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Measuring the performance and maturity of the plastic recycling value chain system: implications and prospects

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Abstract

The sustainability of plastic materials and products requires the continuous improvement of the circular pathways for the material. A key strategy in the circularity of plastic is plastic recycling. Improving the circular pathways requires an understanding of the maturity level of the plastic recycling system. This study evaluated the maturity of the plastic recycling system in South Africa across the plastic value chain. Both secondary and primary data were collected, analysed and cross-validated. The results put the maturity of the country's system at "Visionary" (Level 3) for the value chain stages of primary plastic production, product manufacturing and recycling, whereas waste generation, collection and handling, sorting and recyclate market were rated as "Structured" (Level 2). Furthermore, a set of initiatives to advance the maturity of the system to the desired level of "Connected and Dynamic" (Level 5) were identified. The paper provides a benchmark of performance and determines the stages of the system requiring additional attention. This is aimed at providing insight into policymaking to advance plastic recycling and circularity.

Keywords Plastics, Recycling, Maturity, Performance, Value chain stages, Sustainable initiatives

Introduction

The plastic industry has developed and contributed substantially to the global economy over the years. Globally, in 2021, plastic production was estimated at 390.7 million tons [1], and this volume was projected to be almost double by 2035 and to quadruple by 2050 [2]. The continued increase in plastic use contributes considerably to the total mass of generated waste within the environment. Globally, a significant percentage of plastics is being wasted, with the major share of this generated waste either landfilled, incinerated, or leaked into the ecosystem, and a mere 9% effectively recycled [3]. In the specific area of focus for this study, namely, South Africa, as of 2020, 90% of waste generated was still ending up in the landfill [4].

For the sustainability of plastic as a resource, the circular pathways for the material must be improved. Plastic circularity has been described as a feasible and beneficial alternative to the linear economy (where plastic is simply produced, consumed and disposed). Recycling is one of the many available circular solutions. Although inferior to other measures or strategies found in the waste management hierarchy, it is useful in mitigating the negative impact of plastic waste.

This study shares the perspective that the current performance and level of maturity of the individual stages across the plastic value chain, as well as the whole system, first need to be understood and established to improve plastic circularity. Therefore, this study aimed to determine the level of maturity of the plastic recycling system in South Africa to identify pathways to improvement and

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increase plastic circularity and sustainability. According to Hahladakis and Iacovidou [5], each stage along the plastic value chain needs to be considered separately when assessing the development and sustainability of the system, as all the stages have impacts or implications.

Equally, this study is driven by three basic considerations. First, the complete development of a plastic value chain cannot be achieved by focusing on a single stage in the value chain, but rather on all practices and activities in the different stages of the value chain. Second, no known study has measured the maturity of the plastic recycling system, with specific focus on the value chain stages, as shown in the following section of the study. Third, unlike many studies, this study does not propose a new maturity model, but applied an existing model (Plastic Recycling Value Chain Maturity Model), developed specifically for the plastic system, to a real-life situation and tested its applicability. Most studies tend to propose new maturity models instead of applying existing models to resolve real-life situations.

The maturity measurement of the plastic value chain in South Africa produces a basis for improving the country's recycling system and the respective value chain stages and processes, determining areas requiring additional efforts and developing action plans for bridging the gaps between the current and desired maturity levels. It will contribute to the debate of optimising the plastic recycling option and circular economy in general.

Literature review

Fraser et al. [6] describe the concept of maturity as the growth or progression of a system from a preliminary status to a very advanced status. It involves a sequence of stages forming a desired pathway to an objective or goal [7]. These stages are represented by maturity models where processes are defined, applied and subsequently improved [8]. Pullen [9] describes a maturity model as a structured group made up of elements that define the attributes of processes required at various stages of growth or development. It is an enabler for achieving optimal performance. However, Pöppelbuß and Röglinger [7] propose that the primary focus of the model should not be only on the developmental stages, but also on the set of elements driving the growth process to an improved position.

Maturity models serve various useful purposes for a system, organisation or country. Battista et al. [10] and Van Dyk [11] describe them as tools for assessing an existing situation to guide the formulation of a control and improvement roadmap. Netland and Alfnes [12] indicate that they are applied by organisations or establishments to compare the level of maturity of their system processes with that of best practices. In addition, maturity models assist in benchmarking similar or comparable systems or processes in other organisations, countries or regions [7]. Schumacher et al. [13] maintain that they are appropriate for assessing the degree of resources in place to adopt necessary action.

The roots of maturity models are traceable to the quality maturity grid developed in 1979 by Crosby [14]. This measured organisational processes along the five maturity levels or stages, in ascending order, of uncertainty (stage 1), awakening (stage 2), enlightenment (stage 3), wisdom (stage 4) and certainty (stage 5) [14]. Mettler [15] further developed a framework that classifies maturity models according to the different dimensions they address. These include process maturity (the level of a process being unambiguously defined, measured, managed and controlled), people maturity (the level of people achieving knowledge development and proficiency improvement) and technology maturity (the level of a technology reaching a threshold). However, the majority of maturity models focus on process dimension [16].

Since 1993 when the Capability Maturity Model (CMM) was developed [17], maturity models have continued to enjoy increasing popularity and acceptance. Today, different maturity models have been developed for system or organisational assessment in various disciplines, including supply chain [18–20], energy management [21], product development [6], project management [22], technology [23] and software development [24]. Adopting maturity models has undoubtedly driven huge scholarly interest [25]. Their application in different fields of study, including the plastic system, is expected to continue to increase [26].

Furthermore, plastic sustainability as a resource demands that the circular pathways for the material must be continuously improved across all the stages of the plastic value chain. The objective will be to maximise the value of the plastic material at every value chain stage considering the focus is to keep plastic products and material at their best utility every time in a circular economy [3]. Plastics can potentially be recycled multiple times without compromising their mechanical properties too much, depending on the recovered plastic waste quality, thus contributing substantially to achieving a circular economy. While it is relatively normal to obtain extra value from plastic waste through recycling, this is usually not taken into consideration in the product design mechanism [27]. This situation demands a more complete approach or process all through the value chain stages of plastics production, consumption and end-of-life. Overproduction of plastic needs to be minimised or eliminated. Similarly, the designing and manufacturing of plastic products to facilitate reuse, repair or remanufacture will lead to less plastic products going into the plastic waste stream [3]. Shifting towards circularity of plastic should involve considering all dimensions or aspects of sustainability when closing the loops, while noting that the transition towards circularity can be hindered by different barriers, including regulatory, economic and technical [4].

The development of the circular pathways of plastic requires an understanding of the performance and maturity level of the plastic value chain system, which further requires the assessment or measurement of the system. The South African plastic waste management and recycling system is currently at a developing stage, with a low plastic recycling rate of approximately 13% recorded in 2017 [27]. The country still lags behind in shifting from waste landfilling to recycling, as an estimated 90% of generated waste is being landfilled [4]. Therefore, the level of performance or maturity of the plastic recycling system in South Africa needs to be assessed to inform an improvement roadmap.

As stated earlier, no known study has measured the maturity of the plastic recycling system, with specific focus on the value chain stages. Fletcher et al. [28] developed a framework to assess the maturity of technological applications in plastic waste management and the adoption of circularity principles in hospitals. Montoya et al. [29] adapted a model for measuring reverse logistics maturity in both small and medium organisations, with respect to sustainable solid waste management. Hynds et al. [30] proposed a technique to assess organisational maturity with respect to producing products that are sustainable and also eco-design inclined. Sehnem et al. [31] assessed the models that organisations use for conducting business so as to identify the respective sectors involved in the circular economy and their levels of maturity.

For the maturity measurement of the plastic recycling system, the country's identified plastic recycling stages of the value chain include plastic production, product manufacturing, waste generation, sorting, recycling and recyclate market. The approach to maturity measurement applied in this study is centred upon a maturity model, the Plastic Recycling Value Chain Maturity Model, recently developed by Olatayo et al. [32], based on the importance of the plastic value chain.

Methodology

The different levels of the developed maturity model, in increasing order of maturity, are Level 1: Ad Hoc and Unstructured; Level 2: Structured; Level 3: Visionary; Level 4: Integrated; Level 5: Connected and Dynamic. The assessment indicators (maturity elements) used for measurement include customer satisfaction, process costs, quality data and database, structured processes, performance targets, chain actors' integration and system performance review. Table 1 provides the descriptions of the maturity elements [32]. The application of the maturity elements of the maturity model to the different stages of the plastic value chain involved assessing each of the value chain stages separately against all of the elements. A particular stage is measured or rated based on how it performs when all the elements are considered or applied individually according to the definition of each element.

A dual research process, involving both secondary and primary data analysis, was utilised to generate reliable results regarding the performance and maturity of the plastic recycling system. The process is shown in Fig. 1.

Secondary data

In this phase of the methodological process the performance and maturity of the various value chain stages of the plastic recycling system were evaluated, with reference to the defined maturity elements, using existing secondary data. The approach used for the secondary data

Table 1 Criteria for assessment of the plastic recycling system maturity level

Element	Description
Chain actors' integration	The actors are defined and organisations pursue practices and activities that are integrative and collaborative among all the actors within the plastic value chain
Consumer satisfaction	The system is consumer-driven and responsive to customer satisfaction and process improvements
Performance targets	Process performance targets are set and achieved consistently
Process costs	A huge cost reduction is achieved with respect to processes and practices in the value chains
Quality data & database	Quality and credible mass flow data are available with respect to the flow of plastic material, products and waste along the plastic value chain
Quality recyclables & products	Plastic materials, plastic products, sorted plastic waste and plastic recyclables flowing along the value chain are of high quality
Structured processes	Value chain processes and activities are formally defined, structured and documented
System performance review	The performance and reliability of the plastic recycling system are frequently audited

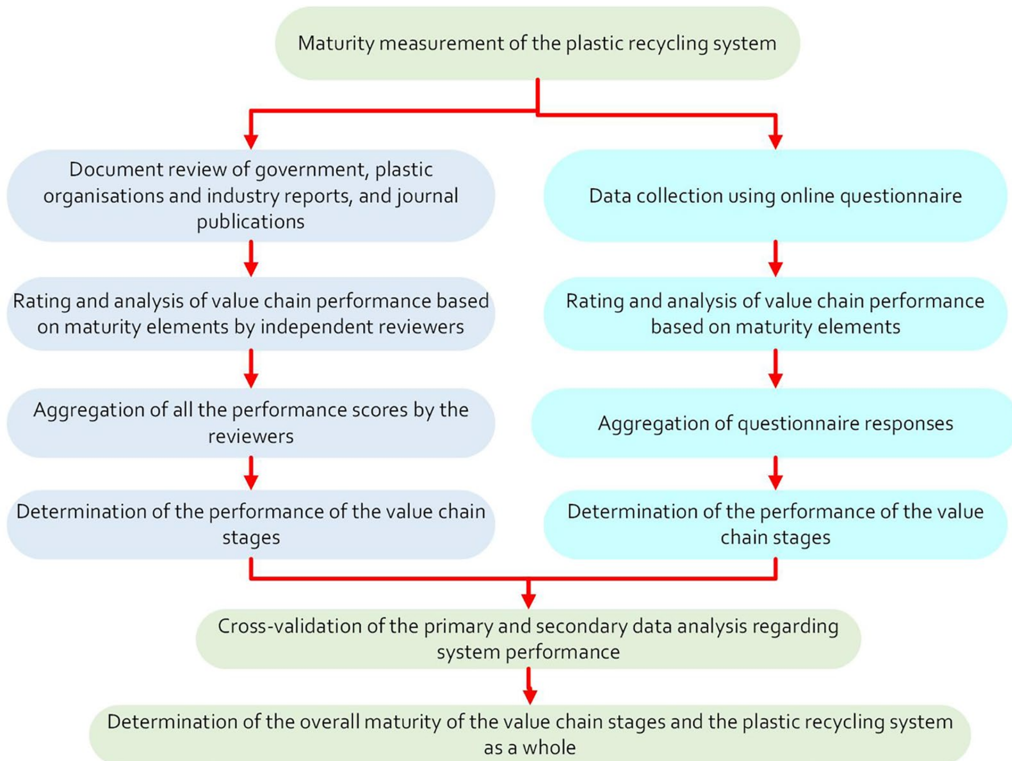

Fig. 1 Maturity measurement process

collection and analysis followed the guidelines described by Ivarsson [33].

Secondary data was collected on all the value chain stages of the plastic recycling system, for each of the defined maturity elements. This data was relevant information (e.g. measures, factors, regulations, plans, indices, values, quantities, qualities, outcomes, estimates, volumes, projections, technology and infrastructure) that described and defined the current status and situations of every stage of the South African value chain. The secondary data was sourced through a desktop review of relevant documents, including government documents, plastic organisations and industry reports, and journal publications. These reports contained information relating to the various value chain stages. The list of the 16 reports analysed for the measurement of the maturity of the plastic recycling system is included in Table S1 of Supplementary Information.

The analysis of the data involved rating the performance of all the value chain stages on a performance scale, in reference to each of the maturity elements. The specified ratings on the performance scale were 1—Very poor; 2—Poor; 3—Average; 4—Good; 5—Excellent. The collated data was analysed by the main researcher and three independent reviewers. The data, as well as the maturity element descriptions and performance scale, were shared with the three reviewers for independent review and quantitative analysis. These reviewers are researchers in this field of study. The activity involved each reviewer making informed decisions and scoring (based on the shared data) the performance of all stages of the value chain on the scale, for each of the defined maturity elements. Where there was no data for any of the maturity elements for any particular stage, the scores were computed based on the number of elements with data.

Subsequently, the four sets of performance scores awarded by the reviewers for all the value chain stages were collated and subjected to further statistical analysis and computation. This involved using multivariate descriptive statistics including the mean, standard deviation, skewness and kurtosis. This followed the approach applied in similar studies involving the Likert scale data collection technique [34, 35]. The mean and standard deviation helped to identify and understand the responses of the participants and determine the level of performance and maturity of the value chain stages; the skewness and kurtosis were analysed to determine the symmetry and the degree of distribution of the data [35]. Thereafter, factor analysis and Cronbach's alpha test were applied to analyse the extent and differences in the scores by the reviewers and to establish the internal consistency and validity of the results [35].

Primary data

This phase involved the collection of data from main actors in the value chain through an online questionnaire and the statistical analysis of this primary data, according to the guidelines described by Forza [36]. The questionnaire was a Likert scale of scores: 1—Very poor; 2—Poor; 3—Average; 4—Good; 5—Excellent. The target population for data collection consisted of stakeholders from the private sector, government and industry associations. They comprised government parastatals (national, provincial and local), manufacturers, distributors, recyclers, collection enterprises, buy-back centres and industry associations.

The questionnaire survey had limitations, as the potential number of stakeholders from the target population with sufficient required knowledge on the subject matter was limited. As expected, getting an adequately large sample of participants was challenging. Initially, about 70 potential participants were identified and contacted, but only 13 experts responded positively and participated in this study, and 8 completed the questionnaire satisfactorily. These satisfactory responses were from two participants belonging to the plastic production/product manufacturing cluster and six to the recycling/recyclate market cluster. While there was limited expert participation in the questionnaire survey, the sample is satisfactory to some degree in the study context, as the participants were deeply engaged in the subject focus and possessed a wealth of experience and knowledge in the required areas. This scenario is acknowledged and upheld by Ma et al. [37], who encountered a similar limitation of a sufficiently large sample of knowledgeable participating experts. Their study was on plastic reduction in fast-moving consumer goods firms in Europe. It is important to emphasise that the need for and dependence on sufficient expert participation could be a potential hurdle in carrying out a maturity evaluation, especially in smaller, local systems.

The collection of data was subsequently followed by analysis, where the performance and maturity of the plastic value chain stages were analysed, with respect to the maturity elements. The primary data enriched the research study and helped validate findings from secondary data and increased validity.

Cross-validation of data

This phase involved the cross-validation of the results of both the primary and secondary data analysis to determine and validate the performance and maturity of the plastic recycling system in South Africa. The cross-validation increased the credibility of these research findings and helped to give a more balanced and detailed representation of the development of this recycling system and its value chain stages in South Africa.

Results

The findings of both the secondary and primary data analysis are presented in this section and the cross-validation of both analyses is given to determine the performance and maturity of the stages of the value chain of the South African plastic recycling system. This is with respect to the maturity elements of customer satisfaction, process costs, quality data and database, structured processes, performance targets, chain actors' integration and system performance review.

Secondary data analysis

The analysis of the secondary data involved computing the descriptive statistics, which comprises the mean, standard deviation, kurtosis and skewness. The statistical analysis, provided in Tables 2, 3, 4, 5, 6, 7, 8, was done for each of the maturity elements, and for all the value chain stages to capture the whole plastic value chain system.

The standard deviation ranged between 0 and 1.785, which represented a relatively normal variation of the reviewer scores for all the value chain stages. For the skewness and kurtosis analyses, all the data analysed ranged between ± 2.0 and -6.0 to $+4.0$. According to the criteria by Byrne [54] and Curran et al. [55], data is referred to as normal or has moderate normality when the skewness and the kurtosis are between ± 2.0 and ± 7.0. None of the skewness and kurtosis values were beyond the specified ranges, suggesting that the data analysed was fairly free from skewness and was not awkwardly distributed.

The mean of the performance scores by the reviewers for each maturity element in the different stages of the system was computed to determine their performance ratings. The element of customer satisfaction apparently had good performance at the sorting and collection and handling stages of the value chain, with a mean score of 3.5 and 2.75, respectively. Process costs are seemingly well-managed at the stages of plastic production (3.25) and product manufacturing (3.25). For quality data and database, the stages of plastic production and product manufacturing apparently performed very well in the value chain at 4.5 and 4.25, respectively. Quality recyclables and products were best (3.75) at the recycling stage and performance was worst (1.5) at the collection and handling stage. The stage of plastic production seemed to have the best structured processes with a mean of 3.25, whereas product manufacturing appeared to be the best at setting performance targets for system improvement at

Table 2 Plastic production statistical analysis of secondary data

Stages	Maturity elements	Reference	Mean	Standard dev	Skewness	Kurtosis
Plastic production	Consumer satisfaction	–	–	–	–	–
	Process costs	Substantial production capabilities despite the high operational costs [38]	3.250	0.829	−0.854	−1.289
	Quality data & database	Consistent availability of various relevant data by Plastics SA, Department of Trade, Industry and Commerce, GreenCape, etc.	4.500	0.866	−2.000	4.000
	Quality recyclables & products	Supply of quality polymers to both local and international markets [38]	2.500	1.118	0.925	−1.200
	Structured processes	Described as well-established, with access to abundant raw materials [38]	3.250	1.299	0.370	−3.901
	Performance targets	–	–	–	–	–
	Chain actors' integration	Some level of collaboration but each stakeholder largely operates separately [39]	1.500	0.500	0	−6.000
	System performance review	Review of records of operating companies and workforce, performance level, market pricing, etc. [38, 39]	4.000	1.225	−1.414	1.500

– indicates no data/value

Table 3 Product manufacturing statistical analysis of secondary data

Stages	Maturity elements	Reference	Mean	Standard dev	Skewness	Kurtosis
Product manufacturing	Consumer satisfaction	–	–	–	–	–
	Process costs	High operational costs, although there are substantial capacities and capabilities for product manufacturing [38]	3.250	1.299	0.370	−3.901
	Quality data & database	Relevant data regularly shared by Plastics SA, Statistics SA and other entities	4.250	0.829	−0.854	−1.289
	Quality recyclables & products	Capacity for quality products, but challenge for investment in modern equipment and technology [38]	2.750	1.299	−0.370	−3.901
	Structured processes	Well-established, although there is insufficiency in some areas [38]	2.250	1.089	1.129	2.227
	Performance targets	Targets in other performance areas seem non-existent, but targets exist to manufacture recyclable packaging [38]	3.250	0.829	−0.854	−1.289
	Chain actors' integration	Some level of collaboration but each stakeholder largely operates separately [39]	1.750	0.829	0.854	−1.289
	System performance review	Reviews including sales growth, production, import and other relevant audits [38, 40]	3.750	1.089	−1.129	2.227

– indicates no data/value

3.25. The element of chain actors' integration was generally low across the value chain, although product manufacturing came top at 1.75. System performance review was carried out well at the stages of plastic production (4.0), product manufacturing (3.75), collection and handling (3.75), sorting (3.75) and recycling (3.0).

The collective performance ratings for the different value chain stages, in reference to the secondary data, are presented in Table 9. The performance scores were calculated using the direct mean data in Tables 2, 3, 4, 5, 6, 7, 8.

Primary data analysis

The responses of the participating experts were analysed and statistical values were computed for the maturity elements for all the plastic value chain stages as shown in Table 10. Table S2 of Supplementary Information shows the questionnaire that was administered for the study. As stated earlier, the limited participation in the survey was compensated for by the deep wealth of experience and knowledge of the eventual participants on the subject focus, an argument which is made by Ma et al. [37] for a similar study on plastics reduction.

Table 4 Waste generation statistical analysis of secondary data

Stages	Maturity elements	Reference	Mean	Standard dev	Skewness	Kurtosis
Waste generation	Consumer satisfaction	Dearth of national awareness campaigns on waste separation at source and waste service delivery [41–43]	1.500	0.500	0	−6.000
	Process costs	Increasing operational costs due to increasing waste generation from population growth, urbanisation and consumption [44, 45]	2.000	0.707	0	1.500
	Quality data & database	Relative availability of data by Plastics SA, Department of Forestry, Fisheries and the Environment (DFFE), etc.; there is a data reliability challenge with respect to waste stream volumes and waste stream types [42]	3.250	1.785	−0.199	−4.858
	Quality recyclables & products	Low quality due to lack of programmes for waste separation at source nationally [42, 46]	2.250	0.433	2.000	4.000
	Structured processes	Littering, illegal dumping, minimal source separation at source and service delivery backlogs [41, 46, 47]	2.750	0.829	0.854	−1.289
	Performance targets	Specified targets for national waste management systems, but some provincial and local government authorities have not domesticated them [42]	2.250	0.433	2.000	4.000
	Chain actors' integration	Insufficient collaboration, with lack of education amidst stakeholders within the sector [46]	1.000	0	–	–
	System performance review	Reviews by local government on access of households to waste management and waste separation rates [39, 41, 42]	2.750	1.089	−1.129	2.227

– indicates no data/value

Table 5 Collection and handling statistical analysis of secondary data

Stages	Maturity elements	Reference	Mean	Standard dev	Skewness	Kurtosis
Collection & handling	Consumer satisfaction	Littering, illegal dumping and waste service delivery backlogs, with the weekly waste removal below the minimum threshold [41, 48]	2.750	1.089	−1.129	2.227
	Process costs	Total costs of waste management risen and the existence of ageing plants and fleet and the strain on infrastructure [48]	2.000	0.707	0	1.500
	Quality data & database	Some data availability for plastic waste collected and managed by Plastics SA, GreenCape and DFFE, though there are challenges regarding waste stream types [42]	3.000	0	–	–
	Quality recyclables & products	Low quality of waste collected due to lack of programmes such as separation at source, except in a number of metropolitan areas [42, 46]	1.500	0.500	0	−6.000
	Structured processes	Implementation of the least cost collection and disposal method and huge dependence on informal waste collectors [42, 46]	2.000	0	–	–
	Performance targets	Setting of some targets, but some levels of government authorities are underperforming [42]	2.000	0	–	–
	Chain actors' integration	Insufficient collaboration in the sector [46]	1.250	0.433	2.000	4.000
	System performance review	Review of government's waste management plans and households' waste management practices [39, 41, 42, 49]	3.750	1.299	−0.370	−3.901

– indicates no data/value

Table 6 Sorting statistical analysis of secondary data

Stages	Maturity elements	Reference	Mean	Standard dev	Skewness	Kurtosis
Sorting	Consumer satisfaction	Recyclers are mostly supplied with well-sorted waste, as buy-back centres sort, clean and bale waste bought from informal waste collectors [50]	3.500	0.866	−2.000	4.000
	Process costs	Overall cost increase of managing waste including equipment hire, maintenance and other related expenses [50]	1.500	0.500	0	−6.000
	Quality data & database	Availability of very little data by Plastics SA, GreenCape and other agencies	1.500	0.500	0	−6.000
	Quality recyclables & products	Supply of quality recyclables, but most on-site sorting activities are labour intensive and not technology driven [50]	2.500	0.500	0	−6.000
	Structured processes	Average structure, as recyclables supply is largely dependent on informal sector; also there is an infrastructure problem [47, 50]	2.250	0.433	2.000	4.000
	Performance targets	–	–	–	–	–
	Chain actors' integration	Inadequate collaboration among stakeholders [46]	1.500	0.866	2.000	4.000
	System performance review	Evidence of some reviews of system performance [47, 50]	3.750	0.433	−2.000	4.000

– indicates no data/value

Table 7 Recycling statistical analysis of secondary data

Stages	Maturity elements	Reference	Mean	Standard dev	Skewness	Kurtosis
Recycling	Consumer satisfaction	–	–	–	–	–
	Process costs	Increasing difficulty for business and tight margins due to the high operational and electricity costs [46]	1.250	0.433	2.000	4.000
	Quality data & database	Availability of data relating to recyclate regularly shared by Plastics SA, GreenCape and other relevant agencies	3.500	0.500	0	−6.000
	Quality recyclables & products	Investments in quality assurance laboratories resulting in improved quality [46, 51]	3.750	1.299	−0.370	−3.901
	Structured processes	Limited infrastructure and huge reliance on informal sectors, but substantial support from associations [39, 42, 47, 52]	2.000	0.707	0	1.500
	Performance targets	–	–	–	–	–
	Chain actors' integration	Inadequate collaboration, with each stakeholder operating individually [39, 46]	1.000	0	–	–
	System performance review	Some reviews on the performance of the system [41, 42]	3.000	0	–	–

– indicates no data/value

Table 8 Recyclate market statistical analysis of secondary data

Stages	Maturity elements	Reference	Mean	Standard dev	Skewness	Kurtosis
Recyclate market	Consumer satisfaction	–	–	–	–	–
	Process costs	–	–	–	–	–
	Quality data & database	Lack of data on trading size and quantity of end-market for recyclates [42]	1.000	0	–	–
	Quality recyclables & products	Investments in quality assurance to improve quality [46, 51]	2.500	0.500	0	−6.000
	Structured processes	Lack of structures and end-markets [42, 53]	1.500	0.866	2.000	4.000
	Performance targets	–	–	–	–	–
	Chain actors' integration	Absence of end-markets for collaboration among stakeholders [39, 42, 46]	1.250	0.433	2.000	4.000
	System performance review	Negligible review of the performance of the system [41, 42]	1.500	0.500	0	−6.000

– indicates no data/value

Table 9 Performance of the value chain stages (secondary data)

Stages	Maturity elements								Performance score
	Consumer satisfaction	Process costs	Quality data & database	Quality recyclables & products	Structured processes	Performance targets	Chain actors' integration	System performance review	
Plastic production	No data	Avg	Excellent	Good	Excellent	No data	Poor	Good	3.8
Product manufacturing	No data	Poor	Good	Good	Good	Poor	Poor	Good	3.1
Waste generation	Very poor	Very poor	Poor	Poor	Poor	Poor	Very poor	Avg	1.8
Collection & handling	Very poor	Very poor	Avg	Poor	Poor	Poor	Very poor	Avg	1.9
Sorting	Good	Very poor	Poor	Avg	Poor	No data	Very poor	Avg	2.3
Recycling	No data	Very poor	Excellent	Avg	Avg	No data	Very poor	Avg	2.7
Recyclate market	No data	No data	Very poor	Avg	Very poor	No data	Very poor	Very poor	1.4

Maturity element rating: 1—Very poor; 2—Poor; 3—Average; 4—Good; 5—Excellent

Table 10 Statistical analysis of primary data

Stages	Maturity elements	Mean	Standard dev	Skewness	Kurtosis
Plastic production & product manufacturing	Consumer satisfaction	3.500	0.500	–	–
	Process costs	2.750	0.250	–	–
	Quality data & database	2.500	0.500	–	–
	Quality recyclables & products	2.750	0.250	–	–
	Structured processes	2.000	1.000	–	–
	Performance targets	2.500	0.500	–	–
	Chain actors' integration	2.750	0.250	–	–
	System performance review	2.250	0.750	–	–
Waste generation, collection and handling & sorting	Consumer satisfaction	No response			
	Process costs				
	Quality data & database				
	Quality recyclables & products				
	Structured processes				
	Performance targets				
	Chain actors' integration				
	System performance review				
Recycling & recyclate market	Consumer satisfaction	3.750	0.479	0.999	−0.248
	Process costs	3.750	0.692	0.774	0.284
	Quality data & database	4.080	0.731	0.041	−1.310
	Quality recyclables & products	3.750	0.692	0.774	0.284
	Structured processes	3.670	0.799	0.248	−0.014
	Performance targets	3.830	0.471	−0.666	0.586
	Chain actors' integration	3.830	0.687	0.313	−0.104
	System performance review	3.750	0.692	0.774	0.284

The standard deviation ranged between 0.25 and 1.0, signifying normal variation. The ranges of the skewness and the kurtosis analyses were from −0.666 to +0.999 and −1.310 to +0.586, respectively, indicating that the values were within the normal range.

From the mean computation of the different variables, the joint stages of plastic production and product manufacturing had customer satisfaction with the best performance at 3.5 and structured processes scored least at 2.0. Similarly, for the collective stages of recycling and recyclate market, quality data and database topped the varied performances of the maturity elements at 4.08, whereas structured processes had the lowest score of 3.67. Regrettably, the joint stages of waste generation, collection and handling, and sorting were not scored, as particular stakeholders for these stages were not responsive to the questionnaire.

Similarly, the collective performance ratings of the stages, with respect to the primary data, are presented in Table 11. Performance scores were computed using the direct mean data in Table 10.

Cross-validation of analysis

The results from the primary and secondary analyses were cross-validated to determine the aggregate performances of the plastic value chain stages and maturity of the whole system. The two analyses were comparatively assessed and the findings are presented in Table 12.

An important observation in the cross-analysis result is the deviation between the results of the primary and secondary data analysis for the recycling/recyclate market. A possible factor is that responses from willing experts could be a self-selection of those parts of the system, where recycling is best established. Follow-on studies with different sets of experts will help to throw more light on these possibilities. On the other hand, recent improvements in the sector, which were not recorded in previous or existing literature (secondary data), could be revealed by the expert participation.

The performance and maturity of the different value chain stages of the system are further illustrated in Fig. 2.

The cross-validation of both analyses established the maturity of the value chain stages of primary plastic production, product manufacturing and recycling to be "Visionary" (Level 3). For waste generation, collection and handling, sorting and recyclate market, the maturity was "Structured" (Level 2).

According to the model developed by Olatayo et al. [32], the features associated with the maturity level of "Visionary" (Level 3) include existence of platforms to formally support recycling activities development; existence of established owners of various processes of the plastic value chain, who are tasked with performance; targets for performance are mostly realised; process costs start to reduce along the value chain; and consumers' inclusion in the improvement of processes starts to produce customer satisfaction. The features of "Structured" (Level 2) are that processes of the value chain begin to be structured; elementary processes are being defined and documented; traditional jobs and practices still exist; quality data pertaining to the system is available in little quantity; targets for performance are rarely realised, even though defined; recyclables and waste are rarely traced; high process costs still exist; improving, but still low customer satisfaction.

Discussion of plastic value chain maturity level

Plastic production

The primary plastic production sector in South Africa can be described largely as "Visionary" (Level 3) in terms of maturity level. The customer satisfaction was "Good" for the primary data analysis, but secondary data was

Table 11 Performance of the value chain stages (primary data)

Stages	Maturity elements								Performance score
	Consumer satisfaction	Process costs	Quality data & database	Quality recyclables & products	Structured processes	Performance targets	Chain actors' integration	System performance review	
Plastic production Product manufacturing	Good	Avg	Avg	Avg	Poor	Avg	Avg	Poor	2.6
Waste generation Collection & handling Sorting	No data	No data	No data	No data	No data	No data	No data	No data	No data
Recycling Recyclate market	Good	Good	Good	Good	Good	Good	Good	Good	3.8

Maturity element rating: 1—Very poor; 2—Poor; 3—Average; 4—Good; 5—Excellent

Table 12 Cross-validation of the primary and secondary data analysis results

Stages	Maturity elements								Perform. score	Aggregate score	Maturity level
	Consumer satisfaction	Process costs	Quality data & database	Quality recyclables & products	Structured processes	Performance targets	Chain actors' integration	System performance review			
Plastic production											
Secondary	No data	Avg	Excellent	Good	Excellent	No data	Poor	Good	3.8	3.2	Visionary (level 3)
Primary	Good	Avg	Avg	Avg	Poor	Avg	Avg	Poor	2.6		
Product manufacturing											
Secondary	No data	Poor	Good	Good	Good	Poor	Poor	Good	3.1	2.9	Visionary (level 3)
Primary	Good	Avg	Avg	Avg	Poor	Avg	Avg	Poor	2.6		
Waste generation											
Secondary	Very poor	Very poor	Poor	Poor	Poor	Poor	Very poor	Avg	1.8	1.8	Structured (level 2)
Primary	No data	No data	No data	No data	No data	No data	No data	No data	–		
Collection & handling											
Secondary	Very poor	Very poor	Avg	Poor	Poor	Poor	Very poor	Avg	1.9	1.9	Structured (level 2)
Primary	No data	No data	No data	No data	No data	No data	No data	No data	–		
Sorting											
Secondary	Good	Very poor	Poor	Avg	Poor	No data	Very poor	Avg	2.3	2.3	Structured (level 2)
Primary	No data	No data	No data	No data	No data	No data	No data	No data	–		
Recycling											
Secondary	No data	Very poor	Excellent	Avg	Avg	No data	Very poor	Avg	2.7	3.3	Visionary (level 3)
Primary	Good	Good	Good	Good	Good	Good	Good	Good	3.8		
Recyclate market											
Secondary	No data	No data	Very poor	Avg	Very poor	No data	Very poor	Very poor	1.4	2.6	Structured (level 2)
Primary	Good	Good	Good	Good	Good	Good	Good	Good	3.8		
Plastic recycling system										2.5	Structured (level 2)

Maturity level: 1—Ad Hoc & Unstructured; 2—Structured; 3—Visionary; 4—Integrated; 5—Connected & Dynamic

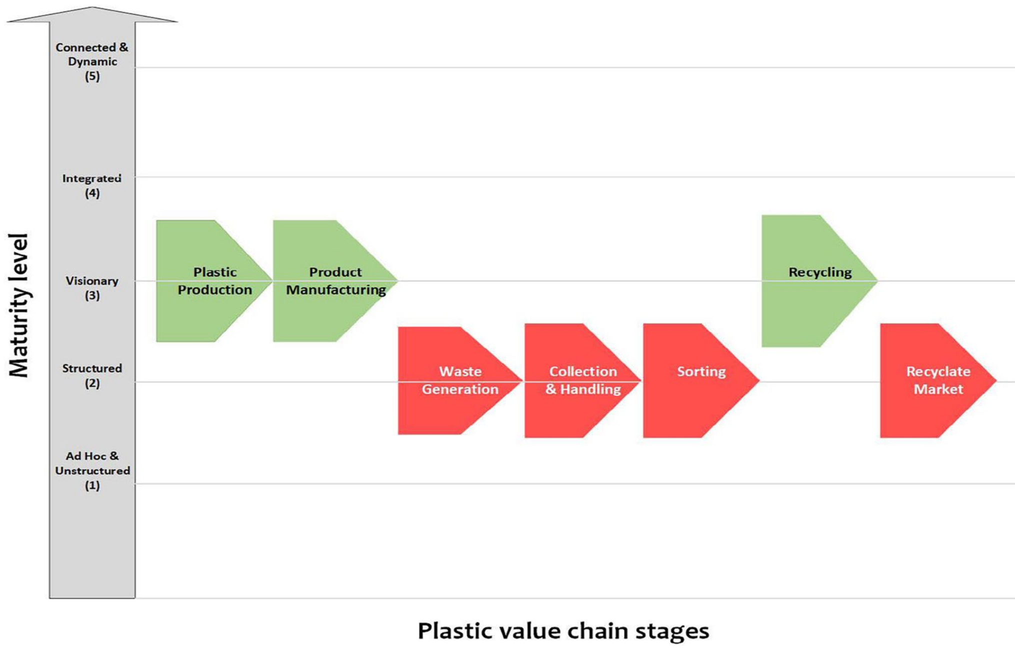

Fig. 2 Maturity levels of the various stages of the plastic recycling system

unavailable. The process costs maturity was "Average" for both the primary and secondary data analysis. There are balanced operational costs to corresponding productivity. According to Mofo [38], South Africa is a huge producer of plastic polymers. Despite the high cost of production, the plastic production stage has substantial capabilities for producing polymers, and pricing of polymers (polypropylene and propylene) as inputs for plastic product manufacturing is high [38]. The performance of quality data and database was rated "Average" and "Excellent" for the primary and secondary data analysis, respectively. There has been consistent availability of varied data, monthly and annual, for total and per capita plastic production and consumption (virgin and recyclate), plastics gross domestic product (GDP) contribution, percentage contribution to GDP, percentage contribution to manufacturing and other important statistics regularly shared by Plastics SA, the Department of Trade, Industry and Commerce, GreenCape, Statistics SA and other relevant departments and agencies. The rating for quality recyclables and products was "Average" and "Good" for the primary and secondary data analysis, respectively. Sasol, a major producer of monomers and polymers in the country, and other players such as Safrisol, supply plastics to both local and international markets [38]. This suggests the capacity for the production of quality outputs. For structured processes, the sector was rated "Poor" and "Excellent" for the primary and secondary data analysis, respectively. The polymer production industry has been described as structured and well-established, with access to raw materials as a result of the abundance of gas reserves in the country [38]. The value chain stage was rated "Average" and "Poor" for chain actors' integration in the primary and secondary data analysis, respectively. While there is some level of collaboration as the sector feeds the local market for plastic product manufacturing, each step of the long value chain adds costs, and each stakeholder operates separately [39]. The rating for system performance review was "Poor" and "Very good" for the primary and secondary data analysis, respectively. Available data shows evidence of review of the system performance, such as records of operating companies and workforce, performance level, market pricing and other relevant audits [38, 39].

Product manufacturing

The maturity level for the product manufacturing stage was ranked "Visionary" (Level 3). The element of customer satisfaction was not rated for the secondary data analysis as a result of non-availability of data, but it was "Good" for the primary data analysis. The process costs performance was rated "Average" and "Poor" for the primary and secondary data analysis, respectively. The sector experiences high operational costs with respect to exorbitant electricity costs from production processes that are energy-intensive, the very high cost of polymers, which are used as input in production, and other related expenses, although there are substantial capacities and capabilities for plastic products manufacturing [38]. Quality data and database was rated "Average" and "Good" for the primary and secondary data analysis, respectively. Some relevant data is available, often shared by Plastics SA, Statistics SA and other related agencies. Similarly, quality recyclables and products was rated "Average" and "Good" for the primary and secondary data analysis, respectively. There is a suggestion of the capacity to manufacture quality products, but the low margins in the sector are a challenge for investment in modern equipment and technology for the local manufacture of plastic products [38]. Structured processes was rated "Poor" and "Good" for the primary and secondary data analysis, respectively. The sector is equally well-established, although there are insufficient skilled employees, minimal advanced manufacturing activities and practices and slow technology upgrade [38]. Regarding performance targets, the ratings were "Average" and "Poor" for the primary and secondary data analysis, respectively. While targets in other performances seem non-existent, there are targets for major retailers in the sector to manufacture recyclable packaging, as research in alternatives to plastic bags and single-use packaging to address plastic impact is being promoted [38]. The performance of chain actors' integration was "Average" and "Poor" for the primary and secondary data analysis, respectively. There is some level of integration among the polymer producers, although each step of the value chain adds no value, but costs, and every stakeholder operates separately [39]. System performance review was rated "Poor" and "Good" for the primary and secondary data analysis, respectively. Available data reveals the review of different performances in the system such as sales growth, production, import and other relevant audits [38, 39]. According to the literature, the sustainable design of plastics to facilitate reuse, repair or remanufacture would result in minimal plastic waste entering into the plastic waste stream [3]. Moving from linearity to circularity of plastic must entail all processes and practices in the production stage of the value chain.

Waste generation

The South African waste generation sector was ranked "Structured" (Level 2) in terms of maturity. Not all the maturity elements for this stage were rated for primary data analysis as some data was not available. For the secondary data analysis, the maturity elements of customer satisfaction, process costs and chain actors' integration were rated "Very poor". With respect to customer satisfaction, the sector is challenged by the absence of incentives (or disincentives) for households to practise separation at source [41] and a dearth of national awareness campaigns and public and private sector programmes on waste separation at source, although some metropolitan areas are implementing the programmes [42, 43]. The stage is also challenged by littering, illegal dumping and waste service delivery backlogs [41]. For process costs, there are increasing operational costs due to increasing waste generation from population growth, urbanisation and increased plastic consumption [44, 45]. Economically, South Africa lost an estimated R17 billion worth of resources in 2012 as a result of waste disposal to the landfills [46]. The assessment of the chain actors' integration shows insufficient collaboration and integration among stakeholders; Van Jaarsveldt [46] reports the lack of awareness and education of stakeholders operating within the waste management sector. Furthermore, the performances of the elements of quality data and database, quality recyclables and products, structured processes and performance targets were rated "Poor". There is relative availability of data records for plastic waste generation, as shown by Plastics SA, DFFE and other studies, although data reliability with respect to waste stream volumes and waste stream types is a challenge as a result of municipalities and the industry not implementing, monitoring and reporting waste management plans [42]. Apparently, there is low quality of waste due to lack of separation at source programmes nationally, although such programmes exist in some metropolitan areas despite challenges [42, 46]. In addition, structured processes were largely lacking, as there is no national separation at source programme, except in some provinces with larger urban populations [46, 47].

The sector has problems of littering, illegal dumping, minimal separation at source and waste service delivery backlogs [41]. In addition, both the industrial and commercial waste generators are responsible for their own waste management [41]. Some performance targets were set for this stage, although many provincial and local government authorities are lagging behind. This is demonstrated by the Waste Act which specifies targets for national waste management systems, yet some provincial and local government authorities have not domesticated the process or targets [42]. The Plastic Bag Regulation of 2002/2003 was projected to reduce plastic bag waste generation by 50% [49]. The element of system performance review was rated "Average", as records show reviews of waste management performances by local government, access of households to waste management and household separation rates [39, 41, 42]. As supported by the literature, a more complete approach must be implemented through all the plastic value chain stages of plastics, particularly monitoring, controlling and minimising the quantity of plastic waste being generated and entering the waste management system through actions and practices that reduce the usage of plastic [26].

Collection and handling

The maturity of the collection and handling stage was ranked as "Structured" (Level 2). According to the assessments, not every maturity element for this stage was rated for primary data analysis as some data was not available. For the secondary data analysis, customer satisfaction was rated "Very poor", as the stage is challenged by littering, illegal dumping and waste service delivery backlogs [41]. The weekly waste removal practice is below the minimum threshold [48]. A rating of "Very poor" was given to process costs, as total costs of waste management have risen with respect to equipment hire, maintenance, overtime and other related expenses; plants and fleet are ageing and infrastructure is under strain [48]. Quality data and database was rated "Average", considering the availability of certain data for plastic waste collected and managed, as shown by Plastics SA, GreenCape and DFFE, although there are challenges regarding waste stream types [42]. The rating for quality recyclables and products was "Poor" as a result of the apparent low quality of waste collected due to the lack of programmes such as separation at source, except in a number of metropolitan areas [42, 46]. Structured processes was rated "Poor" due to the sector not being prioritised and the implementation of the least cost collection and disposal method rather than the integrated waste management system [42]. In addition, there is huge dependence on the informal waste collectors [42, 46].

Performance targets was rated "Poor". Some performance targets are set, but some levels of government authorities are underperforming [42]. The rating for chain actors' integration was "Very poor" because collaboration and integration among stakeholders in the sector are inadequate [46]. System performance review was rated "Average". Available data shows different reviews of government's waste management plans and households' waste management practices and activities [39, 41, 42].

Sorting

The sorting stage of the value chain was ranked as "Structured" (Level 2) with respect to the maturity of the recycling system. Not all maturity elements were rated for primary data analysis as some data was not available. For the secondary data analysis, the performance assessments rated customer satisfaction as "Good". It can be inferred that there is considerable customer satisfaction as recyclers are mostly supplied with well-sorted waste through the buy-back centres. These centres buy waste from mostly the informal sector and thereafter sort, clean and bale it, thereby adding valuable quality to the recyclables before selling to the big recyclers or recycling companies [50]. Process costs was rated "Very poor" as there has been an increase in the overall costs of managing waste, including equipment hire, maintenance and other related expenses. The rating for quality data and database was "Poor" considering the availability of very little data regarding this value chain stage. Quality recyclables and products was rated "Average". While there is a supply of quality recyclables because the waste is mostly well-sorted by the buy-back centres and value is added, most on-site sorting processes and activities are labour intensive and not technology driven [50]. Structured processes received a rating of "Poor" as the sector is on average well-structured. While the buy-back centres play an essential and major role in this stage, the supply of recyclables is largely dependent on the informal sector [50], and the relevant cooperatives working in this stage face infrastructure problems [47]. The element of performance targets could not be rated due to non-availability of data. Chain actors' integration was rated "Very poor" due to the inadequate collaboration and integration among stakeholders within the stage [46]. The rating for system performance review was "Average" as data revealed the existence of certain reviews of system performance [47, 50].

Recycling

The maturity of the recycling sector of the value chain was ranked as "Visionary" (Level 3). All maturity elements for this stage were rated "Good" for primary data analysis. For the secondary data analysis, the elements of customer satisfaction and performance targets were not rated due to non-availability of data. The rating for process costs was "Very poor" considering that recyclers are operating in an environment that is increasingly difficult for business and facing tight margins due to the high costs of operation, rising electricity costs and an economy downturn generally [46]. Quality data and database was rated "Excellent", considering the availability of varied data pertaining to recyclate regularly shared by Plastics SA, GreenCape and other relevant agencies. Quality recyclables and products was rated "Average". Investments in quality assurance are helping to improve the quality of recyclates, as the establishment of quality assurance laboratories has resulted in improved quality, despite the separation at source of recyclables being low [46, 51]. Structured processes was rated "Average" as the structure is of average standard. The sector has limited infrastructure for recycling and recycling processors, and it is based largely on the informal sector collecting recyclables and selling for recycling purposes. However, there has been substantial support from industry-funded associations [39, 42, 44, 47, 52]. The rating of chain actors' integration was "Very poor" as collaboration and integration among stakeholders within the stage are inadequate, with each stakeholder operating individually [39, 46].

System performance review was rated "Average" as data shows that there are some reviews regarding the performance of the system [41, 42]. As expressed in the literature, plastic circularity needs to be consistently improved in every stage of the plastic value chain, as the value of plastic material must be maximised at all these stages [3]. It has been argued that plastic has the potential to be recycled many times, and this can be explored to contribute significantly to realising a circular economy, while taking into consideration the sustainable product design [26].

Recyclate market

The value chain stage of the recyclate market was ranked as "Structured" (Level 2). The respective maturity elements for this stage were rated "Good" for primary data analysis. For the secondary data analysis, customer satisfaction, process costs and performance targets were not rated due to non-availability of data. Quality data and database was rated "Very poor", as data on the trading size and number of available end-markets for recyclates is lacking [42]. Quality recyclables and products was rated "Average", as investments have been made in quality assurance to improve the quality of recyclates, even while the separation at source of recyclables is low [46, 51]. The quality of the recyclates produced has enabled the reuse or application of these recyclates in the production of similar products, particularly in the food packaging sector where packaging waste is recycled and the recyclates are reused for new packaging applications [51].

Structured processes was rated "Very poor" due to the lack of structures and end-markets [42, 53]. Similarly, chain actors' integration was rated "Very poor" considering the absence of end-markets for recyclates and poor collaboration and integration among stakeholders within the system [39, 42, 46]. System performance review was rated "Very poor" as data shows a negligible review of system performance [41, 42].

Performance implications

The above results from the assessment are crucial for the future policymaking of South Africa regarding the advancement of plastic waste recycling, especially in respect of the increasing plastic circularity and sustainability across the respective value chain stages of the system. Significant findings that support the improvement of the various aspects of the plastic value chain stages, with respect to the defined maturity elements (customer satisfaction, process costs, quality data and database, structured processes, performance targets, chain actors' integration and system performance review) are presented and discussed. These findings originated from a detailed review of initiatives that have influenced the development of the various stages of the plastic recycling system, as shown in Table 13.

The prospect of a high-performing plastic recycling value chain in the country would benefit from the adoption of these outlined initiatives in the respective stages of the system. These initiatives are recorded to have had positive impacts on the system. Major initiatives that cut across the value chain stages in the table include legislation, digitalisation, training and skills, education, facilities, reward system, technology and standards.

Achieving an increase in plastic sustainability and circularity through legislation at the production stage of plastics requires manufacturers to comply with regulations or requirements on the minimum content of recyclate that must be included in a certain share of their products or packaging for products. Similarly, integrated legislation will strengthen the generation, collection, handling, transportation, as well as disposal of plastic waste in South Africa. Enacting suitable legislation involving licensing, guidelines, processes, fees and punishment regarding these activities is the first crucial step towards effective plastic waste collection and handling. There is also the need to regulate and set standards (equipment, test and industry) for the plastic recycling sector as it expands in terms of the number of plastic recyclers and the different recyclates or recycled products. This will protect the sector and equally guarantee the value or quality of recycled materials and products. The existence of regulations ensures fair practices in the sector, stabilises the market and enables a market mechanism for the plastic recyclers, operators and buyers.

Digitalisation and data automation in plastic production enable productivity in the sector, as overproduction can be avoided and wastage minimised. Digital platforms can be used in plastic waste collection and handling to connect residents directly to waste collection operators. This involves residents or businesses taking pictures or giving verbal illustrations of the waste generated and uploading them on apps for analysis and advice on where to dispose of it. This enables increased rates of plastic waste collected and recovered for recycling, and also assists the waste generators in reducing their waste collection levy. Digitalising the recycling sector helps business entities to scale up for plastic waste recycling.

Training and skills are required to advance the plastic value chain, as manufacturers, recyclers, waste pickers and waste collectors should have appropriate and sufficient knowledge of the quality, quantity, environmental benefits, best use and administration of plastic recycling and circularity. Providing training to operators in the value chain to acquire skills and competence would improve the effectiveness and efficiency of waste separation, collection, sorting and recycling of plastic. In

Table 13 Initiatives for development of plastic recycling stages

Value chain stages	Initiatives	Implementation examples and impact
Plastic production & Product manufacturing	Regulations on sustainable design	• Action plans are ongoing for new eco-design for plastic products in the European Union, to meet the objective to place, by 2030, all plastic packaging that can be easily reused or recycled in the market [56] • In Denmark, varied tax rates are applied to specific soft PVC products, depending on the use of phthalates as softeners • Regulations for plastic products that are non-biodegradable have been approved in some OECD countries [56]
	Knowledge and skills	• Comprehensive information is essential and required on material or product circularity for recycling purposes, making it crucial for manufacturers to understand relevant quality, best use, quantity and environmental benefits [57] • Research on managing the sustainability risks related to biodegradable and bio-based materials is required
	Digitalisation	• Digital solutions are used, including phone apps, to ease data and information flow along the plastics supply chain, whereby consumers are able to make informed decisions on the purchase of alternatives with fewer environmental impacts. This helps send a market signal to designers and manufacturers regarding consumer preferences [58]
Waste generation	Education	• Mandatory education of the public and stakeholders on proper disposal is legislated considering their critical roles in waste management [59, 60] • The efficacy of information sharing and slogans through campaigns on waste has been established [61, 62] • Governments, manufacturers and schools are important providers of public education on waste, while consumers are targeted recipients [59]
	Digitalisation	• Artificial intelligence is used where consumers use phone cameras to scan their waste and send to appropriate sites for advice on the most suitable ways to dispose of it [63] • An app, My Little Plastic Footprint, was launched in 2017 to guide consumers on reducing their individual plastic footprint, including providing information on plastic waste and encouraging consumers to participate in pledges on plastics consumption [64]
	Source separation	• The combination of both the formal and the informal collectors in waste separation (at source and outside source) is assisting in advancing recycling [42]
Collection & handling	Legislation	• Market-based policy instruments or regulations are applied such as modified EPR integrated into waste management to promote collection [65] • More effectiveness and environmental friendliness could be achieved through a retail take-back scheme in comparison to curbside bins for collection [59]
	Transportation	• A model has been developed in China for the call up of collection vehicles or slot allocation to reduce the time lost or wasted on queuing at collection facilities or points [66]
	Digitalisation	• The flows of material and information in communities is connected and coordinated through automation, censoring, or the Internet of Things for the purpose of collecting and classifying waste generated [58, 67]
	Disposal facilities and technology	• There is demonstration of considerable adaptability in developing facilities for plastic waste in OECD countries, which has brought about a difference or change in the treatment of municipal waste in these countries [56] • Proximity to waste collection facilities greatly influences the disposal behaviours of consumers [68]
Sorting	Technology	• Advanced sorting technologies have been introduced for multi-component products, as poor sorting technology leads to the discarding of almost 18% of target plastic waste [4]
	Knowledge and skills	• Training builds and improves the knowledge and skills of personnel, which in turn improves the efficiency and cleanliness of the process and exercise, as well as the rate of employment of workers with less education [69]
	Digitalisation	• Communities are helped to connect and coordinate the flows of material and information through automation, censoring, or the Internet of Things for sorting of waste [58, 67]

Table 13 (continued)

Value chain stages	Initiatives	Implementation examples and impact
Recycling & Recyclate market	Digitalisation	• Digitalising the sector helps connect and coordinate the flows of material and information through automation, censoring, or the Internet of Things for the purpose of recycling generated waste [58, 67]
	Regulations	• Legislation is contributing greatly to the management of waste electrical and electronic equipment in China [70] • Targets set for used lithium batteries collection and recycling enhance resource sustainability and efficiency, particularly during rapid growth in the production of electric vehicles [71, 72] • Restrictions of waste trade by China has resulted in extra pressure on countries to find alternative measures or solutions for plastic waste [73] • Landfilling and incineration taxes are useful for plastics sustainable use, as these taxes drive recycling [74]
	Standards	• The design and development of numerous standards for the plastics industry such as ISO 83.080.01 have been helpful. The standards have been specific to OECD countries, for example the biodegradable plastics standards in Australia [75]
	Technology	• Advanced technologies are needed for the recycling and recovery of some materials from products, which indicates increasingly complex designs of products. These cases include multi-material and multi-layered products or packaging, and they are largely challenging regarding their recycling [76] • Investments in technology by the private sector should be promoted. For example, the Closed Loop Fund by large corporations in South East Asia raises and supports recycling technology and infrastructure worth USD 100 million [77]

addition, there should be a good reward system for operators in the industry to further develop the system. Waste pickers are examples of important stakeholders that could be considered for employment, reasonable wages, proper training and health insurance.

The provision of education to the consumers and general public regarding the benefits of sustainable plastic consumption, separation at source and proper disposal of plastic waste needs to be promoted sufficiently. This will ensure that waste generators and the public are adequately aware and conscious of their expected roles in advancing plastic sustainability and circularity in the country. Improved behaviour towards waste management could yield a high-performing plastic value chain. Research reports can be made available to government officials, waste managers, recyclers and the general public on resource and waste management plans and strategies, hazards, policy proposals and recycling activities and practices.

Technology is highly important and very valuable in plastic waste sorting and recycling. Advanced technologies could be in the form of sorting, material recovery, recycling or information technology, and they would provide sustainable and lasting solutions. Sorting, recovery or recycling technologies help to advance economic and environmental sustainability; information technology provides solutions for evaluating, monitoring and improving the whole plastic recycling value chain system.

Facilities improvement for plastic waste collection, transportation and storage is a requirement for a sustainable plastic recycling value chain system. Both profit and non-profit collection facilities or stations should be established for the collection of post-consumer plastic waste. The facilities should be accessible to residents, businesses and peddlers. Sorting centres should equally be promoted for pre-treatment before moving to recyclers. A model for transportation allocation for waste collection could be developed for quick collection and to reduce the average time spent queuing at disposal facilities.

Furthermore, standards are applicable to production output and these entail guaranteeing the quality, safety and reliability for the manufacturers, recyclers and consumers. Considering that plastics have numerous applications, maintaining standards involves attending to a broad collection of plastic products or diverse plastic material properties, for example biodegradability of the material.

Conclusion

The plastic recycling value chain and the respective stages in South Africa were separately measured to critically assess the current performance of the value chain stages and the maturity of the whole system, using a developed maturity model, with a set of maturity elements as assessment indicators. This was in response to improving the circularity of plastics in the country. The result of the primary and secondary data analysis showed that the maturity levels of the stages of primary plastic production, product manufacturing and recycling of the plastic value chain in the country can be rated as "Visionary" (Level 3). The individual stages of waste generation, collection and handling, sorting, and recyclate market are rated as "Structured" (Level 2). In addition, a number of initiatives that have influenced the development of the various stages of the plastic recycling system, with respect to the defined maturity elements, were identified from a detailed review of previous works and discussed. These initiatives could assist in advancing the system in South Africa.

The study contributed to the academic community in the areas of identifying critical elements required to be prioritised for the maturity of the plastic value chain. It presented fundamentals for the improvement of the plastic value chain and recycling system of any country. It identified areas, processes and action plans that could be useful in bridging the gap between low maturity level to the highest maturity level. The study highlighted the importance and contribution of every stage of the plastic value chain in achieving total maturity of the plastic system. It contributed to knowledge that would optimise the plastic recycling option and circular economy as a whole. In addition, it extended the body of literature in the areas of maturity of a system and maturity models, as well as the entrenchment of circularity in all stages of the plastic value chain.

Furthermore, considering that the country's plastic value chain still requires future development at every stage of the value chain, it is important for the country to be part of the discussion and development of a globally binding treaty being proposed and championed by the United Nations Environment Programme (UNEP) to curb plastic pollution. This legally binding instrument, being discussed by the Member States of the organisation, is expected to utilise a comprehensive approach to tackle the complete life cycle of plastic, comprising design, production, use and disposal.

Supplementary Information

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Supplementary Material 1.

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Author contributions
KIO processed the methodology, data analysis, software, original draft and investigation. PTM and ALM handled the conceptualisation, supervision, validation, review and editing. All the authors approved the final manuscript.

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Declarations

Ethics approval and consent to participate
This study was approved by the University of Johannesburg Ethics Committee. Informed consent was also obtained from all the participants that took part in the survey.

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interests.

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