3 979.07	15.39
Transport costs MRF-Landfill	832 200	141.56	943.76	3.65	25 916	24.98	29.39	0.11	25 916	24.98	29.39	0.11
(Collection/transport savings)	(499 300)	(84.94)	(566.23)	(2.19)	(88 112)	(84.94)	(99.92)	(0.39)	(132 168)	(127.40)	(149.89)	(0.58)
MRF costs (benefits)	**444 296**	**75.58**	**503.86**	**1.95**	**(1 221 458)**	**(1 177.42)**	**(1 385.20)**	**(5.36)**	**(1 221 458)**	**(1 177.42)**	**(1 385.20)**	**(5.36)**
MRF costs	2 090 320	355.58	2 370.54	9.17	424 566	409.26	481.48	1.86	424 566	409.26	481.48	1.86
(Income from sale of recyclables)	(1 646 024)	(280.00)	(1 866.68)	(7.22)	(1 646 024)	(1 586.68)	(1 866.68)	(7.22)	(1 646 024)	(1 586.68)	(1 866.68)	(7.22)
Disposal costs (benefits)	**(128 000)**	**(21.77)**	**(145.16)**	**(0.56)**	**(128 000)**	**(123.39)**	**(145.16)**	**(0.56)**	**(128 000)**	**(123.39)**	**(145.16)**	**(0.56)**
(Disposal cost savings)	(128 000)	(21.77)	(145.16)	(0.56)	(128 000)	(123.39)	(145.16)	(0.56)	(128 000)	(123.39)	(145.16)	(0.56)
Tonnes of waste collected/ processed and recyclables recovered/diverted through S@S	Households serviced	t/year collected / processed	t/year diverted / recovered		Households serviced	t/year collected / processed	t/year diverted / recovered		Households serviced	t/year collected / processed	t/year diverted / recovered	
	19 000	**5 878.60**	**881.79**		**19 000**	**1 037.40**	**881.79**		**19 000**	**1 037.40**	**881.79**	

Figure 2: Results tab in Version 1 of the model (financial costs and benefits only). Due to size, only the first three options are shown (rich bag option omitted). Values are based on hypothetical input data.

However, a need has been recognized to further expand the model to account for socio-economic and environmental impacts; in addition to financial costs and benefits. Ideally, decision making should be based on a full understanding of the broad range of implications arising from each option; and not only on an assessment of financial costs and benefits. For example, job creation is a key objective of municipalities, and a major potential benefit of S@S programmes. Similarly, it is important to ensure that the environmental benefits associated with source separation (e.g. reduction in methane emissions at the landfill site) are not outweighed by additional environmental costs, e.g. in the form of additional CO_2 emissions associated with collection vehicles. In short, there are financial, socio-economic and environmental trade-offs associated with different approaches to implementing S@S. These should be assessed to the extent possible in order to ensure that decision making is based on as much information as possible. In addition, the socio-economic and environmental impacts should ideally be incorporated within the same cost-benefit framework as the financial impacts, so that trade-offs can be compared using a common metric.

The project described in this report aimed to meet this need. The objectives of the project are described in greater detail in Section 1.3.

1.3 Objectives of this project and structure of the report

The work conducted during this project aimed to expand on the SASCOST model that has been developed to date (Version 1), by incorporating the broader socio-economic and environmental impacts (or 'externalities') of the different source separation options. Specifically, in addition to simply quantifying the socio-economic and environmental impacts (e.g. number of jobs created, net change in greenhouse gas emissions, etc.); it aimed to incorporate these impacts within the cost-benefit framework currently used by the model to assess the financial impacts, so that trade-offs can be compared using a common metric. In other words, the aim is to enable the model to calculate the net cost or benefit of alternative separation and collection options; taking into account financial, socio-economic and environmental costs and benefits. This requires that the socio-economic and environmental impacts are 'valued' in monetary terms, using appropriate economic valuation techniques.

Ultimately, the aim was to develop a tool that can be used by municipal waste management departments (and/or their service providers, or private waste management companies) to inform decision making regarding how best to implement source separation, from an integrated financial, socio-economic and environmental perspective; taking into account their unique circumstances and priorities. Specifically, the aim was to develop Version 2 of the SASCOST model, which will allow for an overall net cost or benefit (including financial, socio-economic and environmental costs and benefits) to be calculated for each option. This will allow for trade-offs to be assessed, and for the full range of financial, socio-economic and environmental implications of each option to be directly compared.

This report provides an overview of the research conducted during this project. The report is structured as follows. Section 2 sets out the approach in broad terms. Section 3 describes the key socio-economic and environmental impacts that were identified as being critical to incorporate in the model. Section 4 describes in detail how each of the identified impacts were modelled, valued in monetary terms, and incorporated into Version 2 of the SASCOST model. Section 5 presents the revised structure of the "Results" tab of Version 2, and provides some indication regarding the extent to which the incorporation of the socio-economic and environmental impacts affects the model results. Section 6 concludes with a discussion of the way forward for the model.

2 Approach

This section briefly outlines the approach in broad terms. More detail on the approach adopted in identifying and incorporating each of the specific socio-economic and environmental impacts is provided in the relevant sub-sections within Sections 3 and 4.

Firstly, potential socio-economic and environmental impacts arising from each option were identified based on a brief review of relevant literature, as well as a brainstorming exercise in which we drew on the prior research and expert knowledge of the project team. A number of criteria were then applied in order to identify which of the identified impacts should be prioritized for inclusion in the model. Ultimately, five key socio-economic and environmental variables were prioritized for incorporation within the model during the course of the project.

Next, the drivers of each of these impacts were identified, in order to be able to model the factors affecting the magnitude of each impact. For example, greenhouse gas emissions arising from collection vehicles are a function of the litres of fuel consumed, which in turn depends on the distance travelled and the fuel consumption per kilometer (which depends on the type of vehicle and the nature of the driving conditions (stop-start vs. open road)).

Then, for each of the socio-economic and environmental variables to be included in the model, a sub-model was developed, which quantifies the magnitude of the impact per tonne of waste, as a function of each of the drivers influencing that variable. For example, fuel emission factors are used to quantify CO_2 emissions (in tonnes of CO_2 equivalent, tCO_2e) per litre of fuel used in collection and transport.

Next, each of the socio-economic and environmental variables were valued in monetary terms, using an appropriate economic valuation technique. This is done so that the impacts can be incorporated within the monetary cost-benefit framework of the model (i.e., so that they can be added to the overall net cost-benefit calculation for each option). For example, costs associated with CO_2 emissions can be quantified based on the 'social cost of carbon', which reflects the damage cost per tonne of CO_2 in terms of the resulting impacts arising from climate change.

Finally, the socio-economic and environmental variables were incorporated into the SASCOST model, which quantifies in monetary terms the costs and benefits associated with each of these variables, for each of the S@S options (in Rand per year, Rand per household/month and Rand per tonne). The costs and benefits can then be taken into account in the aggregated net cost/benefit calculation (alongside financial costs and benefits); to provide an overall assessment of the net cost or benefit associated with each option (from an integrated sustainability perspective, taking into account the financial, economic, social and environmental performance of each option).

The resulting Version 2 of the SASCOST model can be used by any municipality (or its service provider) to make more informed decisions in identifying the most appropriate option for implementing source separation; from an integrated financial, socio-economic and environmental perspective; given its unique circumstances.

3 Identification of socio-economic and environmental impacts to incorporate in the model

Given that the project team have significant combined expertise related to the economic, social and environmental impacts associated with waste management, it was felt that the most efficient approach to conducting this task would be through a team workshop, in which potential impacts associated with each option would be identified through a brainstorming exercise, and criteria developed for refining the set of impacts to incorporate in the model.

Prior to the team workshop, a preliminary set of potential impacts, issues and criteria was identified, based on prior research, expert knowledge within the project team, and a brief review of relevant literature. During the workshop itself, held in Pretoria on 24 May 2016, a broader and more detailed set of impacts and issues associated with each of the four options was identified through a series of brainstorming exercises (see Figure 3); while the criteria for selection were also refined.

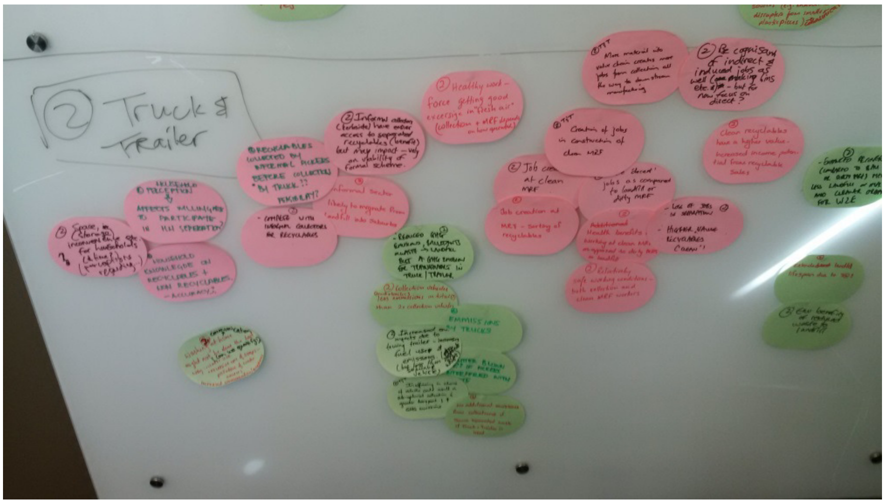

Figure 3: Picture taking during the team workshop aimed at identifying socio-economic and environmental impacts.

Subsequent to the workshop, we applied a number of criteria to refine and finalise the set of impacts that should be incorporated in Version 2 of the model:

- Over-riding criterion (impacts failing this test are excluded from the model): Impact arises within the boundaries of the model (See Figure 1)
- Scoring criteria (impacts are assigned a score of 0, 1 or 2 on each of these criteria. Scores are then aggregated to arrive at a total out of ten, with weightings as per parentheses):
    - Relevant to municipality decision making (20%)

- Magnitude of the impact expected to be significant as compared to the status quo (sufficient to influence decision making) (20%)
- Magnitude expected to differ significantly between options (20%)
- Quantifiable and can potentially be valued in monetary terms and incorporated within model (40%)

Based on this assessment, the following broad groups of impacts were prioritized for incorporation in the model (note these broad groupings of impacts manifest in different ways across each of the options in the model):

1. Impacts of informal collectors on the viability of a S@S programme
2. Impacts on employment and livelihoods (including formal job creation and informal sector livelihoods)
3. Additional/avoided emissions from collection and transport
4. Avoided social and environmental externalities from landfill disposal
5. Landfill airspace savings and increased lifespan

These impacts are described in Table 1. The specific way in which each impact is manifested across each option is also described.

Table 1: Description of each socio-economic and environmental impact in general, and specific details on how they relate to each option

Impact	General description of this impact (across all options)	Specific details of how each impact is manifested in each of the S@S options			
		1. Post separation	**2. Truck and Trailer**	**3. Separate vehicle**	**4. Rich bag**
Impacts of informal collectors on the viability of a S@S programme	Recyclables (particularly the higher value materials) are collected by informal pickers before the collection truck arrives. This may impact on the feasibility of a formal S@S programme; because: 1. lower volumes of recyclables will remain 2. The materials that remain will on average be of lower value, because the high value materials would have been cherry-picked	Not expected to occur to the same extent as it does in Options 2-4, as recyclables have not been pre-separated and are therefore more difficult to identify and access, and are more contaminated (therefore lower value). Likely to occur to the same extent as in the Business as Usual (BAU) scenario (no S@S).	Expected to occur to a greater extent than in the BAU case (no S@S) or Option 1 (post separation), as informal collectors will have easier access to pre-separated, uncontaminated (therefore higher value) recyclables at the kerbside.	Expected to occur to a greater extent than in the BAU case (no S@S) or Option 1 (post separation), as informal collectors will have easier access to pre-separated, uncontaminated (therefore higher value) recyclables at the kerbside.	Expected to occur to a greater extent than in the BAU case (no S@S) or Option 1 (post separation), as informal collectors will have easier access to pre-separated, uncontaminated (therefore higher value) recyclables at the kerbside.
Impacts on employ-ment and livelihoods	- Job creation opportunities for drivers/assistants in collection (for some options); as well as sorters at the MRF (for all options). - Reduced opportunities for pickers at landfill site; will either have migrated to suburbs or get formal work at the MRF. - Previous landfill pickers now working at the MRF are no longer able to access re-usable/high value commodities (e.g. furniture, textiles, E-goods etc). - Jobs at MRF likely to be at minimum wages, but guaranteed income – potentially lower earning potential than in the case of picking and being paid the value of the material which is subject to price fluctuations - Pickers have to walk further when collecting at kerbside as compared to at the landfill to get the same amount of waste and to sell it at a BBC (unless there is a mobile BBC). - For some options it will be easier to access high value materials at the kerbside, if materials have been separated at source	- No additional opportunities for drivers/assistants - For pickers at kerbside: More effort expended per tonne of recyclables as compared to Options 2-4 – have to rummage through whole bin. Also, materials are of lower value as compared to Options 2-4, due to contamination.	- No additional opportunities for drivers (but perhaps for assistants?) - For pickers at kerbside: Less effort per tonne of recyclables as compared to Option 1 – don't have to rummage through whole bin. Also, materials are of higher value as compared to Option 1 – little to no contamination.	- Will be additional opportunities for both drivers and assistants - For pickers at kerbside: Less effort per tonne of recyclables as compared to Option 1 – don't have to rummage through whole bin. Also, materials are of higher value as compared to Option 1 – little to no contamination.	- No additional opportunities for drivers/assistants - For pickers at kerbside: Less effort per tonne of recyclables as compared to Option 1 – don't have to rummage through whole bin. Also, materials are of higher value as compared to Option 1 – little to no contamination.

Additional/ avoided emissions from collection and transport	- In some options there will be additional emissions (including greenhouse gases such as CO_2, as well as local air pollutants) associated with additional collection vehicles, but reduced emissions from reduced collection by compactor vehicles - For all options, there will be reduced emissions associated with reduced transport to landfill - For all options, there will be some additional emissions from transport of residual waste from MRF to landfill	- No increase in emissions from collection as compared to BAU	- May be a slight increase in emissions from transport (as compared to BAU/Option 1) due to increased fuel use associated with towing trailer; but much lower as compared to Option 3	- Overall increase in emissions from collection as compared to BAU and all other options due to use of a second vehicle - But some potential decrease in collection emissions due to switch from compactors to more fuel-efficient vehicles	- No increase in emissions from collection as compared to BAU

Avoided external-ities from landfill disposal	- Reduced waste to landfill will result in a reduction in the socio-economic and environmental impacts of landfilling.
	- Specific impacts associated with inorganic packaging waste (i.e. benefits of diversion) include:
	  o Using up valuable airspace (see below)
	  o Windblown litter
	  o Water accumulates in plastics – breeding ground for mosquitoes, odours, etc.
	  o Paper and packaging burns easily causing fires (methane exacerbates this)
	- Impacts associated with organic waste (which includes paper) include:
	  o Leachate
	  o Landfill gas (methane – global warming)
	  o Odours, pests etc.
		No reason to expect that this would differ between options	No reason to expect that this would differ between options	No reason to expect that this would differ between options	No reason to expect that this would differ between options

Landfill airspace savings and increased lifespan	Diversion of waste from landfill results in airspace savings and increased lifespan of landfills.	No reason to expect that this would differ between options	No reason to expect that this would differ between options	No reason to expect that this would differ between options	No reason to expect that this would differ between options

4 Modelling and valuation of socio-economic and environmental impacts for incorporation in the SASCOST Model

In this section, we describe how each of the socio-economic and environmental impacts identified in Section 3 were incorporated into the SASCOST model. The general approach involved developing a sub-model for each impact, which quantifies the magnitude of the impact per tonne of waste, as a function of each of the drivers influencing that variable. The impacts were then valued in monetary terms, using an appropriate economic valuation technique, such that they can be incorporated within the monetary cost-benefit framework of the model.

Note that to be consistent with the other values currently incorporated in the model; all monetary values that are based on prices from prior to 2015 are inflated to 2015 values, based on Producer Price Index (PPI) inflation as per Reserve Bank (2015). Updating all the values in the model to 2018 values still needs to be done as part of the further refinement of the model going forward.

4.1 Impacts of informal collectors on the viability of a S@S programme

This impact was initially identified for incorporation in the SASCOST model based on some comments received from municipalities during the early development of the tool. Specifically, some municipalities commented that the activities of informal collectors at the kerbside could undermine the viability of a S@S programme, as they would remove recyclables, and particularly the higher-value materials ("cherry picking"), before the collection trucks were able to arrive. This would result in a lower quantity of materials arriving at the MRF, and in a lower recovery rate at the MRF; while the materials recovered at the MRF would be of a lower value. (Note that this is essentially a financial impact, rather than a socio-economic impact).

It could be argued that this issue is not relevant to the SASCOST model; since the focus should be on understanding the costs and benefits of the system from a broader socio-economic perspective, rather than in terms of the financial viability of the programme from the municipality's perspective. In other words, although informal collectors at the kerbside may impact on the financial viability of a S@S programme (as they remove higher value materials from the system), they are still contributing to the ultimate aims of increasing recovery/recycling, improving livelihoods, and diverting waste from landfill. As such, from this broader perspective, it is not necessary to specifically quantify how much waste is recovered in the formal S@S programme as compared to by informal collectors; but only how much is recovered in total.

Ultimately, however, it was decided that it would be useful to be able to highlight the volumes of recyclables specifically recovered by the informal sector relative to the total volumes recovered in the system; as doing so would at least encourage municipalities to think about the informal sector and how to integrate them into their planning. As such, we incorporate this issue in the model by distinguishing between the tonnes (and Rand value) of recyclables recovered by the informal sector, and the tonnes (and Rand value) recovered at the MRF (see the revised version of the results tab in Figure 4). However, we do not yet reflect the impact of the informal sector activities on the financial viability of the S@S programme, partly for the reasons described above, and partly because doing so would require making some fundamental changes to the way in which the overall financial viability of each option is calculated. If required, however, this can be done in further refinement of the model.

In order to incorporate this impact into the model, it was initially proposed that the model will provide or calculate a default percentage of recyclables that will be removed by the informal sector, which will then affect the total tonnage recovered at the MRF. For example, discussions with Dirk van Niekerk of The Waste Group (Van Niekerk, 2015) suggest that, in their experience, recovery rates at the MRF declined from 75% to 30% when informal collectors moved into the serviced area, implying a “loss” of 45% of recyclables to the informal sector. The “lost” recyclables are however sold back into the system by the informal sector, thereby still contributing to recycling. From a private business perspective, this resulted in the company having to purchase sorted recyclables from pickers as opposed to receiving source separated mixed recyclables for free from households and sorting it at the MRF.

However, there are a wide range of complex factors that may affect the extent to which the informal sector are able to remove recyclables from the formal S@S system. These include factors such as:

- whether the houses are in a security complex / gated community etc.,
- proximity of the suburb to informal areas,
- proximity of the suburb to buy-back centres,
- presence of mobile buy-back centres,
- whether source-separated recyclables are collected on the same day as residual waste, or on a different day,
- whether informal collectors are able to find a place to sleep overnight,
- income level of the suburb,
- composition of the recyclables,
- level of sophistication of the informal collectors (affects the materials they are able to carry), etc.

Furthermore, the actual impact will differ across the options, depending on how easy it is to access the recyclables in each case. For example, in Option 1 (post separation – i.e. no separation by household), informal collectors must rummage through the bins, so they will only be able to access a lower proportion of available recyclables; whereas in Options 2-4, where households place recyclables in a separate bag or bin, they are easier for informal collectors to access, and therefore a higher proportion of recyclables are likely to be removed (see Table 1).

Ultimately, therefore, given the lack of reliable quantitative information available, and the wide range of socio-economic, geographical and other factors that would affect informal sector activities, it is not possible to provide a sensible default value for the percentage of recyclables that will be removed by the informal sector. Users will therefore need to enter their own percentage. However, we do allow for differences between the options, as discussed above and in

Table 1. Specifically, users are requested to provide a different percentage for each of the options. In addition, since it is more difficult for the informal sector to access recyclables in the case of post separation (as discussed above), a restriction is placed on the values entered for the other options to ensure that they are higher than the value entered for the post separation option. Based on these percentages, the model is able to calculate the total volumes (and value) that will be recovered by the informal sector, as well as the total volumes (and value) recovered at the MRF.

It could also be argued that, because informal collectors 'cherry pick' the higher value materials, they have an effect not only on the tonnages collected, but on the average value per tonne collected as well. In that case, it will be necessary to adjust the default weighted average value per tonne of waste currently used in the model[3]: Specifically, the weighted average value of materials picked out by the informal sector will be *higher* than the current default (since the informal sector will cherry pick a higher value 'basket' of goods); while the weighted average value of materials recovered at the MRF will be *lower* than the current weighted average (after the higher value materials have been removed). However, there is insufficient information available to make any reliable assumptions regarding the extent to which the weighted value of recyclables collected by the informal sector will differ from that of the materials recovered at the MRF. As such, the issue of differential weighting of the value of the materials recovered by the informal sector versus at the MRF is ignored in Version 2 of the model.

4.2 Impacts on employment and livelihoods

This impact has two broad dimensions; namely impacts on formal job creation, and impacts on informal sector livelihoods. Impacts on informal sector livelihoods are discussed in Section 4.2.5 below.

Formal job creation opportunities resulting from separation at source are likely to arise in collection (e.g. drivers and loaders/assistants), sorting (at the MRF), and in downstream recycling (re-processing). Since the model boundaries currently stop at the point where waste is baled at the MRF and made available for sale to recyclers (i.e. the costs and benefits of the physical re-processing activities are currently excluded), there is an argument for excluding jobs in these downstream activities from the model. However, since in future development it is likely that the boundaries of the model will be expanded to include the downstream recycling activities, it may be useful to establish how jobs in these activities can be quantified in the meantime. The 'upstream' jobs (collection and sorting) will be kept separate from the 'downstream' jobs (jobs in re-processing / physical recycling) in the model, in order to easily identify at what stage in the value chain the jobs are created; so that downstream jobs can be excluded if need be. As such, for the purposes of this project, we add three new variables to the model associated with the various activities along the value chain; namely "job creation – collection and transport", "job creation –

[3] The weighted average value per tonne takes into account the default price per material stream, and the composition of each material within the overall waste stream; for which defaults are applied depending on the income level of the area in question, and which can also be adjusted by the user. The default prices per tonne for each stream are as follows: Paper (R814.13), Plastic (R3 427.37), Glass: (R535.85), Metals (R3 882.17).

MRF" and "job creation - downstream". These can always be combined at a later stage if deemed appropriate.

In addition, we add a fourth variable relating to "indirect and induced" job creation. The jobs referred to above refer to direct jobs in the waste and recycling sectors. Indirect jobs refer to new jobs created further upstream and downstream in the value chain, resulting from new direct employment in the recycling sector. Induced jobs refer to jobs created throughout the economy as a result of the additional spending power of new employees in the recycling sector (both direct and indirect). Again, these will be kept separate in the model so that they can be excluded from the analysis if need be.

In the case of direct jobs created in collection, sorting and re-processing, job creation is quantified in terms of jobs created per 1,000 tonnes of waste; and valued in monetary terms based on typical salaries for the types of job in question. The results tab of the model has now been modified to indicate both the quantity of jobs created, as well as the economic value (see Figure 4). Note that the number of jobs created as reflected in the results sheet is based purely on the quantities of waste collected through the specific S@S programme that is being investigated by the model in that specific application (i.e. for the five suburbs in question). As such, for example, it does not necessarily include all jobs at the MRF, in cases where the MRF serves a wider area than only the five suburbs being assessed in the model.

A report prepared by the CSIR (2017) argues that there is currently no reliable data for South Africa on jobs associated with the upstream collection and sorting activities. We therefore use our own estimates for job creation associated with these activities, as described in sub-sections 4.2.1 and 4.2.2 below.

4.2.1 Job creation in collection and transport

Job creation in collection and transport applies only to the separate vehicle option, where there will be additional vehicles collecting recyclables; and not to the other options, where there are no additional vehicles. Version 1 of the SASCOST model already contains information on the number of drivers and assistants per vehicle, and the number of vehicles required (which is determined by the model on the basis of the number of households serviced), as part of the vehicle costing sub-model. It also contains information on salaries, which are either provided by users or based on default values (currently R11,000 per month for drivers, and R8,000 for assistants, based on the Road Freight Association of South Africa (2014)). The number of drivers and assistants per vehicle is multiplied by the number of vehicles required in order to quantify total job creation in collection and transport; while the salary information is used to calculate the associated economic value.

4.2.2 Job creation at the MRF

In the case of job creation at the MRF, it was necessary to run a statistical model to estimate the number of jobs created per tonne of waste, based on data relating to the number of employees and the tonnes of waste processed per year at MRFs currently operating in South Africa. As a starting point, we utilized existing data, obtained primarily from Linkd Environmental (Mandaza

2015), who provided CSIR with access to the raw data underlying their study for the South African Local Government Association (SALGA 2012)[4]. Other sources of secondary data relating to specific MRFs were The South African Institution of Civil Engineering (2012) and The Waste Group (2015). New primary data was then obtained by contacting local municipalities across South Africa and requesting access to the required data. This further data was used to update and verify the existing secondary data and fill in gaps, as well as to expand on the number of MRFs in the sample. All in all, 23 MRFs were included in the sample.

In some cases, discrepancies were noticed between the secondary data from SALGA (2012) and the new primary data obtained; although these could primarily be explained by the fact that the SALGA data is relatively old. In terms of data relating to the tonnes of waste processed per annum, the model requires that this data relates to the tonnes of waste entering the MRF; rather than the tonnes of recyclables recovered. The SALGA data would appear to relate to the tonnes of waste entering the MRF; on the other hand, in many cases, the new primary data obtained related to the tonnes recovered. This data was therefore worked back to the tonnes of waste entering the MRF based on the average recovery rate of a dirty (15%) or clean (85%) MRF, as relevant. These average recovery rates are those used in the Version 1 of the SASCOST model; and are in turn based on national averages from various sources of information.

This data suggests that anywhere between two and 100 jobs are created per 1,000 tonnes of waste processed at the MRF, with an average of 24 jobs per 1,000 tonnes. The number of jobs created per 1,000 tonnes of waste is likely to vary based on a number of factors, including the 'type' of MRF (clean vs dirty), and the level of mechanization (mechanized vs manual sorting). In addition, there seem to be "economies of scale" at play – generally speaking, the data seems to suggest that as the capacity of the MRF increases (in terms of tonnes processed per annum), the number of employees per 1,000 tonnes of waste decreases.

As such, rather than using a simple average, it was deemed more appropriate to use a statistical regression model that would take into account all of the various factors affecting the number of jobs per 1,000 tonnes of waste, as well as economies of scale. This model would take the following general form:

$$\boldsymbol{Jobs_{MRF}} = \boldsymbol{f}(\boldsymbol{Size_{MRF,}}\, \boldsymbol{Type_{MRF,}}\, \boldsymbol{Mech_{MRF}})$$

Where

- $Jobs_{MRF}$ = the number of people employed at the MRF per annum
- $Size_{MRF}$ = the tonnes of waste processed at the MRF per annum
- $Type_{MRF}$ = whether the MRF can be classified as a 'clean', 'dirty' or 'mixed' MRF.
- $Mech_{MRF}$ = the level of mechanization of the MRF, ranging from a fully manual MRF (manual sorting from table-top), to a semi-mechanised MRF (manual sorting from conveyor), to a fully-mechanised MRF (mechanical sorting).

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[4] We hereby acknowledge Marvelous Nengovhela (SALGA) for granting us permission to use the data and for requesting the data from Linkd Environmental on our behalf; as well as Crispian Olver, Nicola White and Sandra Mandaza (Linkd Environmental) for providing us with access to the data.

This regression model was populated with the data referred to above on the number of employees and tonnes of waste processed per annum at 23 existing MRFs in South Africa; as well as data on the other explanatory variables (i.e. the 'type' of MRF (clean, dirty or mixed) and the level of mechanization of each MRF), where available. All in all, a complete set of data for 20 out of the 23 MRFs was obtained, relating to the following variables:

- Dependent variable:
    - Number of employees
- Explanatory variables:
    - Tonnes of waste processed per annum (explanatory variable)
    - Type of MRF (clean, dirty or mixed)
    - Level of mechanization (manual sorting from table-top/floor; manual sorting from conveyor belt, or fully mechanized).

A multiple regression of the dependent variable on all three explanatory variables revealed that the three explanatory variables explain approximately 92% of the variation in the independent variable (based on the R^2 value), suggesting that the model fits the data extremely well.

However, it was noted that:

- the type of MRF (clean or dirty) does not have a statistically significant influence on the number of jobs, holding all other variables constant
- the level of mechanization had an unexpected influence on results (it was found that, all else being equal, a more mechanized facility creates more jobs than a manual facility); although this can primarily be explained by the fact that only one MRF in the sample was classified as fully mechanized, such that this observation can be seen as an outlier, which does not allow for results relating to the influence of this variable to be generalized.

As such, it was necessary to drop the latter two variables from the regression model. The regression model is therefore revised as follows:

$$\boldsymbol{Jobs_{MRF} = f(Size_{MRF})}$$

Where

- $Jobs_{MRF}$ = the number of people employed at the MRF per annum
- $Size_{MRF}$ = the tonnes of waste processed at the MRF per annum

This revised simple regression model still has an R^2 value of 90%; that is, on its own, the size of the MRF (tonnes of waste processed per annum) explains 90% of the variation in the dependent variable. In addition, it is now possible to use data on all 23 MRFs, rather than only 20 (since for three of the MRFs, data could be obtained for the two variables that now form the regression model; but not for the two variables that have been omitted from the regression model).

The results of the regression analysis are presented in Table 2.

Table 2: Regression results: MRF Employment Model

Regression Statistics					
Multiple R			0.949137		
R Square			0.900862		
Adjusted R Square			0.896141		
Standard Error			17.01738		
Observations			23		
ANOVA					
	df	**SS**	**MS**	**F**	**Significance F**
Regression	1	55261.3	55261.3	190.8253	5.21E-12
Residual	21	6081.413	289.5911		
Total	22	61342.72			
	Coefficients	**Std Error**	**t Stat**	**P-value**	
Intercept	18.82714	3.814181	4.936089	6.97E-05	
X Variable 1	0.00198	0.000143	13.81395	5.21E-12	

These results imply an intercept (starting value) of approximately 19 jobs, which increases by 0.00198 jobs per additional tonne (or 1.98 jobs per additional 1,000 tonnes) of waste processed. The number of jobs for a particular MRF is therefore estimated by applying the following formula:

$$\boldsymbol{Jobs_{MRF}} = (\mathbf{18.827} + \mathbf{0.00198} * \boldsymbol{Size_{MRF}})$$

Some examples of the resulting number of jobs for different sized facilities are provided in Table 3.

Table 3: Number of employees associated with different sized MRFs as predicted by the regression model

Tonnes of waste processed per year	**Number of employees**
50	19
500	20
1 000	21
2 500	24
5 000	29
10 000	39
50 000	118
100 000	217

The number of additional jobs created through the specific S@S programme being investigated by the model is then calculated by dividing the number of jobs for the MRF as a whole by the tonnes of waste processed at the MRF (to get to jobs per tonne processed), and multiplied by the tonnes of waste collected through the specific S@S programme.

The economic value of the additional jobs created is then quantified in monetary terms based on average incomes for employees at a MRF, in order to be incorporated in the SASCOST model as a net benefit per annum. Users of the model have the option to insert their own information on the average salary of an employee at the MRF. Otherwise, a default value is provided, based on primary data obtained from municipalities for a number of MRFs in South Africa. This data indicates that monthly pre-tax salaries for general workers/labourers, operators (of conveyors, compactors and balers), and cleaners range between R3,000 and R15,000, depending on the position and on whether it is a private or public sector facility; with an average of around R6000 per month. This average is therefore presented in the model as a default value.

4.2.3 Job creation in downstream processing

In the case of jobs in downstream processing, CSIR (2017) provides an indication of jobs created per 1,000 tonnes of material recycled, for each of the four material streams (paper, plastics, glass and metals); for both a capital-intensive, low-labour scenario (based on EU data), as well as a more labour-intensive scenario that is likely to be more applicable to South Africa. For direct job creation associated with the labour-intensive scenario of relevance to South Africa, the figures used in CSIR (2017) are summarized in Table 4.

Table 4: Direct Jobs (in re-processing) per 1,000 tonnes of materials recycled (Source: CSIR, 2017).

Packaging type	**Jobs per 1,000 tonnes**
Plastic	26.0
Paper	5.0
Metal (ferrous)	15.1
Metal (non-ferrous)	30.8
Metal (weighted average)[1]	16.4
Glass	2.1

[1] CSIR (2017) provides data showing that 51 720 tonnes of steel/tin-plate packaging is recycled in South Africa per annum, as compared to 4 600 tonnes of aluminium packaging; suggesting an approximate 90:10 split in favour of ferrous metal packaging as compared to non-ferrous (this includes both food and beverage cans as well as other metal packaging). This split was used to calculate the weighted average.

As such, the number of jobs created in downstream processing as a result of recyclable materials recovered through the S@S programme in question are calculated using these figures, taking into account both the actual recovery rate of the materials, as well as the composition.

Again, the economic benefit of this additional job creation is valued based on average salaries for the jobs in question. In this case, however, little information could be found specifically relating to jobs in recycling or re-processing activities. In the absence of such information, we consulted PayScale, Inc (2018), which provides the typical range and median salaries for a variety of job types in different countries. In this case, we used the job type "production operator" in South Africa, as this was deemed to be representative of typical jobs in the re-processing or re-manufacturing sector. The median salary for workers in this category is R122,852 per annum.

4.2.4 Indirect and induced job creation

In terms of indirect and induced jobs, CSIR (2017) provides multipliers by which these can be calculated, based on the number of direct jobs created, as calculated above. The multipliers used in CSIR (2017) are 1.5 for indirect jobs (i.e., for every direct job created, 1.5 indirect jobs are created); and 1.75 for induced jobs (i.e., for every direct job created, 1.75 induced jobs are created). These multipliers were therefore used to calculate the number of indirect and induced jobs created, based on the number of direct jobs created in collection, sorting, and downstream re-processing.

In turn, the economic benefits of these indirect and induced jobs should ideally be calculated based on the salaries associated with the jobs in question. However, this would be an extremely complex task, since it will be difficult to determine exactly what types of jobs will be created, and in what proportion. As such, we simply applied the same set of salaries for the indirect and induced jobs as was used for the direct jobs. The simplest way of doing this was to apply the same multipliers used above to calculate job numbers (1.5 and 1.75 for indirect and induced jobs respectively) to the economic values calculated for the direct jobs; since these economic values already take into account the relevant salaries and are weighted by the proportion of jobs in each activity.

However, it is important to note that, given the large number of indirect and induced jobs that are created (based on application of the above-mentioned multipliers), the associated economic value of this impact is disproportionately large and therefore essentially “blows out” the overall calculated net benefit of S@S across all of the options (to the extent that all options now effectively swing towards yielding significant net benefits). This also applies to jobs in downstream processing activities, discussed in Section 4.2.3 above; although not to the same extent.

From an overall socio-economic perspective, it would be valid to include these benefits in the overall cost-benefit calculation, as these are real benefits to society. However, it is debatable whether these benefits should be incorporated in the cost-benefit calculation for the municipality’s decision making. This may depend on whether the jobs created are within the municipality’s area of jurisdiction, or outside of its boundaries; which may be difficult to determine. Ideally, the model should be designed in such a way that multiple perspectives can be taken into account (e.g. municipal perspective vs. national socio-economic perspective); or at least that the user can easily select which specific categories of costs/benefits should be included in the overall cost-benefit calculation. Since the “Results” tab presents an itemized account in terms of the cost/benefit associated with each specific category, it is possible for the user to exclude those categories of costs/benefits that are not relevant to their decision making; although currently this needs to be done manually. Going forward, the model will be redesigned in such a way as to more easily allow for this flexibility (i.e., users can select which perspective they are interested in; and/or which categories of costs/benefits they would like to include/exclude). In the interim, however, we include the economic benefits associated with this category of job creation in the overall calculation; but as mentioned they can be manually excluded if need be.

4.2.5 Impacts on informal sector livelihoods

Finally, impacts on informal sector livelihoods has two dimensions; namely; the potential increased ability of kerbside pickers to access high value materials (since these have been pre-separated by households), and reduced opportunities for pickers at the landfill site (since recyclables have been diverted from landfill). These impacts have proved to be extremely challenging to quantify. There is very little reliable information regarding which of these two impacts (increased opportunities for kerbside pickers vs. reduced opportunities for landfill pickers) is likely to outweigh the other – it is likely in fact that some pickers will migrate from the landfill site to the suburbs, in search of improved opportunities. While this may have an impact on the livelihood of individual pickers, it is extremely difficult to quantify the overall impact. As such, for the purposes of this project, we assume that these two impacts will essentially cancel each other out. As such, no changes are made to the model to account for these impacts.

4.3 Additional/avoided emissions from collection and transport

Greenhouse gas (GHG) emissions associated with fuel use by vehicles involved in S@S also needs to be taken into account by the model. Ideally, the model should account for:

- Additional emissions associated with additional collection of recyclables from households and transport to the MRF
- Avoided emissions associated with reduced use of vehicles for collecting mixed waste from households and reduced transport to the landfill
- Additional emissions associated with transport of residual fraction from the MRF to the landfill site

Note that these three impacts all need to be assessed in such a way as to ensure that both additional emissions and any savings are taken into account, and in such a way that double-counting is avoided.

Greenhouse gas emissions from vehicles are a function of fuel use (in litres). In turn, this depends on the distance travelled, and fuel use per km for the vehicle in queston. Provided that the change in fuel use (preferably) or km's travelled associated with each of the above impacts are known, the resulting change in emissions can be quantified by applying standard GHG emission factors. These emission factors are generally specified in kg of CO_2 equivalent (kgCO_2e) per litre of fuel used. If fuel use is unknown, emission factors specified in kgCO_2e per km travelled can be used as an alternative; although emission factors based on actual fuel use are preferred, since they are more direct (emissions result directly from fuel use, which is in turn a function of distance travelled and other factors). Such emission factors include emissions of CO_2 as well as other relevant greenhouse gases, such as methane (CH_4) and nitrous oxide (N_20), converted to CO_2 equivalents based on their respective global warming potentials relative to CO_2.

In the following sub-sections, we describe how the change in fuel use or km's travelled is determined, and how emission factors are applied, for each of the three impacts referred to above.

4.3.1 Additional emissions associated with additional collection of recyclables from households and transport to the MRF

This impact only applies in the case of the separate vehicle option, due to the fact that additional vehicles are being used to collect recyclables; as well as in the truck and trailer option (assuming trailers were not being used before), since there will be some additional fuel use associated with towing trailers (due to increased weight and wind resistance etc.).

In the case of the separate vehicle option, the model calculates the total kilometers driven in collecting recyclables and transporting them to the MRF. It also calculates a weighted average fuel consumption index (litres of diesel per 100 km) for each vehicle type; based on fuel use per km during collection and transport, weighted by the proportion of total km's that are driven during collection and transport respectively. The rationale for distinguishing between fuel use during collection and transport is to account for the different driving conditions in each case. During collection, fuel use per km will be higher, as the vehicles will be driving in a 'stop-start' manner, and will therefore mainly be engaging lower gears; whereas during transport, the vehicles will be in 'cruise' mode, i.e. they will be able to shift into higher gear. The model assumes a 30% increase in fuel use per km during collection as compared to transport; based on Groot et al. (2014) and Barnes and Langworthy (2003)[5]. As such, the model can calculate the total litres of fuel used per annum across the collection fleet (the model assumes that the fleet of vehicles collecting recyclables from the area in question will all have similar specifications); by multiplying the km's driven by the weighted fuel consumption index:

$$Fuel_{CT} = \frac{(Distance_{CT} * WFCI)}{100}$$

Where:

- $Fuel_{CT}$ = Litres of fuel used in collection and transport, per annum
- $Distance_{CT}$ = Total km's driven during collection and transport, per annum
- $WFCI$ = Weighted fuel consumption index, in litres per 100km

[5] Groot et al. (2014) use fuel consumption figures of 0.25 litres per km during transport, and 0.33 L per km during collection (excluding idling), which implies a 32% increase for fuel consumption during collection relative to transport. Similarly Barnes and Langworthy (2003) suggest a 31% increase in fuel use for 'stop-start' driving conditions, which also excludes idling. Since it is expected that caged vehicles will not spend as much time idling as is the case for compactor vehicles during normal waste collection, and since these vehicles are in any case not expected to use as much fuel as compactors during idling (since they are not fitted with compaction mechanisms which operate during idling); it was decided to ignore the issue of fuel use during idling; and to instead assume a 30% increase in fuel use per km during collection relative to transport, based on Groot et al. (2014) and Barnes and Langworthy (2003).

Greenhouse gas emissions associated with this fuel use are then calculated using the greenhouse gas emissions factor for diesel of 2.67 $kgCO_2e$ per litre, based on the UK Department for Environment, Food and Rural Affairs (DEFRA, 2017).

The model for calculating CO_2 emissions per annum is therefore as follows:

$$GHG_{CT} = \frac{(Fuel_{CT} * EF)}{1000}$$

Where:

- GHG_{CT} = GHG emissions from collection and transport, in tonnes of CO_2 equivalent emissions (tCO_2e), per annum
- $Fuel_{CT}$ = Litres of fuel used per annum in collection and transport
- EF = Emissions factor, in $kgCO_2e$ / litre of fuel used.

Dividing by 1,000 is necessary to get from emissions in $kgCO_2e$ to tonnes of CO_2e (tCO_2e).

In the case of the truck and trailer option, the model assumes that fuel use per km will increase by a factor of approximately 20%, as a result of the additional weight and wind resistance associated with towing a trailer[6]. This implies that there will be an increase in greenhouse gas emissions associated with collection and transport of recyclables with this option, even though there are no additional vehicles being used. In order to calculate the additional emissions as a result of towing trailers; the model calculates emissions for waste collection and transport both in the case of trailers being used and no trailers being used (using the formulae provided above); and then calculates the difference. (Note, however, that if trailers are already being used anyway, to increase the capacity of the waste collection vehicles (rather than explicitly for separate collection of recyclables), then there will be no change in fuel use or in GHG emissions).

4.3.2 Avoided emissions associated with reduced use of vehicles for collecting mixed waste from households and reduced transport to the landfill

This impact speaks to the fact that, while there will be additional vehicles collecting separated recyclables (at least in the separate vehicle option), there will also be a reduced requirement for collection vehicles collecting mixed waste. This is perhaps most obvious in the case of the separate vehicle option, where there is essentially a reduction in the use of vehicles (typically compactors) collecting mixed waste, but more vehicles (typically caged trucks) collecting separated recyclables. The change in overall emissions deriving from both of these sources need to be taken into account

[6] In developing Version 1 of the SASCOST model, no substantive literature could be found regarding the extent to which fuel consumption will increase as a result of towing a trailer. However, based on expert opinion, personal experience among the project team, and comments on relevant online blogs, it seems evident that towing could increase fuel consumption by between 20% to 40%. The higher values in this range tend to be associated with travelling at speed on the open road, when wind resistance becomes more of a factor. As such, given the driving conditions under consideration in the model, which will tend to involve travelling at lower speeds within urban areas; the increase in fuel consumption is likely to be closer to 20%, rather than 40%. As such, for the truck and trailer option, it is assumed that fuel consumption will increase by 20% when towing a trailer.

in the model. However, the impact also applies to the other options in the model as well (post separation, truck and trailer, and rich bag) – for these options, while there may not (necessarily) be a reduction in the use of collection vehicles (at least, not a reduction that can be easily quantified), there is a reduced requirement for transport of waste to landfill.

In the case of the separate vehicle option, the model unfortunately does not currently generate the information required to calculate avoided emissions from reduced collection and transport (i.e., either the savings in fuel used or in km's travelled by the current collection vehicles in collecting and transporting waste) in a satisfactory way. Adding these variables may add unnecessary complexity to the model; particularly since emissions from collection and transport of waste contribute a relatively small proportion to overall greenhouse gas emissions from waste (Freed et al., 2001); where the bulk of emissions arise from disposal (mainly in the form of methane). This implies that the benefits in terms of avoided emissions from reduced collection and transport are expected to be relatively minor.

As such, it was decided to assess these avoided emissions based on evidence from the literature regarding typical fuel use associated with waste collection vehicles, per tonne of waste (since the model does already calculate the tonnes of waste diverted from normal waste collection and transport). It should be noted that this is not a wholly satisfactory solution, since savings in fuel use will clearly differ markedly depending on the vehicles used and on savings in distances driven and in time spent idling; however, it could provide an indicative measure. In future work, this component of the model will be developed in a more rigorous way.

The only substantive literature in this regard that could be found was that of Hauser (2015), who conducted an assessment of air emissions from solid waste collection vehicles in the United States. She found that, on average, waste collection vehicles used 17.43kg of diesel per ton of waste collected. Note that this is an average between front- and side-loading waste collection vehicles; rear-end loaders were not included in the assessment. This converts to 20.77 litres of diesel per ton of waste, based on a conversion factor of 1.192 kilolitres per metric ton (or 1.192 litres per kg) of diesel (Iowa State University, 2008). Since front- and side-loading collection vehicles are expected to be similar to rear-end loaders in terms of fuel use (this assumption needs to be tested); this figure is therefore applied as the default fuel use per tonne of waste collected, in the case of compactors/rear-end loaders.

In the case of other types of waste collection vehicles (e.g. caged trucks and bush trucks), since these vehicles use far less fuel than compactors/rear-end loaders, the figure is adjusted based on the relative fuel use for these vehicles as compared to compactors/rear-end loaders. According to City of Cape Town (2006), the fuel consumption of collection vehicles in the City (compactors) is approximately 100 litres per 100km. On the other hand, for caged trucks/bush trucks etc., the model draws on the Road Freight Association of South Africa's (2014) Vehicle Costing Schedule (used in Version 1 of the model for calculating the capital and operating costs of the collection vehicles), which indicates that fuel consumption is on average 20 litres per 100km; i.e. one-fifth of the fuel consumption of compactors. As such, we assign a default value for fuel use per tonne of waste for these vehicles equal to one-fifth of that used for compactors (20.77 litres per tonne); i.e. 20.77 / 5 = 4.15 litres per tonne of waste.

A slight adjustment to these calculations is required for the post separation, truck and trailer and rich bag options. As mentioned above, for these options, while there may not (necessarily) be a reduction in the use of collection vehicles (at least, not a reduction that can be easily quantified), there is a reduced requirement for transport of waste to landfill. As such, in this case it is necessary to extract the savings in emissions from fuel use that result specifically from reduced transport of waste to the landfill. This is done based on the assumption that waste collection vehicles spend approximately 70% of their time in 'collection' mode (driving and collecting waste in urban areas), and 30% of their time hauling waste to the landfill site, as per Farzaneh et al. (2009). As such, it is assumed that fuel use during transport alone is 30% of that associated with collection and transport combined, per tonne of waste.

This fuel use per tonne of waste is then multiplied by the tonnages of waste diverted from normal waste collection and transport to landfill through the S@S programme, to derive an estimate of the litres of fuel saved. The savings in terms of GHG emissions are then calculated as follows:

$$GHG_{SAV} = \frac{(Fuel_{SAV} * EF)}{1000}$$

Where:

- GHG_{SAV} = savings in GHG emissions through reduced collection and transport of mixed waste, in tonnes of CO_2 equivalent emissions (tCO_2e), per annum
- $Fuel_{SAV}$ = Litres of fuel saved per annum through reduced collection and transport of mixed waste
- EF = Emissions factor, in $kgCO_2e$ / litre of fuel used.

The same emissions factor is applied as in Section 4.3.1, i.e. 2.67 $kgCO_2e$ per litre of diesel used. Dividing by 1,000 is necessary to get from emissions in $kgCO_2e$ to tCO_2e.

4.3.3 Additional emissions associated with transport of residual fraction from the MRF to the landfill site

Finally, for all options, there will be some additional emissions associated with transport of the residual fraction from the MRF to the landfill site (except in cases where the MRF is located at the landfill site itself). This impact is expected to be higher in the case of "dirty" MRFs as compared to "clean" MRFs, since the residual fraction is higher in the case of a dirty MRF. Calculating this impact is relatively straightforward, since users are already asked to provide the distance from the MRF to the landfill site. We then make an assumption regarding the number of trips required, by dividing the total tonnages of residual waste leaving the MRF per annum by an assumed 30 tonne payload per trip (the model currently assumes that the vehicle transporting residual waste from the MRF to the landfill will be a large freight transport vehicle, although this assumption needs to be tested). This can then be multiplied by the distance per trip to calculate the total distance travelled per annum.

Emissions can then be calculated by applying an appropriate emissions factor specified in $kgCO_2e$ / km. Since the model currently assumes that large freight vehicles are used for this purpose (see above), we apply emissions factors from DEFRA (2017) for articulated diesel trucks with a Gross Vehicle Mass (GVM) above 33 tonnes. In this case, two emissions factors are used; one for the trip from the MRF to the landfill, when the vehicle is assumed to be fully laden (1.1352 $kgCO_2e$ / km), and one for the return trip, when the vehicle is assumed to be empty (0.6858 $kgCO_2e$ / km). The formula for calculating emissions is therefore as follows:

$$GHG_{M-L} = \frac{(Distance_{M-L} * Trips_{M-L} * EF_{FL}) + (Distance_{M-L} * Trips_{M-L} * EF_{NL})}{1000}$$

Where:

- GHG_{M-L} = GHG emissions from transport of the residual fraction from the MRF to the landfill, in tonnes of CO_2 equivalent emissions (tCO_2e), per annum
- $Distance_{M-L}$ = One-way distance from the MRF to the landfill site, in km
- $Trips_{M-L}$ = Number of trips from the MRF to the landfill site, in km
- EF_{FL} = Emissions factor for fully laden vehicle, in $kgCO_2e$ / km travelled
- EF_{NL} = Emissions factor for empty vehicle (no load), in $kgCO_2e$ / km travelled

Note that to simplify this formula in the model itself, we simply take an average of the two emission factors (this is equivalent to the emissions factor for a 50% load of 0.9105 $kgCO_2e$ / km), and multiply this by the total distance travelled per annum (in both directions). Dividing by 1,000 is necessary to get from emissions in $kgCO_2e$ to tCO_2e.

4.3.4 Valuation of emissions in monetary terms

The resulting increase or decrease in emissions associated with each of the factors discussed above is quantified for each option in the model in terms of tCO_2e. In addition, however, in order for the impact to be incorporated within the cost-benefit framework of the model, the net change in emissions can also be valued in monetary terms. One way of doing this is to simply apply a relevant carbon price (e.g. based on an emissions trading market) or carbon tax per tCO_2e. The latest prices on the European Emission Allowances spot and auction markets are in the order of 10 Euros per tCO_2e (as at 28 February 2018), according to the European Energy Exchange (2018). This equates to R143.68 per tCO_2e at an exchange rate of R14.37/Euro (as at 28 February 2018). This is comparable with the proposed carbon tax rate for South Africa of R120 per tCO_2e.

Ideally, however, the valuation of GHG emissions should be done from a 'damage cost' perspective, also known as the "social cost of carbon". That is, the monetary value should reflect the impacts of the emissions in terms of their contribution to the damages caused as a result of climate change; as this more accurately reflects the actual cost or benefit of the associated increase or decrease in emissions. According to the much-cited 'Stern Review on the Economics of Climate Change' (Stern, 2006), "the social cost of carbon today, if we remain on a BAU [business as usual] trajectory, is of the order of $85 per tonne of CO_2 - higher than typical numbers in the literature, largely because we treat risk explicitly and incorporate recent evidence on the risks, but nevertheless well within the range of published estimates" (Stern, 2006: xvi). Indeed, according to the US Environmental Protection Agency (2017), the long term social cost of carbon varies between \$11 and \$212 per tonne of CO_2, between 2015 and 2050, depending on the discount rate applied.

As such, we apply the \$85 per tonne of CO_2 presented in Stern (2006). Based on current exchange rates (R11.76/\$ as at 28 February 2018), this equates to R999.83 per tCO_2e.

4.4 Avoided externalities from landfill disposal

Landfilling of waste gives rise to a number of environmental and social 'externalities', such as emissions of leachate and landfill gas (containing methane, a greenhouse gas with a higher global warming potential than CO_2); and 'disamenities' associated with odour, pests, windblown litter, traffic congestion, etc. (Nahman, 2011). Diversion of waste from landfill through S@S will therefore result in some reduction in these externalities. This positive impact should also be taken into account as an additional benefit of S@S.

The value of the benefit is calculated based on the tonnes of waste diverted from landfill, and on a Rand value of the damage costs associated with these externalities per tonne of waste landfilled. The user of the model has an option to provide their own figure for this Rand value per tonne; however, since most users are not expected to have good information on this, a default value is provided. The default value provided is based on previous work (Nahman, 2011), in which we quantified the social and environmental externality costs per tonne of waste disposed of to landfill, using the City of Cape Town as a case study. An externality cost of R110.59 per tonne of waste was estimated, based on impacts associated with leachate, landfill gas emissions, transport-related emissions, and 'disamenities' such as odours and pests. Excluding the transport-related emissions, so as to avoid double-counting with the impact discussed in Section 4.3 above, results in a value of R86.37 per tonne. This was therefore incorporated in the model as a default value of the avoided externalities per tonne of waste diverted from landfill. To be consistent with other default values in the model; the 2011 value (R86.37 per tonne) was inflated to 2015 values, based on Producer Price Index (PPI) Inflation (Reserve Bank, 2015), resulting in a value of R107.05 per tonne. (Note that this excludes the value of airspace savings, which is discussed in Section 4.5 below). However, the user is also advised that the actual value used should be adjusted based on:

- The actual landfilling standards applied by the municipality in question, as compared to the City of Cape Town, on which the R107.05 per tonne is based. Standards in terms of e.g. landfill gas and leachate management are likely to differ between municipalities, which would in turn have an effect on the environmental impacts at different landfill sites (e.g. in terms of methane emissions and leachate); which would in turn affect the externality cost per tonne of waste, and therefore the avoided cost per tonne diverted.
- The composition of the waste diverted from landfill. The R107.05 per tonne was based on general municipal waste, including both organic and inorganic waste types. It should be borne in mind, however, that methane and leachate are primarily generated through the decomposition of organic waste; whereas the SASCOST model currently focuses only on the diversion of paper and packaging waste from landfill, which is primarily inorganic in composition (with the exception of paper). Nevertheless, there are some environmental

impacts associated with the disposal of inorganic waste (e.g. windblown litter, accumulation of water in plastics which forms a breeding ground for mosquitoes and odours, fires resulting from the fact that paper and packaging burn easily, etc.). As such, it will therefore be necessary to adjust the default value to specifically focus on those impacts associated with paper and packaging waste, rather than general waste. Further, since impacts are likely to differ between the four packaging waste streams (paper, plastic, glass and metals), it will be necessary to take into account the actual composition of recyclables diverted.

In addition to the above assessment of the Rand value of reduced externalities at the landfill site, we also quantify the reduction in greenhouse gas emissions specifically (principally methane), in tCO_2e. This is done by multiplying the tonnes of waste diverted from landfill by an emission factor for disposal of municipal waste at landfill. The emission factor applied is 588.9 $kgCO_2e$ per tonne of waste, as per DEFRA (2017).

This saving in emissions is provided in the model for additional information purposes only, i.e. as an indication of the potential magnitude of savings in emissions due to reduced disposal. We do not put an economic value on this benefit; that is; it is not included in the overall cost-benefit calculation. Although doing so would be relatively straightforward, by applying a rand value per tonne of reduced emissions based on the 'social cost of carbon' as described in Section 4.3.4, we avoid the temptation to do so, for two reasons. Firstly, doing so would result in some double-counting with the calculation of externalities at the landfill site described above. Secondly, the actual generation of greenhouse gases at the landfill site is likely to be highly site-specific (e.g., it would depend on local climatic conditions, whether landfill gas is captured, the composition of the waste, etc.). As such, given the uncertainties in the extent to which the emissions factor used by DEFRA can be applied to a specific case in South Africa, and in order to avoid double-counting, we do not include the resulting economic benefit from reduced disposal-related GHG emissions within the overall cost-benefit calculation; although this can be reconsidered in future refinement of the model.

4.5 Landfill airspace savings and increased lifespan

A final impact of S@S that needs to be more fully accounted for in the SASCOST model is the benefit in terms of landfill airspace savings and increased lifespan of landfills, as a result of the diversion of waste from landfill. Based on discussions and feedback from a number of municipalities, it has become clear that the most appropriate way of capturing this impact within the model is to build it into the existing variable "disposal cost savings", rather than as a separate variable. In other words, it is argued that the "disposal cost savings" variable should be based on the full value of airspace savings. Feedback from municipalities and others involved in testing the model has made it clear that the default unit disposal cost saving provided in the model (approximately R125 per tonne) is far too low, in that it does not take into account the value of airspace, which includes the costs of closure and rehabilitation, costs of future expansion, etc. In other words, the value of airspace comprises the full costs associated with disposal, including CAPEX, OPEX, closure and rehabilitation costs, and replacement costs of building new landfills. Under the new National Norms and Standards for Disposal of Waste to Landfill (DEA, 2013), these costs are likely to increase substantially.

As such, in Version 2 of the model, users are asked to provide the full airspace value per tonne of waste (if known); rather than simply the unit disposal cost. If this is not known, the model provides a default value. Specifically, in Version 2, we have refined the default value for disposal cost savings towards a higher value which is more reflective of full airspace costs, including rehabilitation and closure costs, and particularly in terms of the new National Norms and Standards. For example, according to City of Cape Town (2011), the unit cost of landfill disposal, including normally projected OPEX and CAPEX, as well as additional rehabilitation and closure costs not budgeted for, amounted to R216/t in 2011, and will increase to R248/t in 2019. However, according to a survey for DST (2013), conducted prior to the implementation of the new National Norms and Standards, discussions with consulting engineers working in the waste sector indicated that landfill disposal costs (for general waste) would increase by around 50% in light of the new standards.

As such, more recently, the Western Cape Department of Environmental Affairs and Development Planning have worked out that disposal costs are closer to R250 per tonne (on average for different municipalities in the province) (Hanekom, 2016); while other estimates are as high as R463 per tonne for the City of Cape Town (excluding rehabilitation costs and costs of new landfill development) (Hanekom, 2016), and R480 per tonne in the case of Stellenbosch Local Municipality (based on the full airspace value) (Haider, 2016).

However, it is important to take into account the remaining landfill lifespan for the municipality in question; since there is a strong negative relationship between remaining landfill lifespan and the value of airspace. According to Godfrey et al. (2016):

> *For many municipalities that sit with "surplus" airspace, e.g. 50+ years of landfill lifespan, airspace value remains low at ±R100 per tonne. However, many municipalities face airspace "shortages", with landfill lifespans of <5-10 years. This has resulted in a significant increase in airspace value, as the municipality must consider the replacement value of either building a new landfill, or investing in alternative waste treatment technology, at significant cost to the municipality. In these cases, recent evidence suggests that the actual value of landfill airspace is closer to R400-R500 per tonne (e.g. Stellenbosch, City of Cape Town).*

This suggests that the default value for landfill airspace savings in the model should take into account the remaining landfill lifespan for the municipality in question. Thus, in Version 2 of the model, users are asked to first indicate the remaining landfill lifespan (on average, in the case of more than one landfill site). Then, the model estimates the airspace value (per tonne) based on the remaining landfill lifespan, as indicated in Table 5. Table 5 suggests that, as the remaining landfill lifespan decreases, the airspace value per tonne of waste increases, ranging from R100 per tonne in cases where the remaining lifespan is 50 years or more; to R500 per tonne in cases where there is less than 5 years of available airspace. As per all other values in the model, these will be presented as default values that users can choose to over-ride with their own information, if available. Note that this applies only to the costs of disposal of waste at the municipality's own landfill site(s); for disposal at other landfill sites where the municipality in question pays a tipping fee, costs of disposal are based on the tipping fee.

Table 5: Estimated airspace value per tonne (including closure and rehabilitation costs) based on remaining landfill lifespan

Remaining lifespan	Airspace value (R per tonne)
< 5 years	500
5 – 9 years	450
10 – 14 years	400
15 – 19 years	350
20 – 24 years	300
25 – 29 years	250
30 – 39 years	200
40 – 49 years	150
50 years or more	100

5 Synthesis

Having incorporated the five socio-economic and environmental impacts as described in Section 4, the SASCOST model has been expanded significantly. Version 2 of the SASCOST model can be used by municipal waste management departments (and/or their service providers, or private waste management companies) to inform decision making regarding how best to implement source separation, from an integrated financial, socio-economic and environmental perspective; taking into account their unique circumstances and priorities. Specifically, it allows for an overall net cost or benefit (including financial, socio-economic and environmental costs and benefits) to be calculated for each S@S option. This will allow for trade-offs to be assessed, and for the full range of financial, socio-economic and environmental implications of each option to be directly compared.

In order to accommodate the incorporation of the socio-economic and environmental variables in Version 2 of the model, it was necessary to substantially revise the overall layout of the "Results" tab (see Figure 4), which now provides far more information than in the previous version of the model (refer back to Figure 2). Note that Figure 4 is split over two pages (4a and 4b) due to size.

RESULTS*	POST SEPARATION	TRUCK & TRAILER	SEPARATE VEHICLE
Key indicators	**Per annum**	**Per annum**	**Per annum**
No. of households serviced	19 000	19 000	19 000
T's of waste collected/processed	5 878.60	1 037.40	1 037.40
T's of waste diverted/recovered	881.79	881.79	881.79
Tonnes recovered at the MRF	793.61	705.43	705.43
Tonnes recovered by informal sector	88.18	176.36	176.36
Total value of recyclables recovered (R)	1 464 584.45	1 464 584.45	1 464 584.45
Value of recyclables recovered - MRF	1 318 126.00	1 171 667.56	1 171 667.56
Value recovered - informal sector	146 458.44	292 916.89	292 916.89
Jobs created - collection & transport	0	0	21
Jobs created - MRF**	12	3	3
Jobs created - downstream	11	11	11
Jobs created - indirect and induced	74	44	112
tCO2e - Collection & transport to MRF	0.00	10.65	68.02
(Reduced tCO2e - Col/trans savings)	(19.58)	(3.45)	(11.52)
tCO2e - Transport MRF to Landfill	9.10	0.28	0.28
Increase (decrease) in tCO2e from collection/transport	(10.48)	7.48	56.78
(Reduced tCO2e from reduced disposal)	(519)	(519)	(519)
(Total tonnes CO2e saved)	(530)	(512)	(463)

Figure 4a: Revised Results tab (as per Version 2 of the SASCOST model) incorporating socio-economic and environmental impacts in addition to financial costs and benefits – Part 1 – Key indicators. Due to size, only the first three options are shown (rich bag option omitted). Values are based on hypothetical input data.

RESULTS*	POST SEPARATION				TRUCK & TRAILER				SEPARATE VEHICLE			
Cost-benefit analysis* **	R/year	R/tonne (collected/ processed)	R/tonne (recovered/ diverted)	R/ hhold/ month	R/year	R/tonne (collected/ processed)	R/tonne (recovered/ diverted)	R/ hhold/ month	R/year	R/tonne (collected/ processed)	R/tonne (recovered/ diverted)	R/ hhold/ month
NET COST (OR BENEFIT)	**(8 685 526)**	**(1 477.48)**	**(9 849.88)**	**(38.09)**	**(6 774 817)**	**(6 530.57)**	**(7 683.03)**	**(29.71)**	**(13 046 508)**	**(12 576.16)**	**(14 795.48)**	**(57.22)**
S@S costs (benefits)	**332 900**	**56.63**	**377.53**	**1.46**	**1 087 715**	**1 048.50**	**1 233.53**	**4.77**	**4 436 057**	**4 276.13**	**5 030.74**	**19.46**
Communication costs	0	0.00	0.00	0.00	342 000	329.67	387.85	1.50	342 000	329.67	387.85	1.50
Bag costs	0	0.00	0.00	0.00	691 600	666.67	784.31	3.03	691 600	666.67	784.31	3.03
Collection & transport to MRF	0	0.00	0.00	0.00	116 311	112.12	131.90	0.51	3 508 708	3 382.21	3 979.07	15.39
(Collection/transport savings)	(499 300)	(84.94)	(566.23)	(2.19)	(88 112)	(84.94)	(99.92)	(0.39)	(132 168)	(127.40)	(149.89)	(0.58)
Transport costs MRF to Landfill	832 200	141.56	943.76	3.65	25 916	24.98	29.39	0.11	25 916	24.98	29.39	0.11
MRF costs (benefits)	**625 735**	**106.44**	**709.62**	**2.74**	**(1 040 019)**	**(1 002.52)**	**(1 179.44)**	**(4.56)**	**(1 040 019)**	**(1 002.52)**	**(1 179.44)**	**(4.56)**
MRF costs**	2 090 320	355.58	2 370.54	9.17	424 566	409.26	481.48	1.86	424 566	409.26	481.48	1.86
(Income from sale of recyclables)	(1 464 584)	(249.14)	(1 660.92)	(6.42)	(1 464 584)	(1 411.78)	(1 660.92)	(6.42)	(1 464 584)	(1 411.78)	(1 660.92)	(6.42)
Disposal costs (benefits)	**(293 980)**	**(50.01)**	**(333.39)**	**(1.29)**	**(293 980)**	**(283.38)**	**(333.39)**	**(1.29)**	**(293 980)**	**(283.38)**	**(333.39)**	**(1.29)**
(Disposal cost savings)	(293 980)	(50.01)	(333.39)	(1.29)	(293 980)	(283.38)	(333.39)	(1.29)	(293 980)	(283.38)	(333.39)	(1.29)
Social/environmental costs (benefits)	**(9 350 181)**	**(1 590.55)**	**(10 603.64)**	**(41.01)**	**(6 528 534)**	**(6 293.17)**	**(7 403.73)**	**(28.63)**	**(16 148 566)**	**(15 566.38)**	**(18 313.39)**	**(70.83)**
(Job creation - collect/transport)	0	0.00	0.00	0.00	0	0.00	0.00	0.00	(2 275 137)	(2 193.11)	(2 580.13)	(9.98)
(Job creation - MRF)**	(877 897)	(149.34)	(995.59)	(3.85)	(218 204)	(210.34)	(247.46)	(0.96)	(218 204)	(210.34)	(247.46)	(0.96)
(Job creation - downstream)	(1 297 469)	(220.71)	(1 471.40)	(5.69)	(1 297 469)	(1 250.69)	(1 471.40)	(5.69)	(1 297 469)	(1 250.69)	(1 471.40)	(5.69)
(Job creation - indirect & induced)	(7 069 940)	(1 202.66)	(8 017.71)	(31.01)	(4 925 939)	(4 748.35)	(5 586.30)	(21.60)	(12 320 133)	(11 875.97)	(13 971.73)	(54.04)
Emissions - Collection & transport to MRF	0	0.00	0.00	0.00	10 648	10.26	12.07	0.05	68 006	65.55	77.12	0.30
(Reduced emissions - Col/trans savings)	(19 574)	(3.33)	(22.20)	(0.09)	(3 454)	(3.33)	(3.92)	(0.02)	(11 514)	(11.10)	(13.06)	(0.05)
Emissions - Transport MRF to Landfill	9 098	1.55	10.32	0.04	283	0.27	0.32	0.00	283	0.27	0.32	0.00
(Avoided externalities at landfill)	(94 398)	(16.06)	(107.05)	(0.41)	(94 398)	(90.99)	(107.05)	(0.41)	(94 398)	(90.99)	(107.05)	(0.41)

Figure 4b Revised Results tab incorporating socio-economic and environmental impacts in addition to financial costs and benefits – Part 2 – Cost-benefit analysis. Due to size, only the first three options are shown (rich bag option omitted). Values are based on hypothetical input data

Firstly, it should be noted that in addition to the results of the cost-benefit calculations (which now also incorporate monetary valuation of the socio-economic and environmental impacts, as described in Section 4) (see Figure 4b); the model now also provides results on “key indicators”, in non-monetary terms (Figure 4a); as these are also of interest and relevant to decision making. Some of the key indicators included are as follows:

- Number of households serviced
- Tonnes of waste collected from households
- Tonnes of waste diverted from landfill / recovered for recycling
    - Tonnes recovered at the MRF
    - Tonnes recovered by the informal sector
- Total value of recyclables recovered
    - Value of recyclables recovered at the MRF
    - Value of recyclables recovered by the informal sector
- Job creation:
    - Jobs created in collection and transport
    - Jobs created in sorting at the MRF
    - Jobs created in downstream activities
    - Indirect and induced jobs creation
- Total savings in tCO_2e
    - Increase/decrease in greenhouse gas emissions (tCO_2e) from collection and transport
    - Savings in tCO_2e from reduced disposal

Secondly, it is interesting to note how the incorporation of the socio-economic and environmental impacts changes the results of the model. In Version 1 of the model (financial costs and benefits only); most of the options yielded net costs (although in some cases the truck and trailer option yielded net benefits). For example, based on hypothetical data for a set of 5 high income suburbs in the City of Cape Town, costs ranged from R736 per tonne for the post separation option, to R3 500 per tonne using a separate vehicle approach.

In Version 2, however, with socio-economic and environmental impacts included, there is a big swing toward all options now yielding significant net *benefits*; ranging from R7 683 per tonne for the truck and trailer option, to R14 795 for the separate vehicle option (which now becomes the most attractive option), based on the same set of hypothetical input data. However, as suggested in Section 4.2, these high net benefits are disproportionately dominated by the benefits associated with downstream, indirect and induced job creation; for which there is an argument for excluding from the model results. This is particularly evident in the case of the separate vehicle option, for which there is additional job creation associated with collection (which in turn has a knock-on effect in terms of indirect and induced job creation), which is not the case for the other options. Even excluding these benefits, however, S@S does appear more favourable when socio-economic and environmental impacts are considered as compared to when only financial considerations are taken into account; with a net benefit for some options (e.g. the truck and trailer option shows a net benefit of R625 per tonne, as compared to a net benefit of R297 when only financial costs and benefits are considered); and a net cost of R647 per tonne for the separate vehicle option (as compared to R3 500 per tonne when only financial costs and benefits are considered).

6 Way forward for the SASCOST Model

Through this project, the SASCOST model has now been expanded substantially to incorporate the socio-economic and environmental impacts of the alternative separation at source options. However, throughout the report, we have made reference to a number of other important ways in which the model needs to be updated, expanded or further refined.

For example, going forward, the model will be redesigned in such a way that multiple perspectives can be taken into account (e.g. municipal perspective vs. national socio-economic perspective); or at least that the user can easily select which specific categories of costs/benefits should be included in the overall cost benefit calculation (e.g. to focus only on financial costs and benefits vs including socio-economic and environmental impacts). Since the “Results” tab presents an itemized account in terms of the cost/benefit associated with each specific category, it is possible for the user to exclude those categories of costs/benefits that are not relevant to their decision making; although currently this needs to be done manually. Going forward, the model will be redesigned in such a way as to more easily allow for this flexibility (i.e., users can select which perspective they are interested in; and/or which categories of costs/benefits they would like to include/exclude).

Furthermore, the model should allow for each variable to be ‘weighted’ according to the municipality’s specific needs and priorities (for example, a specific municipality may want to give more weight to job creation potential as compared to environmental impacts). This will allow municipalities to make more informed decisions regarding source separation from an integrated financial, economic, social and environmental perspective; taking into account their specific needs and priorities.

In addition, many of the values in the model need to be updated – Version 1 of the model was originally developed in 2015, and many of the values are due for an update. For example, for the most part, the monetary values in the model are based on 2015 prices. These will need to be updated to 2018 prices as part of the further refinement of the model.

Finally, we would also like to expand the scope of the model. Currently, the model focuses on packaging waste (paper, plastics, glass and metals) from households; however, a clear need has been expressed to expand the model to incorporate other waste sources and streams, particularly organic waste, which is increasingly seen as being a key waste stream to target under a S@S programme. In addition, feedback from municipalities and others suggests that there is a need to assess a broader range of options within the model; including drop-off facilities; retro-fitting existing waste-collection vehicles to allow dual collection in multiple compartments; and the procurement of specialized split-compartment compactor vehicles. Finally, with the exception of job creation benefits, the model currently only assesses costs and benefits from the point where recyclables are collected to the point where they are baled at the MRF and sold to processors; the costs and benefits associated with downstream activities are excluded. There have been some suggestions that the model boundaries should be expanded to consider the full value chain (including downstream recycling and processing).

It should also be noted that, in parallel to this project, we are also busy finalizing the strategy for disseminating the tool to end-users; and developing an online interface for the model, to allow easier access and use. This is expected to be completed early in the new financial year starting 1 April 2018.

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