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Building a circular plastics economy with informal waste pickers: Recyclate quality, business model, and societal impacts

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ABSTRACT

The circular economy rationale is increasingly promoted as a means to move from a global plastic waste dilemma to a plastics economy that is aligned with the principles of sustainable development. However, any such effort will have to account for the socio-economic settings in low-income and middle-income countries of the global south which are the main entry points of mismanaged plastic wastes into the environment. Since waste management and recycling in these economies are characterized by a great degree of informality, there is an urgent need to find models for partnering with the informal recycling sector in an effective, scalable, and sustainable manner. In this work, we present the case of a for-profit company located in Nairobi, Kenya, that operates on the interface between formal and informal by processing post-consumer plastics sourced from local waste pickers through a fair-trade-like business model.

Economic incentives, trust building measures, and a general willingness to learn and adapt were identified as prerequisites for establishing accountable supplier-buyer relationships. The combination of informal material pre-sorting by the individual waste picker and subsequent industrial scale sorting and washing resulted in recyclates that were comparable to commercially available benchmark recyclates from the sophisticated formal recycling system of a high-income country in terms of both composition and selected engineering properties. High-quality mechanical recycling of plastic wastes under informal conditions seems feasible and may even come along with socio-economic benefits for marginalized waste pickers when suitable modes of cooperation are put in place.

1. Introduction

1.1. A circular plastics economy

Recently, the circular economy (CE) concept has received considerable interest in academia (Babbitt et al., 2018; Geissdoerfer et al., 2017; Ghisellini et al., 2016; Kalmykova et al., 2018; Bocken et al., 2016; Alcayaga et al., 2019). It abandons the idea of products and materials ever becoming waste and instead envisions “an economic system that replaces the ‘end-of-life’ concept with reducing, alternatively reusing, recycling and recovering materials in production/distribution and consumption processes. It operates at the micro level (products, companies, consumers), meso level (eco-industrial parks) and macro level (city, region, nation and beyond), with the aim to accomplish sustainable development, thus simultaneously creating environmental quality, economic prosperity and social equity, to the benefit of current and future generations. It is enabled by novel business models and responsible consumers” (Kirchherr et al., 2017).

Plastics in particular have emerged as an intensively discussed material class in this context (European Commission, 2018; Hahladakis and Iacovidou, 2018; Leslie et al., 2016; PlasticsEurope et al., 2018; van Eygen et al., 2018; World Economic Forum and Ellen MacArthur Foundation, 2017) due to their association with single-use products, take-make-dispose consumption patterns, and the multiple facets of the global plastic waste dilemma (Brooks et al., 2018; Jambeck et al., 2015; Eygen et al., 2018; World Economic Forum and Ellen MacArthur Foundation, 2017) due to their association with single-use products, take-make-dispose consumption patterns, and the multiple facets of the global plastic waste dilemma (Brooks et al., 2018; Jambeck et al., 2015; Eygen et al., 2018; World Economic Forum and Ellen MacArthur Foundation, 2017). Humans have produced more than eight billion metric tons of plastics between the beginning of large-scale industrial production in 1950 and the year 2015 (Geyer et al., 2017). While 30% of this amount is believed to be currently in use, thereby contributing to societal materials stocks, it is estimated that about 60% of all plastics ever made are accumulating as wastes in landfills and the natural environment (Geyer et al., 2017). It seems likely that several million metric tons of mismanaged plastic wastes enter the oceans from land-based sources every year (Jambeck et al., 2015). A similar order of magnitude was
derived for the annual discharge of plastic wastes into the oceans through major river systems (Lebreton et al., 2017). Both studies identified important sources of mismanaged plastic wastes in low-income and middle-income countries (Jambeck et al., 2015; Lebreton et al., 2017).

1.2. The informal recycling sector (IRS) in low-income and middle-income countries

In stark contrast to the formalized, often heavily regulated, and publicly and/or privately organized waste management sectors in the high-income countries of the global north (e.g. Europe, North America), waste management and recycling activities in the low-income and middle-income countries of the global south (Africa, Asia, Latin America and the Caribbean) are predominantly informal (Velis, 2017; Wilson et al., 2006). The recovery of dry recyclables from domestic and/or imported wastes relies substantially on an informal recycling sector (IRS) characterized by the absence of formal employment, regulations, and taxation (Ezeah et al., 2013).

The organizational structure and functioning of the IRS is highly context and region-specific (Ezeah et al., 2013; Velis, 2017). In any case, it starts with the collection of recyclable materials from (open) dumpsters, the streets, or directly at the source from households. Recyclables are then passed on to informal junk yard owners, intermediate dealers, or other middlemen in a rather hierarchical and non-transparent value chain where they usually undergo a certain degree of sorting, aggregation, (sometimes) cleaning, and processing before they are reintroduced into the (formal) economy as secondary raw materials (Asim et al., 2012; Ezeah et al., 2013).

Waste pickers or scavengers constitute the large base-of-the-pyramid workforce in any typical IRS (Velis, 2017). They perform the most labor-intensive and least rewarding first steps of recyclables extraction from mixed wastes. Despite their relevance, both environmentally and economically (Aparcana, 2017; Kariuki et al., 2019), waste pickers are often subject to systematic marginalization (Aparcana, 2017; Asim et al., 2012; Sembiring and Nittivattananon, 2010; Wilson et al., 2006). They are regarded as dirty, as outlaws of society, and they have to cope with asymmetric power relations, exploitation, and volatile prices threatening their daily income, which under favorable conditions can be even above a nations minimum salary (Kariuki et al., 2019; Kaseva and Gupta, 1996; Kuria and Muasya, 2010; Wilson et al., 2006).

In any realistic scenario of the near future, waste pickers and the IRS in general are going to be an integral part of the CE in the global south (Kariuki et al., 2019; Velis, 2017). However, despite a considerable body of work on the issue, solutions for formalizing, integrating, or at least partnering with the IRS in a sustainable, socially-inclusive, and forward-oriented way are lacking for many parts of the world (Davis and Garb, 2015; Ezeah et al., 2013; Velis, 2017).

2. Case study design & methods

In view of the limited understanding of how to integrate the IRS in low-income and middle-income countries in an effective, scalable, and sustainable manner to become an essential element of a circular plastics economy, a single embedded case study design (Siggelkow, 2007) was chosen for this work. Case studies are especially suitable “in the early stages of research on a topic or to provide freshness in perspective to an already researched topic” (Eisenhardt, 1989). Furthermore, the case study concept has repeatedly been used to elucidate specific aspects of the IRS in various countries (Davis and Garb, 2015; Gutterlet et al., 2017; Jaligot et al., 2016; Kaseva and Gupta, 1996; Li, 2002; Sasaki and Araki, 2013).

2.1. Case selection & case description

While the debate around plastic waste and informal recycling has recently been characterized by a strong focus on China and South East Asia (Brooks et al., 2018; Velis, 2014), other scholarly work has pointed at the future relevance of the African continent in this context (Jambeck et al., 2015, 2018). In Africa, Kenya is one of the more developed economies, which hosts both a certain degree of domestic plastics demand and an informal recycling sector (Oyake-Ombis et al., 2015). Responding to growing environmental issues, Kenyan authorities have been active in plastics-related policy making in recent years as demonstrated by (in theory) rather strict plastic bag regulations (Njeru, 2006; Xanthos and Walker, 2017). Additionally, Kenya is home to a number of innovative and internationally recognized grass-root approaches to coping with local plastic wastes and simultaneously harvesting associated socio-economic opportunities (Jambeck et al., 2018; Oyake-Ombis et al., 2015; Smith, 2018).

Mr. Green Africa (MGA), a for-profit company and subject of the present case study, is located in Nairobi, Kenya. Established in 2014, MGA was since that time active in trading and processing post-consumer plastic wastes sourced from the local IRS. At the time of conducting this research, the end products of MGA were shredded and hot-washed flakes of post-consumer polyethylene (PE), polypropylene (PP), and polyethylene terephthalate (PET) in different colors, with the plastics flakes being sold mainly to local plastic converters.

In addition to simply buying recyclables from the IRS, MGA put forward strong sustainability claims, especially with regards to socio-economic and societal aspects. The corporate identity of MGA embraces the idea of waste pickers being the “invisible heroes” of informal solid waste management due to their positive contributions to both the local environment and the local economy. In the company’s view, the waste pickers are enablers of a CE and their notorious social marginalization and economic exploitation needs to be addressed. Based on this premise, the company has put in place a CE business model that they describe as “technology enabled, human-centered, and sustainable” (Mr. Green Africa, 2018b; Smith, 2018).

The basic idea is to abandon the traditional value chain of informal recycling based on multiple middlemen and replace it by a direct fair-trade-like relation between the individual waste picker and the recycler, the latter one acting as the immediate link to the formal economy. To do so, the company set up proprietary trading points throughout Nairobi where waste pickers sell collected plastic wastes to MGA buying clerks. The trading price is fixed at a rate of 19 Kenyan Shillings (KSh) per kilogram plastics and hence not subject to market price volatility. That price is openly communicated and chosen such to be very competitive to that offered by other local scrap traders. Every picker is assigned a personal supplier profile in the company’s mobile application that records and analyzes supplier productivity and reliability. Pickers trading regularly with MGA are eligible for a supplier loyalty program that grants a premium price in exchange for meeting monthly supply targets. In this manner, and through personal interaction of waste pickers and MGA agents that allows for educating the waste pickers on which types of plastic wastes to collect, the company maintains a relatively steady supply of pre-sorted post-consumer plastics.

2.2. Operationalization & data collection

To meet the test of construct validity, Yin (2009) recommends the use of multiple sources of evidence. The reason for using multiple sources to collect empirical data is to provide the researcher better insight on what happens in reality and to increase the validity of the research done (Yin, 2009). Therefore, three complementary data sources were captured for this study to ensure adequate triangulation and to reduce bias or error in observation (Lamnek, 2010): (1) desk research, (2) physical recycle characterization, and (3) semi-structured interviews. The desk research included studying scholarly literature on the informal recycling sector (Aparcana, 2017; Davis and Garb, 2015; Ezeah et al., 2013; Kariuki et al., 2019; Kaseva and Gupta, 1996; Kuria and Muasya, 2010; Wilson et al., 2006). The recovery of dry recyclables from domestic and/or imported wastes relies substantially on an informal recycling sector (IRS) characterized by the absence of formal employment, regulations, and taxation (Ezeah et al., 2013).
2.2.1. Materials

Three different waste picker recyclate (WPR) materials were selected from the company’s product portfolio. WPR-1 was made from rigid containers, bottles, and other hollow bodies of mixed colors that were assumed (by the company) to consist of PE. WPR-2 was made from broken yellow canisters and Jerry cans that are abundant in the area as they are used for transporting and storing drinking water by the large group of locals who lack access to drinking water in their homes and have to bring it from district water kiosks or other sources. WPR-3 was made from waste items such as boxes, crates, trays, and lids that are typically injection molded or thermo-formed and were assumed (by the company) to consist of PP. All WPRs were supplied as shredded flakes. For each WPR, a batch of unwashed flakes was compared to a batch of hot-washed flakes to investigate quality differences. The flakes were pelletized into granules, the typical feedstock of the plastics processing industry (see section 2.2.2). An overview of the different processing stages of collected waste, sorted and shredded flakes, and granules after lab-scale processing, is provided in Fig. 1.

The process used by MGA to produce hot-washed flakes included multiple steps of manual sorting; label and metal removal; mechanical wet-crushing; a float-sink-tank for the separation of PET and other materials with a density greater than 1 g/cm³ from polyolefins; a hot-washing stage using a caustic soda solution and water temperatures up to 70 °C; a turbo-washer; and a zig-zag separator. It is hence a combined washing stage using a caustic soda solution and water temperatures up to 70 °C; a turbo-washer; and a zig-zag separator. The BM-2 material was a PE recyclate de-

2.2.2. Sample preparation

This section contains a detailed description of materials processing and specimen fabrication, as many of the final properties of plastics are inherently dependent on the chosen processing parameters. The shredded plastic flakes were pelletized using a ZSE 18 maxx co-rotating twin-screw extruder (Leistritz Extrusionstechnik, Germany) equipped with a vacuum degassing unit. The screw speed was 400 rpm and the mass throughput was 5 kg/h. The resulting melt temperature during extrusion was between 195 °C and 200 °C. The extruded filament was pulled through a water bath at room temperature and strand pelletized into granules.

Prior to pelletizing, the unwashed flake materials were manually screened for larger metal and stone fragments that would potentially harm the extruder used for this work. However, no washing or other pre-treatment was carried out on these unwashed materials. The hot-washed materials did not require any screening. Multi-purpose specimens according to ISO 3167 were produced with a Victory 60 (Engel, Austria) hydraulic injection molding machine. The processing parameters included a barrel temperature profile of 160 °C at the rear end up to 230 °C at the nozzle, a mold temperature of 45 °C, an initial injection rate of 19 cm³/sec resulting in a fill time of approx. 2.7 s, a holding pressure of 700 bar, and a holding time of 14 s.

2.2.3. Interviews

We conducted a single embedded case study (Siggelkow, 2007). At the time of conducting this study, the target company had 50 employees working on a contract basis as permanent staff. In addition, approximately 1,000 waste pickers (up from 250 in early 2017) were active in the company’s supplier network. Exploratory semi-structured interviews were used to gain insights into the company’s daily operational procedures, their way of interacting with the waste picker community, and the achieved outcomes in socio-economic and technical terms. A total of seven interviews were conducted via web-based communication tools, voice recorded, and transcribed for this work in June 2018. The selection of interview partners was based on the roles they occupied within the company. First priority was to interview the core management team and staff members in supervisory positions as they have a broader view on and more detailed insights into interdependencies of elements, participants, and processes of the business model, also owing to the relatively flat hierarchy within the company. For the selection of interview partners, we followed a snowballing strategy using a first contact involved in the case to identify further relevant persons. The guiding idea of this sampling strategy is the focus on interview partners that are relevant to the question rather than on generating a large number.

All interviews followed the same basic semi-structured guideline where interviewees were at first asked to provide information on their personal background including age, education, and work experience. Then, interviewees described their previous and current role(s) within the company and elaborated on their responsibilities and tasks. At this point, interviewees were asked role-specific questions (for short code assignment see Table 1), for instance, to explain details of the sorting and washing process (A, B1, C2), to describe the personal interaction with waste pickers (B2, B3, B4, C1), or to illustrate the company strategy and the interaction with end customers (A, B2). In the next step, interviewees explained what the basic idea behind the company’s activities was and how they personally felt about working with waste pickers. Finally, they were asked to describe the (real or perceived) impact the company was having on the local waste picker community.

3. Data analysis

3.1. Methods for compositional analysis of recyclates

The recyclate composition was characterized using Fourier-transform infrared (FTIR) spectroscopy, differential thermal analysis (DTA), and thermo-gravimetric analysis (TGA). The FTIR measurements were conducted in the attenuated total reflection (ATR) mode on a Spectrum 100 (PerkinElmer, USA). For each recyclate, FTIR-ATR spectra were recorded from three arbitrary surface locations of five individual multi-purpose specimens. For each spectrum, four scans of the spectral range from 4000 cm⁻¹ to 650 cm⁻¹ with a resolution of 4 cm⁻¹ were averaged. The DTA was performed with a DSC 4000 (PerkinElmer, USA) using samples of ca. 5 mg that were cut out from multi-purpose specimens and placed in aluminum pans with holes. Nitrogen was used as a purge gas. The temperature program included an initial isothermal at 20 °C for 1 min, a first heating from 20 °C to 290 °C at 10 °C/min (to cancel the thermal pre-history), a cooling phase from 290 °C to 20 °C at ~10 °C/min, and a second heating from 20 °C to 290 °C at 10 °C/min. Three measurements were done for each recyclate. The TGA was carried out with an STA 6000 (PerkinElmer, USA) using samples of ca. 20 mg that were cut out from multi-purpose specimens and placed in open ceramic crucibles. Nitrogen was used as a purge gas and the
heating rate was 20 °C/min from 30 °C to 950 °C. Three measurements were done for each recyclate.

3.2. Methods for characterization of basic material properties of recyclates

The compositional information was complemented by determination of selected engineering properties via melt flow rate (MFR) measurements, uniaxial tensile tests, and Charpy impact tests. The MFR values were determined from granules using a Mflow device (Zwick Roell, Germany) with a testing mass of 2.16 kg and temperatures of 190 °C and 230 °C for PE and PP materials, respectively. The tensile tests were performed on a Z005 universal testing machine (Zwick Roell, Germany) in accordance with ISO 527-2. Ten multi-purpose specimens were used for each recyclate. Charpy impact tests were carried out with a HIT25P pendulum impact tester (Zwick Roell, Germany) using a 2J impactor and edgewise specimen arrangement. Notched specimens were used for PE materials and unnotched specimens for PP materials. Ten specimens cut out from multi-purpose specimens were used for each recyclate. All mechanical measurements were conducted at a temperature of 23 °C and a relative humidity of 50% with specimens that had been stored under these conditions for more than 96 h after fabrication.

3.3. Interview content evaluation

Transcripts of the semi-structured interviews provided the raw data for qualitative content analysis. This was based on the qualitative technique of Mayring (2010) and MAXQDA was used to conduct the analysis. By using this approach, the empirical data was analyzed on specific content areas based on a category system, i.e. waste picker interaction, technical, and socio-economic aspects. The categories were
Fig. 2. FTIR spectra of WPR-1 (top), WPR-2 (center), and WPR-3 (bottom) recyclates in unwashed and hot-washed quality and their respective benchmarks.

Based on theory; further categories were added inductively through the process of analysis.

An overview of interview partners, their specific roles within the company, and the approximate duration of each interview is provided in Table 1. The group of interviewees included the CEO and co-founder of Mr. Green Africa (A), four members of the management team (B), and two general staff with supervising roles (C). Apart from the CEO and the Head of Sales, Administration & Finance, who were of Swiss and German nationality, respectively, all other interview partners were Kenyan locals.

4. Results & discussion

4.1. Composition and properties of waste picker recyclates

The FTIR spectra of all investigated recyclates are depicted in Fig. 2. There, each row consisting of two diagrams represents a specific material group, e.g. the WPR-1 in both its unwashed (black) and hot-washed (red) form together with the respective benchmark recyclate BM-1 (blue). The curves were stacked and shifted arbitrarily along the vertical axis to aid comparison and interpretation. While the diagrams on the left-hand side of Fig. 2 depict the wavenumber region where typically absorption bands due to CH2- and CH3-vibrations are found (Stuart, 2008), the images on the right-hand side show the lower wavenumber region where carbonyl bands and other chemical groups can be found (Stuart, 2008).

The FTIR spectra of both the WPR-1 and the WPR-2 groups in the top and center row of Fig. 2 are essentially PE spectra (Krimm et al., 1956; Verleye et al., 2001). However, especially in the case of unwashed WPR-1, a knee between 2970 cm\(^{-1}\) and 2950 cm\(^{-1}\) indicates the presence of CH3-groups in higher concentrations than expected for typical PE resins. The same applies to a rather pronounced band at 1377 cm\(^{-1}\) that is attributed to bending vibrations of the CH3-group (Krimm et al., 1956; Stuart, 2008). This is interpreted as a sign of polyolefin cross-contamination, i.e. low levels of PP in PE in this case. While the amount of cross-contamination seems to be invariable for WPR-1 (on an overall lower level), the hot-washing process improved the purity within the WPR-2 group significantly.

Another important observation concerns the fraction of the hot-washed WPR-2 recyclates that was termed “reject” (here short: “R”) due to its higher density that caused it to sink in the float-sink-tank. The FTIR analysis revealed a broad and intense absorption band with a maximum at 1425 cm\(^{-1}\). Together with an additional sharp band at 875 cm\(^{-1}\) which was detected but is not shown here, this is a sign for calcium carbonate (CaCO3) (Hummel, 2002; Stuart, 2008).

Calcium carbonate (CaCO3) is a naturally occurring, low-cost mineral compound abundant in sedimentary rocks such as chalk, limestone, and marble. It has a spherical particle shape, a density of 2.7 g/cm\(^3\) (explaining the material’s tendency to sink in the float-sink-tank), and it is one of the most common fillers used in the plastics industry (Xanthos, 2005). While the primary reason for adding calcium carbonate to plastics is cost reduction by acting as a filler or extender (Xanthos, 2005), a certain degree of property improvements can be achieved by addition of lower amounts of calcium carbonate with suitable particle size and surface treatment. In PE moldings and hollow-bodies, it can increase stiffness and heat deflection temperature, it helps shortening cooling times (further cost reduction), and it enhances surface finishing and printability (Eyerer et al., 2008).

Conventional washing processes in plastics recycling operations remove contaminants from the plastic surface without melting or dissolving the plastic itself. The chemical composition of a washed plastic flake, especially its volume, remains largely unaffected (apart from migration of potentially present low-molecular weight compounds, that is usually negligible at short residence times and atmospheric pressure). Hence, neither calcium carbonate, nor any other solid filler, extender or reinforcement, is commonly removed from plastics during a washing procedure. Removal of calcium carbonate from waste plastics is therefore not to be expected in this context and it is not surprising to find calcium carbonate filled plastic flakes in the bottom discharge fraction of the float-sink-tank.

The spectra of the WPR-3 group are depicted at the bottom row of Fig. 2. While they resemble typical PP spectra (Verleye et al., 2001), it is worth mentioning that the relative intensities of bands attributed to CH2-groups at 2918 cm\(^{-1}\) and 2850 cm\(^{-1}\) compared to those of CH3-groups is rather high, pointing at some degree of polyolefin cross-contamination with PE.

In addition to that, all investigated recyclates including the benchmarks BM-1 and BM-2, revealed weak bands at about 1745 cm\(^{-1}\) and/or at about 1645 cm\(^{-1}\), indicating the presence of carbonyl functionalities (Stuart, 2008) and/or amid compounds (Hummel, 2002), respectively. However, for post-consumer recyclates, this is to some extent expected due to thermal degradation of the polymer(s), the...
presence of legacy additives, organic contaminations or combinations thereof (Al-Salem et al., 2009; Hopewell et al., 2009; Vilaplana and Karlsson, 2008).

The DTA was used as a complementary method to FTIR analysis and the resulting thermograms recorded during the second heating step are illustrated in Fig. 3. Each of the three diagrams depicts the DTA curves of a specific recycate group with WPR-1 on the left, WPR-2 in the center, and WPR-3 on the right. The curves were stacked and shifted arbitrarily along the vertical axis in order to facilitate comparison and interpretation. Only the typical melting temperature range of polyolefins is shown, since no endo- or exo-thermal events were detected below 50 °C and above 190 °C.

Most of the recylcates investigated in this work including the benchmark resins exhibited two distinct endo-thermal events corresponding with the crystallite melting range of high-density polyethylene (PE-HD) at around 130 °C (Ehrenstein et al., 2004) and PP at around 165 °C (Ehrenstein et al., 2004). This is a clear sign of polyolefin cross-contamination and agrees well with the FTIR measurements. A notable exception was hot-washed WPR-2 (both the standard and the rejected “R” fraction), which perhaps were not completely free of contamination with PP either, but at least below the level of reliable detection via DTA. Interestingly, WPR-3 was found to be a quasi-blend of PE-HD and PP where the PE contamination is significantly above the level of mere traces. Furthermore, this material’s composition seemed to be relatively unaffected by the hot-washing process (compare black and red curve on right-hand side of Fig. 3) indicating that more sophisticated sorting would be required to obtain recyclates without polyolefin-cross contamination.

The thermal decomposition process derived from TGA is depicted in Fig. 4 for all investigated recyclates. Again, each row represents a specific group of recyclates, i.e. WPR-1 and the respective benchmark BM-1 in the upper row, WPR-2 and its benchmark in the center, and WPR-3 with its benchmark at the bottom of Fig. 4. Furthermore, the left-hand side of this illustration shows the onset of thermal decomposition, whereas the right-hand side shows the end of the pyrolysis process (note the different values on the left and the right vertical axes) providing information on the presence of thermally stable inorganic components that might either be legacy fillers, reinforcements or solid inorganic contaminations. Typically, pyrolysis of polyolefins is a one-step process with an onset at around 400 °C and ending with almost complete disappearance and negligible ash formation (Ehrenstein et al., 2004). Unwashed recyclates showed earlier onset and more pronounced loss of mass than compared to both hot-washed and benchmark materials. It seems likely that residues of organic contaminations, that were present in the unwashed materials but removed by the hot-washing process, were responsible for this behavior.

Another finding that applied to all WPRs is related to their levels of inorganic residue, i.e. inorganics content. Without the hot-washing process, the WPRs contained up to 5 m% inorganics as demonstrated by the value of the black curves at around 550 °C upon completion of polymer degradation (right-hand side of Fig. 4). Hot-washing lead to inorganics levels comparable to or even lower than in benchmark materials (red vs. blue dashed curves). The reject fraction WPR-2R, that was separated from the WPR-2 stream in the float-sink-tank due to its density of > 1 g/cm³, exhibited a two-step thermal decomposition (center right diagram in Fig. 4). The second step corresponds to the characteristic cleavage of CO₂ from calcium carbonate (CaCO₃) at temperatures above 600 °C (Ehrenstein et al., 2004). Calcium carbonate is a widely used additive in polyolefin materials. Traces of CaCO₃ in the unwashed recyclates as well as in hot-washed WPR-2 might also explain the slightly declining TGA curve sections of these materials at temperatures between 500 °C and 800 °C.

The melt flow rate (MFR) measurement is a widely used standard procedure for incoming goods inspection and quality assurance in the plastics processing industry. For the unwashed WPR materials, MFR values could not be determined in a reproducible way. Since no melt filtration was applied to the unwashed WPRs during the pelletizing step, they contained numerous contaminations that led to flow restriction and die clogging. At times where melt flow did occur, the obtained melt filament showed uneven surface characteristics with visible inclusions, fume formation, and poor melt strength indicating low thermal resistance and overall limited processability and applicability for advanced processes and demanding products.

This behavior was not found for the hot-washed WPRs. The hot-washed batches of WPR-1 and WPR-2 both had an MFR value of 0.7 ± 0.1 g/10 min. The WPR-2R sample yielded a value of 0.3 ± 0.1 g/10 min due to the viscosity increase caused by the calcium carbonate filler. Such values are typical for blow-molding or pipe extrusion resins and they reflect the composition of the waste stream used for WPR-1 and WPR-2, i.e. mostly containers, bottles, and hollow
bodies that are typically made by blow-molding. Furthermore, they indicate relatively high molecular weight that has not been (strongly) deteriorated by aging or the act of recycling. In contrast to that, hot-washed WPR-3 was rather easy flowing with an MFR value of 17 ± 0.1 g/10 min, which is in a range typical for injection molding resins. This too reflects the composition of the waste stream used for WPR-3, which consisted mainly of baskets, boxes, cups, lids, and trays that are typically made by injection molding or thermo-forming.

Basic mechanical properties were characterized using tensile tests and Charpy impact test. Both the Charpy impact strength and especially the strain-at-break value of a tensile test are well suited indicators for contaminations and polymer degradation (Grabmann et al., 2018b, a; Wallner et al., 2018). The stress-strain-curves derived from tensile testing are depicted in Fig. 5 consisting of three individual diagrams, one for each recyclate group. Only one representative stress-strain-curve per material is plotted in Fig. 5 for reasons of simplicity. Furthermore, the graphs of BM-1, hot-washed WPR-1, WPR-2, and WPR-3 were intentionally cut off at about 95% nominal strain despite reaching higher strain-at-break values.

WPR-1 (left-hand side of Fig. 5) exhibited a Young’s Modulus of 650 MPa and a yield stress of 19–20 MPa. The hot-washing process did not affect these properties significantly. However, it led to an increase of the strain-at-break from 90% to 130% indicating potential reductions of contaminations. The WPR-2 material had a modulus of 760 MPa and a yield stress of 20 MPa in the unwashed state. After hot-washing the modulus dropped to 670 MPa for the standard grade while a value of 860 MPa was found for the “R” grade that contained calcium carbonate. The presence of CaCO₃ in this material also increased its yield stress to 22 MPa and caused a drastic reduction in strain-at-break down to 16% as depicted in Fig. 5 (center). BM-1 was found to be comparable to both hot-washed WPR-1 and WPR-2 meaning that these two WPRs can be regarded as high-quality recyclates. Especially in the case of WPR-2 this is likely due to the fact that a very well defined and homogeneous waste stream (essentially only the yellow jerry cans) was used as an input material.

The WPR-3 material (right-hand side of Fig. 5) exhibited a strong

\[ \text{Fig. 4. TGA curves of WPR-1 (top), WPR-2 (center), and WPR-3 (bottom) in unwashed and hot-washed quality and their respective benchmarks.} \]

\[ \text{Fig. 5. Stress-strain-curves for WPR-1 (left), WPR-2 (center), and WPR-3 (right) in unwashed and hot-washed quality and their respective benchmarks.} \]
influence of the hot-washing process on its mechanical properties. While the modulus remained relatively unchanged (1090 MPa unwashed vs. 1120 MPa hot-washed), the yield stress increased from 18 MPa to 24 MPa and the strain-at-break rose from 7% to 185% (though with high standard deviation of ± 80%) through the hot-washing process. A high yield stress allows for material savings in the design phase of products by downgauging wall thicknesses. Generally, high strain-at-break values are only achieved when contamination with dirt or other plastic types (that are incompatible with PE or PP) is low and when there was no excessive degradation of the molecular weight of the polymer during recycling.

The Charpy impact strength is a measure for a material's resistance against brittle failure upon dynamic loads. The higher its value is for a given plastic, the more this plastic is suited for fabrication of impact-loaded objects such as containers (when dropped on the ground), household items (when handled carelessly) or external car parts (when hit by a stone). The notched impact strength at room temperature of all WPRs was significantly increased by the hot-washing process. WPR-1 reached a value of 10 ± 1 kJ/m² when unwashed and 15 ± 1 kJ/m² when hot-washed. A similar increase of impact strength was found for WPR-2 which achieved 8 ± 1 kJ/m² without and 13 ± 1 kJ/m² with hot-washing. WPR-3 showed an impact strength of 4 ± 1 kJ/m² when unwashed compared to 7 ± 1 kJ/m² when hot-washed. Hence, an increase of at least 50% in notched Charpy impact strength was realized by the hot-washing process. The values achieved after hot-washing were comparable to those of the benchmark materials, i.e. 12 ± 1 kJ/m² for BM-1, the benchmark of WPR-1 and WPR-2, and 5 ± 1 kJ/m² for BM-2, the benchmark of WPR-3.

The quality of the recyclates obtained is one of the main determinants for mid- and long-term success of MGA’s attempt to integrate informal waste pickers into formal plastic recycling value chains. The goal is to supply not only to local plastics converters, but also to large international corporations (e.g. in the fast moving consumer goods segment) for which harvesting the additional (potential) sustainability value propositions of fairly sourced recyclates used in their plastics products is an interesting aspect. However, these companies typically have rather stringent technical specifications to be met. This is where composition and purity (as determined by FTIR and DTA), processing properties (roughly characterized by MFR), and final properties (e.g. mechanical) of recyclates become a decisive factor for market entry and penetration that in turn enable sustained long-term positive impacts on the involved waste pickers.

4.2 Interview-based insights on partnering with the informal recycling sector

In this section, the insights gained through the interview sessions are discussed. The findings are structured into two interconnected areas: (1) an evaluation of the company’s model to connect with the IRS and its implications for industrial-scale mechanical recycling of plastics, and (2) the socio-economic and societal aspects of this specific type of formal-informal cooperation.

4.2.1 Connecting with the IRS in Nairobi and implications on formal plastics recycling

The prime challenge of putting in place a high-quality plastics recycling value chain that integrates the local waste pickers was said to be the establishment of a reliable supplier network. The CEO argued: "we knew that this technology from the processing perspective is there, it will be there, and it is continuing to improve. But the tough cookie is to integrate that informal structure into a more formal value chain..." (A).

One crucial factor for building this network was the establishment of the company’s proprietary trading points as concrete points of interaction. They guarantee proximity to the suppliers (A, B4) who are usually active only in distinct areas and often cannot afford transporting collected wastes over longer distances (Lubaale and Nyang’oro, 2013). Furthermore, the trading point model allowed for direct interaction with the pickers (A, B4), which in turn strengthens transparency in trading materials (A, B3), builds trust (A, B1, B3), and enables immediate feedback on collected materials (A, B3, B4, C1). In short, the company’s approach on integration was described as "[…] what we do is we play the role of the yard, we play the role of the transporters, and the converter. So, we play all these three roles in one integrated supply chain" (A). This is a major contrast to the conventional structure of an IRS that includes multiple hierarchical levels of middlemen, aggregators, brokers, and informal processors (Aparcana, 2017; Ezeah et al., 2013; Sasaki and Araki, 2013).

Waste pickers are the weakest link in this conventional system and often face exploitation (Aparcana, 2017; Lubaale and Nyang’oro, 2013). In return, it is common for them to try to take advantage of buyers when they get the chance to do so (e.g. by putting water into traded plastic bottles to increase their weight (A)). This led to the experience that trust was described as both a very important and a very challenging issue (A, B1, B3, see also section 4.2.2).

Economic incentives were another crucial factor for establishing effective and reliable supplier-buyer-relations with the waste pickers. These incentives were given in the form of a guaranteed price of 19 Kenyan Shillings (KSh) per kilogram plastic (A, C1) in combination with bonus payments for trading regularly and surpassing certain trading volumes on a monthly basis (A). In fact, Velis (2017) argued that the dawn of CE business models and enabling (mobile) technology might be an opportunity to advance integration of the IRS. The company analyzed herein did so by launching a mobile application that creates personalized supplier profiles and productivity monitoring (A, C1) for each waste picker and that is used by buying clerks for transactions at the trading points.

Ensuring consistency of supply was a major prerequisite to putting a formal industrial-scale recycling business into operation. Several tons of plastics wastes are processed daily in MGA’s central facility (B1, B3, B4). In this regard, it was pointed out that by operating a higher number of trading points and integrating other informal collectors such as informal scrap yard owners who buy from waste pickers in other areas and hence supply in larger quantities of up to 500 kg per delivery (B3, C1), it was possible to compensate for supply fluctuations to a certain extent (B3). Furthermore, the number of active suppliers has grown from 250 in early 2017 to over 2,500 in mid-2019 (Mr. Green Africa, 2017, 2018b, 2019; Smith, 2018). However, despite having established a way of sourcing recyclables from the IRS, the company still had to cope with supply fluctuations. As a matter of fact though, this can be an equally pressing issue under the supposedly better conditions of formal recycling systems in high-income countries (OECD; Watts et al., 2001).

In addition to input material volume fluctuations, quality of the sourced post-consumer plastic wastes plays an important role (Hahladakis and Iacovidou, 2018; OECD; Vilaplana and Karlsson, 2008). Through direct interaction of trained buying clerks and waste pickers at the trading points the company had some degree of control over material types and qualities delivered. This first step of material pre-sorting directly at the source was reported to be essential for maintaining an adequate level of productivity in all consecutive sorting and processing steps at the central facility (A). As MGA is focusing on processing rigid plastics only, all other materials such as flexibles, foams or polyvinyl chloride (PVC) have to be sorted out properly. However, due to sourcing primarily from the outside environment, weather influences such as rainfalls causing excessive soiling of the plastic wastes were occasionally observed (C2). This underlines the importance of robust and effective washing processes to keep recyclate quality somewhat constant despite variable input quality.

4.2.2 Socio-economic and societal aspects of the MGA model

All interviewees (A, B1, B2, B3, B4, C1, C2) mentioned the financial benefits through higher income for the individual waste picker as the
main positive impact the company had on the IRS. This collective perception was underlined by the observation that some non-monetary forms of compensation or “help” did in fact not achieve the anticipated effect. For instance, an earlier version of the company’s supplier loyalty program granted protective gloves and boots to eligible waste pickers (A). The result was, however, that despite occupational hazards being a major concern and a daily challenge for many waste pickers (Kuria and Muasya, 2010), they simply sold those protective items to generate some extra income. The CEO explained: “In the end it came down to fundamentals: food, shelter, trust, sustainability [meaning sustained income], reliability, and consistency. (…) Instead of giving them gloves and so on, we are now basically giving them a more beneficial price for reaching a certain target [of supplied materials]”.

A higher income was obviously perceived as more valuable and beneficial than potential improvements in occupational health. MGA’s purchasing price of 19 KSh/kg plastic (A, B3) was claimed to be 30% higher than prices offered by other local waste buyers, a mechanism which is similar to fair-trade practices in other commodities (e.g. coffee). Considering that a typical waste picker within MGA’s supplier network deals around 10–20 kg of plastic waste per visit at a trading point (B3, C1) and many were said to come every single or second day, this would correspond to a monthly income of 4300–8500 KSh, or 41–82 US dollars (Google Currency converter) without accounting for bonus payments for surpassing supply targets of the loyalty program. A study on the informal economy in Nakuru, the fourth largest city in Kenya, found that the average monthly income of waste pickers was below 5000 KSh in 2012 (Lubale and Nyang’oro, 2013). However, statements on waste picker income are often subject to rather high standard deviations (Lubale and Nyang’oro, 2013). Additional effects that hinder comparability are very individual differences between personal turnover and income (e.g. for pickers who have to cover expenses for storage or transportation of their goods vs. those who have traders nearby) and multiple changing and supplementary sources of (informal) income generation. Nevertheless, the price policy of MGA seemed to be attractive to Nairobi’s waste pickers as their number within the company’s supplier network has grown from 250 in early 2017 to over 2500 in mid-2019 (Mr. Green Africa, 2017, 2018b, 2019; Smith, 2018). Some pickers were even said to be very happy about the possibility to sell to MGA now (B4).

An important aspect in this context might be the relative income stability established by this kind of purchasing model. Of course, the picker’s income still depends on the amount of plastic waste found. However, any suitable material found can be monetized at the guaranteed price of 19 KSh/kg at any given day, regardless of the current market situation (A, B3). And indeed, price volatility and too less buyers in low-price phases, a lack of transparent market information, and unfair trade practices by middlemen such as cartel formation are among the most severe concerns for waste pickers (Kuria and Muasya, 2010; Lubale and Nyang’oro, 2013).

Apart from the socio-economic aspects of income level and stability, the MGA model brought along rather subtle societal changes too. For example, the company started hosting “tea parties” (A, B2, B3, B4, C2) at selected trading points, where tea and cookies were provided for free to interested waste pickers regardless of participation in the supplier network. It was claimed that these tea parties together with the general friendliness and openness of MGA staff demonstrated toward the waste picker community seemed to create a certain “sense of belonging” (B1) for them and it was said to serve as a trust-building measure (A). In fact, cases were reported where waste pickers actively sought help or advice of MGA staff concerning personal worries and issues other than waste trade, which was seen as a sign of being trusted and accepted by the waste picker community (B3, B4, C2).

Interestingly, this kind of close interaction between waste pickers and formally employed staff (who typically have a different educational, family, and social background) led to a change of perception of the informal sector. Treating waste pickers with respect and valuing their contributions to the company’s business and to society at large was reported to be a learning process for some of the company staff (A). The company’s head of sourcing, who had an academic background in psychology, pointed out that awareness raising and trust-building measures were necessary to arrive at the good form of interaction between pickers and staff that was said to be in place now (B3). Eventually, many of the MGA staff claim to see both waste pickers and waste through a different lens now (A, B1, B4) which in the long run might help alleviate part of the widespread traditional marginalization of the human beings behind the IRS.

However, despite “changing” or “improving lives” of waste pickers (A, B1, B2, B3) it was admitted that none of the interviewees were aware of any waste picker within their supplier network who had actually made the transition out of poverty and informality yet. Though trials of involving reliable waste pickers in more formalized forms of waste management such as household pick-up services had already been considered (A, B2), it was pointed out that broader, more diversified, and sustained improvements in the lives of waste pickers might be achieved through involvement of external philanthropic parties. NGOs or other stakeholders who typically face difficulties in engaging with the rather isolated and mistrustful waste picker community (Kuria and Muasya, 2010; Sasaki and Araki, 2013) could make use of MGA’s established and trusted link to the informal sector (A, B2, B3). First steps into this direction have already been taken, e.g. by organizing a “medical day” where waste pickers received a medical check-up and treatment for free at one of the trading points. However, it was argued that much more could be done by involving more stakeholders and by acquiring suitable funding (A, B1, B4).

Improving the visibility and public perception of the IRS locally and globally was a core concern of MGA according to the CEO (A) and it was claimed to be one of the major outcomes of their fair-trade-like business model. Especially multinational corporations like brand owners and producers of fast moving consumer goods (A, B2) seemed to be interested in obtaining and actively marketing information on “social benefits” through more responsibly sourced materials. While such activities might, of course, open the door for green washing and exaggerated sustainability claims, they may also serve as a vehicle to sensitize a wider audience, both locally and in high-income countries, for the issue of informal work and the role of waste pickers.

5. Conclusion

Recycling is not the only element of the CE, but especially in the case of plastics it will play an important role in the quest for sustainable development as it allows for tackling multiple challenges that are pervading the economic, the environmental, and the social sphere alike. More creative and diversified efforts to integrate the IRS in low-income and middle-income countries into high-quality plastics recycling value chains via suitable modes of cooperation are needed. Locally adapted and socially-oriented CE business models that combine a human-centered approach with state-of-the-art technology seem to be a promising strategy here and should be addressed in future research on circular business models (Fraccascia et al., 2019).

The case discussed herein highlighted that post-consumer plastic wastes sourced from informal waste pickers in a lower-middle income country can be processed into materials that are comparable to state-of-the-art recyclates obtained from an advanced formal recycling system in a high-income country in terms of both composition and basic engineering properties. If the right model of cooperation is found, this can come along with socio-economic and societal improvements for the people working and living in the informal sector. Future research complementing the insights gained here could focus on field-work with waste pickers involved in such a fair-trade-like CE business model to better understand the changes to their working conditions, perceptions, and expectations. Elucidating the perspective of recycle buyers who incline to monetizing the sustainability value propositions of more
responsibly sourced recyclates would be another interesting area for future research.

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